Caltrans

CALTRANS CLIMATE CHANGE VULNERABILITY ASSESSMENTS

2019

District 5

Technical Report

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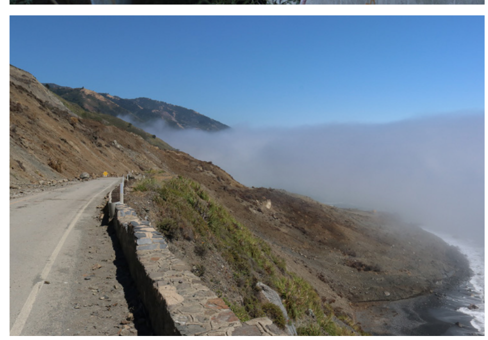

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ACRONYMS AND ABBREVIATIONS

ADAP	Adaptation Decision-Making Assessment Process
CalFire	California Department of Forestry and Fire Protection
Caltrans	California Department of Transportation
CAP	Climate Action Plan/Planning
CCC	California Coastal Commission
CEC	California Energy Commission
CGS	California Geological Survey
DWR	California Department of Water Resources
EPA	Environmental Protection Agency
GCM	Global Climate Model
GHG	Greenhouse Gas
GIS	Geographic Information System
IPCC	Intergovernmental Panel on Climate Change
LOCA	Localized Constructed Analogues
RCP	Representative Concentration Pathway
Scripps	The Scripps Institution of Oceanography
SHS	State Highway System
SRES	Special Report Emissions Scenarios
USGS	US Geological Survey
USFS	US Forest Service
VHT	Vehicle Hours Traveled

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1. INTRODUCTION

The following report, developed for the California Department of Transportation (Caltrans), summarizes a vulnerability assessment conducted for that portion of the State Highway System (SHS) located in Caltrans District 5.[1] Though there are multiple definitions of vulnerability, the assessment specifically considers vulnerability for climate change.

Climate change and extreme weather events have received increasing attention worldwide as one of the greatest challenges facing modern society. Many state agencies—such as the California Coastal Commission (CCC), the California Energy Commission (CEC), and the California Department of Water Resources (DWR)—have developed approaches for understanding and assessing the potential impacts of a changing climate on California's natural resources and built environment. State agencies are invested in defining the implications of climate change and many of California's academic institutions are engaged in developing resources for decision-makers. Caltrans initiated the current study to better understand the vulnerability of California's SHS and other Caltrans assets to future changes in climate. The vulnerability study had three objectives:

- Understand the types of weather-related and longer-term climate change events that will likely occur with greater frequency and intensity in future years,
- Conduct a vulnerability assessment to determine those Caltrans assets vulnerable to various climate-influenced natural hazards, and
- Develop a method to prioritize candidate projects for actions that are responsive to climate change concerns, when financial resources become available.

The current study focuses on the 12 Caltrans districts, each facing its own set of challenges regarding future climate conditions and potential weather-related disruptions. The District 5 report is one of the district reports, which are each in various stages of development.

1.1. Purpose of Report

This *District 5 Technical Report* is one of two documents developed to describe the work completed for the District 5 vulnerability assessment, the other being the *District 5 Summary Report*. The *Summary Report* provides a high-level overview on methodology, the potential implications of climate change to Caltrans assets, and how climate data can be applied in decision making. It is intended to orient non-technical readers on how climate change may affect the SHS in District 5.

This *Technical Report* is intended to provide a more in-depth discussion, primarily for District 5 staff. It provides background on the methodology used to develop material for both reports and general information on how to replicate those methods, if desired. The report is divided into sections by climate stressor (e.g., wildfire, temperature, precipitation) and each section presents:

- How that climate stressor is changing,
- The data used to assess SHS vulnerabilities from that stressor,
- The methodology for how the data was developed,

[1] This assessment was conducted for the SHS in District 5 and does not include other Caltrans assets or state/local roads.

- Maps of the portion of district SHS exposed to that stressor,
- And where applicable, mileage of exposed SHS.

Finally, this *Technical Report* outlines a recommended framework for prioritizing projects that might be considered by Caltrans in the future. This framework was developed based on research of other prioritization frameworks used by transportation agencies developed to guide decision-making and investments in the face of climate change.

All data used in the District 5 Technical and Summary Reports was collected into a single database. Caltrans will be able to use this data in their own mapping efforts and technical analyses. This database is expected to be a valuable resource for ongoing resiliency planning efforts. The contents of the District 5 database will also be available for the public to view in an online, interactive mapping tool.

1.2. District 5 Characteristics

Caltrans District 5 is headquartered in San Luis Obispo, California. District 5 is responsible for the SHS in Santa Barbara, San Luis Obispo, Monterey, San Benito, and Santa Cruz Counties—collectively referred to as the Central Coast. District 5 has 33 cities. One of the most defining characteristics of the district's travel flows is its location—the heavily urbanized Los Angeles Basin is to the south, the San Francisco Bay Area is to the north, and the San Joaquin Valley (that crosses the Sierra Madre, La Panza, and Diablo Mountain Ranges) is to the east. Given the District is situated amongst these large metropolitan areas there has been noticeable rush-hour traffic into and out of the district's northern and southern portions, with very noticeable traffic along US 101 in San Luis Obispo County. These communities are experiencing a jobs and housing imbalance because of the high cost of living in and around employment centers. Urbanization within the Central Coast Counties is occurring along major highway corridors, with Salinas in Monterey County being the largest city in the District by population.

District 5's diverse terrain and climatic conditions provide a range of experiences for residents and visitors. Four of the five counties in the district have beaches on the Pacific Ocean. To the east, the Santa Cruz Mountains and the Santa Lucia Range provide rugged terrain, and to the east the Salinas Valley is centered on the Salinas River that empties into Monterey Bay. The Santa Barbara Coastal plain is bounded to the south by the Pacific Ocean and to the north by the Santa Ynez Mountains. The District is comprised of various biomes, including coastal chaparral, oak woodlands and savannas, grasslands in Carizzo Plain and Salinas Valley, and coastal redwood forests in the Santa Cruz Mountains. Because of this diversity and unique combination of geology, topography and climates, District 5 is the home to more than 355 special-status species.

Tourism and agriculture are two of the most important sectors contributing to the district's economy. The mild Mediterranean climate, abundant beaches, many historic buildings (e.g. Spanish missions) and numerous parks (e.g. four National Parks/Forests, 49 state parks, forests, and beaches) are natural attractions to a vibrant and growing tourist industry. A recent study estimated that tourism in the district counties contributed over $5 billion to the Central Coast economy.

Tourist visits to coastal areas increase drastically during high heat alerts due to the relatively cooler beach climates on the central coast. This results in traffic surges and increased wear and tear on coastal roadways. Additionally, as PG&E continues its seasonal power outages due to increased fire risks, winds, and inclement weather, the Central Coast may see increased tourism from large metropolitan areas in Northern California who are seeking recreational activities while waiting for outages to end. These factors compound to create significant operational and maintenance risks for the Central Coast region's transportation system.

The Central Coast is also a major source of agricultural products in the state with more than half of the fruits, vegetables, and nuts grown in the United States and 8 percent of the nation's agricultural output by value coming from the district farms. Cut flowers, nursery stock, ornamentals, and seed crops are also a part of this important economic base for the district. Agriculture is particularly sensitive to changes in weather and climate change threatens this key economic sector. If climate warming extends the growing season, harvest volumes may increase, resulting in higher truck volumes over a longer period.

There are 30 freeways and highways located within District 5 with a cumulative 1,169 centerline miles. Motorists travel over 6.9 billion vehicle miles through the district each year. The performance of the SHS reflects the different demands associated with travel purposes. For example, the Santa Barbara and Santa Cruz County segments of routes US Route (US) 101, State Route (SR) 17, and SR 1 and SR 25 in San Benito County experience high levels of congestion due to commuter traffic into employment centers in Los Angeles, San Francisco, and Silicon Valley.

US 101 is the major north/south route through the Central Coast of California and the principal inter-city coastal route for numerous communities between Los Angeles and San Francisco. Due to geological and geographic reasons, many of the district's communities concentrate along the coast and the US 101 corridor. Given the different types of development mentioned above, US 101 handles significant interregional traffic, including commercial and agricultural trucking, tourist, and national defense-related and business traffic. As noted in the District System Management Plan, US 101 also "serves as an alternate route for a portion of Interstate 5 (I-5), the state's major north-south route of the interstate highway system that links major California cities. At times, I-5 closes in both directions at the 'Grapevine,' located in the Tehachapi Mountains at the southern end of the Central Valley due to fires, extreme weather, traffic incidents, or other adverse conditions. In such cases, traffic is diverted to US 101 for north-south travel within the state."[2] US 101 also serves as the major goods movement artery for the Central Coast and connects to SR 46, which provides east-west interregional connectivity for freight movement both statewide and nationally.

[2] Caltrans District 5, "District System Management Plan," San Luis Obispo, CA, 2015, Last accessed August 23, 2019, http://www.dot.ca.gov/dist05/planning/sys_plan_docs/dsmp.pdf

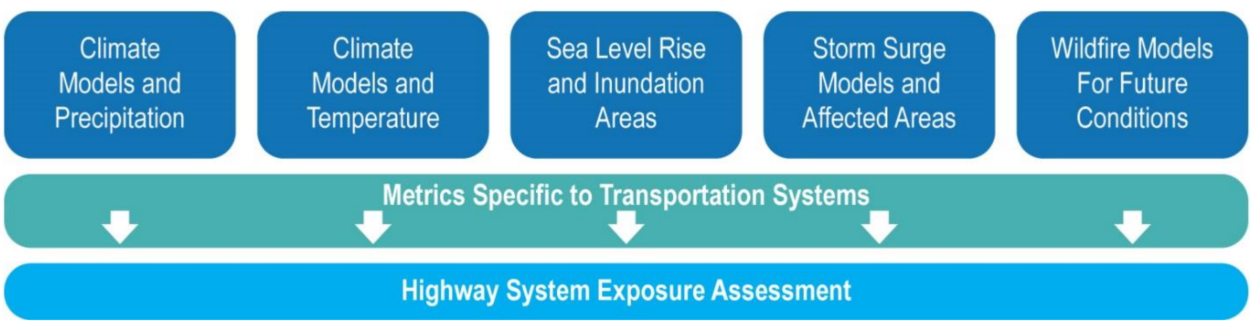
The 2015 District System Management Plan acknowledged some of the climate change-related impacts that may affect the district's communities. As noted in the Plan, "the Central Coast region may face one or more of the following climate change-related impacts: increased temperatures, reduced precipitation, reduced agricultural productivity, sea level rise-coastal flooding and infrastructure damage, biodiversity threat, public health threats, and reduced tourism. The following areas are likely to see coastal recreation resources such as beaches, wharves, and campgrounds affected by sea level rise: Santa Barbara, Pismo Beach, Morro Bay, Monterey Peninsula, Santa Cruz, and Half Moon Bay. In addition, several large, downtown areas – including those in Santa Barbara, Monterey, Castroville, and Santa Cruz – lie within areas subject to coastal flooding that will be exacerbated by sea level rise. A 1.4-meter rise in sea level will increase the population vulnerable to a 100-year coastal storm from 26,070 to 38,000."

2. POTENTIAL EFFECTS FROM CLIMATE CHANGE ON THE STATE HIGHWAY SYSTEM IN DISTRICT 5

Climate and extreme weather conditions are changing as increasing concentrations of atmospheric greenhouse gas (GHG) emissions lead to rising temperatures worldwide. These changing conditions are anticipated to affect District 5, as well as other Caltrans districts and their assets. These impacts may appear in a variety of ways and may increase District 5's infrastructure's exposure to environmental factors that exceed their original design considerations. The project study team, made up of consultant staff and subject matter experts, considered a range of climate stressors and how they align with Caltrans design criteria/other metrics specific to transportation systems.

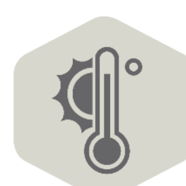
Figure 1 illustrates the general process for deciding which metrics should be included in the overall SHS vulnerability assessment. First, Caltrans and the project study team considered which climate stressors affect transportation systems. Then, Caltrans and the project study team decided on a relevant metric that the climate stressor data could inform. For example, precipitation data was formatted to show the 100-year storm depth given that the 100-year storm is a criterion used in the design of Caltrans assets.

FIGURE 1: CONSIDERATIONS FOR THE STATE HIGHWAY ASSESSMENT



Extreme weather events already disrupt and damage District 5 infrastructure. The following examples include weather-related issues and events that Caltrans District 5 has addressed in the past, which may become more prevalent as climate changes:

Temperature – District 5 has a Mediterranean climate, with cooler climatic conditions in the mountainous areas to the east. California's July 2017 heatwave not only set daily and monthly temperature records statewide, but also established a record-breaking streak of 100+ degree days across much of the Central Coast. San Luis Obispo reached 108 degrees in October 2017, shattering the record of 103 set in 1959. Santa Maria reached 102 degrees, passing its record of 97 set in 1965.



Precipitation – For decades, District 5 has experienced heavy precipitation events followed by flash floods, landslides, mudslides, and debris flows. Flooding along coastal roads (such as SR 1) have disrupted traffic, and these events caused by heavy rainfall have significantly impacted the district's roads. The Mud Creek landslide (2017) closed SR 1 for over a year and necessitated $54 million in reconstruction and adaptation costs. In February 2017, heavy rains triggered a landslide that damaged the SR 1 Pfeiffer Canyon Bridge beyond repair and cut off access to Big Sur from both directions. A $24 million emergency project was required to replace the previous two-column bridge with a single-span steel girder structure. These two examples alone show how damaging and expensive heavy precipitation can be.

Wildfire – As temperatures rise and precipitation patterns become more unpredictable, wildfire risk is expected to increase. California's Fourth Climate Change Assessment states that, "by 2100, if greenhouse gas emissions continue to rise, one study found that the frequency of extreme wildfires burning over approximately 25,000 acres would increase by nearly 50 percent, and that average area burned statewide would increase by 77 percent by the end of the century."[3] From 1980 to 1989 (a period used as a baseline because it is prior to the more noticeable climate change impacts that occurred later), 72 wildfires of at least 490 acres (and many much higher) in size consumed a total of 404,975 acres in the Central Coast Region.[4] In 2018 alone, wildfires burned over 6,100 acres in District 5, and three people died as a result. In 2010, approximately 12% (6,883 of San Benito County's total population of around 55,269 lived in fire hazard zones rated at medium to very high risk.[5]

FIGURE 2: US 1 PFEIFFER CANYON DAMAGED BRIDGE, 2017

[3] Louise Bedsworth, Dan Cayan, Guido Franco, Leah Fisher, Sonya Ziaja (California Governor's Office of Planning and Research, Scripps Institution of Oceanography, California Energy Commission, California Public Utilities Commission), "Statewide Summary Report," California's Fourth Climate Change Assessment, Publication number: SUMCCCA4-2018-013.

[4] Neil Maizlish, Dorette English, Jacqueline Chan, Kathy Dervin, Paul English. 2017. "Climate Change and Health Profile Report: San Benito County. Sacramento, CA: Office of Health Equity," California Department of Public Health. https://www.cdph.ca.gov/Programs/OHE/CDPH%20Document%20Library/CHPRs/CHPR069SanBenito_County2-23-17.pdf

[5] Ibid.

Sea Level Rise – District 5 is already facing challenges associated with sea level rise. Since 1920, sea levels have risen by about 0.06 inches (1.57 millimeters)[6] per year in Monterey Bay and around 0.04 inches (one millimeter)[7] per year in Port San Luis. By the end of the century, Central Coast sea levels will likely rise by anywhere from 0.7 to 9.9 feet above current levels (for more detail on projections, see Section 7.1). Rising sea levels will exacerbate flooding at high tides and may eventually lead to permanent inundation in low-lying areas. Highways of concern currently for sea level rise and storm surge include Highway 1, US 101 and SR 46 West - which may require prioritized actions to address appropriately.

Storm Surge – A storm surge is short-term rising of sea levels due to low pressure weather systems and/or strong winds. For high-intensity storms, storm surge can be devastating to coastal areas. Increasing sea levels combined with changes to storm patterns are expected to alter and increase the effects of storm surge in coastal areas. Storm surge is currently considered in coastal transportation facility design but increasing water levels and more powerful future surges represent a very different stress than was likely considered in past designs. In addition, infrastructure originally assumed to be outside of the surge zone may now be exposed to the effects of storm surge. Storm surge is also expected to increase coastal erosion and landslides, causing shoreline retreat and exposing roadways to increased effects from flooding.

Cliff Retreat - District 5 is already facing challenges associated with cliff retreat. The City of Santa Cruz, which sits on the northern edge of Monterey Bay, is developing an Adaptation and Management Plan for its most famous coastal roadway, West Cliff Drive. West Cliff Drive has become increasingly unstable as it erodes into the sea. The city's Climate Adaptation Plan notes that the cliffs are protected by sea walls and rip rap but protecting West Cliff Drive will be an ongoing challenge as sea levels rise over the coming century.[8] As noted later in this report, there are sections of SR 1 that are also at risk of cliff retreat throughout District 5. The Association of Monterey Bay Area Governments (AMBAG) is conducting a resiliency study for the Moss Landing/Elkhorn Slough Corridor of SR 1 to understand the risks associated with cliff retreat and sea level rise in this area. The end goal of this AMBAG study is identify adaptation alternatives for the corridor that meets transportation needs, while promoting healthy coastal habitats.

Combined Effects – When extreme weather events follow one another, the impacts can become even more severe. For example, a wildfire followed by an extreme precipitation event with rain intensities of multiple inches within an hour can bring about extremely damaging landslide and debris flow conditions. This was the case in January 2018, when a winter storm followed the December 2017 Thomas Fire in Santa Barbara County, leading to a devastating debris flow in Montecito. In another example, heavy winter rains in early 2017 followed the 2016 Soberanes Fire, which caused fire-downed tree branches to clog culverts throughout Monterey County. This resulted in seasonal waterways overflowing onto roadways, washing out facilities, and in some instances washing out culverts and small

[6] NOAA, "Relative Sea Level Trend: 9413450 Monterrey, California," NOAA Tides and Currents, Last accessed August 23, 2019 from https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=9413450

[7] NOAA, "Relative Sea Level Trend: 9412110 Port San Luis, California," NOAA Tides and Currents, Last accessed August 23, 2019 from https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=9412110

[88] City of Santa Cruz, "Climate Adaptation Plan Update: 2018 – 2023," October 9, 2018, http://www.cityofsantacruz.com/home/showdocument?id=73396

bridges. There are preventative steps that can be taken to reduce the risks associated with the combined effects of extreme precipitation and wildfire.

FIGURE 3: PAULS SLIDE ON SR 1

FIGURE 4: SR 35 WASHOUT

3. ASSESSMENT APPROACH

3.1. State of the Practice in California

California has been on the forefront of climate change policy, planning, and research across the nation. State officials have been instrumental in developing and implementing policies that foster effective greenhouse gas mitigation strategies and the consideration of climate change in State decision-making. California agencies have also been pivotal in creating climate change data sets that can be used to consider regional impacts across the State. At a more local level, efforts to plan for and adapt to climate change are underway in communities across the state. These practices are key to the development of climate change vulnerability assessments in California and were found to be very helpful in the development of the District 5 report. The sections below provide some background on the current state-of-the-practice in adaptation planning and how specific analysis methods were considered/applied in the District 5 vulnerability assessment.

3.1.1. Policies

Various policies implemented at the state level have directly addressed not only GHG mitigation, but climate adaptation planning. These policies require State agencies to consider the effects of climate in their investment and design decisions, among other considerations. State adaptation policies that are relevant to Caltrans include:

- **Assembly Bill 32** (2006) or the "California Global Warming Solution Act" was marked as being the first California law to require a reduction in emitted GHGs. The law was the first of its kind in the country and set the stage for further policy in the future.[9]
- **Executive Order S-13-08** (2008) directs state agencies to plan for sea level rise and climate impacts through the coordination of the state Climate Adaptation Strategy.[10]
- **Executive Order B-30-15** (2015) requires the consideration of climate change in all state investment decisions through full life cycle cost accounting, the prioritization of adaptation actions that also mitigate greenhouse gases, the consideration of the state's most vulnerable populations, the prioritization of natural infrastructure solutions, and the use of flexible approaches where possible.[11]
- **Assembly Bill 1482** (2015) requires all state agencies and departments to prepare for climate change impacts through (among others) continued collection of climate data, considerations of climate in state investments, and the promotion of reliable transportation strategies.[12]

[9] California Air Resources Board, "Assembly Bill 32 Overview," modified August 5, 2014, Last accessed August 23, 2019, https://www.arb.ca.gov/cc/ab32/ab32.htm

[10] Adaptation Clearinghouse, "California Executive Order S-13-08 Requiring State Adaptation Strategy," Last accessed August 23, 2019, https://www.adaptationclearinghouse.org/resources/california-executive-order-s-13-08-requiring-state-adaptation-strategy.html

[11] Office of Governor Edmund Brown, "Governor Brown Establishes Most Ambitious Greenhouse Gas Reduction Target in North America," modified April 29, 2015, Last accessed August 23, 2019, https://www.ca.gov/archive/gov39/2015/04/29/news18938/

[12] California Legislative Information, "Assembly Bill No. 1482," October 8, 2015, Last accessed August 23, 2019, https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201520160AB1482

- **Senate Bill 246** (2015) establishes the Integrated Climate Adaptation and Resiliency Program to coordinate with regional and local efforts with state adaptation strategies.[13]
- **Assembly Bill 2800** (2016) requires that state agencies account for climate impacts during planning, design, building, operations, maintenance, and investments in infrastructure. It also requires the formation of a Climate-Safe Infrastructure Working Group represented by engineers with relevant experience from multiple state agencies, including the Department of Transportation.[14]

These policies are among the factors state agencies consider when addressing climate change. Conducting an assessment such as this one for District 5 is a key step towards preserving Caltrans infrastructure against future extreme weather conditions and addressing the requirements of the relevant state policies above, such as Executive Order B-30-15, Assembly Bill 1482, and Assembly Bill 2800. Other policies, such as Executive Order S-13-08, stimulate the creation of climate data that can be used by state agencies in their own adaptation planning efforts. It is important for Caltrans staff to be aware of the policy requirements defining climate change response and how this assessment may be used to indicate compliance, where applicable.

