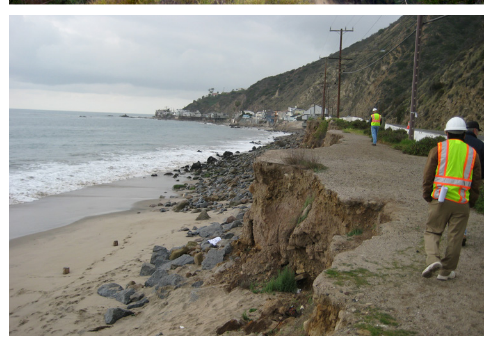
CALTRANS CLIMATE CHANGE VULNERABILITY ASSESSMENTS

2019

District 7
Technical Report



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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
CCC	California Coastal Commission
CEC	California Energy Commission
CoSMoS	Coastal Storm Modeling System
EPA	Environmental Protection Agency
DWR	California Department of Water Resources
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
GCM	Global Climate Model
GHG	Greenhouse Gas
GIS	Geographic Information System
IPCC	Intergovernmental Panel on Climate Change
LIDAR	Light Detection and Ranging
LOCA	Localized Constructed Analogs
MHHW	Mean Higher High Water
NOAA	National Oceanic and Atmospheric Administration
PCH	Pacific Coast Highway (State Route 1)
RCP	Representative Concentration Pathway
Scripps	The Scripps Institution of Oceanography
SLR	Sea Level Rise
SRES	Special Report Emissions Scenarios
USACE	US Army Corps of Engineers
USFS	US Forest Service
USGS	US Geological Survey
VHT	Vehicle Hours Traveled

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1. INTRODUCTION

The following report was developed for the California Department of Transportation (Caltrans) and summarizes a vulnerability assessment conducted for the portion of State Highway System in Caltrans District 7.[1] Though there are multiple definitions of vulnerability, this assessment specifically considers vulnerabilities from 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 have 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 State Highway System and other Caltrans assets to future changes in climate. The study has 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 7 report is one of 12 district reports that are in various stages of development.

1.1. Purpose of Report

The *District 7 Technical Report* is one of two documents developed to describe the work completed for the District 7 vulnerability assessment, the other being the *District 7 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 State Highway System in District 7.

This *Technical Report* is intended to provide a more in-depth discussion, primarily for District 7 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 State Highway System vulnerabilities from that stressor,
- The methodology for how the data was developed,

[1] This analysis focuses solely on the State Highway System and does not include other Caltrans assets or state/local roadways.

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

Finally, this *Technical Report* outlines a recommended framework for prioritizing a list of 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 and alternative frameworks developed to guide decision-making given climate change.

1.2. District 7 Characteristics

District 7 lies in Southern California and includes Los Angeles and Ventura Counties. The climate is generally dry and mild but it can vary due to the area's topological diversity which includes mountain ranges, low-lying coastal plains, beaches, lakes, deserts, and large urban areas. Major District 7 features include the Santa Monica and San Gabriel mountain ranges, the Los Padres and Angeles National Forests, and the cities of Los Angeles, Long Beach, and Oxnard.[2] The district also includes a portion of the Mojave Desert, the Tehachapi Mountains, and two Channel Islands, San Clemente and Santa Catalina.

The District has the second largest workforce of all 12 Caltrans districts and employs nearly 2,500 people. District 7 manages 1,173 miles of state highway in Los Angeles County and 300 miles in Ventura County. These are some of the most heavily trafficked roads in California, with usage of around 111 million vehicle miles on an average day. District 7 is actively maintaining the heavily used infrastructure in both counties, and working to reduce congestion in a variety of ways, including high-occupancy vehicle (HOV) lanes. The district manages 550 HOV lane-miles in Los Angeles County and 7.5 HOV lane-miles in Ventura County, with more under construction. Senate Bill 1 is expected to fund $2.6 billion in new projects for Los Angeles and Ventura Counties, with the funds dedicated to improving infrastructure and reducing congestion.

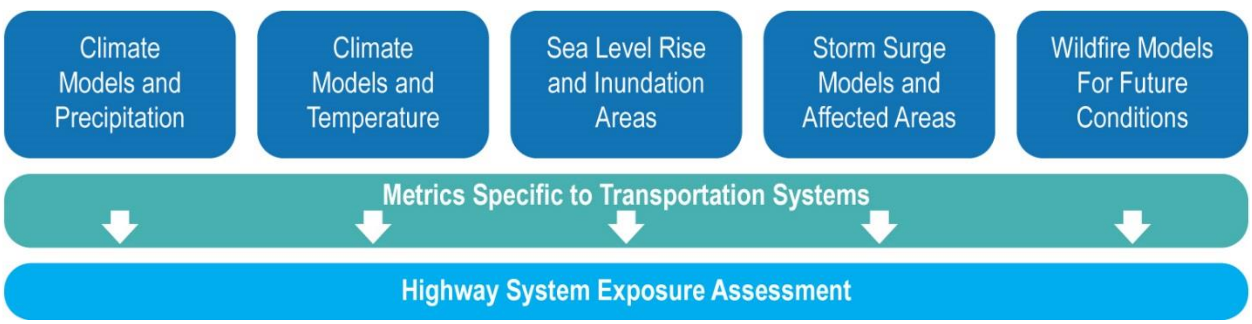
[2] "Decennial Census of Population and Housing," US Census Bureau, last accessed April 30, 2019, https://www.census.gov/programs-surveys/decennial-census/decade.2010.html

2. POTENTIAL EFFECTS FROM CLIMATE CHANGE ON THE STATE HIGHWAY SYSTEM IN DISTRICT 7

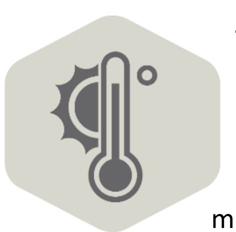
Climate and extreme weather conditions in District 7 are changing as greenhouse gas (GHG) emissions lead to higher temperatures and influence changes in precipitation patterns. These changing conditions are anticipated to affect the State Highway System in District 7 and other Caltrans assets. These impacts may appear in a variety of ways and may increase exposure to environmental factors beyond the original design considerations. The project study team (made up of WSP staff and subject matter experts) considered a range of climate stressors and how they tie into 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 State Highway System 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, as the 100-year storm is a criterion used in the design of Caltrans assets.

FIGURE 1: CONSIDERATIONS FOR THE STATE HIGHWAY EXPOSURE ASSESSMENT



The following climatic/extreme weather conditions (also referred to as "stressors" and hazards in this report) were evaluated for this assessment. Past events are not necessarily related to the changing climate, but provide examples as to the types of events Caltrans District 7 could face more frequently in the future.



Temperature – As greenhouse gas (GHG) emissions rise, so do atmospheric temperatures. Areas along the coast are expected to experience less temperature rise compared to inland locations. As temperature rises, precipitation patterns could change and become more volatile.[3] Scientists have already suggested that the period of drought from 2012 to 2014 was most likely intensified by climate change by anywhere from 15 to 20%.[4] This drought weakened trees across the state and in District 7, leading to bark beetle infestation and

[3] Suraj Polade, Alexander Gershunov, Dan Cayan, Michael Dettinger, & David Pierce, "Precipitation in a warming world: assessing projected hydro-climate changes in California and other Mediterranean climate regions," *Scientific Reports* volume 7, Article number: 10783 (2017) https://www.nature.com/articles/s41598-017-11285-y

[4] Park Williams, Richard Seager, John Abatzoglou, Benjamin Cook, Jason Smerdon, and Edward Cook, "Contribution of anthropogenic warming to California drought during 2012-2014," *Geophys. Res. Lett*., 42, 6819–6828, doi:10.1002/2015GL064924, (August, 2015), http://onlinelibrary.wiley.com/doi/10.1002/2015GL064924/full

disease. In 2016, District 7 requested emergency funds to remove dead, diseased, and drought-inflicted trees from their portion of State Highway System Right-of-Way (ROW). Following inspection by their arborist, Caltrans District 7 concluded that 4,800 trees (primarily in Ventura County) would need to be removed prior to winter storms, Santa Ana winds, and wildfire season. District officials also noted that these trees presented a hazard to the State Highway System and their users, due to the compromised root structures of the trees. Drought events may become more frequent and severe, and these types of emergency activities may become more commonplace and necessary for District 7.

Precipitation – Projecting changes in precipitation for California is a complicated task, as California lies between two climatic zones: the temperate and subtropic. These zones are expected to become wetter and drier, respectively.[5] Most climate forecasts for the state suggest that it will be hotter and more drought-prone, with infrequent, heavy storm events, but new research from University of California Riverside projects a wetter future.[6] Despite uncertainty inherent in projections, scientists agree that California will have more volatile precipitation and more extreme events due to a warmer atmosphere heavy with water vapor.[7]

District 7 has already experienced the effects of heavy rain events in the form of flooding, landslides, and mudslides. For example, the heavy rain and resulting mudslides near Point Mugu in 2014 closed the Pacific Coast Highway between Yerba Buena Road and Las Posas Road.[8] The rain caused a total of 12 to 15 different slides along the highway, with four to six feet of mud in some locations. Caltrans District 7 hired a contractor to remove the mud and debris, repair highway shoulders, and replace rip rap that washed away.[9] See Sections 10 and 11.1.1 for more on the Pacific Coast Highway in District 7.

FIGURE 2: CALTRANS STAFF CLEAR DEBRIS FROM POINT MUGU SLIDE IN 2015

[5] Robert Allen and Rainer Luptowitz, "El Niño-Like Teleconnection Increases California Precipitation in Response to Warming," Nature Communications volume 8, Article number: 16055 (2017), https://www.nature.com/articles/ncomms16055
[6] Ibid.
[7] Suraj Polade, Alexander Gershunov, Dan Cayan, Michael Dettinger, & David Pierce, "Precipitation an a Warming World: Assessing Projected Hydro-Climate Changes in California and Other Mediterranean Climate Regions," *Scientific Reports* volume 7, Article number: 10783 (2017) https://www.nature.com/articles/s41598-017-11285-y
[8] "Mud Slides Close Pacific Coast Highway," Caltrans District 7, last modified December 15, 2014, http://caltransd7info.blogspot.com/2014/12/mud-slides-close-pacific-coast-highway.html
[9] Ibid.

Sea Level Rise – Historic sea level rise in the Los Angeles area has been at a rate of around a third of an inch per year (or one millimeter per year).[10] However, by end of century Los Angeles area sea level rise is projected to be anywhere from 0.7 to 6.7 feet, with an extreme high of 9.9 feet (for more detail on sea level rise projections, see Section 7.1). High surf has already caused problems to the State Highway System in District 7. In 2010, District 7 requested emergency funding for the Pacific Coast Highway (PCH), or State Route 1, in northern Ventura County where high surf conditions damaged the highway, drainage infrastructure, and rock slope shore protection. Caltrans District 7 staff repaired the damage, totaling $750,000, before additional storm surge could destroy larger sections of highway. As sea levels rise, the PCH could become more vulnerable to high surf damage as well as periodic storm surges.

Wildfire – The 2017 wildfire season included some of the most destructive and deadly wildfires in California's history.[11] District 7 was affected by the 10th most destructive, the Thomas Fire, which burned in Ventura and Santa Barbara counties. The fire was fueled by warm Santa Ana winds, which worsened the effects and size of the fire.[12] Fires of this magnitude destroy structures, destabilize slopes, lead to debris in drainage infrastructure, and destroy roadside infrastructure like signs and fencing, which require immediate attention from Caltrans. For more information on the after effects of the Thomas Fire, see "Wildfire and Flooding" below.

Sea Level Rise and Storm Surge – Sea level rise will exacerbate the effects of coastal storm surges, as more forceful waves reach higher on shore. District 7 has already experienced the effects of storm surge on the State Highway System, specifically on the Pacific Coast Highway. These storm events can lead to erosion, scour, and washouts underneath the highway itself (see Section 9 on cliff retreat for more details). District 7 is preparing for these effects and is taking future sea level rise into account in coastal rehabilitation (the Las Tunas Beach Rehabilitation Project is one example).

Combined Effects – The combined effects of these stressors may have an even more severe impact on the State Highway System. These can include (but are not limited to) the following:

- **Wildfire and Flooding** – The flash floods and mudslides of early 2018 in Southern California are a recent and telling example of the danger inherent in combined wildfire and flood events. A timeline of the events and its effects on District 7 are as follows:
    - The Thomas Fire started December 4, 2017 at 6:28 PM.

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[10] "Relative Sea Level Trend," NOAA, last accessed May 1, 2019, https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=9410660

[11] "Top 20 Most Destructive California Wildfires," CalFire, last modified March 14, 2019, http://www.fire.ca.gov/communications/downloads/fact_sheets/Top20_Destruction.pdf

[12] P., Krishnakumar, & J., Fox, "Why the 2017 Fire Season Has Been One of California's Worst," *Los Angeles Times*, October 13, 2017, http://www.latimes.com/projects/la-me-california-fire-seasons/

- The Thomas Fire burned from Santa Barbara to the north and Ventura in the south, causing forced evacuations and burning 281,893 acres before contained.[13]
- Heavy rain fell on Santa Barbara, Ventura and Los Angeles Counties on January 8, 2018, totaling five inches of rain north of Ojai in Ventura County.[14]
- The rain triggered mudslides in affected counties and evacuation orders were issued for worst affected areas.
- Road closures were issued across affected counties, including a 30 mile stretch of US 101 within the Thomas Fire burn area, limiting access for evacuations and emergency vehicles.[15]
- 275 traffic collisions occurred on Los Angeles-area freeways.[16]
- Rescue operations started at the first light on January 9, 2018.

This tragic series of events in Districts 5 and 7 led to the deaths of at least 21 people and injured far more.[17]

Sections 4-10 provide more detail on how each of these climate change stressors could affect the future performance of the State Highway System in Caltrans District 7. The study was based on the best data and science available from state and regional agencies, as well as universities and laboratories.

[13] "Thomas Fire: InciWeb Incident Information Systems," InciWeb – Incident Information System, last accessed April 30, 2019, https://inciweb.nwcg.gov/incident/5670/

[14] James Queally, Joseph Serna, Michael Livingston, & Ruben Vives, "At Least 13 Dead as Heavy Rains Trigger Flooding, Mudflows, and Freeway Closures Across Southern California," *Los Angeles Times*, January 9, 2018, http://www.latimes.com/local/lanow/la-me-ln-rainfall-mudflow-20180109-story.html

[15] Ibid.

[16] Ibid.

[17] Steve Almasy and Mayra Cuevas, "Body of Montecito Woman Found, Brings Mudslide Death Toll to 21," *CNN*, January 20, 2018, https://www.cnn.com/2018/01/20/us/california-mudslide-death-toll/index.html

3. ASSESSMENT APPROACH

3.1. Stakeholder Involvement

The Caltrans study of potential impacts of climate change on the State Highway System involved multiple agencies and academic institutions across California. The material presented in this report was developed in coordination with various local partners in District 7, including:

- California Coastal Commission-South Central/South Coast
- Climate Resolve
- Los Angeles County Department of Regional Planning
- Los Angeles Regional Collaborative (LARC)
- Office of Historic Preservation
- Southern California Association of Governments (SCAG)
- US Army Corps of Engineers (USACE)
- US Forest Service (USFS)
- Ventura County
- Ventura County Resource Management Agency

The development of this report required extensive coordination with Caltrans District 7, and included:

- Coordination on previous work sponsored by and completed by District 7 staff to identify available data, and review findings and lessons learned.
- Working in partnership with District 7 staff through a series of efforts including:
  - A kickoff meeting to discuss the methodology for completing the study, understand expected deliverables, and identify district contacts.
  - A cooperative review of vulnerability assessment material.
  - Collection of photos, background information, and report input through a list of requests.

The methods used as part of the vulnerability assessment shown in the following pages also included coordination with California organizations responsible for climate model and data development. These agencies and research institutions will be discussed in more detail in the following pages (see Section 3.2.2) and in the respective sections on each stressor.

3.2. 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 7 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 7 vulnerability assessment.

3.2.1. 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.[18]
- **Executive Order S-13-08** (2008) directs state agencies to plan for sea level rise (SLR) and climate impacts through the coordination of the state Climate Adaptation Strategy.[19]
- **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.[20]
- **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.[21]
- **Senate Bill 246** (2015) establishes the Integrated Climate Adaptation and Resiliency Program to coordinate with regional and local efforts with state adaptation strategies.[22]
- **Assembly Bill 2800** (2016) requires that state agencies account for climate impacts during planning, design, building, operations, maintenance, and investments in

[18] "Assembly Bill 32 Overview," California Air Resources Board, last modified August 5, 2014, https://www.arb.ca.gov/cc/ab32/ab32.htm
[19] "California Executive Order S-13-08 Requiring State Adaptation Strategy," Adaptation Clearinghouse, last accessed April 30, 2019, https://www.adaptationclearinghouse.org/resources/california-executive-order-s-13-08-requiring-state-adaptation-strategy.html
[20] "Governor Brown Establishes Most Ambitious Greenhouse Gas Reduction Target in North America," Office of Governor Edmund Brown, last modified April 29, 2015, https://www.ca.gov/archive/gov39/2015/04/29/news18938/
[21] "Assembly Bill No. 1482," California Legislative Information, October 8, 2015, https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201520160AB1482
[22] "Senate Bill No.246," California Legislative Information, October 8, 2015, https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB246

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.[23]

These policies are among the factors State agencies consider when addressing climate change. Conducting an assessment such as this one for District 7 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.[24]

3.2.2. 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 7 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.[25] 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 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

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

[24] Governor's Office of Planning and Research, "Planning and Investing for a Resilient California: a Guidebook for State Agencies," March 13th, 2018, http://opr.ca.gov/planning/icarp/resilient-ca.html

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

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 identified for use in California, as outlined in the California Fourth Climate Change Assessment section.

Emissions Scenarios

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.[26] 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.[27]

California Fourth Climate Change Assessment

The California Climate Change Assessments are inter-agency research and “model downscaling” efforts for multiple climate stressors. The California Fourth Climate Change Assessment was led by the California Energy Commission (CEC), but other contributors include agencies such as the Department of Water Resources (DWR), the Natural Resources Agency, the Governor’s Office of Planning and Research, as well as academic institutions such as the Scripps Institution of Oceanography (Scripps) and the University of California, Merced.[28]

Model downscaling is a statistical technique that refines the results of GCMs to a regional level. The model downscaling used in the California Fourth Climate Change Assessment is a technique called Localized Constructed Analogs (LOCA), which “uses past history to add improved fine scale detail to

[26] “Representative Concentration Pathways,” IPCC, last accessed April 30, 2019, http://sedac.ipcc-data.org/ddc/ar5_scenario_process/RCPs.html
[27] Meinshausen, M.; et al. (November 2011), "The RCP greenhouse gas concentrations and their extensions from 1765 to 2300 (open access)", Climatic Change, 109 (1-2): 213–241
[28] “California’s Fourth Climate Change Assessment,” State of California website (CA.gov), last accessed June 5th, 2019, http://www.climateassessment.ca.gov/

GCMs."[29] 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.[30] 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.[31] 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.[32] 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 used in this study.

3.3. Other District 7 Efforts to Address Climate Change

In addition to and concurrent with statewide efforts, there are regional efforts underway within District 7 related to climate change planning, research, and modeling.

3.3.1. Climate Action Plans

Many cities and counties in District 7 have adopted Climate Action Plans (CAPs) designed to mitigate GHG emissions and reduce the impacts of climate change to their communities. Los Angeles County has adopted a Community CAP (CCAP) to mitigate and limit GHG emissions associated with community activities in unincorporated Los Angeles County. The CCAP addresses emissions from buildings, land use, transportation, water consumption, and waste. The measures and actions outlined in the CCAP will connect the county's existing climate change initiatives and provide a blueprint for a more sustainable future. The CCAP identifies emissions related to community activities, establishes a GHG reduction target consistent with AB 32, and provides a roadmap for successfully implementing the county's GHG reduction measures.[33]

[29] "LOCA Downscaled Climate Projections," Cal-Adapt, last accessed April 30, 2019, http://cal-adapt.org/
[30] David Pierce, Dan Cayan, Bridget Thrasher, "Statistical Downscaling Using Localized Constructed Analogs," *Journal of Hydrometeorology*, (December 2014), http://journals.ametsoc.org/doi/abs/10.1175/JHM-D-14-0082.1
[31] "LOCA Downscaled Climate Projections," Cal-Adapt, last accessed April 30, 2019, http://cal-adapt.org/
[32] For more information, visit http://cal-adapt.org/
[33] Los Angeles County Department of Regional Planning, "Community Climate Action Plan," last accessed April 29, 2019, http://planning.lacounty.gov/CCAP

Similarly, the County of Ventura has committed to cutting its GHG emissions by 15 percent by 2020.[34] The county's Climate Protection Plan lays out a roadmap and strategies to meet this goal by addressing six action areas:

- **Climate Protection Leadership:** Create long-term, structural policies necessary for meeting climate protection targets.
- **Countywide Responsibility:** Establish overarching activities that reduce GHG emissions.
- **Facilities:** Reduce electricity and natural gas use in the county's physical infrastructure (buildings and facilities).
- **Vehicle (Fleet) Operations:** Reduce gasoline and diesel fuel emissions in employees' work-related travel.
- **Employee Commute:** Reduce GHG emissions from employees' commuting trips.
- **Expanded Sustainability Goals:** Consider broader environmental goals, such as efficiencies in waste reduction and water conservation.

While these strategies are still primarily GHG mitigation focused, reports and studies are also addressing the need for climate adaptation.

3.3.2. One Water Los Angeles Plan

The City of Los Angeles is developing the One Water LA 2040 Plan, which is focused on increasing local collaboration in water-planning processes.[35] The plan is a roadmap, connecting ideas and people to discover better and more fiscally-responsible water-planning solutions. The plan specifically identifies projects, programs, and policies that will yield sustainable, long-term water supplies for Los Angeles and promote greater resiliency to drought conditions and climate change.

3.3.3. Climate Resolve

Climate Resolve is a Los Angeles-based nonprofit organization focused on local solutions for global climate change.[36] The organization works to make California more sustainable now and in the future by promoting reduced climate pollution and proactively preparing for climate impacts. To achieve their mission, Climate Resolve works to reduce GHG emissions and build collaborative partnerships to implement regional climate initiatives. Climate Resolve helps keep cities resilient in the face of climate change by disseminating information to make local climate impacts relatable and solutions actionable.

3.3.4. Los Angeles Regional Collaborative for Climate Adaptation

The Los Angeles Regional Collaborative (LARC) is a founding member of the Alliance of Regional Collaboratives for Climate Adaptation (ARCCA). ARCCA is a network comprised of regional collaboratives from across California. ARCCA's collaboratives are already coordinating and supporting climate

[34] Ventura County, "Climate Protection Plan for Government Operations: A Community Commitment," April 2012, http://sustain.ventura.org/downloads/climate_protection_plan.pdf

[35] "One Water LA," Los Angeles County, last accessed April 30, 2019, https://www.lacitysan.org/san/faces/home/portal/s-lsh-es/s-lsh-es-owla;jsessionid=nIWSh38gyqcdCZr4Y3SIsT1tDxNZmySMnbqAXvduCfkzLsSlyX9M!1668673566!-1983634654?_afrLoop=7596676063405412&_afrWindowMode=0&_afrWindowId=null#!%40%40%3F_afrWindowId%3Dnull%26_afrLoop%3D7596676063405412%26_afrWindowMode%3D0%26_adf.ctrl-state%3D10t2h03gdu_4

[36] "About Us," Climate Resolve, last accessed April 30, 2019, http://climateresolve.org/about-us/

adaptation efforts in their own regions to enhance public health, protect natural systems, build economies, and improve local quality of life. Projects and initiatives specific to LARC include[37]:

Regional Framework for Climate Action and Sustainability: LARC has crafted a county-wide CAP to reduce greenhouse gas emissions and prepare the region to adapt to the impacts of climate change. Known as "A Greater L.A.: Climate Action Framework," this effort is a multi-year process to integrate numerous county-wide and jurisdiction-specific efforts with best practices and model ordinances that ensure a resilient and vibrant future for local communities.

LA Energy Atlas: The LA Energy Atlas provides Californians with the opportunity to interact with the largest set of disaggregated energy data in the nation. This interactive website can be used to inform energy planning and research in Los Angeles, and throughout California, as the state works to achieve its energy goals and local regions work to create sustainable energy. The Atlas improves transparency of building energy consumption in the most populous county in the United States.

Regional Adapt LA: Coastal Impacts Planning in the LA Region: This initiative led to the development of a comprehensive shoreline change and coastal erosion model for the Los Angeles region. The model was developed by a team focused on shoreline and beach response, with the work led by the U.S. Geological Survey to develop a coastal storm modeling system (CoSMoS) for Southern California (for more on CoSMoS, see Section 7.2). The City of Santa Monica served as the grant lead, but the project was conducted in close collaboration with other participating jurisdictions including: the University of Southern California (USC) Sea Grant Program, the CA State Coastal Conservancy, Heal the Bay, the Santa Monica Bay Restoration Commission (SMBRC), TerraCosta Consulting Group, and ESA PWA.

LA County 2010 Community GHG Inventory: The LARC, in partnership with Los Angeles County Internal Services Division Office of Sustainability, recently released 2010 community GHG inventories for every city in Los Angeles County as well as county unincorporated communities. These data serve as a baseline and starting point for critical Climate Action Planning work that must occur throughout the region to comply with the mandates set forth in AB 32 – the Global Warming Solutions Act.

3.4. 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.

3.4.1. 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

[37] "Projects & Initiatives," Los Angeles Regional Collaborative for Climate Action and Sustainability, last accessed April 30, 2019 http://www.laregionalcollaborative.com/projects/

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).

3.4.2. 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 (a screenshot of the GIS database is shown in Figure 6). The general approach for each hazard's geospatial analysis went as follows:

Obtain/conduct hazard 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 hazard thresholds: Some hazards, namely temperature, precipitation and wildfire, vary in intensity across the landscape. In many locations, the future change in these hazards is not projected to be high enough to warrant special concern, whereas other areas may see a large increase in hazard risk. To highlight the areas most affected by climate change, the geospatial analyses for these hazards defined the critical thresholds for which the value of (or the change in value of) a hazard would be a concern to Caltrans. For example, the wildfire geospatial analysis involved several steps to indicate which areas are considered to have a moderate, high, and very high fire exposure based on the projected frequency of wildfire.

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

Summarize the miles of roadway affected: The final step in the geospatial analyses involved running the segments of roadway exposed to a hazard 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 hazard. 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. 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 in future climate adaptation planning activities.

4. TEMPERATURE

Temperature rise is a direct outcome of increased concentrations of GHGs in the atmosphere. Temperatures in the west are projected to continue rising and heat waves may become more frequent.[38] The potential effects of extreme temperatures on District 7 assets will vary by asset type and will depend on the specifications followed in the original design of the facility. For example, the following have been identified in other studies in the United States as potential impacts of increasing 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.

Resources available for this study did not allow for a detailed assessment of all the impacts temperature might have on Caltrans activities. Instead, it was decided to take a close look at one of the ways in which temperature will 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 is reliant, in part, on the following two temperature variables:

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

These climate metrics are critical to determining the extreme temperatures a roadway may experience over time. This is important to understand, because 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).

The work completed for this effort included assessing the expected low and high temperatures for pavement binder specification in three future 30-year periods centered on the years 2025, 2055, and 2085. Understanding the metrics for these periods will enable Caltrans to gain insight on how pavement

[38] "Extreme Weather," U.S. National Climate Assessment, accessed April 29, 2019, http://nca2014.globalchange.gov/report/our-changing-climate/extreme-weather

design may need to shift over time. 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, 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.

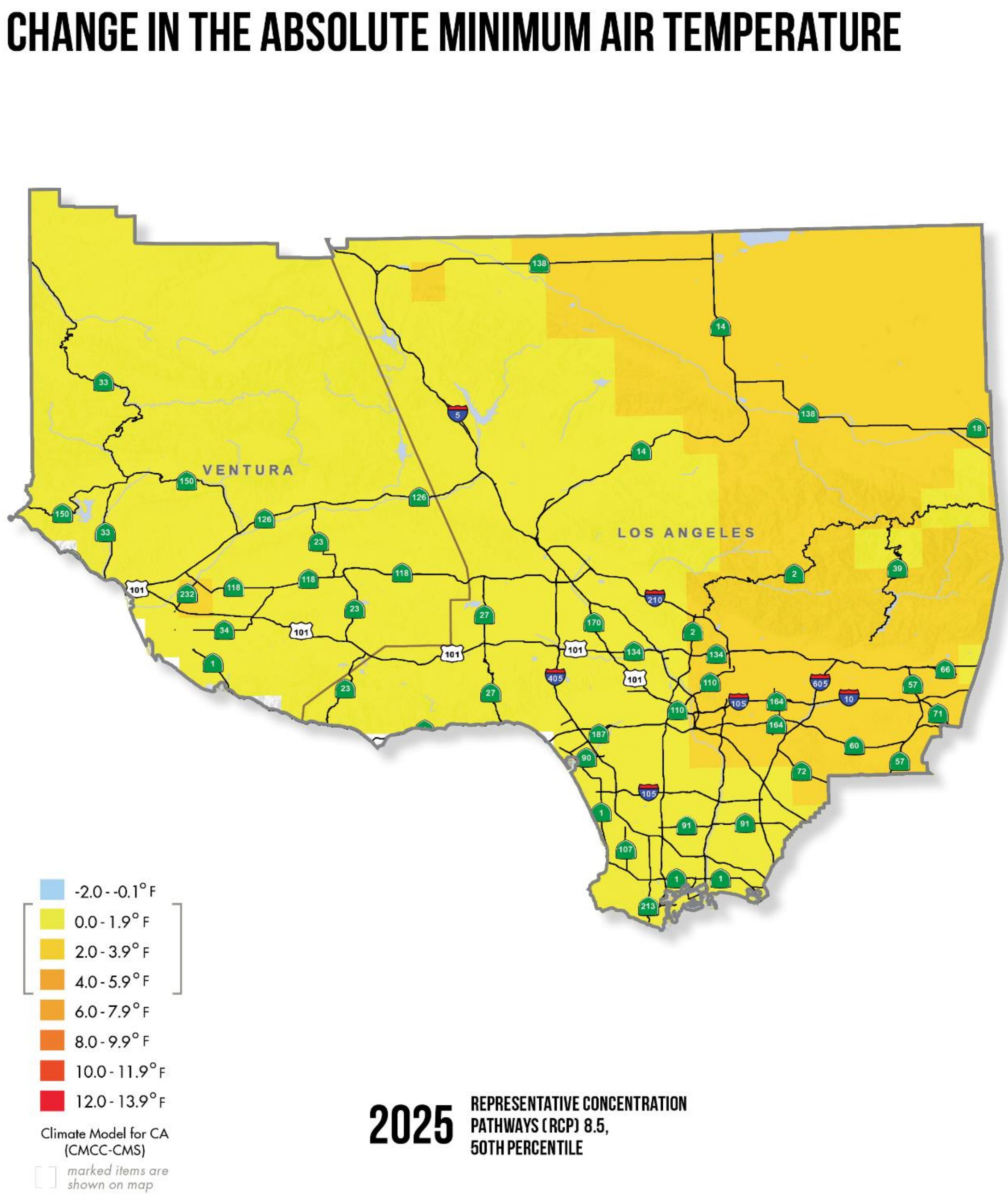
The project study team used the LOCA climate data developed by Scripps for this analysis of temperature,[39] which has a spatial resolution of 1/16 of a degree or approximately three and a half to four miles.[40] This data set was queried to determine the annual lowest temperature and the average seven-day consecutive high temperature. 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 scenarios, and for the three time periods noted.