One of the most important climate adaptation policies out of those listed above is Executive Order B-30-15. Guidance specific to the Executive Order and how state agencies can begin to implement was released in 2017, titled *Planning and Investing for a Resilient California.* This guidance will help state agencies develop methodologies in completing vulnerability assessments specific to their focus areas and in making adaptive planning decisions. *Planning and Investing for a Resilient California* created a framework to be followed by other state agencies, which is important in communicating the effects of climate change consistently across agencies.

3.1.2. Research

California has been on the forefront of climate change research nationally and internationally. For example, Executive Order S-03-05, directs that State agencies develop and regularly update guidance on climate change. These research efforts are titled the California Climate Change Assessments, which is in its fourth edition (Fourth Climate Change Assessment). To understand the research and datasets coming out of the Fourth Climate Change Assessment, which are utilized in this District 5 vulnerability assessment, some background is needed on Global Climate Models and emissions scenarios.

Global Climate Models (GCMs)

GCMs have been developed worldwide by many academic or research institutions to represent the physical processes that interact to cause climate change, and to project future changes to GHG emission levels.[15] These models are run to reflect the different estimates of GHG emissions or atmospheric concentrations of these gases, which are summarized for use by the Intergovernmental Panel on Climate Change (IPCC).

The IPCC is the leading international body recognized for its work in quantifying the potential effects of climate change and its membership is made up of thousands of scientists from 195 countries. The IPCC

[13] California Legislative Information, "Senate Bill No.246," October 8, 2015, Last accessed August 23, 2019, https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB246

[14] California Legislative Information, "Assembly Bill No. 2800," September 24. 2016, Last accessed August 23, 2019, http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160AB2800

[15] Intergovernmental Panel on Climate Change (IPCC), "What is a GCM?", Last accessed April 30, 2019, http://www.ipcc-data.org/guidelines/pages/gcm_guide.html

periodically releases Assessment Reports (currently in its 5th iteration), which summarize the latest research on a broad range of topics relating to climate change. The IPCC updates research on GHG emissions, identifies scenarios that reflect research on emissions generation, and estimates how those emissions may change given international policies. The IPCC also summarizes scenarios of atmospheric concentrations of GHG emissions to the end of the century.

There are dozens of climate models worldwide, but there are a set of GCMs that have been identified for use in California, as outlined in the California's Fourth Climate Change Assessment section.

Emissions Scenarios and Concentration Pathways

There are two commonly cited sets of emissions data that are used by the IPCC:

1. The Special Report Emissions Scenarios (SRES)
2. The Representative Concentration Pathways (RCPs)

RCPs represent the most recent generation of GHG scenarios produced by the IPCC and are used in this report. These scenarios use three main metrics: radiative forcing, emission rates, and emission concentrations.[16] Four RCPs were developed to reflect assumptions for emissions growth, and the resulting concentrations of GHG in the atmosphere. The RCPs developed are applied in GCMs to identify projected future conditions and enable a comparison of one against another. Generally, the RCPs are based on assumptions for GHG emissions growth and an identified point at which they would be expected to begin declining (assuming varying reduction policies or socioeconomic conditions). The RCPs developed for this purpose include the following:

- RCP 2.6 assumes that global annual GHG emissions will peak in the next few years and then begin to decline substantially.
- RCP 4.5 assumes that global annual GHG emissions will peak around 2040 and then begin to decline.
- RCP 6.0 assumes that emissions will peak near the year 2080 and then start to decline.
- RCP 8.5 assumes that high GHG emissions will continue to the end of the century.[17]

California's Fourth Climate Change Assessment

California's Climate Change Assessments are inter-agency research and "model downscaling" efforts for multiple climate stressors. California's Fourth Climate Change Assessment (Fourth Assessment) was led by the California Energy Commission (CEC) with other contributors including agencies such as the Department of Water Resources (DWR), and the Natural Resources Agency (NRA), as well as academic institutions such as the Scripps Institution of Oceanography (Scripps) and the University of California, Merced.

[16] IPCC, Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. "Climate Change 2014: Synthesis Report," IPCC, Geneva, Switzerland, 151 pp., Last accessed August 23, 2019. https://ar5-syr.ipcc.ch/topic_summary.php

[17] Malte Meinshausen, S.J. Smith, J.S. Daniel, et al. "The RCP Greenhouse Gas Concentrations and Their Extensions From 1765 To 2300 (Open Access)," *Climatic Change*, (2011) 109:213, Last accessed June 29, 2019. https://doi.org/10.1007/s10584-011-0156-z

Model downscaling is a statistical technique that refines the results of GCMs to a regional level. The model downscaling used in the Fourth Assessment is a technique called Localized Constructed Analogs (LOCA), which "uses past history to add improved fine scale detail to GCMs."[18] This effort was undertaken by Scripps and provides a finer grid system than is found in other techniques, enabling the assessment of changes in a more localized way than was previously available, since past models summarized changes with lower resolution.[19] Out of the 32 LOCA downscaled GCMs for California, 10 models were chosen by state agencies as being most relevant for California. This effort was led by DWR and its intent was to understand which models to use in state agency assessments and planning decisions.[20] The 10 representative GCMs for California are:

- ACCESS 1-0
- CanESM2
- CCSM4
- CESM1-BGC
- CMCC-CMS
- CNRM-CM5
- GFDL-CM3
- HadGEM2-CC
- HadGEM2-ES
- MIROC5

Data from these models are available on Cal-Adapt 2.0, California's Climate Change Research Center.[21] The Cal-Adapt 2.0 data is some of the best available data in California on climate change and, for this reason, selections of data from Cal-Adapt and the GCMs above were utilized in this study.

3.2. Other District 5 Efforts to Address Climate Change

In addition to the work completed and in progress across the state, there are regional efforts underway in District 5 relating to climate change planning and preparedness. Some examples of these efforts in District 5 include:

- **California Energy Commission, Developing Adaptation Strategies for San Luis Obispo County** [22]
  This report focused on climate change-related vulnerabilities to the social systems of San Luis Obispo County. The analysis examined the county's demographics (wealth, race, education,

[18] Cal-Adapt. "LOCA Downscaled Climate Projections," Last accessed July 2, 2019 from http://cal-adapt.org/

[19] Pierce, David; Cayan, Dan; Thrasher, Bridget. "Statistical Downscaling Using Localized Constructed Analogs." Journal of Hydrometeorology, (December 2014). Last accessed August 23, 2019. http://journals.ametsoc.org/doi/abs/10.1175/JHM-D-14-0082.1.

[20] California Department of Water Resources, "Perspectives and Guidance for Climate Change Analysis," Climate Change Technical Advisory Group, August 2015, Last accessed June 15, 2019. https://water.ca.gov/LegacyFiles/climatechange/docs/2015/1_14_16_PerspectivesAndGuidanceForClimateChangeAnalysis_MasterFile_FINAL_08_14_2015_LRW.pdf

[21] For more information, visit http://cal-adapt.org/

[22] Susanne C. Moser, Julia Ekstrom. (Susanne Moser Research & Consulting, Santa Cruz and University of California, Berkeley). 2012. "Developing Adaptation Strategies for San Luis Obispo County: Preliminary Climate Change Vulnerability Assessment for Social Systems." California Energy Commission. Publication number: CEC-500-2012-054. Last accessed August 23, 2019 https://www.slocounty.ca.gov/getattachment/865fdd93-4868-4884-aa08-1b435cd9d948/Climate-Change-Vulnerability-Assessment.aspx

special populations, etc.), locally important economic sectors (tourism, agriculture, fishing, etc.), and important infrastructure and community services (water supplies, transportation, and emergency management, etc.). The major conclusions from the study included:

- Different social vulnerabilities will occur to a range of impacted populations such as the elderly, infants, and outdoor (migrant) workers. Attention was given to an aging population.
- Large institutional land use (e.g., hospitals, prisons, and colleges) are of special concern due to their location in flood zones or landslide and fire risk zones.
- Important regional agriculture resources due to dependence on scarce water resources and sensitivity to heat is highly vulnerable to climate change.
- Coastal residents along eroding beaches and cliffs and in low-lying areas are particularly vulnerable to sea-level rise and related hazards such as flooding, erosion and cliff failure.
- Crucial supporting infrastructure and services will experience greater demands or challenges as climate change-related risks grow, including for already scarce water supplies, transportation and energy infrastructure, and emergency preparedness and services. Several climate-related hazards (such as landslides and fire) may interrupt these critical services more frequently than in the past.

- **Climate Change and Health Profile Reports for District 5 Counties –** The five District 5 counties, in cooperation with the California Department of Public Health, produced reports about climate change and future health impacts to county residents. Each of the reports included regional climate projections for temperature, heat waves, fire, precipitation, and snowpack, and described how these changes in climate could impact public health (the counties are in the Central Coast climate impact area as defined by the California Adaptation Planning Guide). Climatic changes can cause a range of impacts to water and air quality, weather, and the local environment that can subsequently lead to disease, injuries, malnutrition, and mental health effects in humans. These impacts may be disproportionately felt by vulnerable populations such as the very young or elderly, disabled, low income, or those with health conditions. To identify the size of these population groups who are at the highest risk, the county reports provided local population demographic profiles. As an example, some of these statistics are summarized below for San Benito County:

  - In 2012, nearly 46% of adults (149,059; pooled with Monterey County) reported one or more chronic health conditions including heart disease, diabetes, asthma, severe mental stress or high blood pressure.
  - Among climate-vulnerable groups in 2010 were 4,092 children under the age of 5 years and 5,360 adults aged 65 years and older. In 2010, there were approximately 289 people living in nursing homes, dormitories, and other group quarters where institutional authorities would need to provide transportation in the event of emergencies.

- In 2005-2010, there was an annual average of 5 heat-related emergency room visits and an age-adjusted rate of 8 emergency room visits per 100,000 persons (the statewide age-adjusted rate was 10 emergency room visits per 100,000 persons).
- In 2010, San Benito County had approximately 3,994 outdoor workers whose occupation increased their risk of heat illness. In 2010, roughly five percent of households did not own a vehicle that could be used for evacuation (statewide average was eight percent).
- In 2009, approximately 78% of households were estimated to lack air conditioning.[23]

Each report suggested ways that the counties can act to protect these people and the rest of the public against the projected climate-related health impacts. Some of these suggestions can be enacted in the near-term, like starting a public outreach campaign, improving heat warning systems, and further research on the nexus between climate change and health. Other suggestions are long-term goals, such as developing resiliency funding opportunities.[24]

- **City of Santa Barbara Climate Action Plan** – The City of Santa Barbara developed a Climate Action Plan in 2012 that focuses on strategies to, 1) reduce carbon emissions in energy consumption, travel and land use, vegetation, waste reduction, and water conservation, and 2) adapt to expected climate change impacts.[25] The potential climate change-related impacts that City officials identified include:
  - Increased frequency and severity of heatwaves, droughts, and wildfires,
  - Larger storms and associated flooding and erosion,
  - Increased air and water pollution, and changes in pest and vector transmission,
  - Sea level rise effects on storm damage, inundation, beach loss, and coastal cliff erosion,
  - Changes to water, agriculture, and food supplies,
  - Increased energy demand,
  - Effects on wildlife and habitats,
  - Changes to local economies such as tourism and fisheries.

  Santa Barbara's Climate Action Plan identifies some specific responses and needs including the following strategies:

  - Conduct local vulnerability analysis for future climate change effects,

[23] Neil Maizlish, et al, 2017. Op cit.
[24] Neil Maizlish, et al, 2017. Op cit.
[25] City of Santa Barbara, "Climate Action Plan," 2012, Last accessed August 23, 2019, https://www.santabarbaraca.gov/civicax/filebank/blobdload.aspx?BlobID=17720

- Identify options and priorities for feasible adaptation planning projects, programs, and updates to land use and safety policies, ordinances, and development standards for hazard areas,
- Continue to pursue grant funding opportunities to help fund local climate change studies and adaptation programs,
- Incorporate into the City' response strategies for emergency preparations the potential effects of climate change, including extreme weather, sea level rise, epidemics, and other effects on humans and the built and natural environments,
- Conduct the resilience planning process as a broad, cross-sector effort in coordination with the South Coast to engage public and institutional involvement,
- Conduct periodic sea level rise studies that provide risk analysis indicating probability and magnitude of future impacts to Santa Barbara due to sea level rise to support future adaptation planning,
- As applicable, private development and public facilities and services may be required to incorporate measures to minimize contributions to climate change and to adapt to climate changes anticipated to occur within the life of each project.

Importantly, the plan proposed that the provisions (through 2030) be reassessed and amended as needed as a part of a regular monitoring and reporting process.

- **Central Coast Climate Collaborative** – The Central Coast Climate Collaborative (4C) is a member of the Alliance of Regional Collaboratives for Climate Adaptation (ARCCA), which is a coalition of collaboratives across California that strive to build regional resilience to climate change impacts. The mission of 4C is to foster a network of local and regional partnerships for climate change mitigation and adaptation. In 2018, 4C held a series of workshops focused on topics such as building resilient communities and funding adaptation strategies in Central Coast communities. One of the presentations made the economic case for resilience, and suggested conducting full project-lifecycle cost accounting to achieve the triple bottom line (social, environmental, and financial). Other workshop topics focused on emergency preparedness, disaster response, fire suppression, and vulnerability assessment findings.[26] These presentations, along with other resources for Central Coast communities, are available on 4C's website, centralcoastclimate.org.
- **City of Santa Cruz Climate Adaptation Plan –** The City of Santa Cruz adopted an updated Climate Adaptation Plan (CAP) in 2018 that included the city's first sea level rise vulnerability assessment. The assessment included: climate hazard map projections for 2030, 2060 and 2100, the first social vulnerability assessment with maps of census blocks deemed to be the most socially vulnerable, that intersect with climate hazard projections, updated non-coastal impacts, and a description of progress since the 2011 CAP. The plan describes one of the most active adaptation efforts of any community in the nation. For example, the progress identified in the updated plan included the following milestones for the city:

[26] "Resources, Central Coast Climate Collaborative, 2018, Last accessed August 24, 2019, http://www.centralcoastclimate.org/resources/

- Relocated Emergency Operations Center to a less vulnerable location,
- Initiated a Local Coastal Program Update,
- Converted a reservoir to two elevated tanks with solar panels,
- Increased the urban tree canopy through grant funded tree plantings and are currently developing urban tree inventory as management tool,
- Conducted sea level rise and social vulnerability assessments,
- Raised all San Lorenzo River bridges except SR 1 bridge & train trestle,
- Initiated a habitat restoration plan,
- Completed an Urban Water Master Plan,
- Completed coastal revegetation projects,
- Designed beach nourishment from the San Lorenzo River.[27]

Some of the strategies in the plan include: addressing the effects of climate change through changes in land use and building codes for low-lying areas, identifying which areas should be protected from the combined forces of sea level rise and increased storm intensity, identifying policies to identify and implement realignment of roads and utility infrastructure, developing policies that establish review processes for proposed Capital Improvement Projects located within existing and future hazard zones to minimize risk and maximize capital investment, and relocating or upgrading any facilities or infrastructure that may be impacted by ongoing or increased storm events, such as sea level rise, permanent coastline or cliff erosion, repetitive flooding or salt water intrusion.

- **Santa Barbara Area Coastal Ecosystem Vulnerability Assessment –** California Sea Grant, along with University of California Santa Barbara, the National Oceanic and Atmospheric Administration (NOAA), the Scripps Institution of Oceanography, and other research/academic institutions, developed this study to "investigate future changes to southern Santa Barbara County climate, beaches, watersheds, wetland habitats and beach ecosystems."[28] The study identified that temperatures are rising across the county, but increases are more pronounced in the inland, mountainous areas. Extreme heat days are expected to roughly double by mid-century, which could stress vulnerable ecosystems. Precipitation change remains uncertain, but sea level rise is guaranteed, and rates of rise will be much greater than historic observed sea level rise. The areas most vulnerable to flooding from sea level rise and storm surge include: Carpinteria, Santa Barbara Harbor/East Beach, Santa Barbara Airport, Devereux Slough, and Gaviota State Park. A key focus of the study was on beach and estuary impacts, and the effort identified that high salt marsh and transition habitats will be highly vulnerable to sea level rise.

[27] City of Santa Cruz. 2018." Climate Adaptation Plan Update 2018-2023. Last accessed August 23, 2019. http://www.cityofsantacruz.com/home/showdocument?id=73396

[28] Myers, M. R., Cayan, D. R., Iacobellis, S. F., Melack, J. M., Beighley, R. E., Barnard, P. L., Dugan, J. E. and Page, H. M., 2017. Santa Barbara Area Coastal Ecosystem Vulnerability Assessment. CASG-17-009. Last accessed October 29, 2019. https://caseagrant.ucsd.edu/sites/default/files/SBA-CEVA-final-0917.pdf

- **US Geological Survey (USGS) Debris Flow Evaluation –** Following the aftermath of the 2018 debris flows that hit Montecito, the USGS teamed up with local partners to survey the area and model future risks to Montecito. They did this through a geohazard assessment of the area, with the support of the California Geological Survey and the California Department of Forestry and Fire Protection (CalFire). Assessment findings identified that the burn scar area from the Thomas Fire may be vulnerable to debris flows for up to two years after the event.[29] Mapped results of at-risk areas are available on the county and USGS websites.

3.3. General Methodology

The adaptation planning methodology varies from stressor to stressor, given that each uses a different set of models, emissions scenarios, and assumptions, leading to data and information on which to develop an understanding of potential future climate conditions. The specific methods employed are further defined in each stressor section; however, there are some general practices that apply across all analysis approaches.

3.3.1. Time Periods

It is helpful to present climate projections in a way that allows for consistent comparison between analysis periods for different stressors. For this study, those analysis periods have been defined as the beginning, middle, and end of century, represented by the out-years 2025, 2055, and 2085, respectively. These years are chosen because some statistically derived climate metrics used in this report (e.g. the 100-year precipitation event) are typically calculated over 30-year time periods centered on the year of interest. Because currently available climate projections are only available through the end of the century, the most distant 30-year window runs from 2070 to 2099. 2085 is the center point of this time range and the last year in which statistically derived projections can defensibly be made. The 2025 and 2055 out-years follow the same logic but applied to each of the prior 30-year periods (2010 to 2039 and 2040 to 2069, respectively).

3.3.2. Geographic Information Systems (GIS) and Geospatial Data

Developing an understanding of Caltrans assets exposed to sea level rise, storm surge, and projected changes in temperature, precipitation, and wildfire required complex geospatial analyses. The geospatial analyses were performed using ESRI geographic information systems (GIS) software. The general approach for each stressor's geospatial analysis went as follows:

Obtain/conduct stressor mapping: The first step in each GIS analysis was to obtain or create maps showing the presence and/or value of a given hazard at various future time periods, under different climate scenarios. For example, extreme temperature maps were created for temperature metrics important to pavement binder grade specifications; maps of extreme (100-year) precipitation depths were developed to show changes in rainfall; burn counts were compiled to produce maps indicating future wildfire frequency; and sea level rise, storm surge, and cliff retreat maps were made to understand the impacts of future tidal flooding and erosion.

Determine critical stressor thresholds: Some stressors, namely temperature, precipitation and wildfire, vary in intensity across the landscape. In many locations, the future change in these stressors is not projected to be high enough to warrant special concern, whereas other areas may see a large increase in

[29] "USGS Geologists Join Efforts in Montecito to Assess Debris-Flow Aftermath," USGS, Last accessed October 29, 2019, https://www.usgs.gov/news/usgs-geologists-join-efforts-montecito-assess-debris-flow-aftermath

hazard risk. To highlight the areas most affected by climate change, the geospatial analyses for these stressors defined the critical thresholds for which the value of (or the change in value of) a stressor would be a concern to Caltrans. For example, the wildfire geospatial analysis involved several steps to indicate which areas are considered to have a medium, high, and very high fire exposure based on the projected frequency of wildfire.

Overlay the stressor layers with Caltrans SHS to determine exposure: Once high stressor areas had been mapped, the next general step in the geospatial analyses was to overlay the Caltrans SHS centerlines with the stressor data to identify the segments of roadway most exposed to each stressor.

Summarize the miles of roadway affected: The final step in the geospatial analyses involved running the segments of roadway exposed to a stressor through Caltrans' linear referencing system. This step was performed by Caltrans and provides an output GIS file indicating the centerline miles of roadway affected by a given stressor. Using GIS, this data can then be summarized in many ways (e.g. by district, county, municipality, route number, or some combination thereof) to provide useful statistics to Caltrans planners.