The maps shown are for the model that represents 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 maximum and minimum metrics. 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 13.9 °F by the end of the century. Finally, for both metrics, temperature changes are generally greater further inland, due to the moderating influence of the Pacific Ocean.

The projected change shown on the maps provided in the following pages. This data can be added to Caltrans' current source of historical temperature data to determine final pavement design value for the future. Summarized temperature data can be used by Caltrans to identify how pavement design practices may need to shift over time given the expected changes in temperature. This can help inform decisions on how to provide the best pavement quality for California State Highway System users.

[39] A more detailed description of the LOCA data set and downscaling techniques can be found at the start of this report.
[40] "LOCA Downscaled Climate Projections," Cal-Adapt, last accessed May 1, 2019, http://cal-adapt.org/data/loca/

FIGURE 3: CHANGE IN ABSOLUTE MINIMUM AIR TEMPERATURE 2025

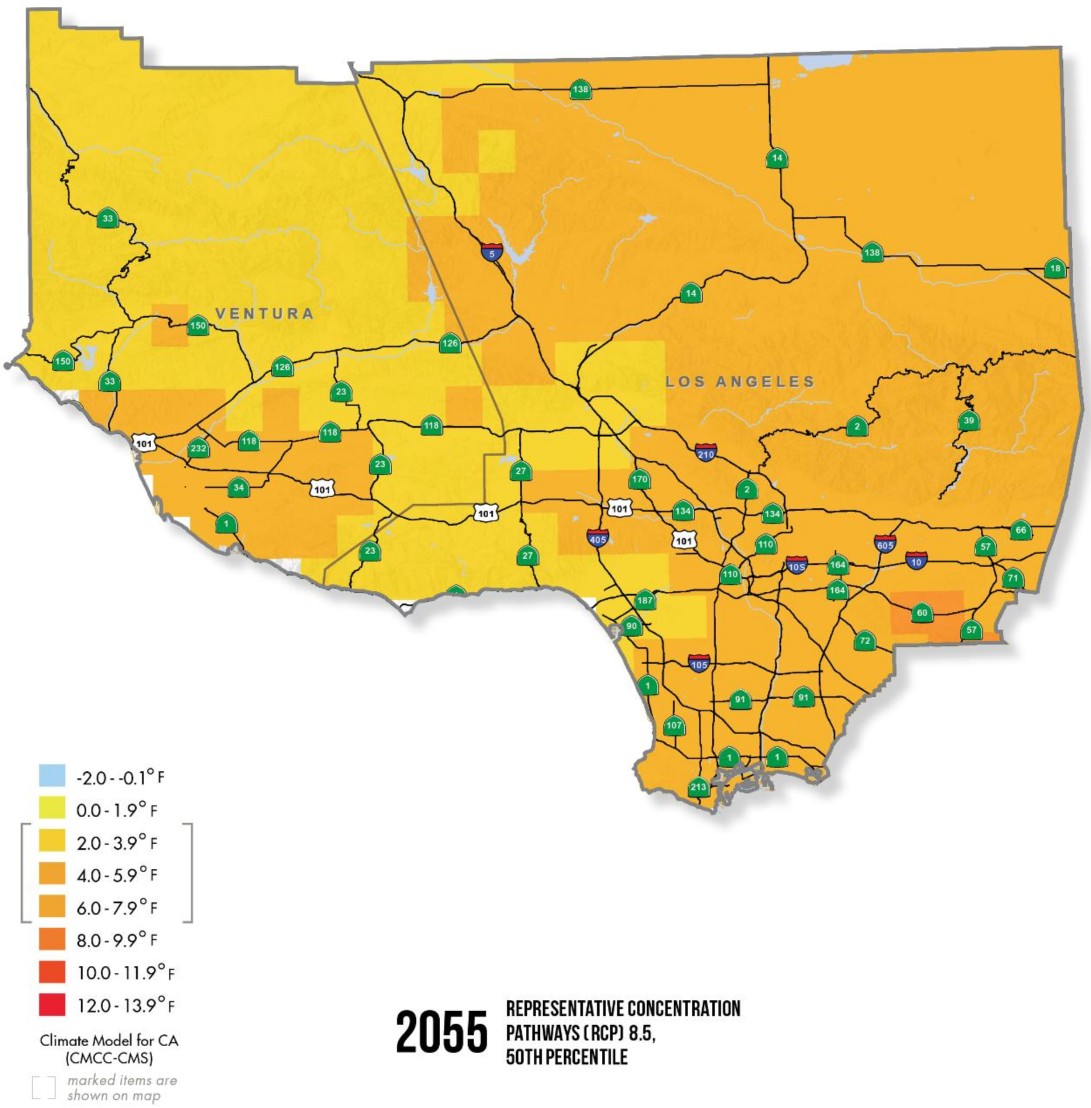


Future Change in the Absolute Minimum Air Temperature within District 7, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 7. 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.

FIGURE 4: CHANGE IN ABSOLUTE MINIMUM AIR TEMPERATURE 2055

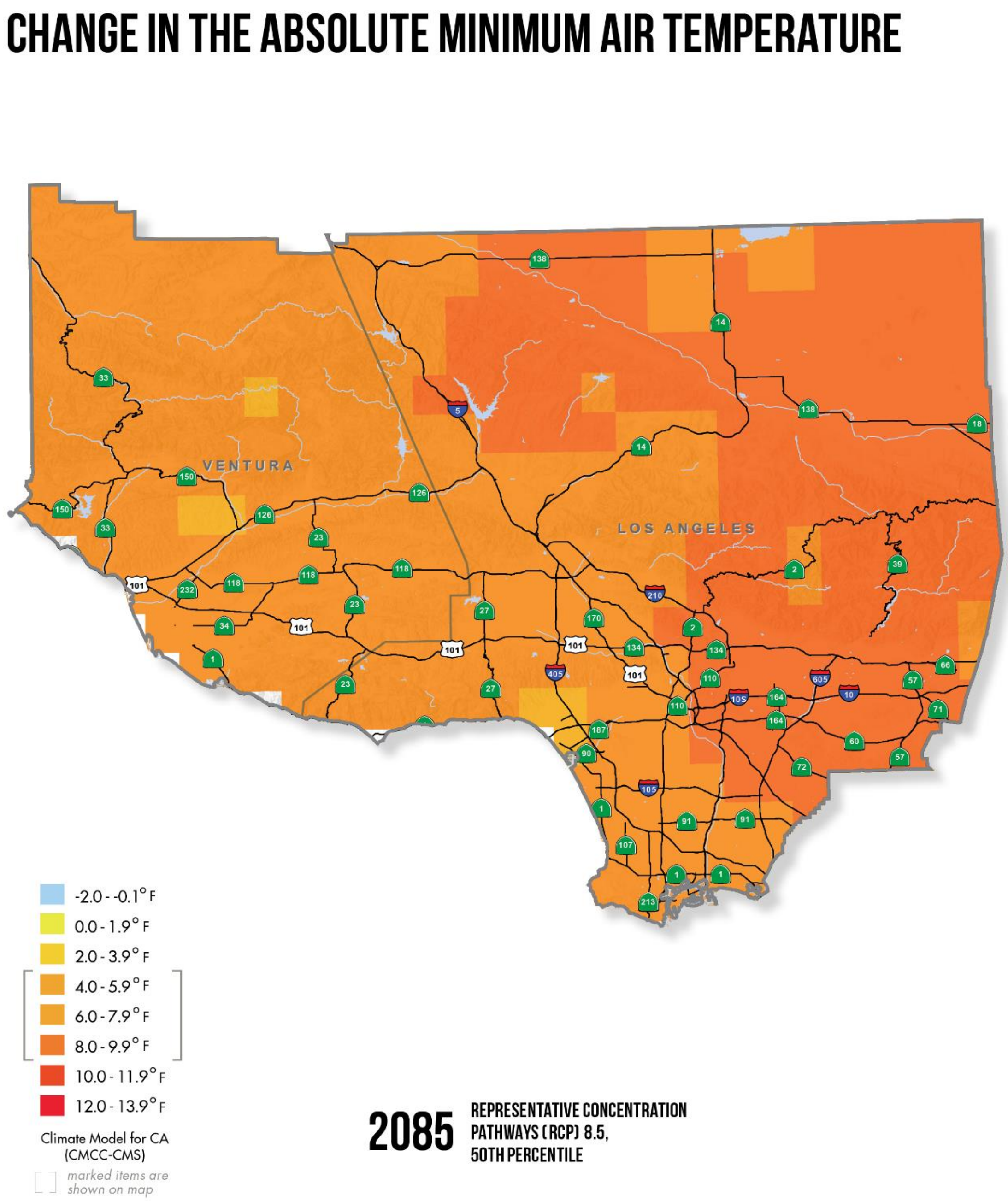
CHANGE IN THE ABSOLUTE MINIMUM AIR TEMPERATURE



Future Change in the Absolute Minimum Air Temperature within District 7, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 7. 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.

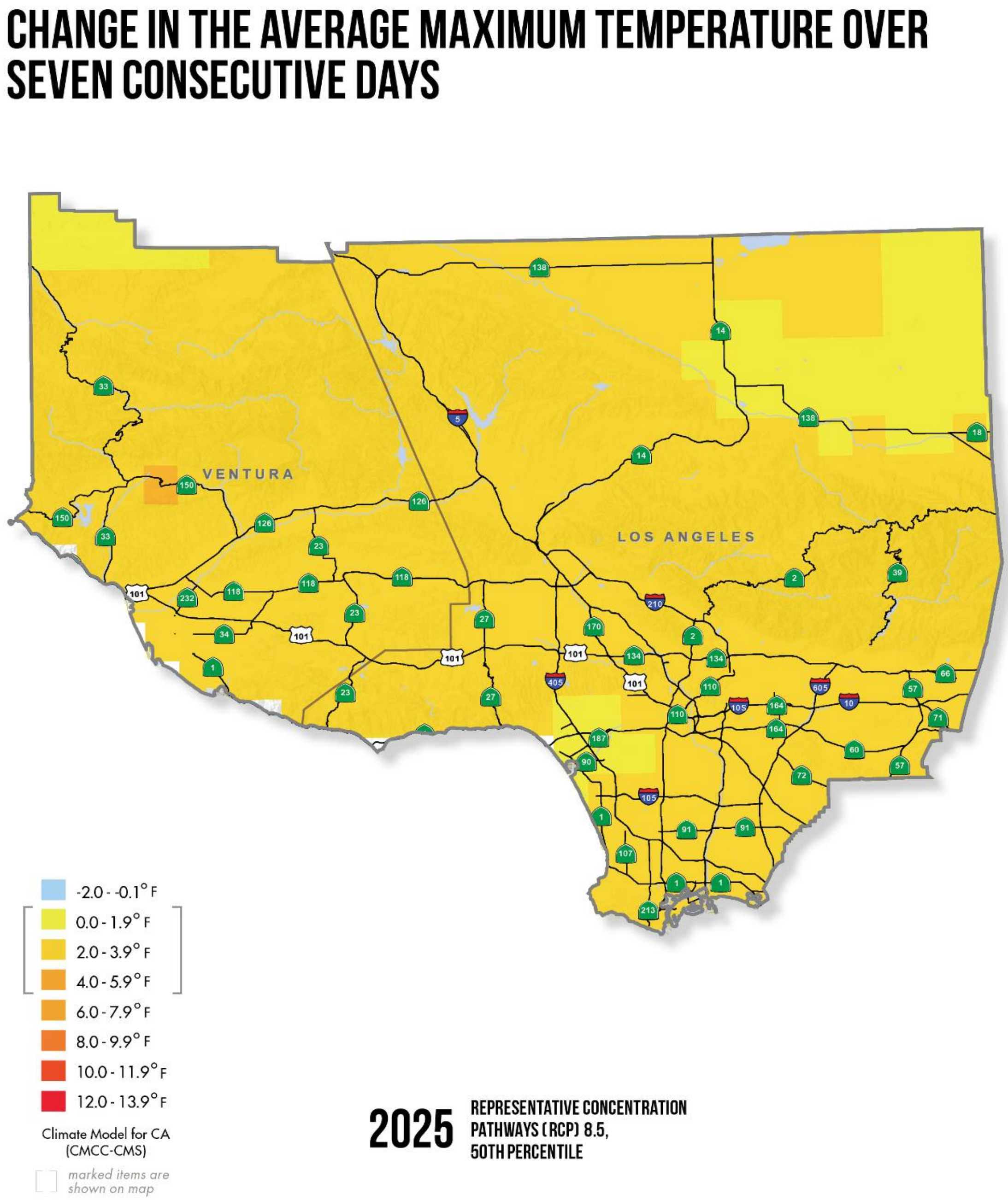
FIGURE 5: CHANGE IN ABSOLUTE MINIMUM AIR TEMPERATURE 2085



Future Change in the Absolute Minimum Air Temperature within District 7, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 7. 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.

FIGURE 6: CHANGE IN AVERAGE MAXIMUM TEMPERATURE OVER SEVEN CONSECUTIVE DAYS 2025

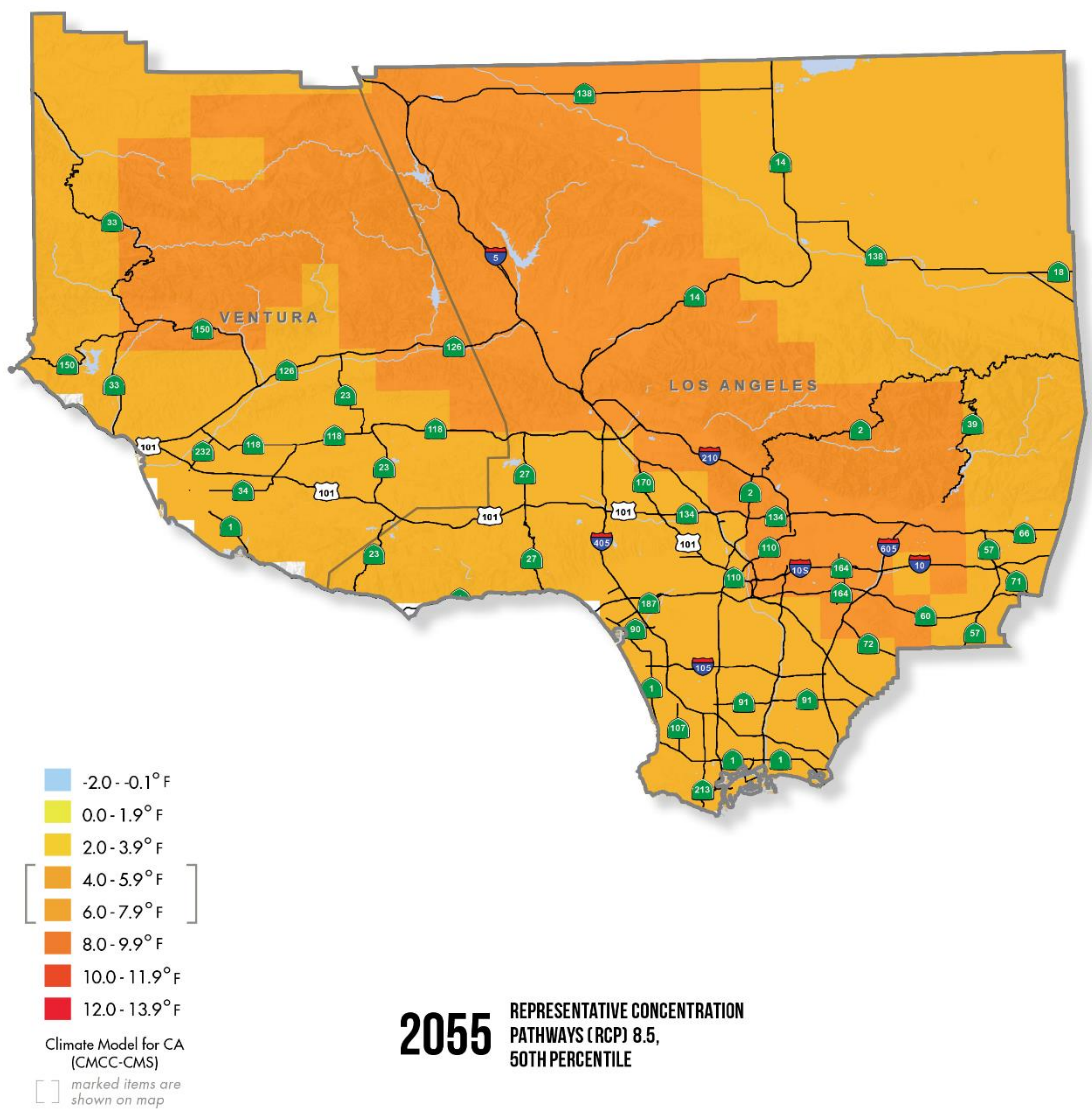


Future Change in the Average Maximum Temperature over Seven Consecutive Days within District 7, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 7. 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.

FIGURE 7: CHANGE IN AVERAGE MAXIMUM TEMPERATURE OVER SEVEN CONSECUTIVE DAYS 2055

CHANGE IN THE AVERAGE MAXIMUM TEMPERATURE OVER SEVEN CONSECUTIVE DAYS

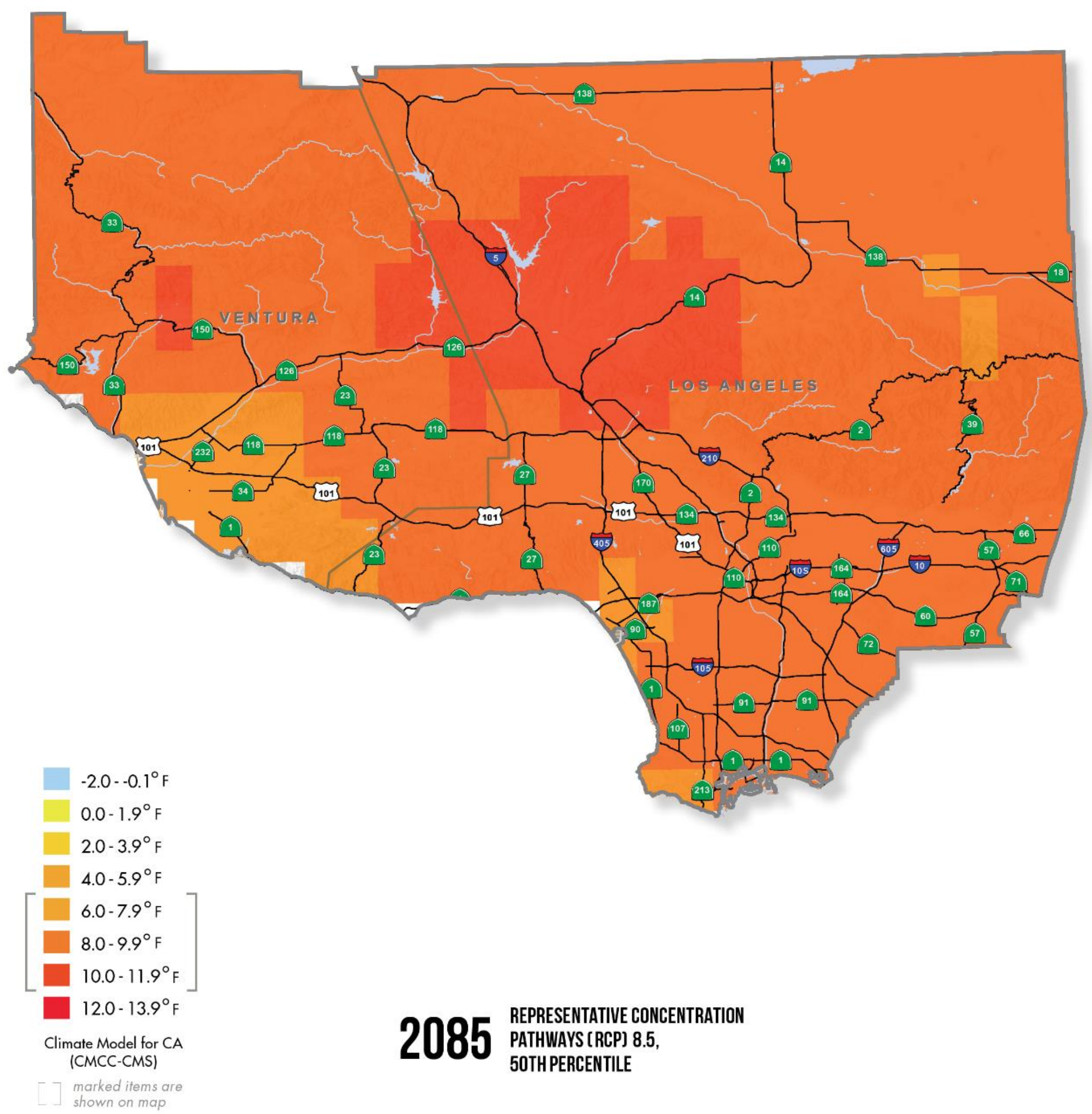


Future Change in the Average Maximum Temperature over Seven Consecutive Days within District 7, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 7. 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.

FIGURE 8: CHANGE IN AVERAGE MAXIMUM TEMPERATURE OVER SEVEN CONSECUTIVE DAYS 2085

CHANGE IN THE AVERAGE MAXIMUM TEMPERATURE OVER SEVEN CONSECUTIVE DAYS



Future Change in the Average Maximum Temperature over Seven Consecutive Days within District 7, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 7. 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.

5. PRECIPITATION

The Southwest region of the United States has been identified as expecting less precipitation overall[41], but with the potential for heavier individual events, with more precipitation falling as rainfall. This section of this report focuses on how these heavy precipitation events may change and become more frequent over time. Current transportation design utilizes return period storm events as a variable to include in asset design criteria (e.g. for bridges, culverts). 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.[42] Therefore, this metric was analyzed to determine how 100-year storm rainfall is expected to change.

Precipitation data is traditionally used at the project level by applying statistical analyses of historical rainfall, most often through the NOAA Atlas 14.[43] Rainfall values from the program are estimated across various time periods—from 5 minutes to 60 days. This data also shows how often rainfall of certain depths may occur in any given year, from an event that would likely occur annually, to one that would be expected to happen only once every 1,000 years. This information has been assembled based on rainfall data collected at rain gauges across the country.

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 by Caltrans. Assessing future precipitation was done by analyzing the broad range of potential effects predicted by a set, or ensemble, of models.

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. The project study team was interested in determining how a 100-year event may change over time for the purposes of analyzing vulnerabilities to the Caltrans State Highway System from inundation. Scripps currently maintains daily rainfall data for a set of climate models and two future emissions estimates for every day to the year 2100. The project study team worked with researchers from Scripps to estimate extreme precipitation changes over time. Specifically, the team requested precipitation data across the set of 10 international GCMs that were identified as having the best applicability for California.

This data was only available for the RCP 4.5 and RCP 8.5 scenarios and was analyzed for three time periods to determine how precipitation may 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 as used for the temperature metrics.

The project study team analyzed the models to understand two important points:

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[41] Melillo, Jerry M., 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.

[42] Caltrans, "Highway Design Manual," December 14, 2018, http://www.dot.ca.gov/hq/oppd/hdm/hdmtoc.htm

[43] National Oceanic and Atmospheric Administration, "Precipitation-Frequency Atlas of the United States," 2018, https://www.nws.noaa.gov/oh/hdsc/PF_documents/Atlas14_Volume11.pdf

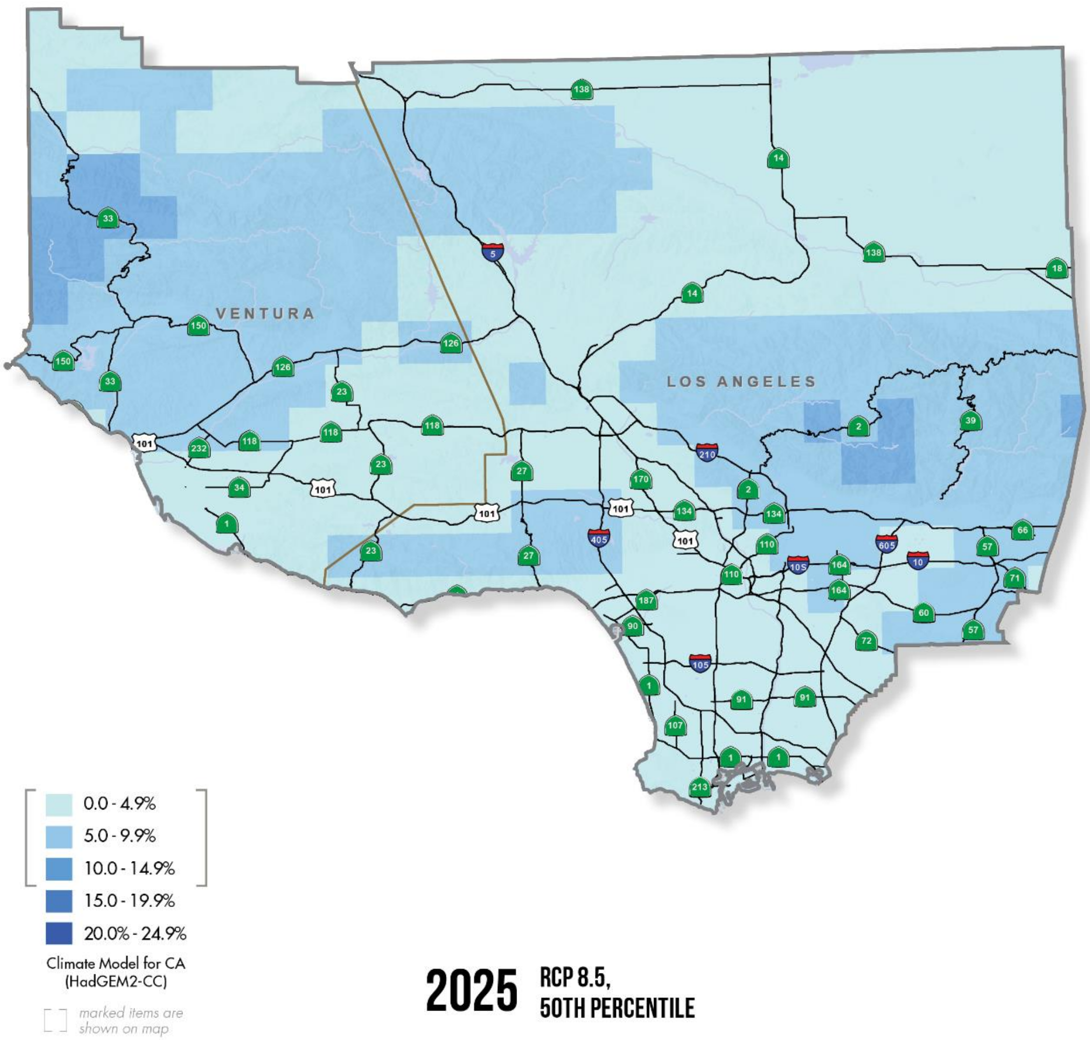
- Were there indications of change in return period storms across the models that should be considered in decision-making when considering estimates for future precipitation?
- What was the magnitude of change for a 100-year return-period storm that should be considered as a part of facility design looking forward?