Upon completion of the geospatial analyses, GIS data for each step was saved to a database that was supplied to Caltrans after the study was completed. Limited metadata on each dataset was also provided in the form of an Excel table that described each dataset and its characteristics. This GIS data will be useful to Caltrans for future climate adaptation planning activities

4. TEMPERATURE

The Earth's average surface temperature is rising due to increased concentrations of GHGs in the atmosphere.[30] Temperatures in the west are projected to continue rising and heat waves are expected to become more frequent.[31] The potential effects of extreme temperatures on District 5 assets will vary by asset type and will depend on the specifications used in the original design of the facility. The following have been identified in other US studies as potential impacts of rising temperatures:

4.1. Design

- Pavement design includes an assessment of temperature in determining material.
- Ground conditions and more/less water saturation can alter the design factors for foundations and retaining walls.
- Temperature may affect expansion/contraction allowances for bridge joints.

4.2. Operations and Maintenance

- Extended periods of high temperatures will affect safety conditions for employees who work long hours outdoors, such as those working on maintenance activities.
- Right-of-way landscaping and vegetation must survive higher temperatures.
- Extreme temperatures could cause pavement discontinuities and deformation, which could lead to more frequent maintenance.

The scope of this study did not allow for detailed assessment at this time of all impacts of changing temperatures on Caltrans facilities. To illustrate such impacts, however, a close look was taken at one of the ways in which higher temperatures could affect Caltrans---the selection of a pavement binder grade. Binder is essentially the "glue" that ties together the aggregate materials in asphalt. Selecting the appropriate and recommended pavement binder relies, in part, on the following two temperature inputs:

- **Low temperature** – The mean of the absolute minimum air temperatures expected over a pavement's design life.
- **High temperature** – The mean of the maximum temperatures over seven consecutive days.

These climate metrics are critical to determine the extreme temperatures a roadway may experience over time. A binder must be selected that can maintain pavement integrity under both extreme cold conditions (which leads to contraction) and high heat (which leads to expansion). Understanding the metrics for binder design in the future will enable Caltrans to gain insight on how pavement design may need to shift over time.[32]

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[30] "Global Warming," National Aeronautics and Space Administration (NASA), 2010, Last accessed July 1, 2019. https://earthobservatory.nasa.gov/features/GlobalWarming/page2.php

[31] U.S. National Climate Assessment, U.S. Global Change Research Program, 2014, Last accessed August 24, 2019. http://nca2014.globalchange.gov/report/our-changing-climate/extreme-weather

[32] Note: The ideal low temperature range varies based on the type of binder being used and, in some cases, the placement temperature. Per the Caltrans Highway Design Manual, there are potentially several different types of binder being used in District 5 (dense-graded HMA, open-graded HMA, and rubberized asphalt). Thus, there is no single value that covers all binder application in the district; the value is different for each binder type.

This study examined expected low and high temperatures for pavement binder specification in three future 30-year periods centered on the years 2025, 2055, and 2085. Per the Caltrans Highway Design Manual (HDM), the pavement design life for new construction and reconstruction projects shall be no less than 40 years. For roadside facilities, such as parking lots and rest areas, a 20-year pavement design life may be used. The design life of asphalt pavements is close to the 30-year analysis periods used in this report. Because asphalt overlays of different specifications are often used to prolong roadway life, they can be used as short-term actions until it is clear how climate conditions are changing.

LOCA climate data developed by Scripps were used for the analysis of future temperatures. The data were available at a spatial resolution of 1/16th of a degree or approximately three and a half to four miles,[33] This dataset was queried to determine the average absolute minimum temperature and the average maximum temperature over seven consecutive days. Temperature values were identified for each 30-year period. The values were derived separately for each of the 10 California-appropriate GCMs for both RCP 4.5 and 8.5 scenarios, and for the three time periods noted. The projected change in temperatures are shown in the following figures.

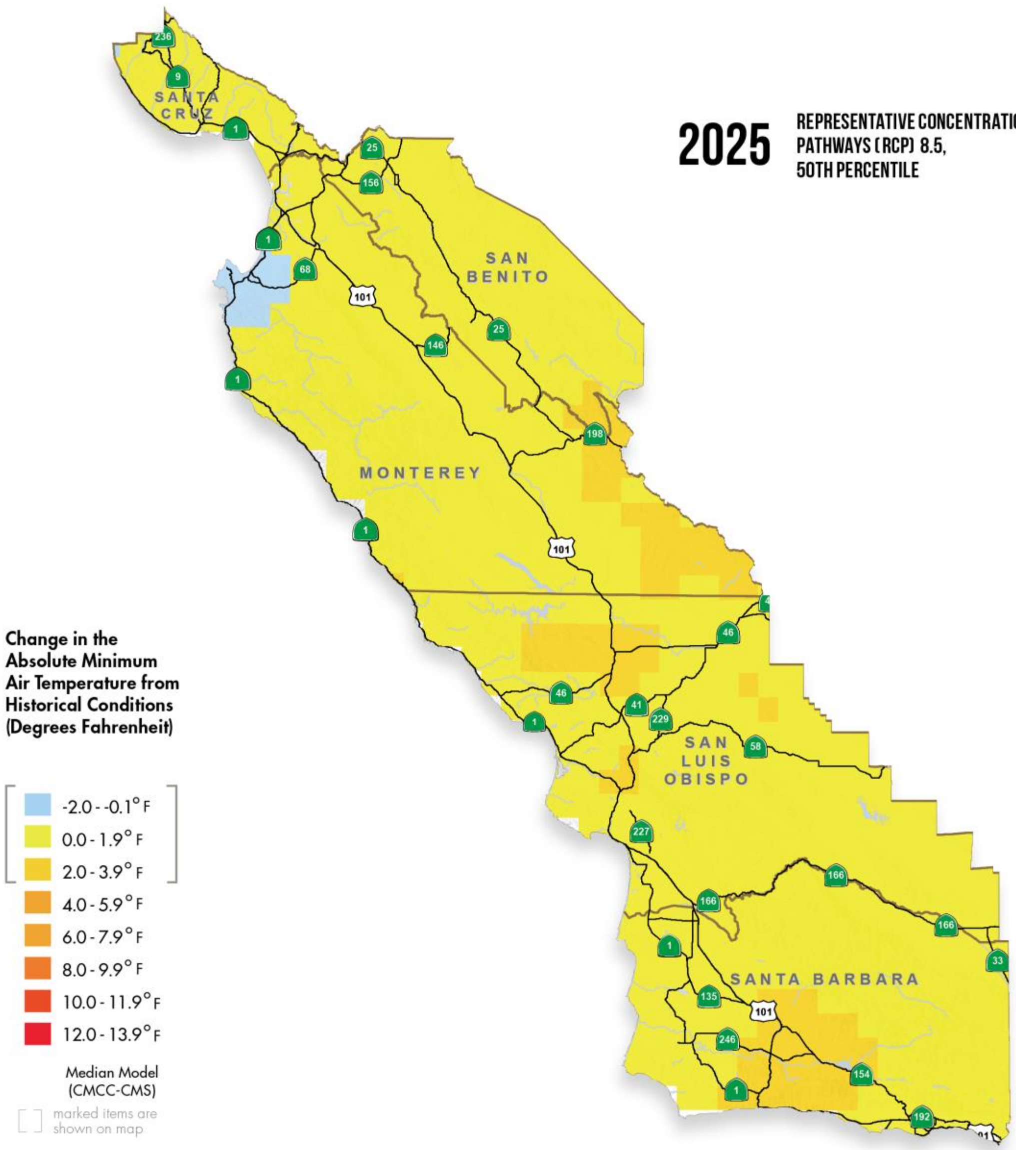
These figures show the median change across the state (the CMCC-CMS model), among all California-approved climate models for RCP 8.5 (data for RCP 4.5 was analyzed but for brevity is not shown here). The maps highlight the temperature change expected for both the high and low temperature metrics. Both temperature metrics increase over time, with the maximum temperature changes generally being greater than the minimum changes. Both temperature metrics increase over time with the maximum temperature changes generally being greater than the minimum changes. Some areas may experience change in the maximum temperature metric upwards of between 4 and 10 °F by the end of the century, depending on the area of the district. Finally, for both metrics, temperature changes are generally greater farther inland due to the moderating influence of the Pacific Ocean.

The projected changes shown in the following figures can be added to Caltrans' current source of historical temperature data to determine final pavement design value for future designs. Generally, this information can be used by Caltrans to identify how pavement design practices may need to shift over time given the expected changes in temperatures and help inform decisions on how to provide the best pavement quality for California SHS users.

[33] Cal-Adapt, "LOCA Downscaled Climate Projections," Last accessed May 16, 2019, https://cal-adapt.org/data/loca/

FIGURE 5: CHANGE IN THE ABSOLUTE MINIMUM AIR TEMPERATURE, 2025

CHANGE IN THE ABSOLUTE MINIMUM AIR TEMPERATURE



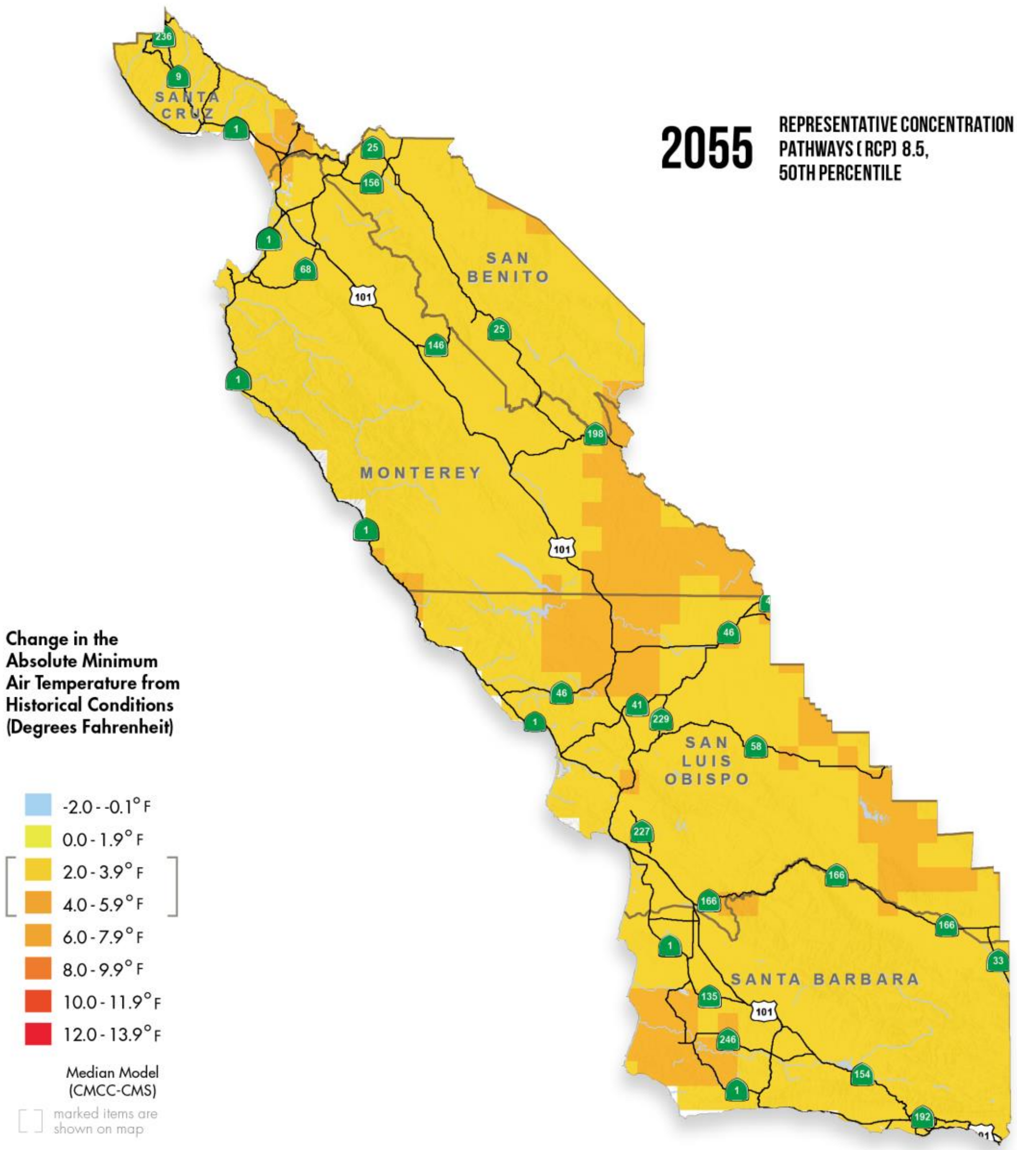
Future Change in the Absolute Minimum Air Temperature within District 5, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 5. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown was generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

Results represent the 50th percentile of downscaled climate model outputs under RCP 8.5 for the metric shown, as calculated across the state using the area weighted mean.

FIGURE 6: CHANGE IN THE ABSOLUTE MINIMUM AIR TEMPERATURE 2055

CHANGE IN THE ABSOLUTE MINIMUM AIR TEMPERATURE



Future Change in the Absolute Minimum Air Temperature within District 5, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 5. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown was generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

Results represent the 50th percentile of downscaled climate model outputs under RCP 8.5 for the metric shown, as calculated across the state using the area weighted mean.

FIGURE 7: CHANGE IN THE ABSOLUTE MINIMUM AIR TEMPERATURE 2085

Future Change in the Absolute Minimum Air Temperature within District 5, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 5. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown was generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

Results represent the 50th percentile of downscaled climate model outputs under RCP 8.5 for the metric shown, as calculated across the state using the area weighted mean.

FIGURE 8: CHANGE IN THE AVERAGE MAXIMUM TEMPERATURE OVER SEVEN CONSECUTIVE DAYS 2025

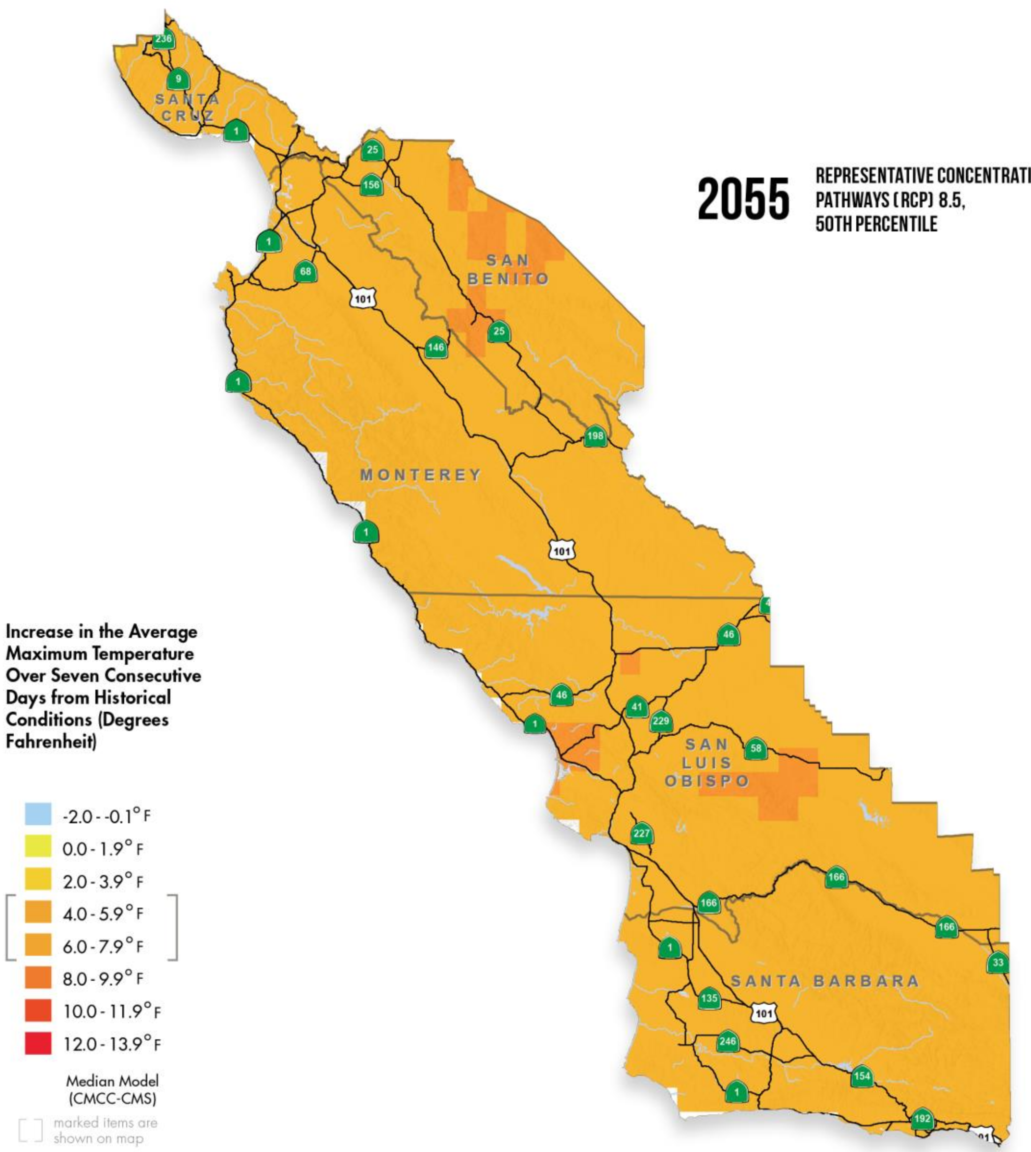
Future Change in the Average Maximum Temperature over Seven Consecutive Days within District 5, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 5. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown was generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

Results represent the 50th percentile of downscaled climate model outputs under RCP 8.5 for the metric shown, as calculated across the state using the area weighted mean.

FIGURE 9: CHANGE IN THE AVERAGE MAXIMUM TEMPERATURE OVER SEVEN CONSECUTIVE DAYS 2055

CHANGE IN THE AVERAGE MAXIMUM TEMPERATURE OVER SEVEN CONSECUTIVE DAYS A REQUIRED MEASURE FOR PAVEMENT DESIGN

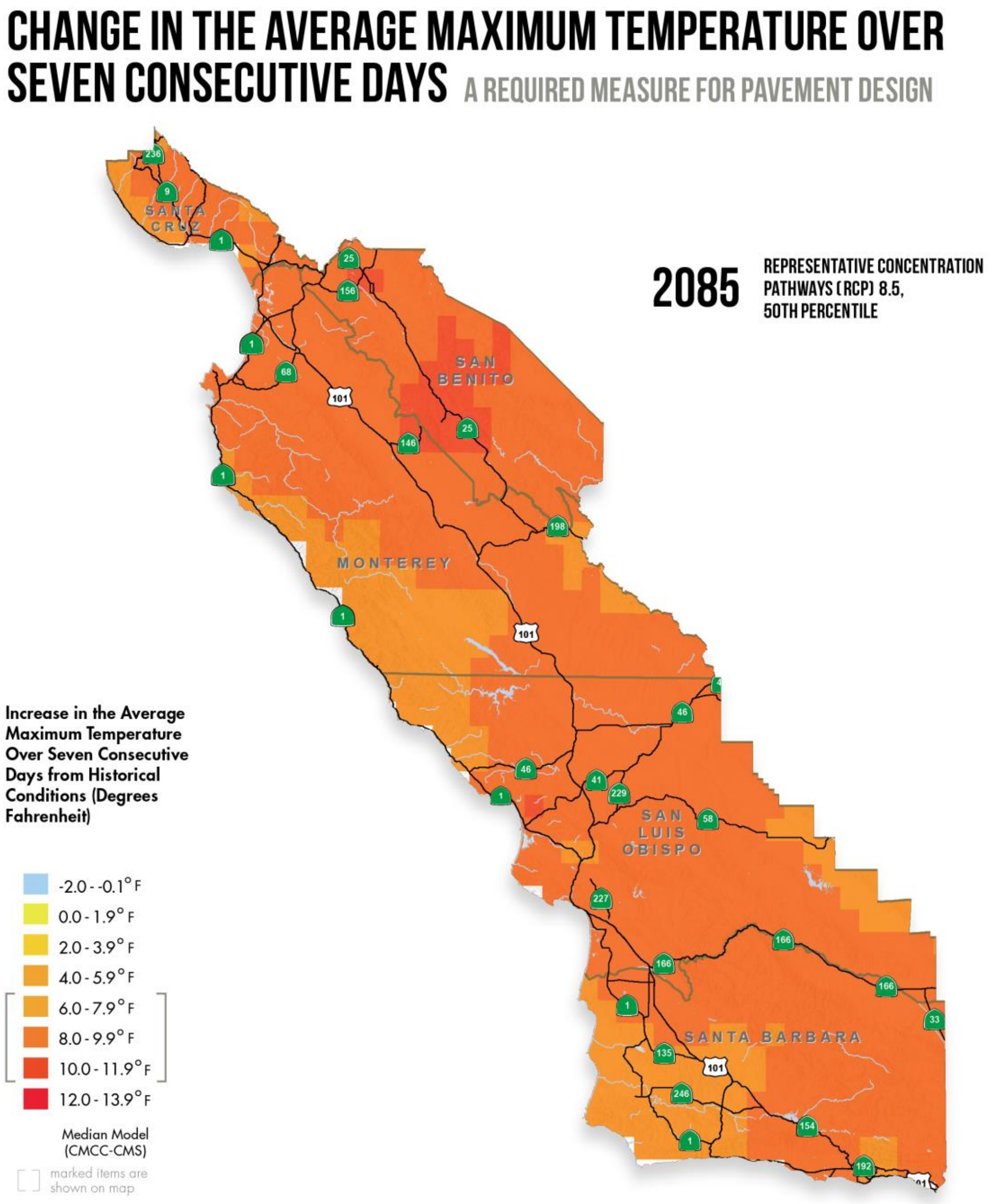


Future Change in the Average Maximum Temperature over Seven Consecutive Days within District 5, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 5. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown was generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

Results represent the 50th percentile of downscaled climate model outputs under RCP 8.5 for the metric shown, as calculated across the state using the area weighted mean.

FIGURE 10: CHANGE IN THE AVERAGE MAXIMUM TEMPERATURE OVER SEVEN CONSECUTIVE DAYS 2085



Future Change in the Average Maximum Temperature over Seven Consecutive Days within District 5, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 5. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown was generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

Results represent the 50th percentile of downscaled climate model outputs under RCP 8.5 for the metric shown, as calculated across the state using the area weighted mean.

5. PRECIPITATION

The Southwest region of the United States is expected to have less precipitation overall in the future[34], but with the potential for heavier individual events, with more precipitation falling as rainfall. This section of this report focuses on how heavy precipitation events may change and become more frequent and severe over time.

Analysis of future precipitation is, in many ways, one of the most challenging tasks in assessing long-term climate risk. Modeled future precipitation values can vary widely. Thus, analysis of trends is considered across multiple models to identify predicted values and help drive effective decisions. Future precipitation was analyzed through a broad range of potential effects predicted by a set, or ensemble, of models. There are several methodological challenges with using downscaled global climate model projections to derive estimations of future extreme precipitation events, addressable through vetted and available methods. Results should be compared across multiple models to conduct a robust assessment of how changing precipitation conditions may impact the highway system, and to make informed decisions.

Transportation assets in California are affected by precipitation in a variety of ways—from inundation/flooding, to landslides, washouts, or structural damage from heavy rain events. Current transportation design uses return period storm events as a variable to include in asset design criteria (e.g. for bridges or culverts). A return period storm event is the historical intensity of storms based on how often such level of storms have occurred in the past. A 100-year design standard is often applied in the design of transportation facilities and is cited as a design consideration in Section 821.3, Selection of Design Flood, in the *Caltrans Highway Design Manual*.[35] This metric was analyzed to determine how 100-year storm rainfall is expected to change, using best available precipitation projections available for the state.

The Scripps Institution for Oceanography, other academic institutions, and state agencies are working to better understand future precipitation projections. The most up-to-date precipitation research for the state was compiled as a part of California's Fourth Climate Change Assessment. Scripps and the researchers behind the Fourth Assessment developed daily rainfall data for a set of climate models, and RCPs 4.5 and 8.5, for every day to the year 2100. Climate change specialists from the study team worked with researchers from Scripps to estimate extreme precipitation changes over time. Specifically, the team requested precipitation datasets across the set of 10 international GCMs that were identified as having the best applicability for California, for both RCPs 4.5 and 8.5.

For this assessment, these raw datasets were then processed to provide the percent change in the 100-year storm precipitation depth over a 24-hour period. The historical data used to calculate the percentage changes are synthetic historical "backcasted" data from the climate models over the period 1950 to 2005.[36] Standard practice in climate science is to derive the percentage changes using backcasted historical modeled data and future projected modeled data. This mitigates against model

[34] Jerry Melillo, Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program, 841 pp. doi:10.7930/J0Z31WJ2. Last accessed August 25, 2019, https://www.nrc.gov/docs/ML1412/ML14129A233.pdf

[35] Caltrans, "Highway Design Manual," July 2, 2018, Last accessed August 23, 2019. http://www.dot.ca.gov/hq/oppd/hdm/hdmtoc.htm

[36] "Backcasted" data is when a GCM is ran in "reverse," or provides outputs for historical periods.

bias affecting the derivation of the percent change.

This newly processed data was analyzed for three time periods to determine how precipitation might change through the end of century. The years shown in the following figures represent the mid-points of the same 30-year statistical analysis periods used for the temperature metrics and explained in the Time Periods Section. To reiterate, these time periods are: 1) 2010 to 2039, where the mid-point year is 2025, 2) 2040 to 2069, where the mid-point year is 2055, and 3) 2070 to 2099, where the mid-point year is 2085.

The results of this assessment are shown in the District 5 maps below. The three maps depict the percentage change in the 100-year storm rainfall event predicted for the three analysis periods, and for the RCP 8.5 scenario (the RCP 4.5 results are not shown here). The median precipitation model (HadGEM2-CC) was used in this mapping. Note that the change in 100-year storm depth is positive throughout District 5, indicating heavier rainfall during storm events.

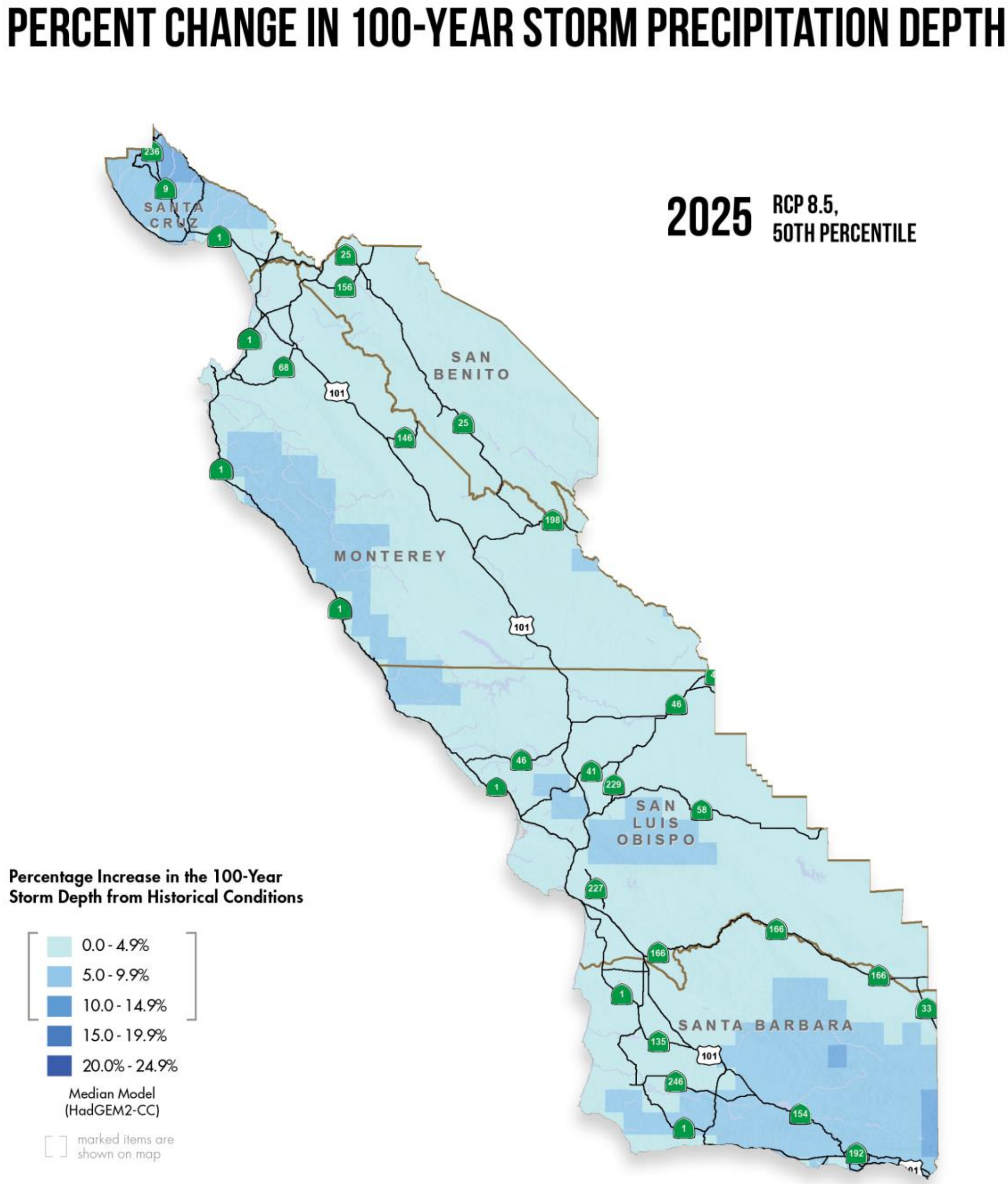
Heavy storm events could have serious implications for the SHS. Understanding those implications will help Caltrans engineers and designers implement designs that are more adaptive to changing conditions. That said, site-specific, hydrological analysis of flood flows is necessary to determine how future projections of precipitation will affect bridges and culverts. These site-specific analyses should consider a range of models and future conditions to determine the best possible responses.

The 100-year storm depth is projected to increase by anywhere from 0–15% in District 5 depending on the timeframe and location. The mountainous areas show higher precipitation increases. These changes could increase flash flood frequency. There are several mitigation efforts the district can use to reduce flooding and landslide risk, including changing drainage design requirements, using vegetation to reduce runoff, and building barriers to protect roadways from land or rockslides.

Indications of increased precipitation in District 5 mean that Caltrans must assume higher rainfall and associated flooding, and plan improvements to the SHS accordingly. This situation can be exacerbated by increased development, which reduces the natural absorption capacity of the land in drainage areas. Complex conditions like these require a longer-term view be considered for design and flood response for facilities in these areas to ensure that they remain operational to the end of their design lives. Improving long-term resiliency will require that Caltrans conduct a comprehensive assessment of future conditions and incorporate new values for precipitation in design.

At first glance, the precipitation increases may appear to conflict with the wildfire analysis, which shows that wildfire events are expected to increase due to drier conditions. However, precipitation conditions in California are expected to change so that there are more frequent drought periods, but heavier, intermittent rainfall. These heavy storm events may have implications for the SHS and understanding those implications may help Caltrans engineers and designers implement an adaptive design solution. That said, a hydrological analysis of flood flows is necessary to determine how this data will affect specific bridges and culverts.

FIGURE 11: PERCENT CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH 2025



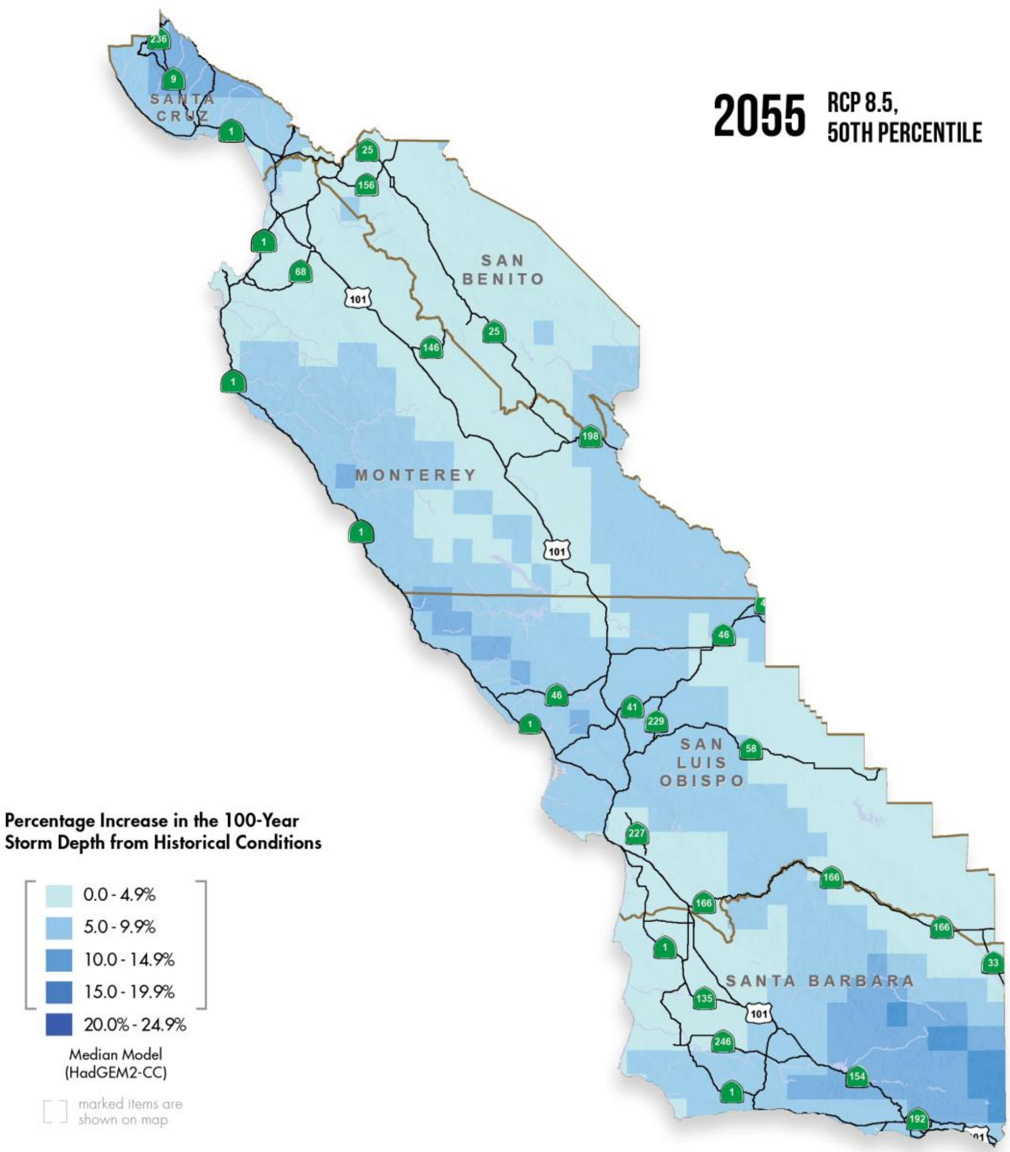
Future Percent Change in 100-year Storm Precipitation Depth within District 5, Based on the RCP 8.5 Emissions Scenario

Caltrans Transpotation Asset Vulnerability Study, District 5. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown were generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

Results represent the 50th percentile of downscaled climate model outputs under RCP 8.5 for the metric shown, as calculated across the state using the area weighted mean.

FIGURE 12: PERCENT CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH 2055

PERCENT CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH

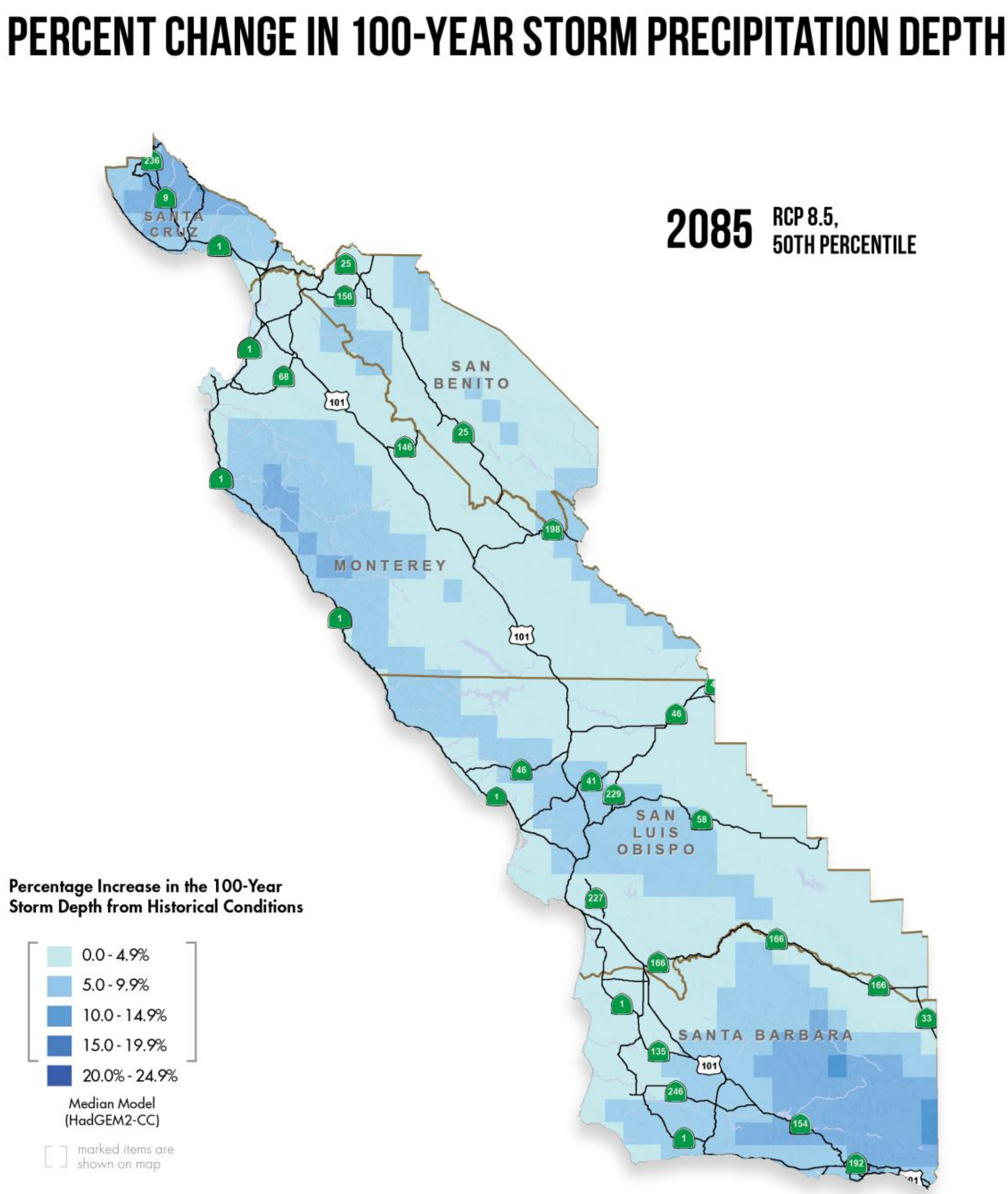


Future Percent Change in 100-year Storm Precipitation Depth within District 5, Based on the RCP 8.5 Emissions Scenario

Caltrans Transpotation Asset Vulnerability Study, District 5. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown were generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

Results represent the 50th percentile of downscaled climate model outputs under RCP 8.5 for the metric shown, as calculated across the state using the area weighted mean.

FIGURE 13: PERCENT CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH 2085



Future Percent Change in 100-year Storm Precipitation Depth within District 5, Based on the RCP 8.5 Emissions Scenario

Caltrans Transpotation Asset Vulnerability Study, District 5. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown were generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

Results represent the 50th percentile of downscaled climate model outputs under RCP 8.5 for the metric shown, as calculated across the state using the area weighted mean.

6. WILDFIRE

Increasing temperatures, changing precipitation patterns, and resulting changes to land cover, are expected to affect wildfire frequency and intensity. Human infrastructure, including the presence of electrical utility infrastructure, or other sources of fire potential (mechanical, open fire, accidental or intentional) may also influence the occurrence of wildfires. Wildfire is a direct concern for driver safety, system operations, and Caltrans infrastructure, among other issues.

Wildfires can indirectly contribute to:

- Landslide and flooding exposure, by burning off soil-stabilizing land cover and reducing the capacity of the soils to absorb rainfall.
- Wildfire smoke, which can affect visibility and the health of the public and Caltrans staff.

The years 2017 and 2018 were notable for the significant wildfires that occurred both in northern and southern California.[37] These devastating fires caused property damage, loss of life, and damage to roadways. The wildfires in many cases stripped the land of protective cover and damaged the soils, such that subsequent rainstorms led to disastrous debris flows that caused catastrophic damage to state highways in several locations. The costs to Caltrans for repairing such damage could extend over months for individual events and could require years of investment to maintain the viability of the SHS for its users. The conditions that contributed to these impacts, notably a wet rainy season followed by very dry conditions and heavy winds, are likely to occur again in the future as climate conditions change and storm events become more dynamic.

The information gathered and assessed to develop wildfire vulnerability data for District 5 included research on the effect of climate change on wildfire recurrence. This is of interest to several agencies, including the U.S. Forest Service (USFS), the Environmental Protection Agency (EPA) and the California Department of Forestry and Fire Protection (CalFire), who have developed their own models to understand the trends of future wildfires throughout the US and in California.

6.1. Ongoing Wildfire Modeling Efforts

Determining the potential impacts of wildfires on the SHS included coordination with other agencies that have developed wildfire models for various applications. Models used for this analysis included the following:

- **MC2 - EPA** Climate Impacts Risk Assessment (CIRA), developed by John Kim, USFS
- **MC2 - Applied Climate Science Lab (ACSL)** at the University of Idaho, developed by Dominique Bachelet, University of Idaho
- **University of California Merced model,** developed by Leroy Westerling, University of California Merced

[37] CalFire. "CalFire Statewide 2017 Incidents." Last accessed August 25, 2019. https://www.fire.ca.gov/incidents/2017

The MC2 models are second generation models, developed from the original MC1 model made by the USFS. The MC2 model is a Dynamic Global Vegetation Model, developed in collaboration with Oregon State University. This model considers projections of future temperature, precipitation and changes these factors will have on vegetation types/habitat area. The MC2 model outputs used for this assessment are from the current IPCC Coupled Model Intercomparison Project 5 (CMIP5) dataset. This model was applied in two different studies of potential wildfire impacts at a broader scale by researchers at USFS of the University of Idaho. The application of the vegetation model and the expectation of changing vegetation range/type is a primary factor of interest in the application of this model.

The second wildfire model used was developed by Leroy Westerling at the University of California, Merced. This statistical model was developed to analyze the conditions that led to past large fires (defined as over 1,000 acres) in California and uses these patterns to predict future wildfires. Inputs to the model included climate, vegetation, population density, and fire history. This model then incorporated future climate data and projected land use changes to project wildfire recurrence in California to the year 2100.

Each of these wildfire models used inputs from downscaled climate models to determine future temperature and precipitation conditions that are important for projecting future wildfires. The efforts undertaken by the EPA/USFS and UC Merced used the LOCA climate data set developed by Scripps, while the University of Idaho effort used an alternative downscaling method, the Multivariate Adaptive Constructed Analogs (MACA).