The results of this assessment are shown in the District 7 maps on the following pages that depict the percentage change in the 100-year storm rainfall event for the three analysis periods, and for the RCP 8.5 emissions scenario (the RCP 4.5 results are not shown). The model most closely representing the median change for the state was used in this mapping (the HadGEM2-CC model). Note that the change in 100-year storm depth is positive throughout District 7, indicating heavier rainfall during storm events

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 State Highway System 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 9: CHANGE IN 100-YEAR STORM EVENT 2025

PERCENT CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH

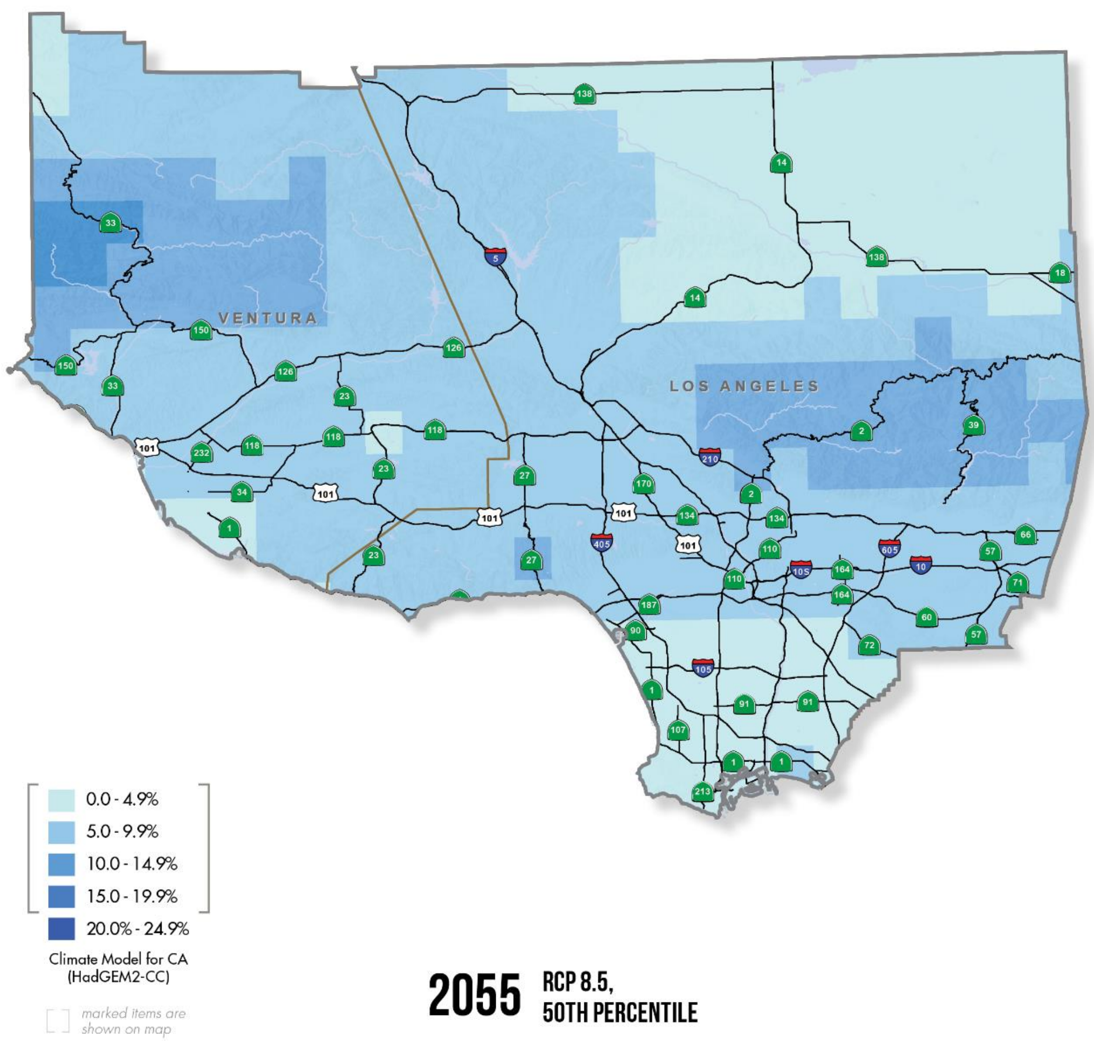


Future Percent Change in 100-year Storm Precipitation Depth within District 7, Based on the RCP 8.5 Emissions Scenario

Caltrans Transpotation Asset Vulnerability Study, District 7. 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.

FIGURE 10: CHANGE IN 100-YEAR STORM EVENT 2055

PERCENT CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH

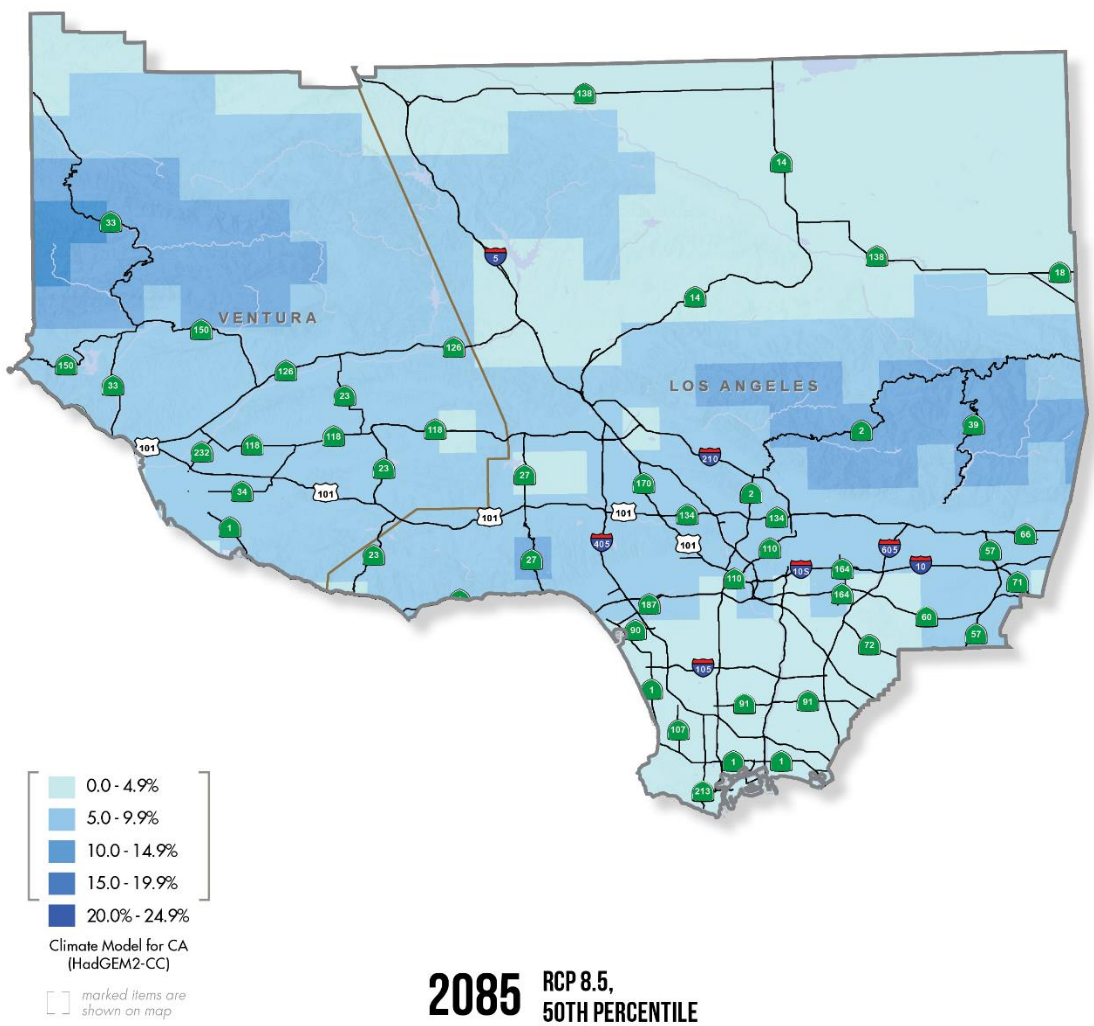


Future Percent Change in 100-year Storm Precipitation Depth within District 7, Based on the RCP 8.5 Emissions Scenario

Caltrans Transpotation Asset Vulnerability Study, District 7. 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.

FIGURE 11: CHANGE IN 100-YEAR STORM EVENT 2085

PERCENT CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH



Future Percent Change in 100-year Storm Precipitation Depth within District 7, Based on the RCP 8.5 Emissions Scenario

Caltrans Transpotation Asset Vulnerability Study, District 7. 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.

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 the visibility and health of the public and Caltrans staff.

The last few months of 2017 were notable for the significant wildfires that occurred both in northern and southern California. These devastating fires caused property damage, loss of life, and damage to roadways. The wildfires in Santa Barbara County stripped the land of protective cover and damaged the soils, such that subsequent rain storms led to disastrous mudslides that caused catastrophic damage to the City of Montecito and Highway 101 in Santa Barbara County. 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 State Highway System 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 7 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 State Highway System 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

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 - University of Idaho
- UC Merced/Westerling

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 - ACSC			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 1/16 of a degree square for the MC2 - EPA and UC Merced/Westerling models, which matches the grid cell size for the LOCA climate data applied in developing these models. The MC2 - University of Idaho effort generated data at 1/24 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 decided 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%,
- Moderate 15-50%,
- High 50-100%,

- Very High 100%+.[44]

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, showing moderate (or medium) to very high wildfire risk, as defined in the classification scheme explained above. These figures show projections for RCP 8.5 only and areas of the State Highway System shown in red indicated all areas exposed to moderate (or medium) to very high wildfire risk.[45] Table 2 summarizes the centerline miles of these District 7 State Highway System exposed areas, by year and District 7 county.

TABLE 2: CENTERLINE MILES OF STATE HIGHWAY SYSTEM EXPOSED TO WILDFIRE FOR THE RCP 8.5 SCENARIO

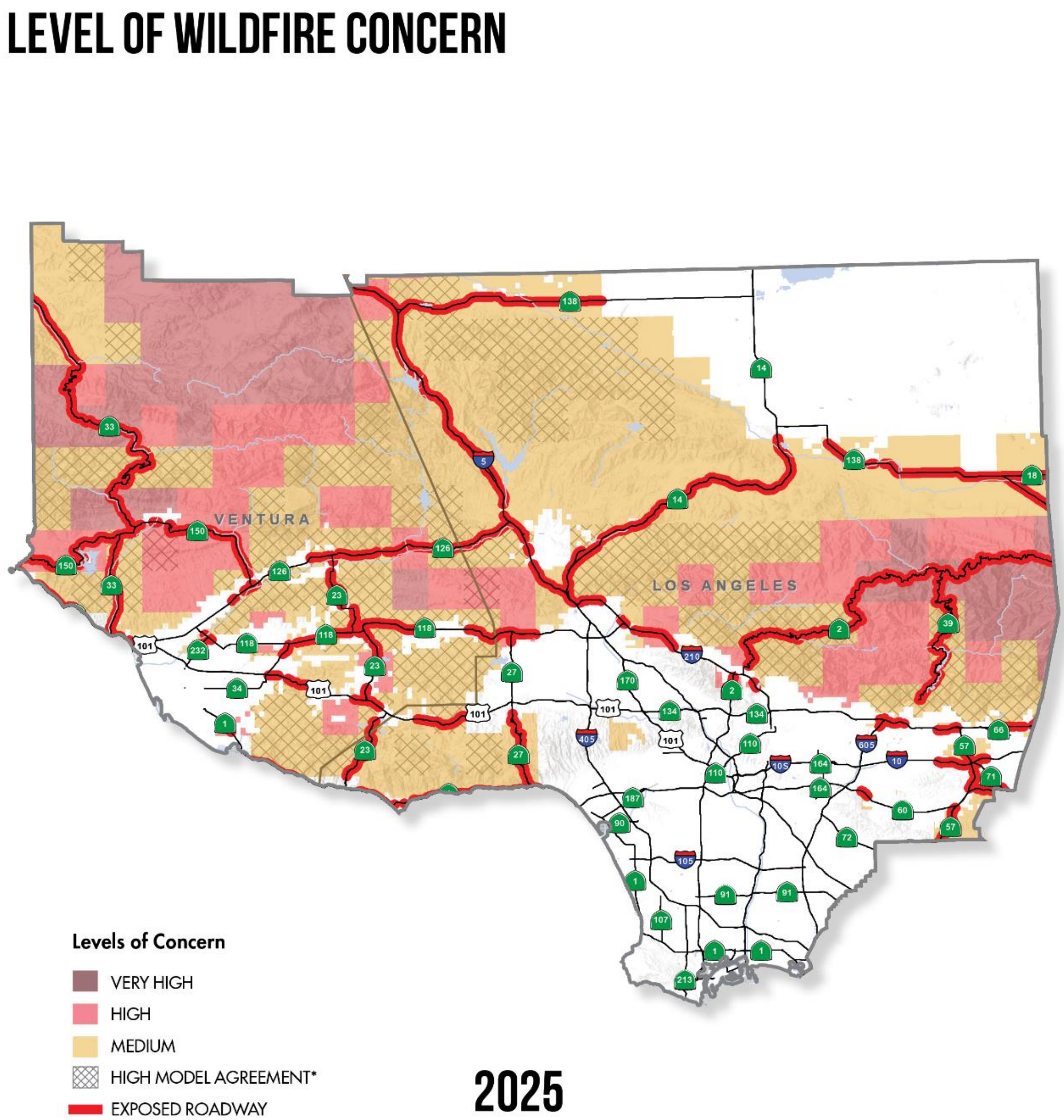
	Year		
District 7 Counties	**2025**	**2055**	**2085**
Los Angeles	297.2	303.3	311.6
Ventura	152.7	155.6	157.6

TABLE 3: CENTERLINE MILES OF STATE HIGHWAY SYSTEM EXPOSED TO WILDFIRE FOR THE RCP 4.5 SCENARIO

	Year		
District 7 Counties	**2025**	**2055**	**2085**
Los Angeles	258.6	274.4	269.9
Ventura	149.2	157.6	157.6

[44] A cell can have greater than 100% burn if burned twice or more in the same time period.
[45] Areas on the maps shown in white do not necessarily have no associated wildfire risk - the classification is below moderate.

FIGURE 12: INCREASE IN WILDFIRE EXPOSURE 2025



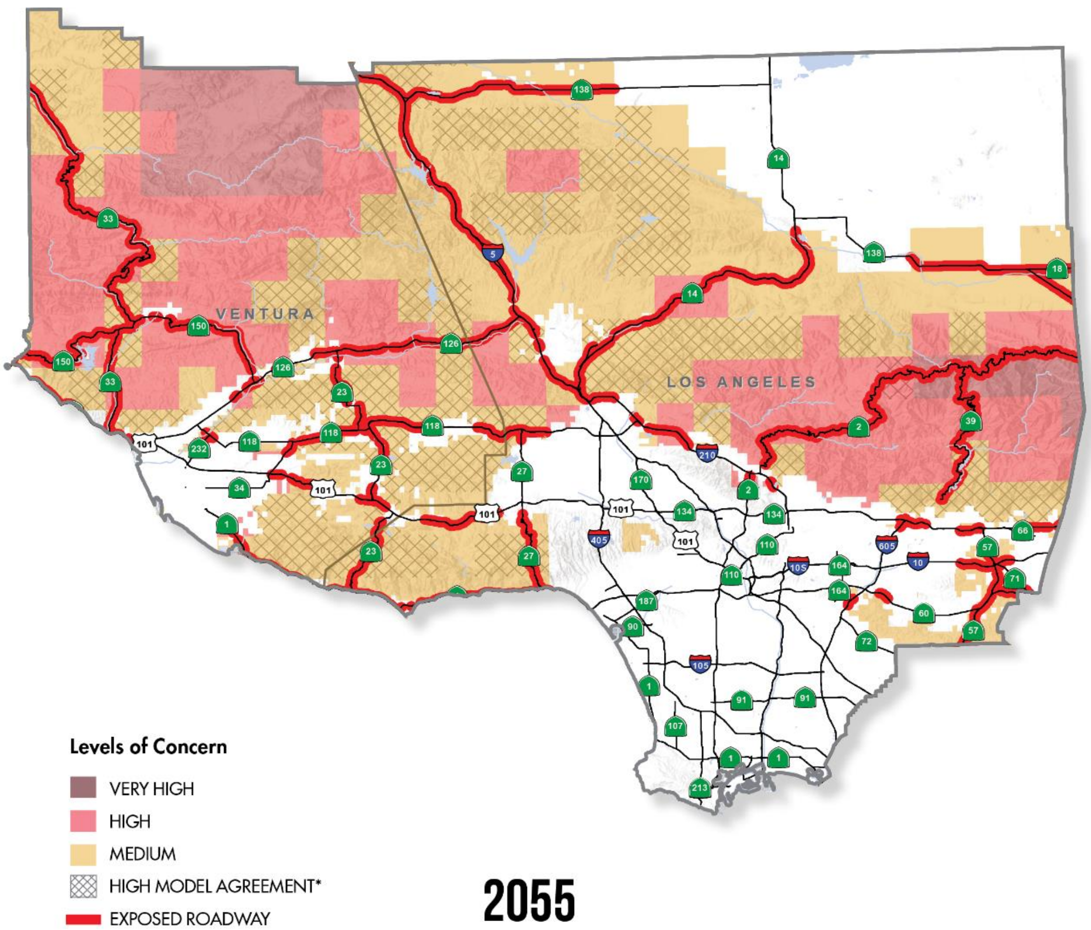
Future Level of Wildfire Concern for the Caltrans State Highway System within District 7, Based on the RCP 8.5 Emissions Scenario

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 GCMs: (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.