For the purposes of this report, these three available climate models will be identified from this point forward as:

- MC2 - EPA
- MC2 - ACSL
- UC Merced

6.2. Global Climate Models Applied

Each of the efforts used a series of GCM outputs to generate projections of future wildfire conditions. In this analysis, the project study team used the four recommended GCMs from Cal-Adapt for wildfire outputs (CAN ESM2, CNRM-CM5, HAD-GEM2-ES, MIROC5). In addition, all three of the modeling efforts used RCPs 4.5 and 8.5, representing realistic lower and higher ranges for future GHG emissions. Table 1 graphically represents the wildfire models and GCMs used in the assessment.

TABLE 1: WILDFIRE MODELS AND ASSOCIATED GCMS USED IN WILDFIRE ASSESSMENT

Wildfire Models								
MC2 - EPA			MC2 - ACSL			UC Merced		
CAN ESM2	HAD-GEM2-ES	MIROC5	CAN ESM2	HAD-GEM2-ES	MIROC5	CAN ESM2	HAD-GEM2-ES	MIROC5

6.3. Analysis Methods

The wildfire projections for all model data were developed for the three future 30-year time periods used in this study (median years of 2025, 2055, and 2085). These median years represent 30-year averages, where 2025 is the average between 2010 and 2039, and so on. These are represented as such on the wildfire maps that follow.

The wildfire models produce geospatial data in raster format, which is data that is expressed in individual “cells” on a map. The final wildfire projections for this effort provides a summary of the percentage of each of these cells that burns for each time period. The raster cell size applied is 1/16th of a degree square for the MC2 - EPA and UC Merced models, which matches the grid cell size for the LOCA climate data applied in developing these models. The MC2 - ACSL effort generated data at 1/24th of a degree square, to match the grid cells generated by the MACA downscaling method.

The model data was collected for all wildfire/GCM combinations, for each year to the year 2100. Lines of latitude (the east to west lines on the globe) are essentially evenly spaced when measuring north to south; however, lines of longitude (the north-south lines on the globe, used to measure east-west distances) become more tightly spaced as they approach the poles, where they eventually converge. Because of this, the cells in the wildfire raster are rectangular instead of square and are of different sizes depending on where one is (they are shorter when measured east-west as you go farther north). The study team ultimately summarized the data into the 1/16th grid to enable comparisons and to summarize across multiple models. The resulting area contained within these cells ranged in area between roughly 8,000 and 10,000 acres for grid cells sizes that are 6 kilometers on each side.

An initial analysis of the results of the wildfire models for the same time periods for similar GCMs noted differences in the outputs of the models, in terms of the amount of burn projected for various cells. This difference could be caused by any number of factors, including the assumption of changing vegetation that is included in the MC2 models, but not in the UC Merced/Westerling model.

6.4. Categorization and Summary

The final method selected to determine future wildfire risks throughout the state takes advantage of the presence of three modeled datasets to generate a broader understanding of future wildfire exposure in California. The project team determined this would provide a more robust result than applying only one of the available wildfire models. A cumulative total of percentage cell burned was developed for each cell in the final dataset. This data is available for future application by Caltrans and their partners.

As a means of establishing a level of concern for wildfire impacts, a classification was developed based on the expected percentage of cell burned. The classification is as follows:

- Very Low 0-5%,
- Low 5-15%,
- Medium 15-50%,
- High 50-100%,

- Very High 100%+.[38]

Thus, if a cell were to show a complete burn or higher (8,000 to 10,000 acres+) over a 30-year period, that cell was identified as a very high wildfire exposure cell. Developing this categorization method included removing the CNRM-CM5 data point from the MC2 - University of Idaho and UC Merced/Westerling datasets to have three consistent points of data for each cell in every model. This was done to provide a consistent number of data points for each wildfire model.

Next, the project study team looked at results across all models to see if any one wildfire model/GCM model combination indicated a potential exposure concern in each grid cell. The categorization for any one cell in the summary identifies the highest categorization for that cell across all nine data points analyzed. For example, if a wildfire model result identified the potential for significant burn in any one cell, the final dataset reflects this risk. This provides Caltrans with a more conservative method of considering future wildfire risk.

Finally, the project study team assigned a score for each cell where there is relative agreement on the categorization across all the model outputs. An analysis was completed to determine whether 5 of the 9 data points for each cell (a simple majority) were consistent in estimating the percentage of cell burned for each 30-year period.

The figures on the following pages show the results of this analysis, using the classification scheme explained above. These figures show projections for RCP 8.5 only and red highlights show portions of the Caltrans SHS that are likely to be most exposed to wildfire. The tables summarize the miles of District 5 SHS that are exposed to Medium to Very High wildfire risk, by District 5 county.

The more-densely forested areas in the northern portion of the district have the highest wildfire risk, with the greatest occurring in central forested areas of the district. District 5 can mitigate wildfire risk in these areas by using fire-resistant materials and maintaining defensible space for district assets and using fire-safe landscaping along roadways. The district can also limit wildfire concern by actively reducing fuel through dead or diseased tree removal, thinning practices, and coordinating with/supporting partner agencies such as CalFire and the US Forest Service.

[38] A cell can have greater than 100 percent burned if burned twice or more in the same time period.

TABLE 2: CENTERLINE MILES EXPOSED TO MEDIUM TO VERY HIGH WILDFIRE CONCERN UNDER RCP 8.5

District 5 County	2025			2055			2085		
	Med	High	Very High	Med	High	Very High	Med	High	Very High
Monterey	122	29	3	34	137	7	44	124	22
Santa Barbara	113	48	4	113	58	4	93	77	4
San Benito	17	21	25	16	35	13	4	59	0
Santa Cruz	27	17	0	16	32	34	4	38	57
San Luis Obispo	234	78	22	128	179	33	170	172	8
District 5 Totals by Level of Concern and Year	**514**	**193**	**54**	**306**	**440**	**91**	**315**	**469**	**90**
District 5 Total by Year	**761**			**837**			**875**		

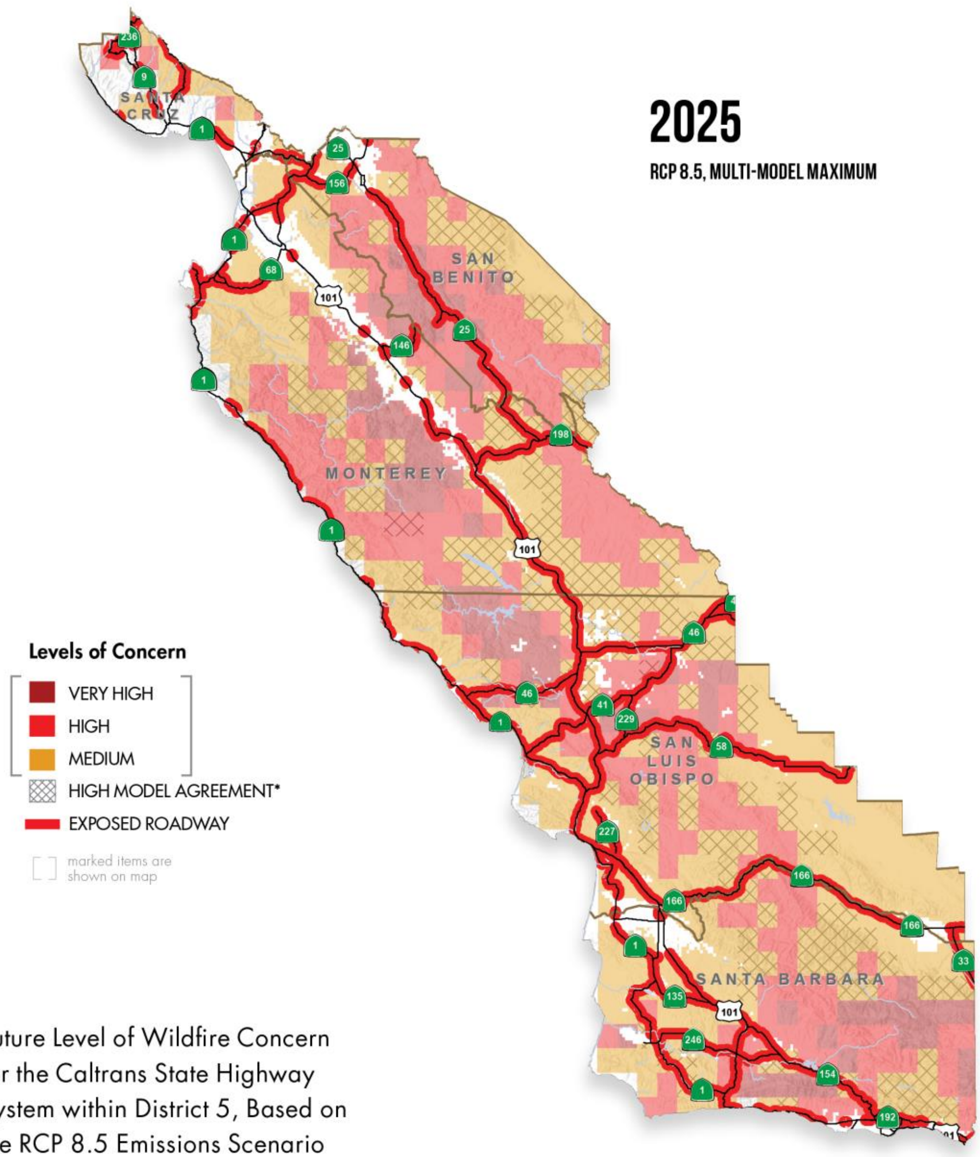
TABLE 3: CENTERLINE MILES EXPOSED TO MEDIUM TO VERY HIGH WILDFIRE CONCERN UNDER RCP 4.5

District 5 County	2025			2055			2085		
	Med	High	Very High	Med	High	Very High	Med	High	Very High
Monterey	164	27	5	151	44	8	154	50	0
Santa Barbara	144	30	4	131	42	4	123	50	4
San Benito	17	22	25	34	24	6	17	47	0
Santa Cruz	34	31	0	20	45	0	28	53	1
San Luis Obispo	232	94	21	225	110	10	237	99	4
District 5 Totals by Level of Concern and Year	**590**	**203**	**54**	**561**	**266**	**28**	**558**	**298**	**9**
District 5 Total by Year	**848**			**855**			**865**		

NOTE: MILEAGES REPORTED DO NOT INCLUDE LOCAL ROADS.

FIGURE 14: INCREASE IN WILDFIRE EXPOSURE 2025

LEVEL OF WILDFIRE CONCERN



Future Level of Wildfire Concern for the Caltrans State Highway System within District 5, Based on the RCP 8.5 Emissions Scenario

The fire model composite summaries shown are based on wildfire projections from three models: (1) MC2 - EPA Climate Impacts Risk Assessment, developed by John Kim, USFS; (2) MC2 - Applied Climate Science Lab at the University of Idaho, developed by Dominque Bachelet, University of Idaho; and (3) University of California Merced model, developed by Leroy Westerling, University of California Merced. For each of these wildfire models, climate inputs were used from three Global Climate Models: (1) CAN ESM2; (2) HAD-GEM2-ES; and (3) MIROC5. The maps show the multi-model maxima for each grid cell across the nine combinations of the three fire models and the three GCMs.

Areas in white do not necessarily mean there is no wildfire risk, only that the risk classification is below moderate. More information on models used and the classifications for levels of concern can be found in the associated Technical Report.

* The hashing shows areas where 5 or more of the 9 models fall under the same cumulative % burn classification as the one shown on the map.

FIGURE 15: INCREASE IN WILDFIRE EXPOSURE 2055

LEVEL OF WILDFIRE CONCERN

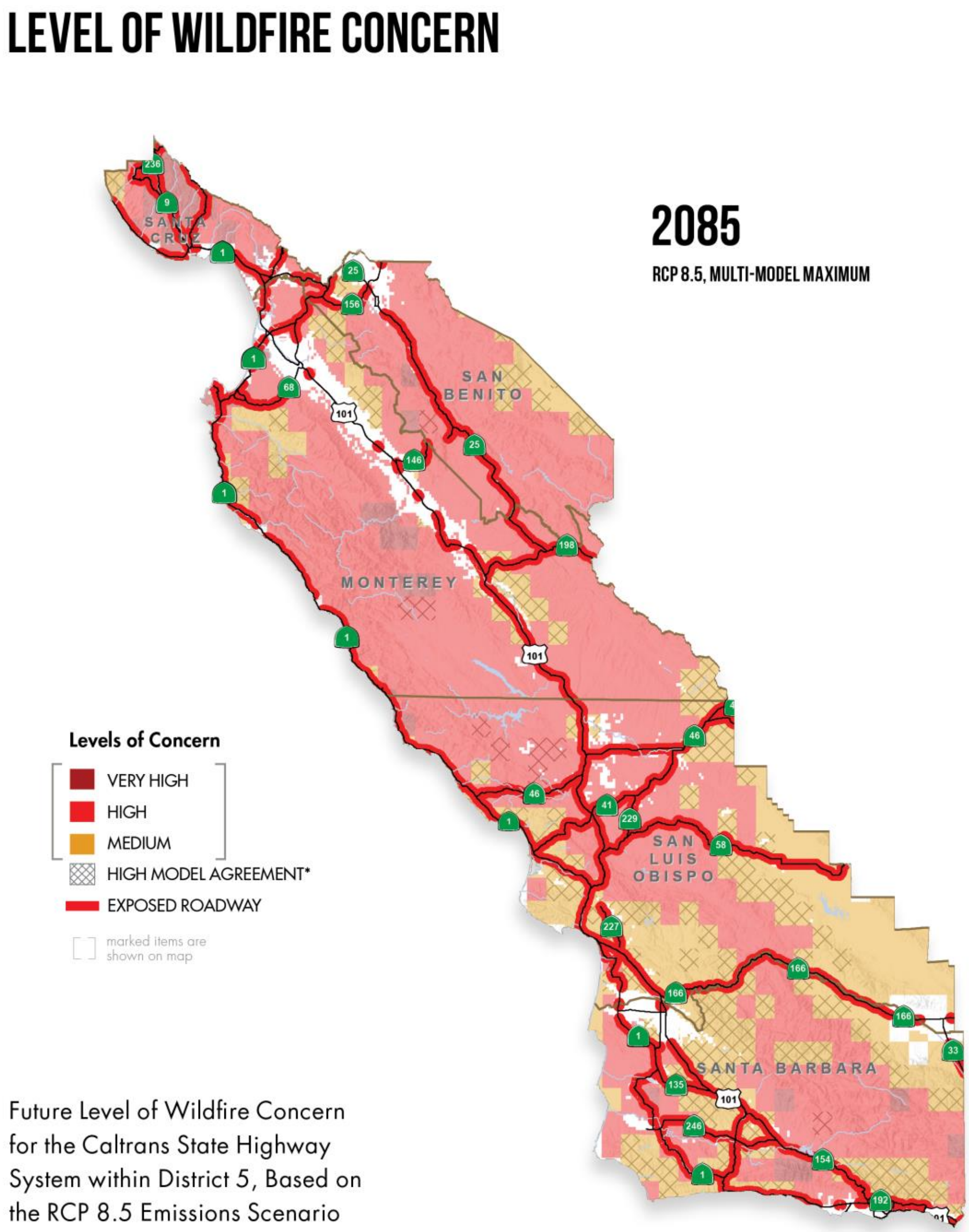
Future Level of Wildfire Concern for the Caltrans State Highway System within District 5, Based on the RCP 8.5 Emissions Scenario

The fire model composite summaries shown are based on wildfire projections from three models: (1) MC2 - EPA Climate Impacts Risk Assessment, developed by John Kim, USFS; (2) MC2 - Applied Climate Science Lab at the University of Idaho, developed by Dominque Bachelet, University of Idaho; and (3) University of California Merced model, developed by Leroy Westerling, University of California Merced. For each of these wildfire models, climate inputs were used from three Global Climate Models: (1) CAN ESM2; (2) HAD-GEM2-ES; and (3) MIROC5. The maps show the multi-model maxima for each grid cell across the nine combinations of the three fire models and the three GCMs.

Areas in white do not necessarily mean there is no wildfire risk, only that the risk classification is below moderate. More information on models used and the classifications for levels of concern can be found in the associated Technical Report.

* The hashing shows areas where 5 or more of the 9 models fall under the same cumulative % burn classification as the one shown on the map.

FIGURE 16: INCREASE IN WILDFIRE EXPOSURE 2085



The fire model composite summaries shown are based on wildfire projections from three models: (1) MC2 - EPA Climate Impacts Risk Assessment, developed by John Kim, USFS; (2) MC2 - Applied Climate Science Lab at the University of Idaho, developed by Dominque Bachelet, University of Idaho; and (3) University of California Merced model, developed by Leroy Westerling, University of California Merced. For each of these wildfire models, climate inputs were used from three Global Climate Models: (1) CAN ESM2; (2) HAD-GEM2-ES; and (3) MIROC5. The maps show the multi-model maxima for each grid cell across the nine combinations of the three fire models and the three GCMs.

Areas in white do not necessarily mean there is no wildfire risk, only that the risk classification is below moderate. More information on models used and the classifications for levels of concern can be found in the associated Technical Report.

* The hashing shows areas where 5 or more of the 9 models fall under the same cumulative % burn classification as the one shown on the map.

7. SEA LEVEL RISE

The datasets considered for this analysis came from the Ocean Protection Council (OPC) and the National Oceanic and Atmospheric Administration (NOAA). The OPC developed a new set of sea level rise projections and scenarios for the state, which were chosen for consideration in this analysis to follow state guidance on sea level rise planning and use the best available sea level rise projections.[39] These projections were paired with a NOAA sea level rise model to identify approximately when potential impacts to the SHS might occur in District 5. The OPC projections and the NOAA sea level rise model used are explained in more detail in the following section.

7.1. State of California Sea Level Rise Guidance: 2018 Update

Estimates of sea level rise have been developed for California by various agencies and research institutions. Figure 17 below reflects estimates recently developed for the Port San Luis, CA tide gauge by a scientific panel for the 2018 Update of the State of California Sea-Level Rise Guidance, an effort led by the OPC. These projections were developed for gauges along the California coast based on global and local factors that drive sea level rise such as thermal expansion of ocean water, glacial ice melt, and the expected amount of vertical land movement.

Sea level rise projection scenarios in the OPC guidance identify several values or ranges, including:

- A median (50%) probability scenario
- A likely (66%) probability scenario
- A 1-in-20 (5%) probability scenario
- A low (0.5%) probability scenario
- An extreme (H++) scenario to be considered when planning for critical or highly vulnerable assets with a long lifespan

Each of these values are presented for low (RCP 2.6) and high (RCP 8.5) emissions pathways to provide information on the full range of potential projections over time. The OPC recommends using only RCP 8.5 for projects that have a lifespan to 2050, and using both scenarios for projects with longer lifespans. The OPC also recommends assessing a range of future projections before making decisions on projects, given the uncertainty inherent in modeling inputs. Guidance is provided for when best to consider certain projections, given the risks associated with projects of varying type:

- For low risk aversion decisions, the OPC recommends using the likely (66%) probability sea level rise range. In the graphic to the right, this range is shaded in light blue for the RCP 8.5 scenario and is shaded in light green for RCP 2.6.
- For medium to high risk aversion decisions, the OPC recommends using the low (0.5%) probability scenario. This value is shown in dark green for RCP 2.6 and in dark blue for RCP 8.5 in the graphic to the right.

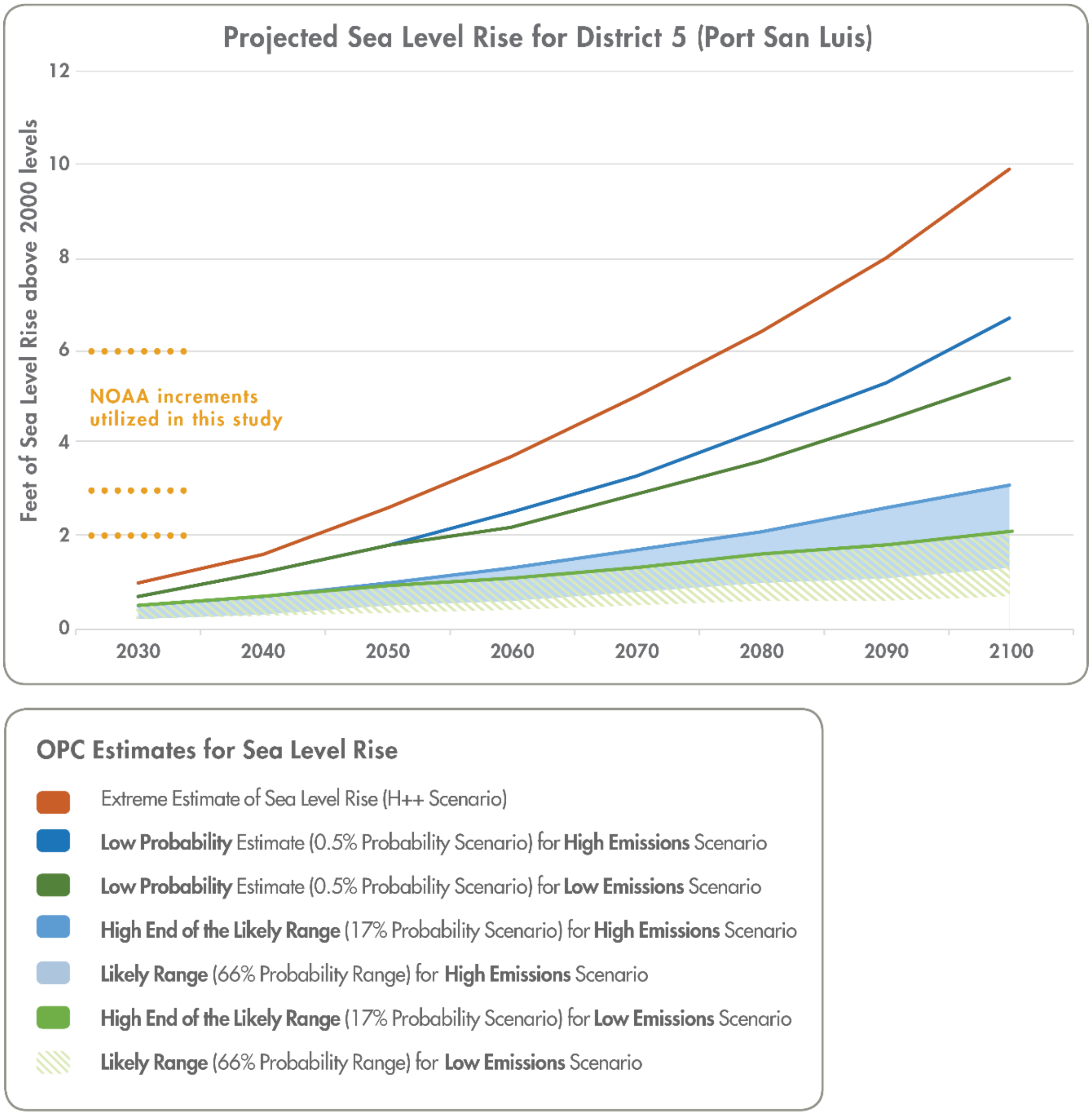
[39] California Ocean Protection Council (OPC). 2018. "State of California Sea-Level Rise Guidance: 2018 Update." Last accessed July 3, 2019. http://www.opc.ca.gov/webmaster/ftp/pdf/agenda_items/20180314/Item3_Exhibit-A_OPC_SLR_Guidance-rd3.pdf

- For high risk aversion decisions, the OPC recommends considering the extreme (H++) scenario. This projection is shown in dark orange in the graphic to the right.

This guidance was developed by the OPC to help state and local governments understand future risks associated with sea level rise and incorporate these projections into work efforts, investment decisions, and policy mechanisms. Given varying rates of subsidence and highway uplift in District 1 and given that many highway structures will last for many decades, planners and analysts need to carefully consider likely future sea levels depending on where the project is located along the coast. The Coastal Commission is recommending that projects be planned for the Medium-High Risk Aversion and the Extreme Risk Aversion/H++ scenarios. This is a good place to begin an analysis, but as noted varying rates of subsidence need to be considered as well.

The OPC recognizes that the science surrounding sea level rise projections is still improving and anticipates updating their guidance at least every five years. Given that new findings are inevitable, Caltrans will use best-available sea level rise modeling, projections, and guidance as the science evolves over time.

FIGURE 17: OPC 2018 SEA LEVEL RISE PROJECTIONS FOR PORT SAN LUIS, CA



7.2. NOAA Model Used

The previous section described estimated sea level rise levels from the OPC and the guidance for using them; this section discusses the NOAA model used in this study alongside these projections. The model data can be viewed and downloaded from the *NOAA Sea Level Rise Viewer.*[40] The NOAA Office for Coastal Management developed the data to provide coastal managers and scientists with a preliminary view of sea level rise and coastal flooding impacts across the United States.

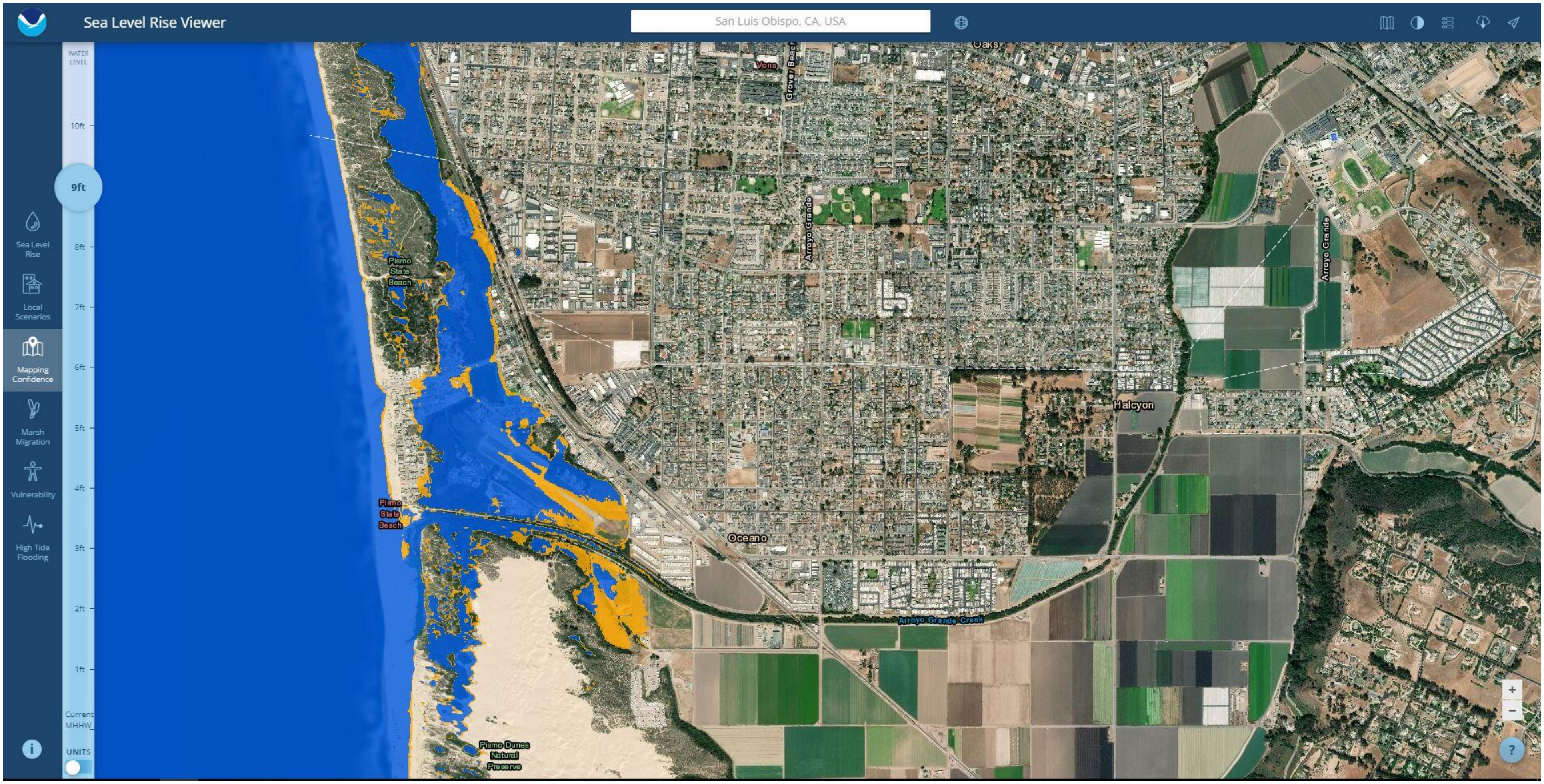
The NOAA data is available in GIS shapefiles for sea level rise from one to ten feet above mean higher high water (MHHW). Each of these increments was used in this study to assess vulnerability to the SHS. However, the analysis presented in this report is specific to three increments of sea level rise: two, three, and six feet. See Figure 17 to identify approximately when the OPC sea level rise scenarios will reach these sea level rise heights and note the large range between projections for each height. For example, six feet of sea level rise may be reached as soon as around 2075, or as late as 2100 or later.

The NOAA data was developed through a modified bathtub approach that accounts for regional variability such as tidal patterns and hydrological connectivity.[41] NOAA used a Digital Elevation Model (DEM) to identify the base land elevation, which they added subsequent sea level rise heights on top of to identify areas that would be permanently inundated from sea level rise. The dataset also includes accompanying low-lying polygons for each level of sea level rise, which indicate areas that are low-lying enough to flood, but there is currently a barrier that prevents inundation as identified in the DEM.

More details on the NOAA sea level rise data can be accessed through: https://coast.noaa.gov/sea level risedata/. See Figure 18 for a screenshot of the online NOAA sea level rise viewer.

[40] Our Coast Our Future can be accessed here: http://ourcoastourfuture.org/
[41] The model does not account for erosion, subsidence, or any future changes in an area's hydrodynamics.

FIGURE 18: NOAA SEA LEVEL RISE VIEWER

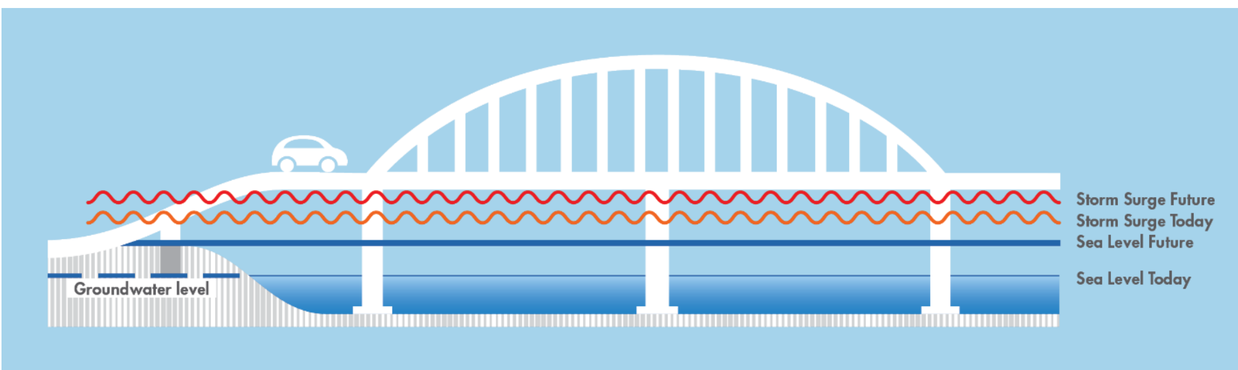


7.3. Bridge Exposure

When considering bridge exposure to sea level rise, it is important to note that facilities are typically designed based on historical data as opposed to future projections. Changes in baseline conditions due to sea level rise or storm surge may make a facility more vulnerable to damage. Bridge deck flooding is an obvious concern from sea level rise and storm surge, but there are other risks posed to bridges that need to be considered. For example, changing water levels can cause groundwater changes that may destabilize bridge columns or approaches. The full list of concerns includes:

1. A rising groundwater table may inundate supports on land that were not built to accommodate saturated soil conditions leading to erosion of soils and loss of stability.
2. Higher sea levels mean greater forces on the bridge during normal tidal processes, increasing scour effects on bridge structure elements.
3. Higher water levels mean that storm surge will be higher and have more force than today. These forces would potentially impact scour on bridge substructure elements.
4. Bridge road approaches where the roadway transitions to the bridge deck may become exposed to surge forces and may become damaged during storms.
5. Surge and wave effects may loosen or damage portions of the bridge, requiring securing, re-attaching or replacing those parts.

FIGURE 19: BRIDGE EXPOSURE



For these reasons, Caltrans has decided to define all bridges that are in the path of sea level rise and storm surge as “exposed” for the time being. Site-specific analysis will be needed to parse out which bridges are safe from future sea level rise impacts and which ones may be at-risk.

7.4. Sea Level Rise Analysis Results in District 5

The figures on the following pages depict the 2 ft (0.60 m), 3 ft (0.91 m), and 6 ft (1.83 m) increments, and indicate District 5 roadways at risk of permanent inundation or exposure from higher sea levels. The term “inundation” is used to describe sea level rise in this section, as these areas may be permanently inundated, whereas areas identified in the storm surge section may temporarily flood. Slightly different language is used between these sections to make this distinction. As noted, more detailed, site-specific analysis will be necessary to determine if areas will be overtopped and permanently inundated, especially for bridges.

TABLE 4: DISTRICT 5 HIGHWAY CENTERLINE MILES VULNERABLE TO SEA LEVEL RISE

	Sea Level Rise		
District 5	**2 ft (0.60 m)**	**3 ft (0.91 m)**	**6 ft (1.83 m)**
Monterey	0.3	0.4	2.0
Santa Barbara	0.0	0.0	0.1
Santa Cruz	0.0	0.0	0.0
San Luis Obispo	0.0	0.0	0.3
Total	**0.3**	**0.5**	**2.5**

NOTE: VERY SMALL PORTIONS OF THE HIGHWAY SYSTEM ARE VULNERABLE TO SEA LEVEL RISE IN SANTA BARBARA, SANTA CRUZ, AND SAN LUIS OBISPO COUNTIES. MILEAGES REPORTED DO NOT INCLUDE LOCAL ROADS.

FIGURE 20: INUNDATION FROM 2 FEET (0.60 M) OF SEA LEVEL RISE

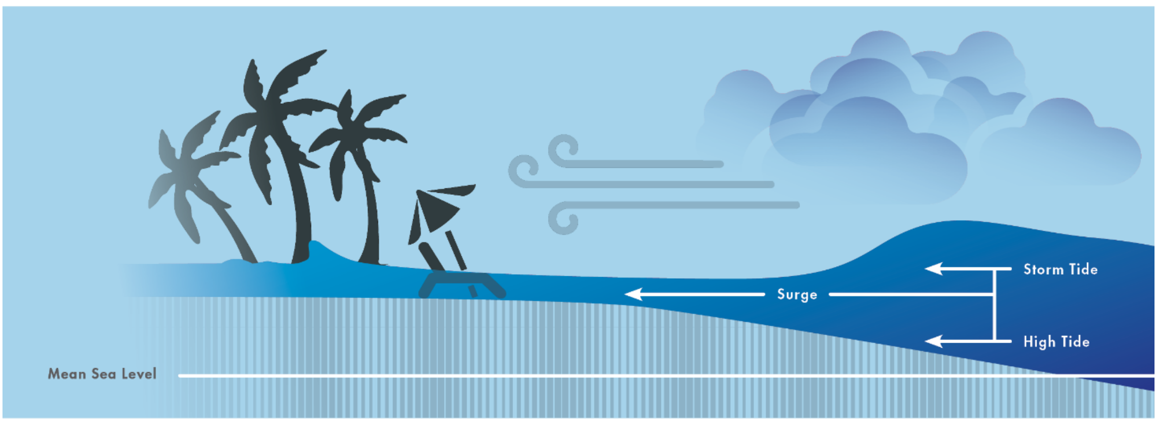
FIGURE 21: INUNDATION FROM 3 FEET (0.91 M) OF SEA LEVEL RISE

FIGURE 22: INUNDATION FROM 6 FEET (1.83 M) OF SEA LEVEL RISE

8. STORM SURGE

Rising seas translate into more water in motion during storm surge events that potentially increase long-term risks to infrastructure. Estimates of future storm surge must consider the impact of new storm types resulting from climate change, that is, the possible effect on storm intensities from a warming ocean or atmosphere. Figure 23 identifies the basic elements of storm surge and how it is different from normal tidal conditions. The graphic, supplied by NOAA and edited for this study, shows the effect and movement of surge over the land and the additional concern of waves at the shoreline.

FIGURE 23: EXAMPLE OF STORM SURGE COMPARED TO TIDES



SOURCE: NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

The sea level rise CalFloD-3D model (also referred to as the 3Di model)42 available from Cal-Adapt was used to predict flooding assuming sea level rise of 0.50 m (1.64 ft), 1.00 m (3.28 ft), and 1.41 m (4.62 ft), along with a near 100-year storm. Figure 24 to Figure 26 show the threatened areas along the SHS in District 5. Table 5 summarizes the centerline miles of the Caltrans District 5 SHS that could flood with sea level rise and during a 100-year storm event.

TABLE 5: DISTRICT 5 HIGHWAY CENTERLINE MILES VULNERABLE TO SEA LEVEL RISE AND A 100-YEAR STORM EVENT

	Sea Level Rise		
District 5	**1.64 ft (0.50 m)**	**3.28 ft (1.00 m)**	**4.62 ft (1.41 m)**
Monterey	2.5	3.3	12.5
Santa Barbara	0.2	0.2	0.7
Santa Cruz	0.0	0.0	0.2
San Luis Obispo	0.0	0.1	0.5
Total	**2.7**	**3.5**	**13.9**

NOTE: MILEAGES REPORTED DO NOT INCLUDE LOCAL ROADS.

[42] Cal-Adapt. 2019. "Sea Level Rise CalFloD-3D." Last accessed August 23, 2019, https://cal-adapt.org/data/slr-calflod-3d/

FIGURE 24: FLOODING FROM 1.64 FEET (0.50 M) OF SEA LEVEL RISE AND A 100-YEAR STORM EVENT

SEA LEVEL RISE AND 100-YEAR STORM DATA ARE FROM UC BERKELEY AND AVAILABLE ON CAL-ADAPT.

FIGURE 25: FLOODING FROM 3.28 FEET (1.00 M) OF SEA LEVEL RISE AND A 100-YEAR STORM EVENT

SEA LEVEL RISE AND STORM SURGE IMPACTS IN DISTRICT 5

3.28 FT (1.00 M)

SEA LEVEL RISE AND 100-YEAR STORM DATA ARE FROM UC BERKELEY AND AVAILABLE ON CAL-ADAPT.

FIGURE 26: FLOODING FROM 4.62 FEET (1.41 M) OF SEA LEVEL RISE AND A 100-YEAR STORM EVENT

SEA LEVEL RISE AND 100-YEAR STORM DATA ARE FROM UC BERKELEY AND AVAILABLE ON CAL-ADAPT.

9. CLIFF RETREAT

The 1,100-mile California coastline, shaped by various forces over time, is well known for its active areas of erosion, landslides, and cliff retreat. Estimates from a recent coastline study estimated that approximately 72 percent of the California coast has eroding coastal cliffs[43] due to the various forces at play in these areas, including the effects of ocean wave energy on beaches and cliffs. Another study documenting past cliff erosion rates statewide noted that highest rates were found in San Onofre, Portuguese Bend, Palos Verdes, Big Sur, Martins Beach, Daly City, Double Point, and Point Reyes.[44]

The areas where land and oceans meet in California are some of the most highly valued in the country, and many of its vistas, communities, and infrastructure are recognizable worldwide. These areas serve as an important resource for state residents and visitors alike. The management of these areas has been an ongoing effort of many agencies, most notably the California Coastal Commission.

As noted in earlier sections, climate change is anticipated to result in higher sea levels, resulting in more regular inundation, higher tides, and an increase in wave forces during coastal storms. The effects of these tidal and storm events are anticipated to stretch farther inland, with greater water and wave penetration than what has been observed and planned for in the past.

The impact of erosion and cliff retreat on transportation infrastructure is a significant concern given the potential of the erosion of the soil foundation for roads and bridges. Caltrans already acts in many coastal areas to protect transportation infrastructure, and the designation of those assets at risk from this effect is a concern for long term planning and design decisions. The implications of cliff retreat will be even more important if the infrastructure footprint is to be maintained, requiring actions to protect infrastructure from further encroachment.

Research has been conducted on the implications of climate change and the higher water levels on the California coastal environment, including a preliminary assessment of the potential effect on shorelines and cliffs. The USGS completed a multi-year study to develop three-dimensional survey information for current coastal conditions using Light Detection and Ranging (LIDAR) technology. This effort was the first of a series of efforts undertaken to develop a greater understanding of future sea level rise and how tidal and storm surge forces may reshape the coastline. One outcome of this effort was the development of the Coastal Storm Modeling System (CoSMoS) model applied in this assessment.

For the Central Coast and Southern California, an updated version of the CoSMoS dataset was used to estimate erosion and cliff retreat, in addition to sea level rise and storm surge effects. As noted in the information provided in the technical documentation that accompanies the CoSMoS data: “As sea level rises, waves break closer to the sea cliff, more wave energy impacts the cliffs, [and] cliff erosion rates

[43] Cheryl Hapke & David Reid, “National Assessment of Shoreline Change, Part 4: Historical Coastal Cliff Retreat along the California Coast,” U.S. Geological Survey Open-file Report 2007-1133, 2007, Last accessed June 20, 2019. https://pubs.usgs.gov/of/2007/1133/of2007-1133.pdf

[44] University of California San Diego, “Study Identifies California Cliffs at Risk of Collapse,” December 20, 2017, Last accessed August 24, 2019. https://phys.org/news/2017-12-california-cliffs-collapse.html

accelerate."[45] The USGS effort developed two estimates of the future assuming two different conditions – one which included armoring the coast (known as "hold the line"), and one which assumed that cliff retreat continues unimpeded (known as "do not hold the line").[46]

An analysis was conducted to identify which District 5 SHS highways might be impacted by cliff retreat. The analysis was conducted using CoSMoS for all available sea level rise scenarios (zero to 16.4 feet). The heights presented in this report are 1.64, 3.28, and 5.74 feet (0.50, 1.00, and 1.75 meters, respectively). For this analysis, the "do not hold the line" condition was used to identify areas along the coastline that would erode from sea level rise if not protected and/or hardened. The figures on the following page show the results of this analysis. Table 6 summarizes the mileage of the District 5 SHS that may be eroded or otherwise affected by cliff retreat.