*The hashing shows areas where five or more of the nine models fall under the same cumulative percentage burn classification as the one shown on the map.

FIGURE 13: INCREASE IN WILDFIRE EXPOSURE 2055

LEVEL OF WILDFIRE CONCERN



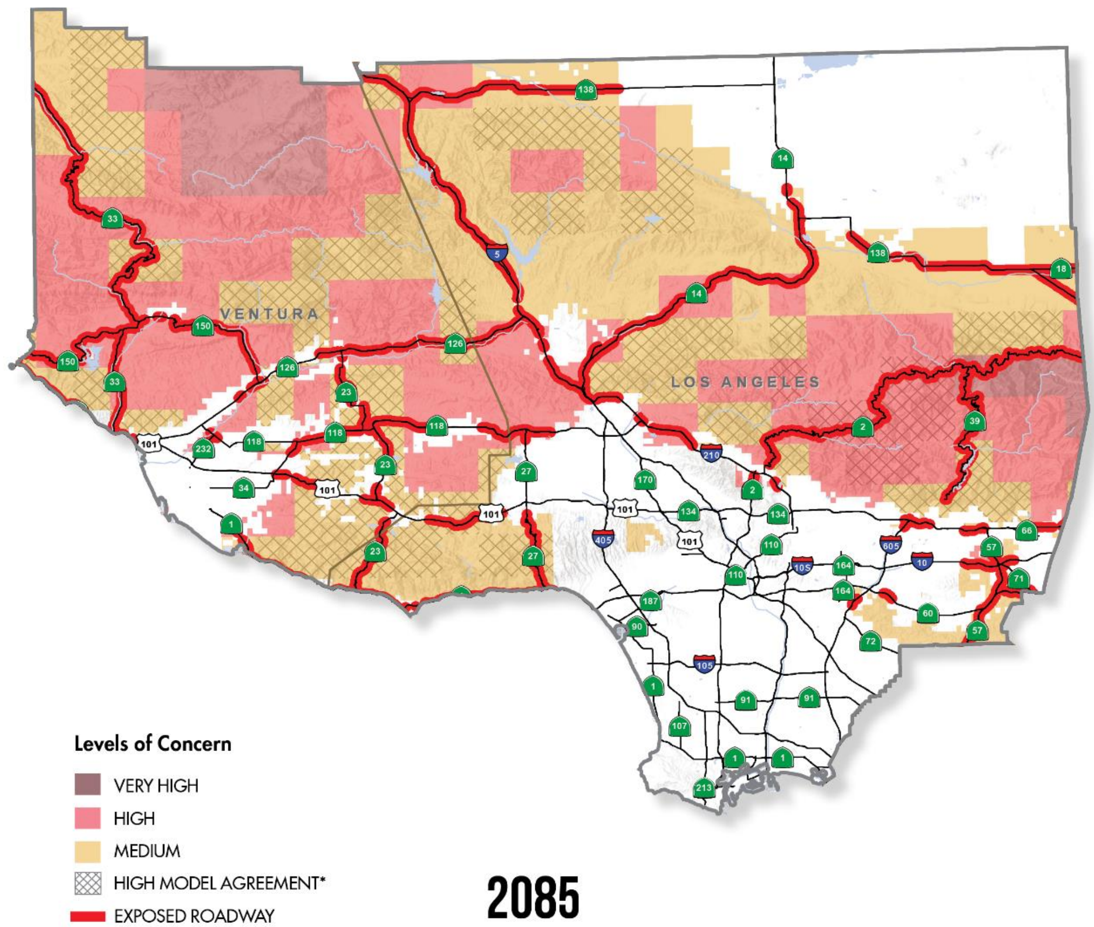
Future Level of Wildfire Concern for the Caltrans State Highway System within District 7, Based on the RCP 8.5 Emissions Scenario

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 GCMs: (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.

*The hashing shows areas where five or more of the nine models fall under the same cumulative percentage burn classification as the one shown on the map.

FIGURE 14: INCREASE IN WILDFIRE EXPOSURE 2085

LEVEL OF WILDFIRE CONCERN



Future Level of Wildfire Concern for the Caltrans State Highway System within District 7, 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 GCMs: (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.

*The hashing shows areas where five or more of the nine models fall under the same cumulative percentage burn classification as the one shown on the map.

7. SEA LEVEL RISE

The data sets considered for this analysis came from new state projections from the Ocean Protection Council (OPC).[46] This set of SLR scenarios was chosen for consideration in this analysis to follow state guidance on SLR planning and to use the best available SLR projections developed for California. For this analysis, these projections are paired with a model that includes sea level rise and storm surge, to identify approximately when potential impacts to the State Highway Network may occur in District 7. For more information on how the projections are used given the model, see Section 4.1.4 below.

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 15 below reflects estimates recently developed for Los Angeles by a scientific panel for the 2018 Update of the State of California Sea-Level Rise Guidance, an effort led by the Ocean Protection Council (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 presented 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 scenarios 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:

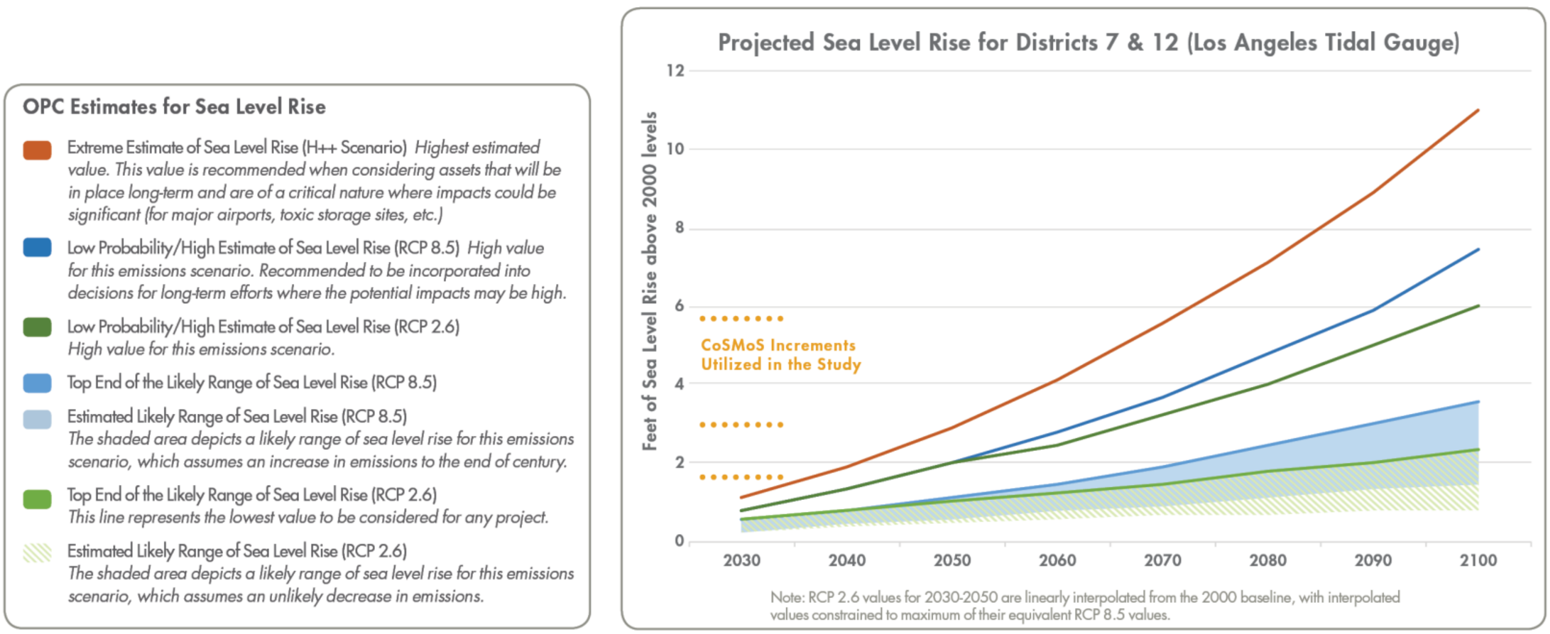
- For low risk aversion decisions, the OPC recommends using the likely (66%) probability sea level rise range. In the graphic to the right, this range is shaded in light blue for the RCP 8.5 scenario and is shaded in light green for RCP 2.6.
- For medium to high risk aversion decisions, the OPC recommends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

[46] California Ocean Protection Council, "State of California Sea-Level Rise Guidance: 2018 Update," March 14, 2018, 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. 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, and will be working in the coming months to define how this data is incorporated into capital investment decisions.

FIGURE 15: OPC 2018 DRAFT GUIDANCE SEA LEVEL RISE PROJECTIONS FOR LOS ANGELES



Note: The OPC guidance outlines an approach for incorporating sea level rise into planning, permitting, and investment decisions which recognizes the uncertainties for future sea level rise. The sea level rise estimates shown above are the values the guidance identifies that practitioners should consider. When making decisions, practitioners are advised to address the impacts of various water levels on project alternatives, identify possible adaptive designs that can be altered to adjust to changing future conditions, and consider the risk tolerance for assets.

1 - http://www.opc.ca.gov/webmaster/_media_library/2017/11/State-of-California-Sea-Level-Rise-Guidance_draft-final_11.15.17.pdf

7.2. Model Used

The previous section described estimated SLR levels from the OPC and the guidance for using them; this section discusses the CoSMoS storm model used in this study alongside these projections. The CoSMoS model was developed by the United States Geological Survey (USGS) and model data can be viewed and downloaded from the *Our Coast Our Future* site.[47] The model was funded by stakeholders interested in understanding the associated impacts of storm events combined with future SLR along the California coast and within San Francisco Bay. The CoSMoS model is robust in the variables considered and is conservative in its estimates by always considering maximum water levels for simulated storm events.

[47] "Flood Map," Our Coast, Our Future, last accessed May 1, 2019, http://data.pointblue.org/apps/ocof/cms/

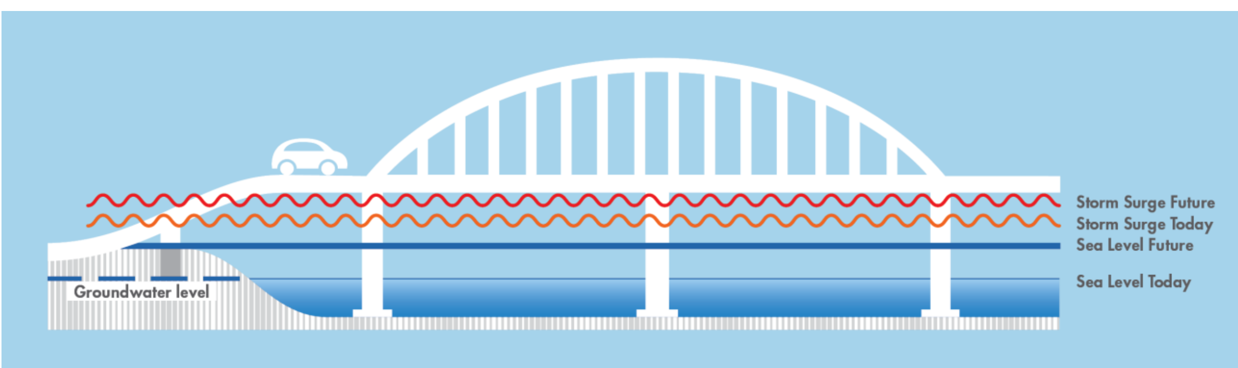
CoSMoS data is available in GIS shapefiles and was developed for SLR from 0.00 to 2.00 meters, in quarter-meter increments, and for 5.00 meters to reflect longer-term change. Analysis of the State Highway System was completed for all CoSMoS increments. However, the analysis presented in this report is specific to three increments of SLR developed by the model: 1.64, 3.28, and 5.75 feet (0.50, 1.00, and 1.75 meters, respectively). See Figure 15 to identify approximately when the OPC SLR scenarios will reach these SLR heights and the range between projections. In addition to considering each increment of SLR rise, the project study team analyzed the effects from an annual storm event (a storm that happens on average once a year). A one-year return period storm event was used to identify when the initial effects of SLR may begin to impact the District 7 State Highway System or other District 7 assets.

7.3. Bridge Exposure

Bridges are often designed to historical water levels and flood conditions which may not be applicable as those conditions change. Figure 16 provides some examples as to how a bridge could be affected by rising sea levels and storm surge. Changing water levels can cause a wide range of impacts to Caltrans bridges and a bridge does not necessarily need to be overtopped to be damaged. It will be important for Caltrans to consider all potentially at-risk bridges and pursue additional analysis as necessary. As sea levels rise, Caltrans bridges may be exposed to the following risks:

- A rising groundwater table may inundate supports that were not built to accommodate saturated soil conditions, leading to erosion of soils and loss of stability.
- Higher sea levels can mean greater forces on the bridge during normal tidal processes, increasing scour effects on bridge support structures.
- Higher water levels mean storm surges will be higher and have more force than today. These forces could cause scour on bridge substructure elements.
- Bridge approaches (where the roadway transitions to the bridge deck) may be damaged during storms.
- Surge and wave effects may loosen or damage portions of the bridge, requiring securing, re-attaching, or replacing these parts.