TABLE 6: DISTRICT 5 HIGHWAY CENTERLINE MILES EXPOSED TO CLIFF RETREAT

	Sea Level Rise		
District 5	**1.64 ft (0.50 m)**	**3.28 ft (1.00 m)**	**5.75 ft (1.75 m)**
Monterey	4.0	6.3	8.3
Santa Barbara	0.2	0.7	1.5
Santa Cruz	0.5	0.9	0.9
San Luis Obispo	0.8	1.2	1.7
Total	**5.5**	**9.0**	**12.4**

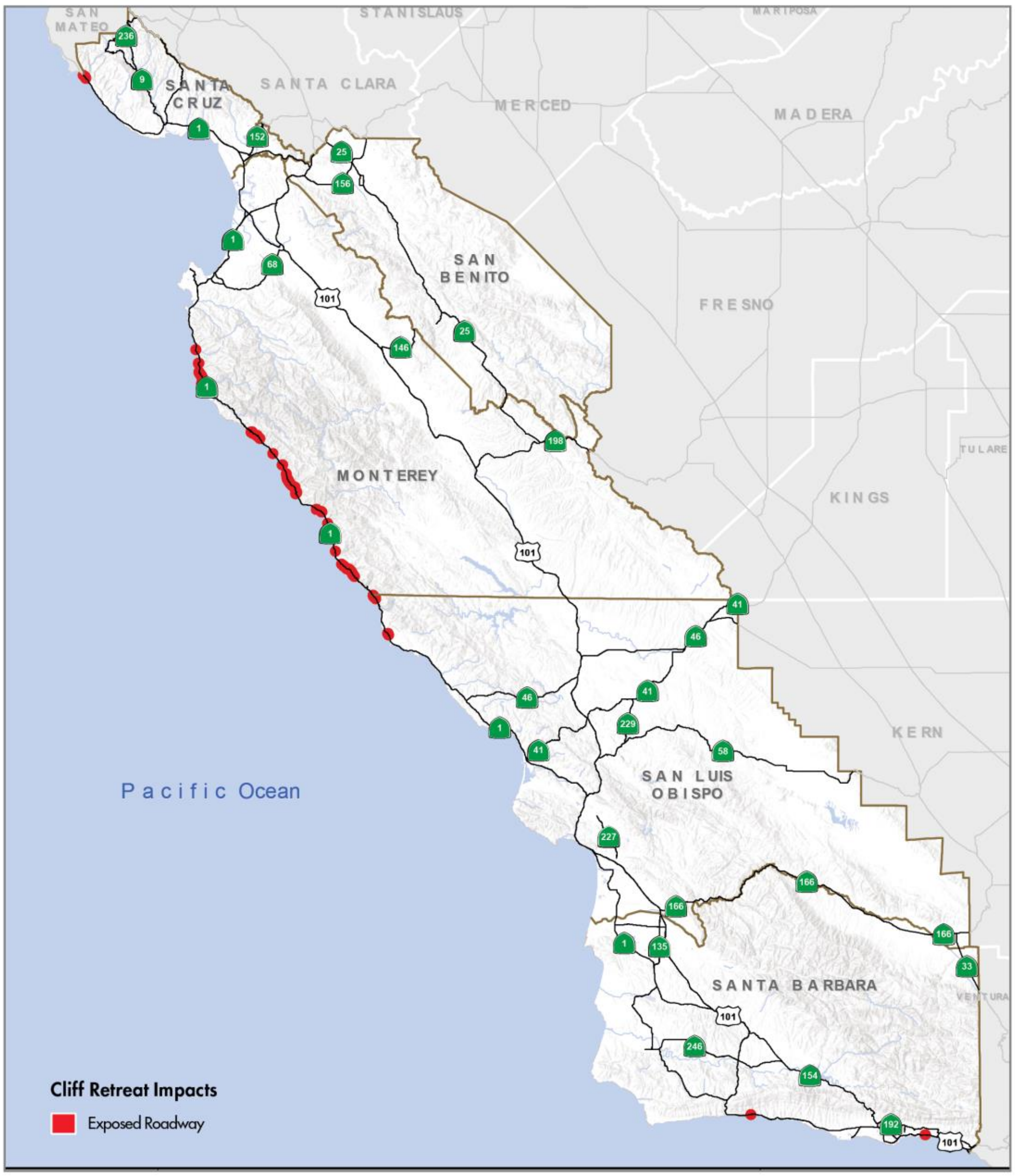
NOTE: MILEAGES REPORTED DO NOT INCLUDE LOCAL ROADS.

[45] US Geological Survey (USGS), "Cosmos Southern California V3.0 Phase 2 Projections of Coastal Cliff Retreat Due To 21st Century Sea-Level Rise," Last accessed May 1, 2019, https://www.sciencebase.gov/catalog/item/57f4234de4b0bc0bec033f90

[46] US Geological Survey (USGS), "Cosmos Southern California V3.0 Phase 2 Projections of Coastal Cliff Retreat Due To 21st Century Sea-Level Rise," Last accessed May 1, 2019, https://www.sciencebase.gov/catalog/item/57f4234de4b0bc0bec033f90

FIGURE 27: CLIFF RETREAT FROM 1.64 FT (0.50 M) OF SEA LEVEL RISE

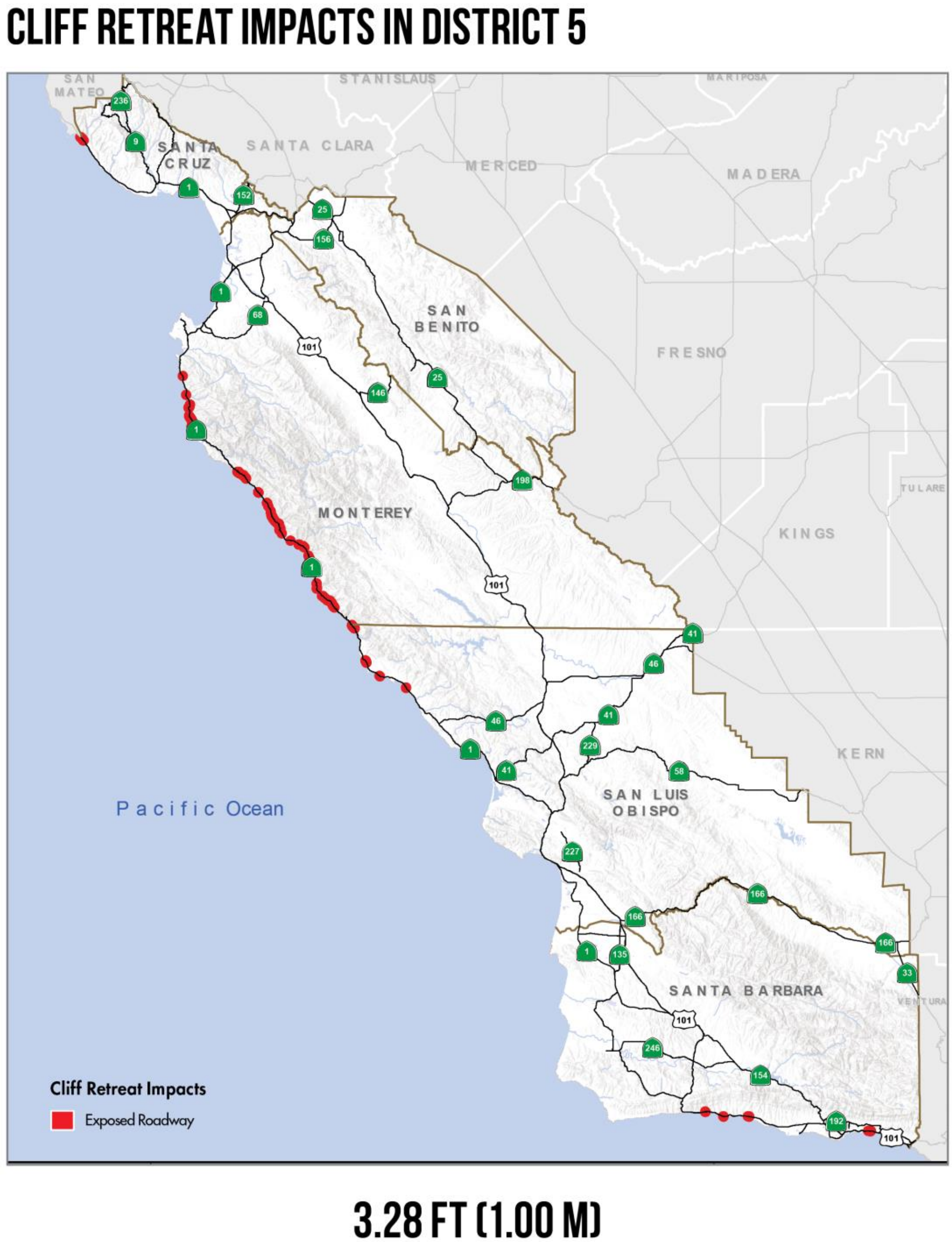
CLIFF RETREAT IMPACTS IN DISTRICT 5



1.64 FT (0.50 M)

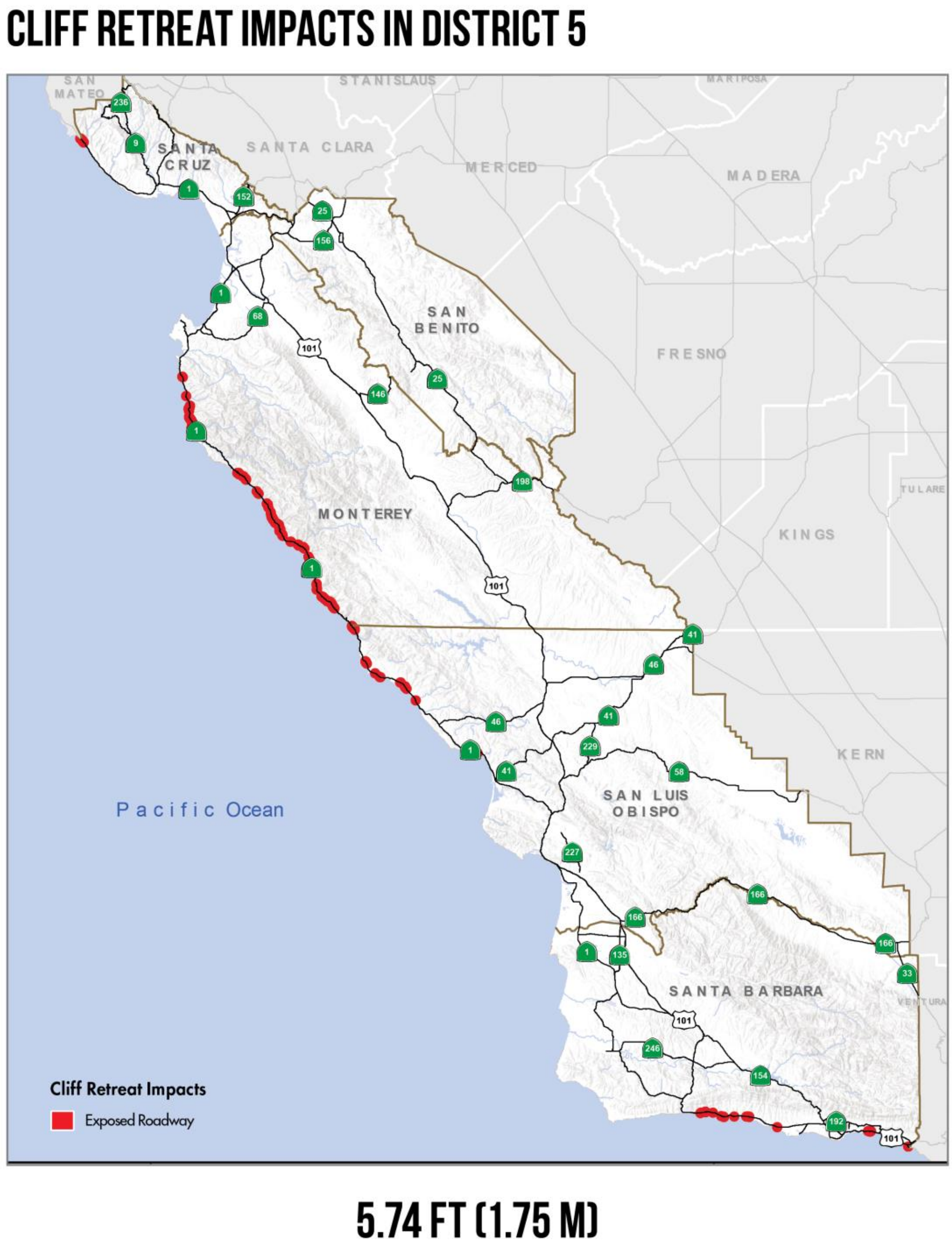
CLIFF RETREAT DATA ARE FROM THE US GEOLOGICAL SURVEY, COASTAL STORM MODELING SYSTEM (COSMOS). THIS DATA APPLIES THE "DO NOT HOLD THE LINE" MANAGEMENT OPTION, WHICH ASSUMES THAT CLIFF RETREAT CONTINUES UNIMPEDED. SEE [Our Coast, Our Future] AND THE [USGS CoSMoS] WEBPAGE FOR MORE INFORMATION ON THE MODEL

FIGURE 28: CLIFF RETREAT FROM 3.28 FT (1.00 M) OF SEA LEVEL RISE



CLIFF RETREAT DATA ARE FROM THE US GEOLOGICAL SURVEY, COASTAL STORM MODELING SYSTEM (COSMOS). THIS DATA APPLIES THE "DO NOT HOLD THE LINE" MANAGEMENT OPTION, WHICH ASSUMES THAT CLIFF RETREAT CONTINUES UNIMPEDED. SEE Our Coast, Our Future AND THE USGS CoSMoS WEBPAGE FOR MORE INFORMATION ON THE MODEL

FIGURE 29: CLIFF RETREAT FROM 5.74 FEET (1.75 M) OF SEA LEVEL RISE



CLIFF RETREAT DATA ARE FROM THE US GEOLOGICAL SURVEY, COASTAL STORM MODELING SYSTEM (COSMOS). THIS DATA APPLIES THE "DO NOT HOLD THE LINE" MANAGEMENT OPTION, WHICH ASSUMES THAT CLIFF RETREAT CONTINUES UNIMPEDED. SEE Our Coast, Our Future AND THE USGS CoSMoS WEBPAGE FOR MORE INFORMATION ON THE MODEL

10. INFRASTRUCTURE IMPACT EXAMPLES

As climate changes, California could be affected by more frequent, extreme weather events. In recent years, California has been through a severe drought (2011 – 2017), a series of extreme storm events that caused flash flooding and landslides across the state (2017 – 2018), the most deadly and severe wildfire season on record (2018), and deadly debris slides (2018). These emergencies demonstrate what could become more commonplace for California in the future. It is important to learn from these events, take actions to prevent them wherever possible, and increase the resiliency of transportation infrastructure for near- and long-term threats. This section provides several examples of District 5 efforts to respond to and protect against weather-related disruptions.

10.1. Piedras Blancas Roadway Realignment

SR 1, from Point Piedras Blancas to North of the Arroyo de la Cruz Bridge in northern San Luis Obispo County, had been experiencing severe coastal erosion (nearly 5 feet per year in some areas) resulting in numerous projects for rock slope protection and minor realignment over 20 years. Given that SR 1 is a State Scenic Route, a National Scenic Byway, an All-American Road and on the Pacific Coast Bicycle Route, these projects affected many users of the roadway. District 5 determined that the temporary shore armoring was not sufficient to protect the road---a long-term solution was needed. Approximately 2.8 miles of SR 1 was moved inland (at the maximum, about 475 feet from the existing road). This placed the new alignment outside of the area where erosion was predicted to be the most severe over the next 100 years. Caltrans explicitly considered future climate-related impacts of increased erosion in setting the anticipated 100-year erosion line.

The project also included enhancement of 12 acres of offsite state parkland mitigation sites to mitigate the impacts to areas disturbed by project construction. This is an element of an arrangement with neighboring property owners to allow for similar realignments at five locations along the 18-mile stretch of SR 1. The historic Hearst Scenic Conservation easements allow for highway realignments in vulnerable areas and includes the dedication of land to state parks.

10.2. US 101 Montecito Debris Flow

US Highway 101 is a major artery linking Ventura County to the south and San Luis Obispo County to the north, with approximately 90,000 vehicles traveling through this corridor each day. In January 2018, a large debris flow occurred in January 2018, which killed 23 and shut down US 101 for 12 days. Caltrans District 5 responded to the US 101 shutdown by redirecting motorists, but at one point, a quarter-mile section of US 101 was under 12 feet of water and the necessary detours were lengthy. At the peak of the aftermath, one-quarter mile section of US Highway 101 rested under 12 feet of water. Over 105,000 cubic yards of material was removed from the highway with 40 pieces of equipment and 1,500 trucks. After clearing the water and debris from the right-of-way, Caltrans re-installed or repaired guardrail, performed repairs on nearby slopes and embankments, cleared major drainage facilities, replaced the striping and fixed minor damage to the concrete pavement. There were 13,000 individual truck trips to and from this location. At the peak of operation, excavators were filling four large trucks with debris every three minutes. At the peak of operation, excavators were filling four large trucks with debris every three minutes.

To give a sense of the magnitude of the response to this disruption, the response for the total effort involved approximately 45,000 total person-hours, responding to 9 locations over 11 miles and 8 creek crossings, and cost approximately $11.25 million.

10.3. Pfeiffer Canyon Bridge

Pfeiffer Canyon Bridge was a three-span bridge on SR 1 in the community of Big Sur, Monterey County. A column was displaced by an active landslide in mid-February 2016 moving eight inches in one night and destabilizing the bridge. Caltrans closed the bridge to all traffic and determined it was beyond repair. This section of SR 1 was closed for eight months, cutting off access to Big Sur via SR 1 from the north. A new bridge was opened in October 2017.

10.4. Paul's and Mud Creek Slides

The dramatic, rocky cliffs near Big Sur are susceptible to landslides. In the past 10 years in Monterey County numerous landslides have affected the portions of SR 1 that traverse this rugged coastline. In 2017, following a wet winter with extreme rainfall events, two large landslides closed SR 1 to all traffic. In March 2017, Paul's Slide buried SR 1 with debris and left only 11 feet of roadway. Approximately 435 residents were caught between the slide and the SR 1 closure at Pfeiffer Canyon Bridge to the north. Shortly after, in May 2017, the Mud Creek landslide north of Gorda covered a ¼-mile section of SR 1 in six million cubic yards of debris. This portion of SR 1 was re-opened in July of 2018 and SR 1 crossing the Paul's Slide area re-opened in February 2019.

Because these two slide areas are prone to falling rock and damage in heavy storms, Caltrans now closes the road when it receives notice from the National Weather Service of "a significant storm" and reopens it after crews have completed safety inspections.

10.5. Clogged Culvert on SR 154

SR 154 was closed in February 2019 due to flooding caused by a debris-filled culvert. The debris — mainly large downed trees and limbs — came from the 2017 Whittier Fire burn area following heavy rains. At one point, the culvert was under 30 feet of water. The 8-foot-high arched culvert is supposed to allow water flowing down the mountain to pass under the highway and into Lake Cachuma. The district used pumps and heavy equipment to clear the culvert.

Other projects in the district have constructed new culverts, channeled water flows in sediment basins, installed down drains and basins, and captured debris flow, while assisting National Park resource staff to restore the water and habitat. Given expected changes in projected precipitation conditions in the district, these types of projects are expected to be even more common in the future.

FIGURE 30: SR 1 BEFORE AND AFTER REALIGNMENT

FIGURE 31: PFEIFFER CANYON BRIDGE BEFORE AND AFTER

FIGURE 32: MUD CREEK SLIDE AND AFTER

11. INCORPORATING CLIMATE CHANGE INTO DECISION-MAKING

11.1. Risk-Based Design

A risk-based decision approach considers the broader implications of damage and economic loss in determining the approach to design. Climate change is a risk factor that is often omitted from design, but is important for an asset to function over its design life. Incorporating climate change into asset-level decision-making has been a subject of research over the past decade, much of it led or funded by the Federal Highway Administration (FHWA). The FHWA undertook a few projects to assess climate change and facility design – including the Gulf Coast II project (Mobile, AL) and the Transportation Engineering Approaches to Climate Resiliency Study. Both assessed facilities of varying types, which were exposed to different climate stressors. They then identified design responses that could make the facilities more resilient to change.

One outcome of the FHWA studies was a step-by-step method for completing facility (or asset) design, such that climate change was considered and inherent uncertainties in the timing and scale of climate change were included. This method, termed the Adaptation Decision-Making Assessment Process (ADAP),[47] provides facility designers with a recommended approach to designing a facility when considering possible climate change effects. The key steps in ADAP are shown in Figure 33: FHWA's Adaptation Decision-Making Process.

The first five steps of the ADAP process cover the characteristics of the project and the context. The District 5 Vulnerability Assessment has worked through these first steps and the data used in the assessment has been provided to Caltrans for future use in asset level analyses. These five steps should be addressed for every exposed facility during asset level analyses.

Step five focuses on conducting a more detailed assessment of the performance of the facility. When analyzing one facility, it is important to assess the highest impact scenario. This does not necessarily correspond to the highest temperature range, or largest storm event. In this case, the analysis should determine which scenarios will have the greatest effect on a facility. For example, a 20-year storm may cause greater impacts than a 100-year storm, depending on wind and wave directions. If the design criteria of the facility are met even under the greatest impact scenario, the analysis is complete. Otherwise, the process moves onto developing adaptation options.

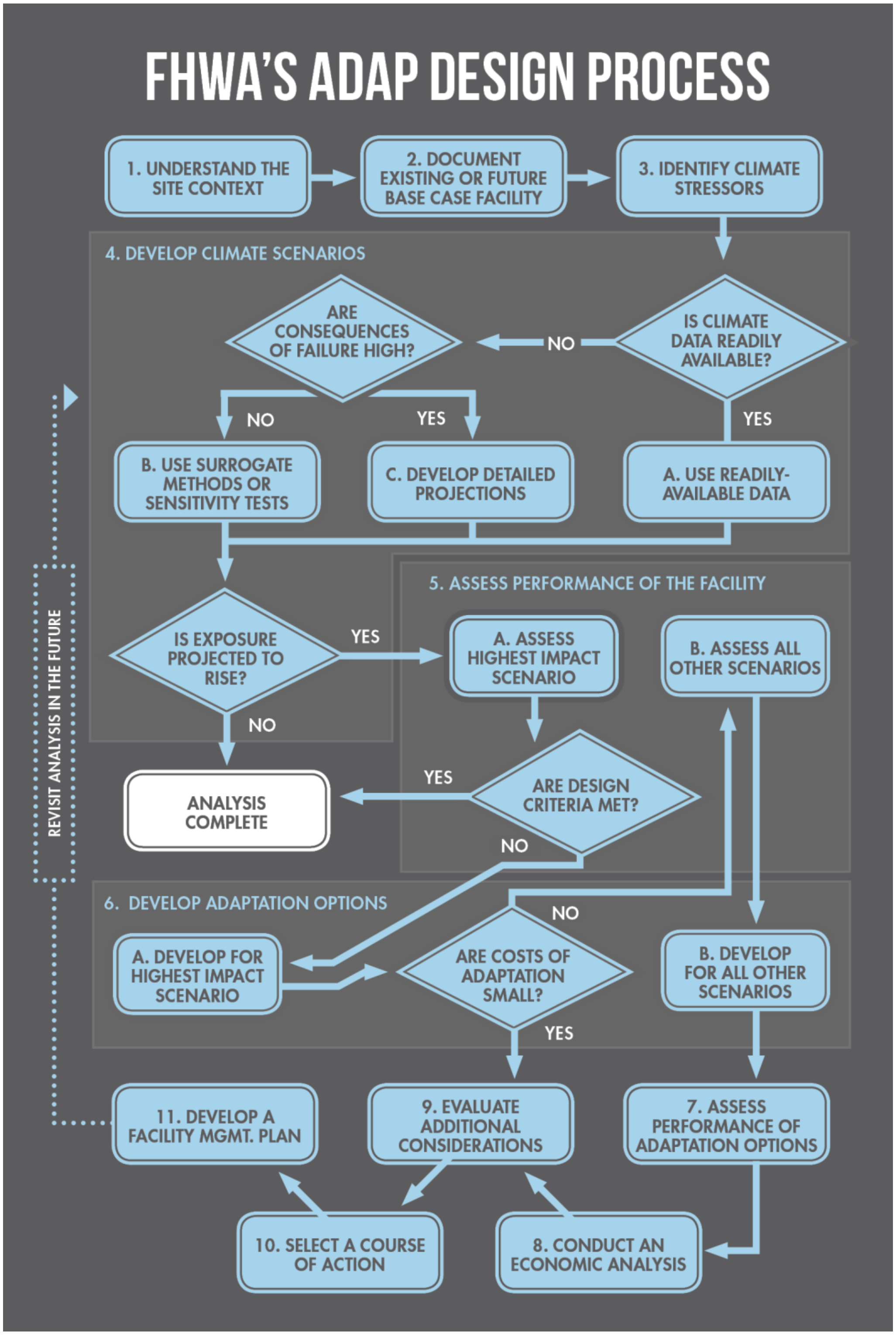
Options should be developed that will adapt the facility to the highest impact scenario. If these options are affordable, they can move to the final steps of the process. If they are not, other scenarios can be considered to identify more affordable options. These alternative design options will need to move through additional steps to critique their performance and economic value. Then, they also move to the final steps of the process. These last three steps are critical to implementing adaptive designs. Step nine involves considering other factors that may influence adaptation design and implementation. For example, California Executive Order B-30-15 requires consideration of:

[47] Federal Highway Administration. "Adaptation Decision-Making Assessment Process (ADAP)," January 12, 2018. Last accessed August 23, 2019. https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/teacr/adap/index.cfm

- full life cycle cost accounting
- maladaptation,
- vulnerable populations,
- natural infrastructure,
- adaptation options that also mitigate greenhouse gases,
- and the use of flexible approaches where necessary.

At this step in the ADAP process, it is important to understand the greater context of the designs developed and whether they meet state, Caltrans, and/or other requirements. This also allows for the opportunity to consider potential impacts of the project outside of design and economics, including how it may affect the surrounding community and environment. After evaluating these additional considerations, a course of action can be identified and a facility management plan implemented.

FIGURE 33: FHWA'S ADAPTATION DECISION-MAKING PROCESS



For additional information about ADAP please see the FHWA website at: https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/teacr/adap/index.cfm

11.2. Prioritization of Adaptive Response Projects

The project prioritization approach outlined below is based on a review of the methods developed by other transportation agencies and lessons learned from other adaptation efforts. These methods—mostly developed and used by departments of transportation in other states—address long-term climate risks and are intended to inform project priorities across the range of diverse project needs. This prioritization approach is specific to climate change effects only providing a process by which to guide decisions. It is not intended as the sole factor in agency prioritization which includes broader measures, but instead forwards a method to choose among projects that are identified as having potential climate change risks. The method outlined below recognizes the following issues when considering climate change adaptation for transportation projects:

- The implications of damage or failure to a transportation facility due to climate change-related stresses.
- The likelihood or probability of occurrence of an event.
- The timeframe at which the events may occur, and the shifting of future risks associated with climate change.

The recommended prioritization method is applied to those facilities with high exposure to climate change risk; it is not applied to the entire transportation network. The method assumes that projects have been defined in sufficient detail to allow some estimate of implementation costs.

Guiding principles for the development of the prioritization method included the following:

- It should be straightforward in application, easily discernable, describable and it should be relatively straightforward to implement with common software applications (Excel, etc.).
- It should be based on best practices in the climate adaptation field.
- It should avoid weighting schemes and multi-criteria scoring, since those processes tend to be difficult to explain and are open to interpretation among professionals with varying perspectives.
- It should be focused on how departments of transportation do business, reflect priorities for program delivery to stakeholders and recognize the relative importance of various assets.
- It should have the ability to differentiate between projects that may have different implications of risk—like near-term minor impacts and long-term major impacts—to set project priorities.
- It should facilitate decisions among different project types, for example, projects for repairs or for continuous minor damage as compared to one-time major damage events.
- It should enable the comparison among all types of projects, regardless of the stressor causing impacts.

The prioritization method requires the following information:

- Facility loss/damage estimates (supplied by Caltrans engineering staff) should capture both lower level recurring impacts and larger loss or damage. These should include a few key pieces of information, including:

    What are the levels for stressors (sea level rise, surge, wildfire, etc.) that would cause damage and or loss?

    What are the implications of this damage in terms of cost to repair and estimated time to repair?

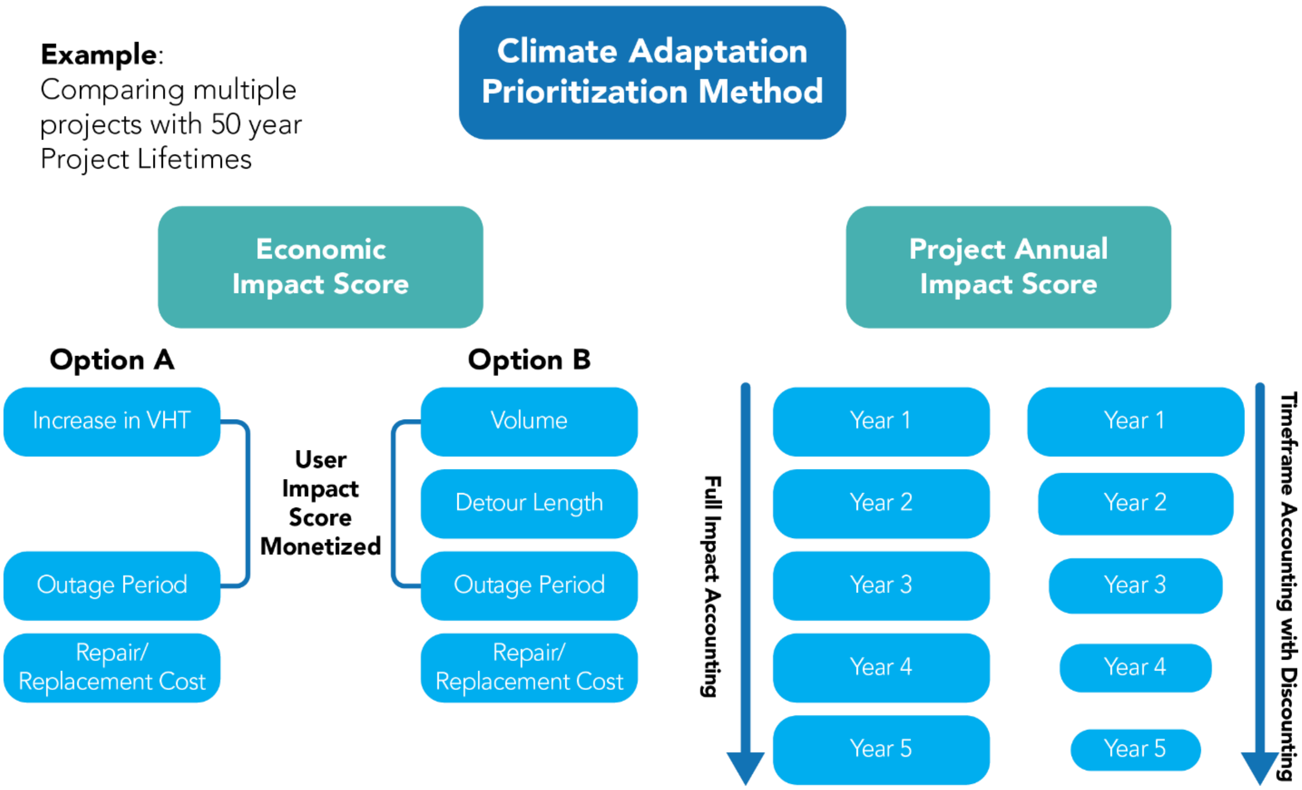
- System impacts (supplied by Caltrans planning staff) – the impacts of the loss of the facility on the broader system. This could be in terms of increase in Vehicle Hours Traveled (VHT) if using a traffic model, or an estimated value using volume and detour length as surrogates.
- Probability of occurrence (supplied by Caltrans climate change staff through coordination with state climate experts) – the probability of events occurring as estimated from the climate data for chosen climate scenarios. Estimated for each year out to the end of the facility lifetime.

A project annual impact score is used to reflect two conditions, summarized by year:

- The expected cumulative loss estimated for the project over the project lifetime (full impact accounting).
- A method of discounting losses over years– to enable prioritization based on nearer term or longer-term expected impacts (timeframe accounting).

These two pieces of information are important to better understand the full cost of impacts over time. Figure 34 shows the general approach for the prioritization method.

FIGURE 34: APPROACH FOR PRIORITIZATION METHOD



The two side-by-side charts represent various approaches to calculating values to be used for prioritization. The left side (Economic Impact Score) shows two methods for determining costs to the system user. The right-side show how costs could be counted in two ways, one which utilizes a full impact accounting that basically sums all costs to the end of the asset useful life while the other uses annual discounting to reflect "true costs" or current year dollar equivalent values to calculate the final impact score for the asset. These are presented as shown in part to provide an option for determining these values and in part to outline the various methods that are being used on similar projects nationally. The final selected method would require input and leadership from Caltrans to define the parameters for the approach to inform decisions.

The prioritization method would need estimates of at a minimum repair/replacement cost (dollars) and, if broadened, a system users impact (in dollar equivalents). System user costs would be summarized for this effort as transportation service impacts, and would be calculated in one of two ways:

- Estimate the impacts to a transportation system by identifying an expected detour routing that would be expected with loss of access or a loss/damage climate event. This value would be combined with average daily traffic and outage period values to result in an estimate of VHT increase associated with the loss of use of a facility.
- Utilize a traffic model to estimate the impacts on the broader SHS from damage/loss of a facility or facilities anticipated to occur because of a climate event. The impact on the system would be summarized based on the net increase in VHT calculated in the model.

The advantage of the system method is that it determines impacts of multiple loss/failure assessments consecutively and is not confined to only the assessment of each individual project as an individual project concern. It also allows for comparisons to the broader system and scores facilities with heavier use and importance to an integrated system as higher in terms of impact and prioritization.

Probabilities of an event occurring over each year would be used to summarize costs per year as well as a summarized cumulative total cost for the project over the lifetime. The resulting values would set the prioritization metric in terms of net present value for Caltrans to apply in selecting projects. The identification of an annual cost metric, which includes discounting, enables the important decision-making process on which project should advance given limited project resources. Table 7 highlights how the method would be implemented, with the project selected in the out years selected by the calculated annual cost metric. The impacts noted in the time period beyond the selected year (shown in shaded color) would be expected to have been addressed by the adaptation strategy. Thus, in the table, Project 1 at year 5 has the highest annual cost associated with disruptions connected to an extreme weather event. The project with the next greatest annual cost is Project 2, where this cost is reached at year 15. The next project is Project 3 at year 35 and the final project is Project 4 at year 45.

TABLE 7: EXAMPLE PROJECT PRIORITIZATION

Year	5	10	15	20	25	30	35	40	45	50
Project 1	$5	$5	$5	$5	$7	$7	$7	$9	$9	$9
Project 2	$4	$4	$6	$6	$6	$6	$8	$8	$8	$8
Project 3	$3	$3	$4	$4	$4	$6	$8	$8	$8	$8
Project 4	$2	$2	$2	$4	$4	$4	$6	$8	$10	$10

The project prioritization method outlined above requires the development of new approaches to determining how best to respond to climate change risks. It does not rely on existing methods as they are not appropriate to reflect climate risk effectively and facilitate agency level decision making. Climate change, with its uncertain timing and non-stationary weather/climate impacts, requires methods that incorporate this reality into Caltrans' decision-making processes.

It would be possible to implement a tiered prioritization process once work required to complete the steps as outlined above has been completed. Assets at risk from climate change with comparable present values could be compared for their capability to address other policy concerns – like goods movement, access for low income / dependent communities, sustainability measures, or other factors that would help Caltrans meet statewide policy goals. The primary focus of this assessment should be on the impacts to the system; however, these secondary measures can help clarify or reorder the final list and help guide implementation.

12. CONCLUSIONS AND NEXT STEPS

This report represents an initial effort to identify areas of exposure to potential climate change for facilities owned and operated by Caltrans District 5. The study utilized various data sources to identify how climatic conditions may change from today and where these areas of high exposure to future climate risks appear in District 5. The study distilled the larger context of climate change down to a more localized understanding of what such change might mean to District 5 functions and operations, District 5 employees, and the users of the transportation system. It is intended, in part, as a transportation practitioner's guide on how to include climate change into transportation decision making.

Much of today's engineering design is based on historical conditions, and it is emphasized throughout this report that this perspective should change. A review of climate data analyzed for this study shows that, for those stressors analyzed (sea level rise, storm surge, wildfire, temperature, and precipitation), there are clear indications that future conditions will be very different from today's, with likely higher risks to highway infrastructure. These likely future conditions vary in terms of when threshold values will occur (that is, when sea levels, or precipitation and temperature values exceed a point at which risks will increase for assets) and on the potential impact to the SHS. This is an important consideration given that transportation infrastructure investment decisions made today will have implications for decades to come given the long lifetimes for roadway facilities.

This report provides District 5 with the information on areas of climate change exposure it can utilize to proceed to more detailed, project-level assessments. In other words, the report has identified where climate change risks are possible in District 5 and where project development efforts for projects in these areas should consider changing future environmental conditions. There are several steps that can be taken to transition from a traditional project development process based on historical environmental conditions to one that incorporates a greater consideration for facility and system resiliency. This process can incorporate the benefits associated with climate change adaptation strategies and use climate data as a primary decision factor. District 5 staff, with its recent history of assessing long-term risks associated with climate change, has the capacity to adopt such an approach and ensure that travelers in the region are provided with a resilient system over the coming years.

The following section provides some context as to what the next steps for Caltrans and District 5 may be, to build upon this work and create a more resilient SHS.

12.1. Next Steps

The work completed for this effort answers a few questions and raises many more. The scope of this work was focused on determining what is expected in the future and how that may affect the Caltrans SHS. This analysis has shown that climate data from many sources indicates an expanded set of future risks – from increased extreme precipitation, to higher temperatures, and an increase in wildfires – all concerns that will need to be considered by District 5.

There are a few steps that will be required to improve decision making and help Caltrans achieve a more resilient State Highway Network in District 5. These include:

- Policy Changes
  - Agency leadership will need to provide guidance for incorporating findings from this assessment into decision making. This area is a new focus and requires a different perspective that will not be possible without strong agency leadership.
    - Addressing climate change should be integrated throughout all functional areas and business processes; including Planning, Environmental, Design, Construction, Maintenance and Operations.
  - Risk-based decision-making. The changing elements of climate change require the consideration of the implications of those changes and how they may affect the system. Caltrans will need to change its methods to incorporate measures of loss, damage and broader social or economic costs as a part of its policies.
- Acquisition of Improved Data for Improved Decision-Making
  - Determining potential impacts of precipitation on the SHS will require additional system/environmental data to complete a system-wide assessment. This includes:
    - Improved topographic data across District 5 (and the state of California).
    - Improved asset data – including accurate location of assets (bridges, culverts) and information on the waterway opening at those locations.
  - The assessment of wildfire potential along the SHS is an ongoing effort. Follow up will be required to determine the results of new research and whether updated models indicate any additional areas of risk.
  - The precipitation and temperature data presented in this report is based off a data set that is newly released. Methods to summarize this data across many climate models is ongoing and the conclusions of that work may yield information that may more precisely define expected future changes for these stressors.
  - There are efforts underway to refine the understanding of other stressors, including landslide potential. Further refinements of those efforts will require additional investment and coordination to complete. Research efforts are constantly being refined and Caltrans will need to be an active partner in participating in, and monitoring, the results of these efforts to determine how to best incorporate the results of these efforts into agency practices.
- Implementation
  - The data presented in this report indicates directions and ranges of change. These data points will need to become a part of Caltrans practice for planning and design for all future activities.
  - The use of this data will require the development of educational materials and the training of Caltrans staff to ensure effective implementation.

Not every concern and future requirement could be addressed or outlined in this report. Thus, the report should be considered the first step of many that will be required to address the implications of climate change to the SHS. Much work remains to create a resilient SHS across California.

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14. GLOSSARY

50th percentile downscaled model outputs (for temperature and precipitation projections) – 50th percentile results represent the median of downscaled climate model outputs under RCP 8.5 for the metric shown, as calculated across the state using the area weighted mean.

100-year design storm: Design criteria for infrastructure projects that address expected conditions for the 100-year storm. Considered Base Flood Elevation by the Federal Emergency Management Agency.

Cal-Adapt: A web-based data hub and information guide on recent California-focused climate data and analysis tools. Visualization tools are available to investigate different future climate scenarios.

Climate change: Change in climatic conditions due to the presence of higher greenhouse gas concentrations in the atmosphere. Examples include higher temperatures and sea level rise.

Downscaling: An approach to refine the outputs of global climate models to a more local level.

Emissions Scenarios: Multiple, long-term forecasts of greenhouse gases in the atmosphere based on global policy and economics.

Exposure: The degree to which a facility or asset is susceptible to climate stressors that might damage or disrupt the component.

Global Climate Model (GCM): Models used by climate scientists to project future, worldwide climate conditions. This term is sometimes used interchangeably with General Circulation Model.

Representative Concentration Pathways (RCP): A specific set of emission scenarios developed by the Intergovernmental Panel on Climate Change that project future concentrations of greenhouse gases in the atmosphere.

Resilient transportation facilities: Transportation facilities that are designed and operated to reduce the likelihood of disruption or damage due to changing weather conditions.

Return period storm event: Historical intensity of storms based on how often such level of storms have occurred in the past. A 100-year storm event is one that has the intensity of a storm that statistically occurs once every 100 years.

Scour (Bridge): Typically, a result of swiftly moving water removing soil/sediment from around structural elements like abutments or piers. It can increase risk of failure for the structure.

State Highway System (SHS): The designated highway network in California for which Caltrans is responsible.

Storm surge: Refers to elevated sea levels during a storm event due to a combination of onshore wind and reduced atmospheric pressure. Higher than normal waves during the storm, themselves the results of high winds, can contribute to the storm surge impacts.

Stressor: Climate conditions that could cause negative impacts. Examples include higher temperatures or more volatile precipitation.

Tidal flooding: As sea level rises, tides will get progressively higher and lead to longer periods of inundation at high tide. Eventually rising sea levels will lead to permanent inundation.

Vulnerability assessment: A study of areas likely to be exposed to future climate stressors and the consequence of that exposure.

Vulnerable populations: "Vulnerable populations include, but are not limited to women; racial or ethnic groups; low-income individuals and families; individuals who are incarcerated or have been incarcerated; individuals with disabilities; individuals with mental health conditions; children; youth and young adults; seniors; immigrants and refugees; individuals who are limited English proficient (LEP); and Lesbian, Gay, Bisexual, Transgender, Queer, and Questioning (LGBTQQ) communities, or combinations of these populations."[48]

[48] Governor's Office of Planning and Research (OPR), "Planning and Investing for a Resilient California: A Guidebook for State Agencies," March 13th, 2018, Last accessed June 20, 2019. http://opr.ca.gov/planning/icarp/resilient-ca.html