FIGURE 16: BRIDGE EXPOSURE



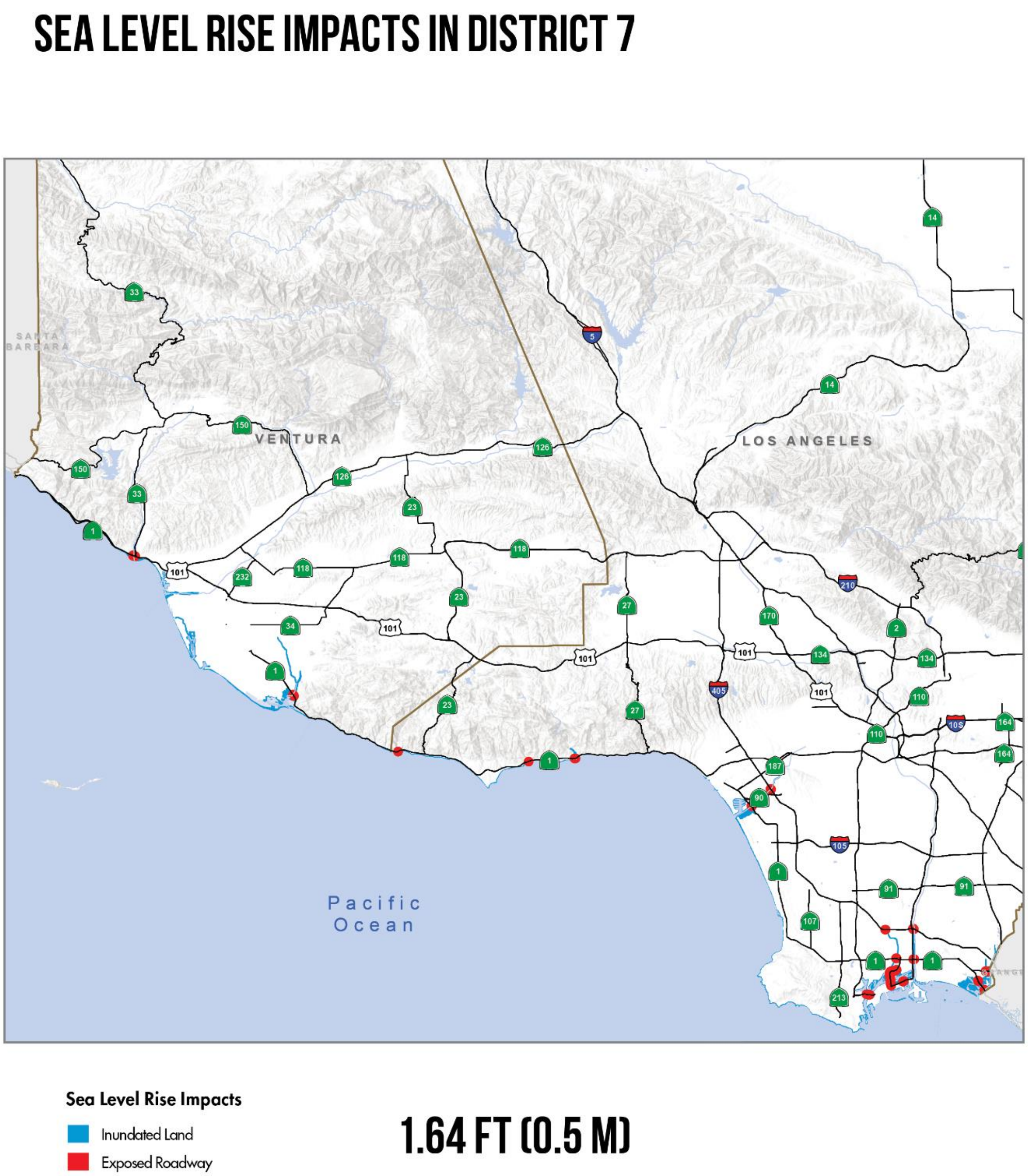
7.4. Analysis Summary

The portion of State Highway System centerline miles in District 7 that are exposed to the three sea level rise increments with an annual storm are summarized in Table 4, by county. These Centerline miles include bridges, which may not be inundated under these sea level rise increments depending upon their freeboard, but could be exposed to other impacts as explained above. District 7 may choose to prioritize adaptation efforts where these exposed roadways are, using the GIS data provided by the project study team. Full district-scale maps of sea level rise exposure on the State Highway System are provided in the following pages.

TABLE 4 DISTRICT 7 CENTERLINE MILES EXPOSED TO SEA LEVEL RISE AND AN ANNUAL STORM

	Sea Level Rise		
District 7 Counties	1.64 ft (0.50 m)	3.28 ft (1.00 m)	5.74 ft (1.75 m)
Los Angeles	2.61	4.03	6.91
Ventura	0.20	0.21	2.39

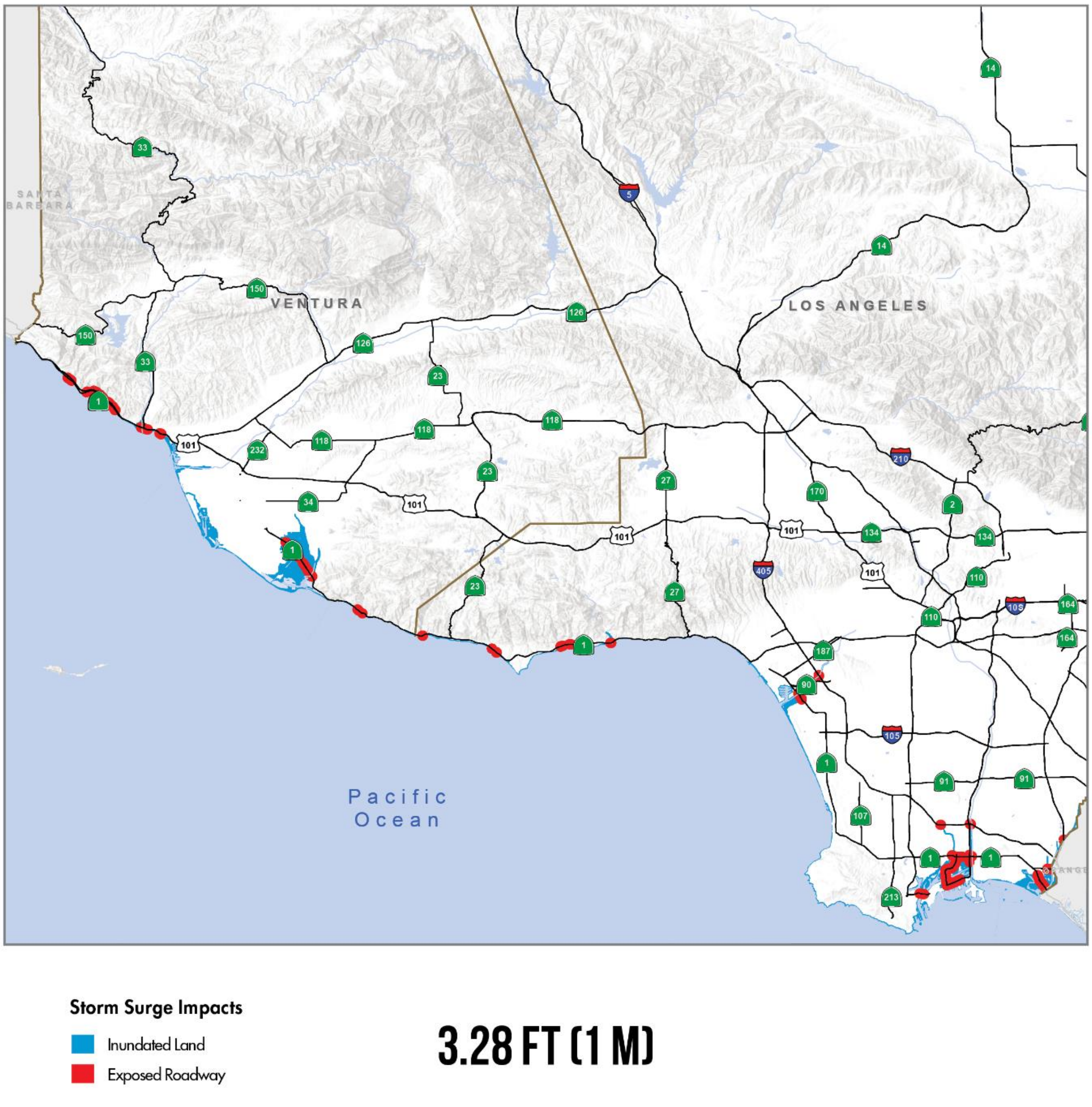
FIGURE 17: DISTRICT 7 EXPOSURE TO 1.64 FEET (0.50 METERS) SEA LEVEL RISE



SEA LEVEL RISE DATA ARE FROM THE US GEOLOGICAL SURVEY, COASTAL STORM MODELING SYSTEM (COSMOS). SEE Our Coast, Our Future AND THE USGS CoSMoS webpage FOR MORE INFORMATION ON THE MODEL.

FIGURE 18: DISTRICT 7 EXPOSURE TO 3.28 FEET (1.00 METER) SEA LEVEL RISE

SEA LEVEL RISE AND STORM SURGE IMPACTS IN DISTRICT 7



SEA LEVEL RISE DATA ARE FROM THE US GEOLOGICAL SURVEY, COASTAL STORM MODELING SYSTEM (COSMOS). SEE Our Coast, Our Future AND THE USGS CoSMoS webpage FOR MORE INFORMATION ON THE MODEL.

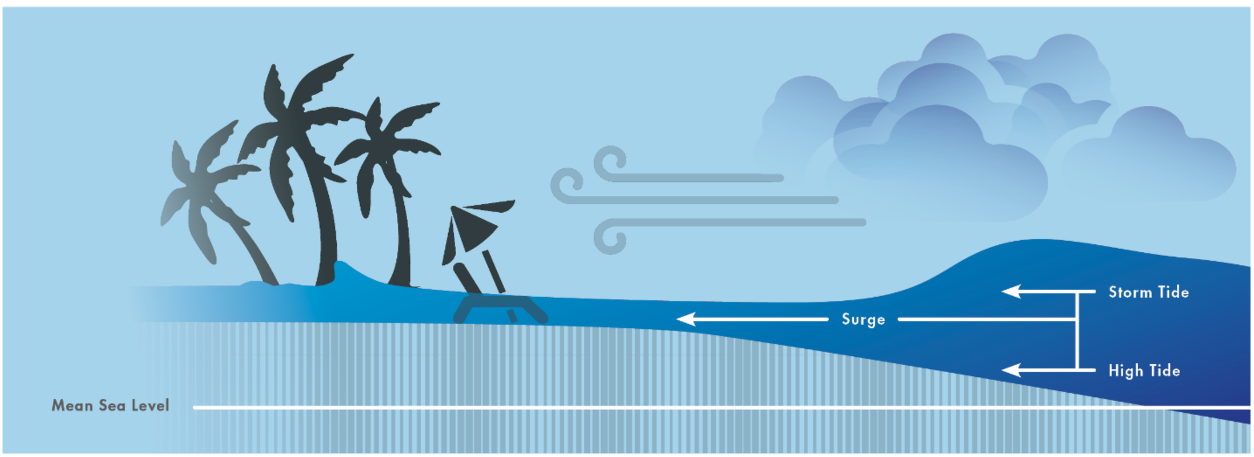
FIGURE 19: DISTRICT 7 EXPOSURE TO 5.74 FEET (1.75 METERS) SEA LEVEL RISE

SEA LEVEL RISE DATA ARE FROM THE US GEOLOGICAL SURVEY, COASTAL STORM MODELING SYSTEM (COSMOS). SEE [Our Coast, Our Future] AND THE [USGS CoSMoS webpage] FOR MORE INFORMATION ON THE MODEL.

8. STORM SURGE

As seas rise, more water is in motion during storm surge events. Increased inundation from higher water levels and more forceful storm surge will increase long-term risks to infrastructure. Figure 20 identifies the basic elements of storm surge and how it is different from normal tidal conditions. The graphic, created by the National Oceanic and Atmospheric Administration (NOAA) and edited for this study, shows how water levels increase and reach farther on land in storm surge conditions than that of a regular high tide.

FIGURE 20: BASIC ELEMENTS OF STORM SURGE



SOURCE: NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

CoSMoS models potential inundation of storm surge combined with SLR for most of the California coast and the Bay Area. F To estimate storm surge exposure for Caltrans District 7 roadways, the project study team mapped SLR of 1.64, 3.28, and 5.74 feet (or 0.50, 1.00, and 1.75 meters, respectively) combined with the 100-year storm event. The 100-year storm event is a design standard for infrastructure projects and is the Base Flood Elevation (BFE) as determined by the Federal Emergency Management Agency (FEMA). Therefore, the 100-year storm event is an important metric for Caltrans infrastructure. Table 5 summarizes, by county, the centerline miles of the Caltrans District 7 highways and bridges that could be exposed during the 100-year storm event combined with SLR.[48]

TABLE 5: DISTRICT 7 CENTERLINE MILES EXPOSED TO SEA LEVEL RISE AND THE 100-YEAR STORM

		Sea Level Rise	
District 7 Counties	1.64 ft (0.50m)	3.28 ft (1.00m)	5.74 ft (1.75m)
Los Angeles	3.72	5.83	8.36
Ventura	1.94	2.82	8.82

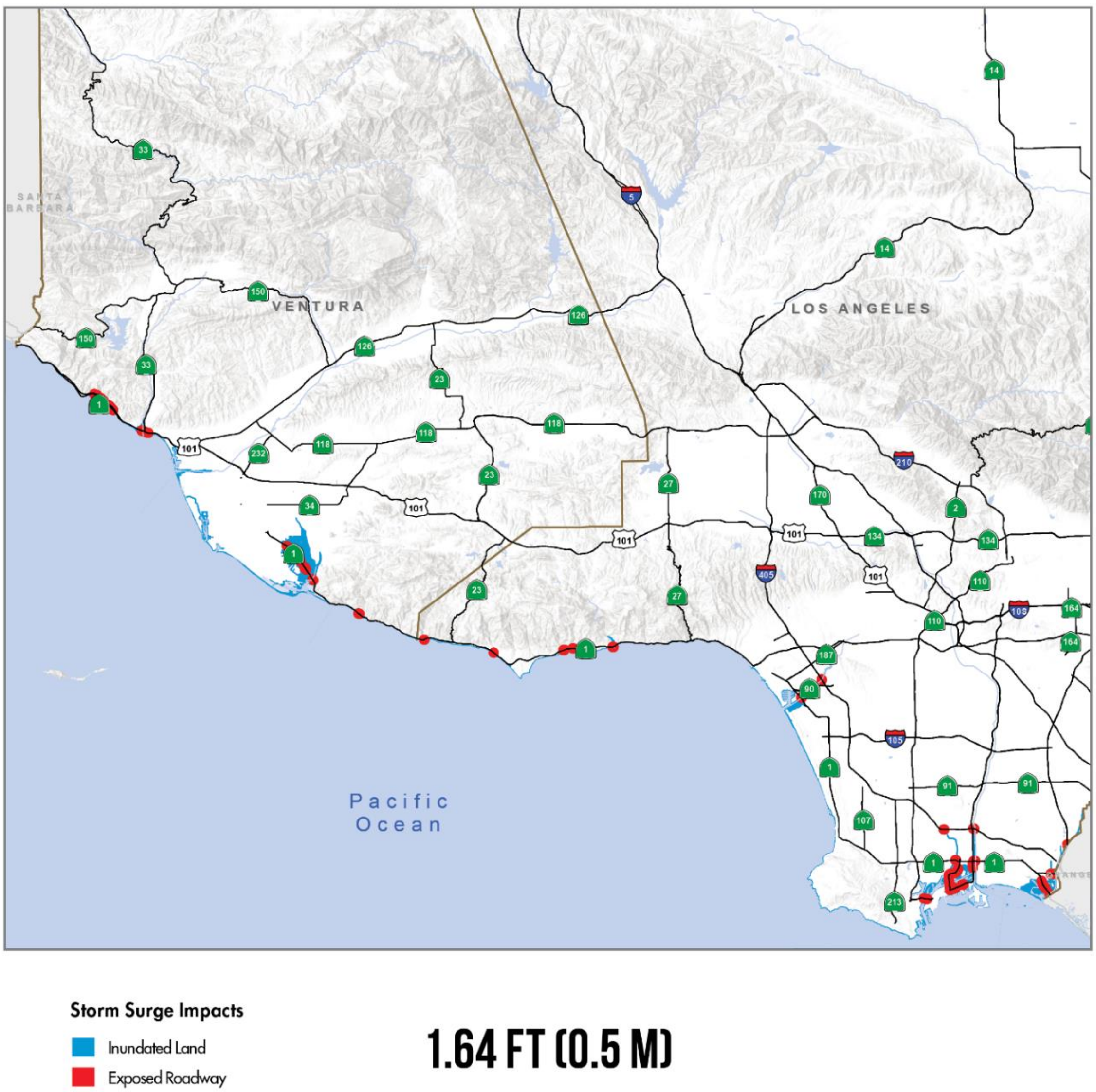
As mentioned in Section 2, the roadway most vulnerable to sea level rise impacts in District 7 is the Pacific Coast Highway. Under 1.64 feet (0.50 meters) of sea level rise with a 100-year storm there are small portions of the PCH exposed to inundation from both boundaries of Ventura to Los Angeles

[48] Exposed State Highway System mileage includes previous sea level rise inundation.

counties. Under the highest SLR increment, or 5.74 feet (1.75 meters) of sea level rise, the portion of the PCH exposed to a 100-year storm event starts to move further up the coast in both counties. As shown in Table 5, the mileage of highway exposed is comparable between Ventura and Los Angeles counties. Full district-scale maps of sea level rise and storm surge exposure on the State Highway System are provided for District 7 on the following pages.

FIGURE 21: DISTRICT 7 EXPOSURE TO 1.64 FEET (0.50 METERS) SEA LEVEL RISE AND 100-YEAR STORM

SEA LEVEL RISE AND STORM SURGE IMPACTS IN DISTRICT 7



SEA LEVEL RISE AND STORM SURGE (100-YEAR STORM) DATA ARE FROM THE US GEOLOGICAL SURVEY, COASTAL STORM MODELING SYSTEM (COSMOS). SEE [Our Coast, Our Future] AND THE [USGS CoSMoS webpage] FOR MORE INFORMATION ON THE MODEL.

FIGURE 22: DISTRICT 7 EXPOSURE TO 3.28 FEET (1.00 METER) SEA LEVEL RISE AND 100-YEAR STORM

SEA LEVEL RISE AND STORM SURGE (100-YEAR STORM) DATA ARE FROM THE US GEOLOGICAL SURVEY, COASTAL STORM MODELING SYSTEM (COSMOS). SEE Our Coast, Our Future AND THE USGS CoSMoS webpage FOR MORE INFORMATION ON THE MODEL.

FIGURE 23: DISTRICT 7 EXPOSURE TO 5.74 FEET (1.75 METERS) SEA LEVEL RISE AND 100-YEAR STORM

SEA LEVEL RISE AND STORM SURGE (100-YEAR STORM) DATA ARE FROM THE US GEOLOGICAL SURVEY, COASTAL STORM MODELING SYSTEM (COSMOS). SEE [Our Coast, Our Future] AND THE [USGS CoSMoS webpage] FOR MORE INFORMATION ON THE MODEL.

9. CLIFF RETREAT

The 1,100 mile California coastline has been shaped by various forces over time and is well known for its active areas of erosion, landslides, and cliff retreat. Estimates from a recent study of the coastline identified that approximately 72% of the California coast is eroding because of ocean wave energy on beaches and cliffs.[49]. 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[50].

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 (like the Bixby Bridge) 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.

Recent erosive effects on the California coast are occurring at the same time as a period of rapid development and actions are being taken to reduce loss of land at the coast. Over the past century, sea levels rose roughly 6 inches[51] and are continuing to rise, which will result in more regular inundation, higher tides and an increase in wave forces during coastal storms. The effects of all tidal and storm events are anticipated to stretch farther inland and with higher water and wave elevation than what has been observed and planned for in the past.

There are several that agencies research the implications of climate change and the effects of higher water levels on the California coastline. The US Geological Survey 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 CoSMoS data on sea level rise and coastal storms, as explained in Sections 4 and 8 of this report.

For southern California (defined in this instance as the area extending from Point Conception in Santa Barbara County to Imperial Beach in San Diego County), the USGS developed an additional CoSMoS dataset that estimates future cliff retreat given changes in sea level. 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 accelerate."[52]. The USGS effort developed two cliff retreat scenarios, assuming two different conditions: one that assumes that the current armoring of the coast will be maintained and 100% effective as stopping future

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[49] 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), https://pubs.usgs.gov/of/2007/1133/of2007-1133.pdf

[50] University of California San Diego, "Study Identifies California Cliffs at Risk of Collapse," December 20, 2017, https://phys.org/news/2017-12-california-cliffs-collapse.html

[51] "Sea Level Trends," NOAA Tides & Currents, last accessed May 1, 2019, https://tidesandcurrents.noaa.gov/sltrends/sltrends.html

[52] "CoSMoS Southern California v3.0 phase 2 projections of coastal cliff retreat due to 21st century sea-level rise," USGS, last accessed May 1, 2019, https://www.sciencebase.gov/catalog/item/57f4234de4b0bc0bec033f90

cliff erosion (Hold the Line), and one which assumed that cliff retreat continues unimpeded (Do Not Hold the Line)[53].

The USGS CoSMoS team estimated future erosion and cliff retreat by developing "numerical and statistical models based on field observations such as historical cliff retreat rate, submarine slope, coastal cliff height, and mean annual wave power."[54] These models estimated wave height and when that wave height would be expected to heavily impact coastal cliffs. The final estimates of future cliff positions were generated by developing an average of the estimates of these models.

The impact of cliff retreat on transportation infrastructure is a significant concern for Caltrans, as this retreat could undermine State Highway System infrastructure. Protecting highway in Caltrans coastal districts may become more difficult and costly in the future due to cliff retreat. This is especially true if Caltrans acts to keep the current highway alignment where it is, rather than retreating with erosion.

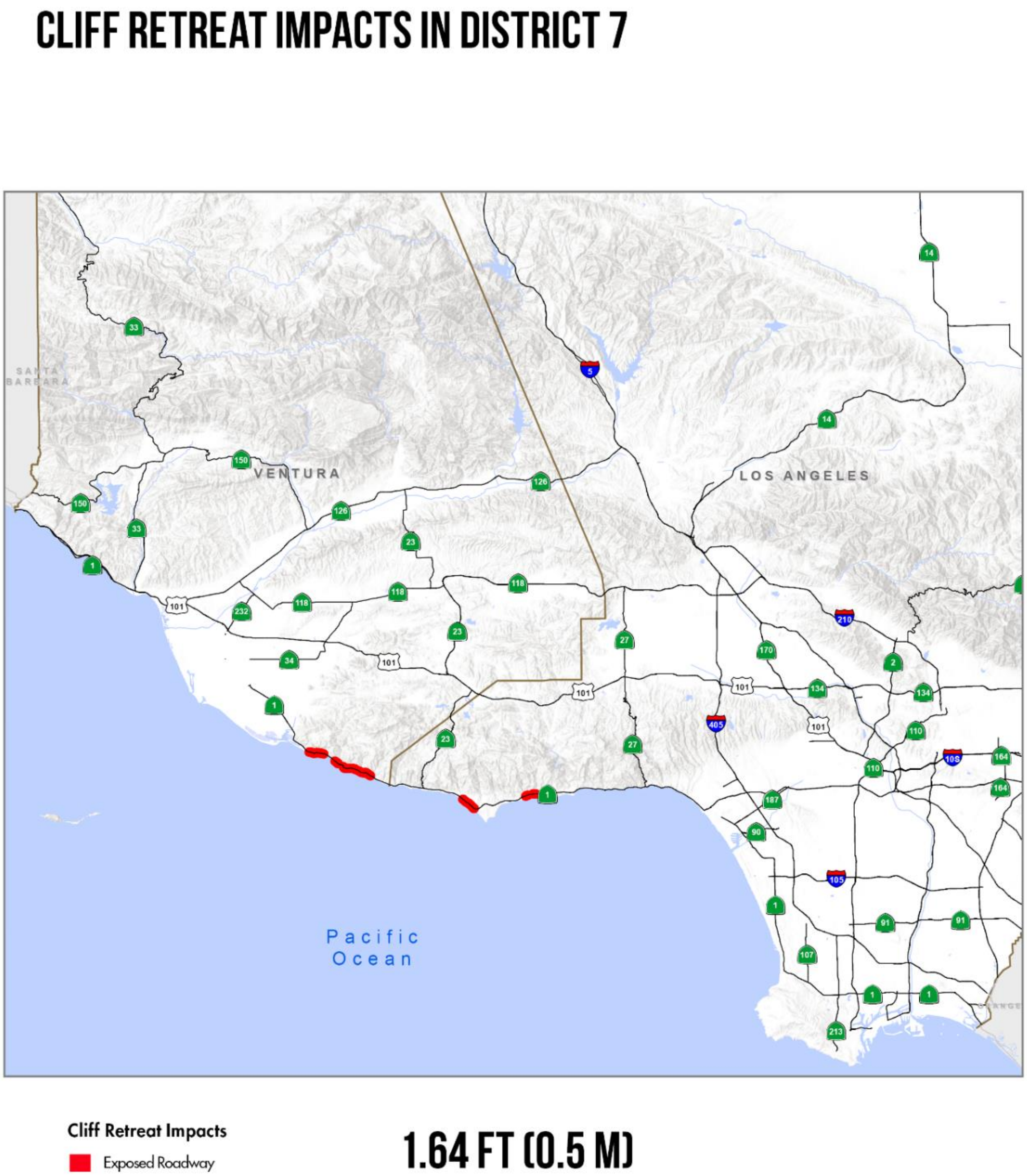
Cliff retreat data from the CoSMoS effort by USGS was used in this analysis. The project study team found areas of the State Highway System exposed to cliff retreat for all sea level rise scenarios provided by USGS. For presentation in this report, only the SLR increments used in the sea level and storm surge sections of this report (1.64, 3.28, and 5.74 feet or 0.50, 1.00, and 1.75 meters, respectively) are shown for the cliff retreat analysis. The "Do Not Hold the Line" scenario was used to identify those areas along the coastline that would erode if not protected and/or hardened. The results of the cliff retreat analysis for District 7 are shown in Table 6 and on the following pages.

TABLE 6: DISTRICT 7 CENTERLINE MILES EXPOSED TO CLIFF RETREAT

		Sea Level Rise	
District 7 Counties	1.64 ft (0.50m)	3.28 ft (1.00m)	5.74 ft (1.75m)
Los Angeles	1.38	1.57	1.63
Ventura	3.00	3.75	4.24

[53] "CoSMoS Southern California v3.0 phase 2 projections of coastal cliff retreat due to 21st century sea-level rise," USGS, last accessed May 1, 2019, https://www.sciencebase.gov/catalog/item/57f4234de4b0bc0bec033f90
[54] Ibid.

FIGURE 24: DISTRICT 7 EXPOSURE TO 1.64 FEET (0.50 METERS) SEA LEVEL RISE AND ASSOCIATED CLIFF RETREAT



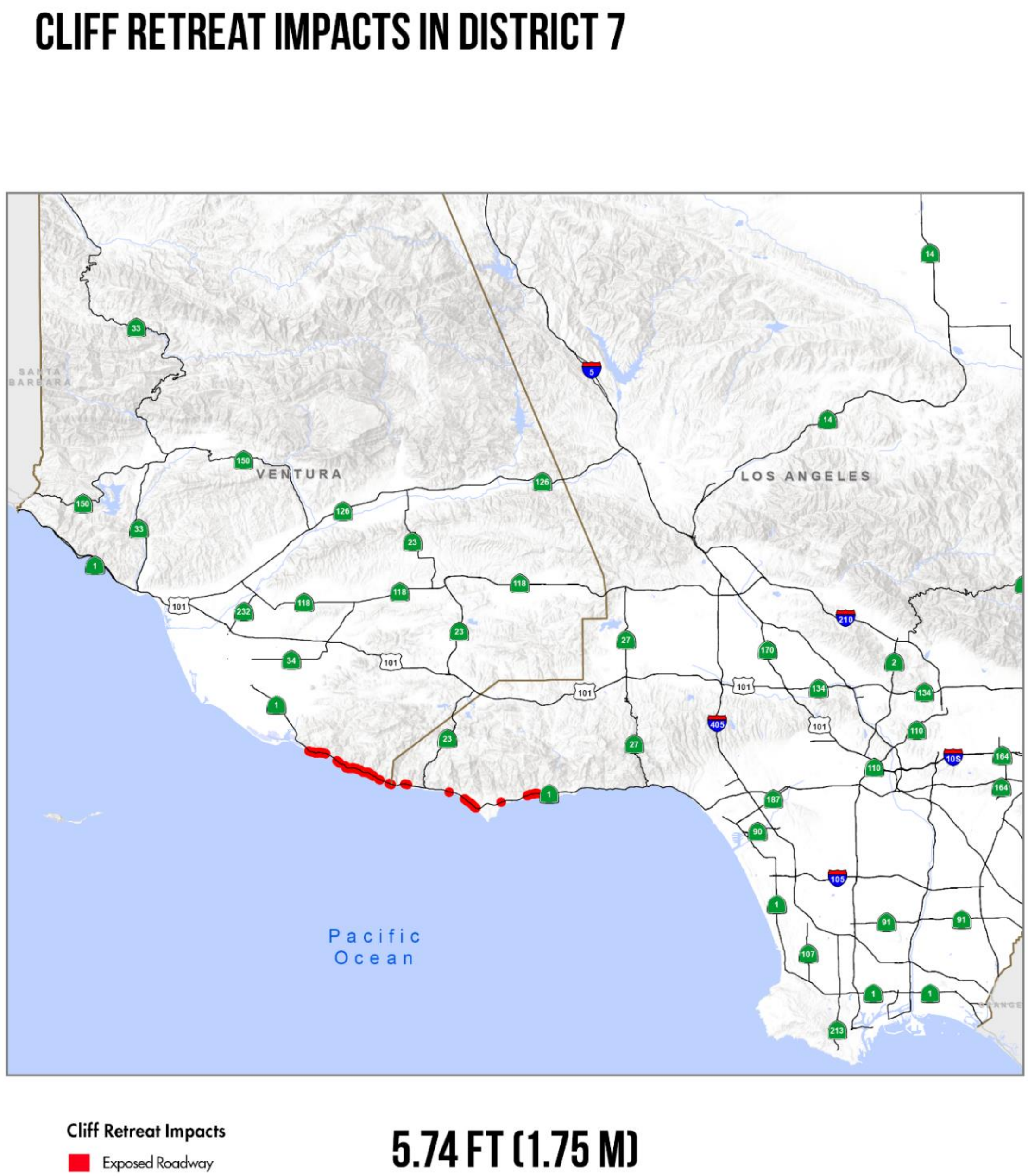
CLIFF RETREAT DATA ARE FROM THE US GEOLOGICAL SURVEY, COASTAL STORM MODELING SYSTEM (COSMOS). THIS DATA APPLIES THE "DO NOT HOLD THE LINE" MANAGEMENT OPTION, WHICH ASSUMES THAT CLIFF RETREAT CONTINUES UNIMPEDED. SEE [Our Coast, Our Future] AND THE [USGS CoSMoS] WEBPAGE FOR MORE INFORMATION ON THE MODEL.

FIGURE 25: DISTRICT 7 EXPOSURE TO 3.28 FEET (1.00 METER) SEA LEVEL RISE AND ASSOCIATED CLIFF RETREAT

CLIFF RETREAT IMPACTS IN DISTRICT 7

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 26: DISTRICT 7 EXPOSURE TO 5.74 FEET (1.75 METERS) SEA LEVEL RISE AND ASSOCIATED CLIFF RETREAT



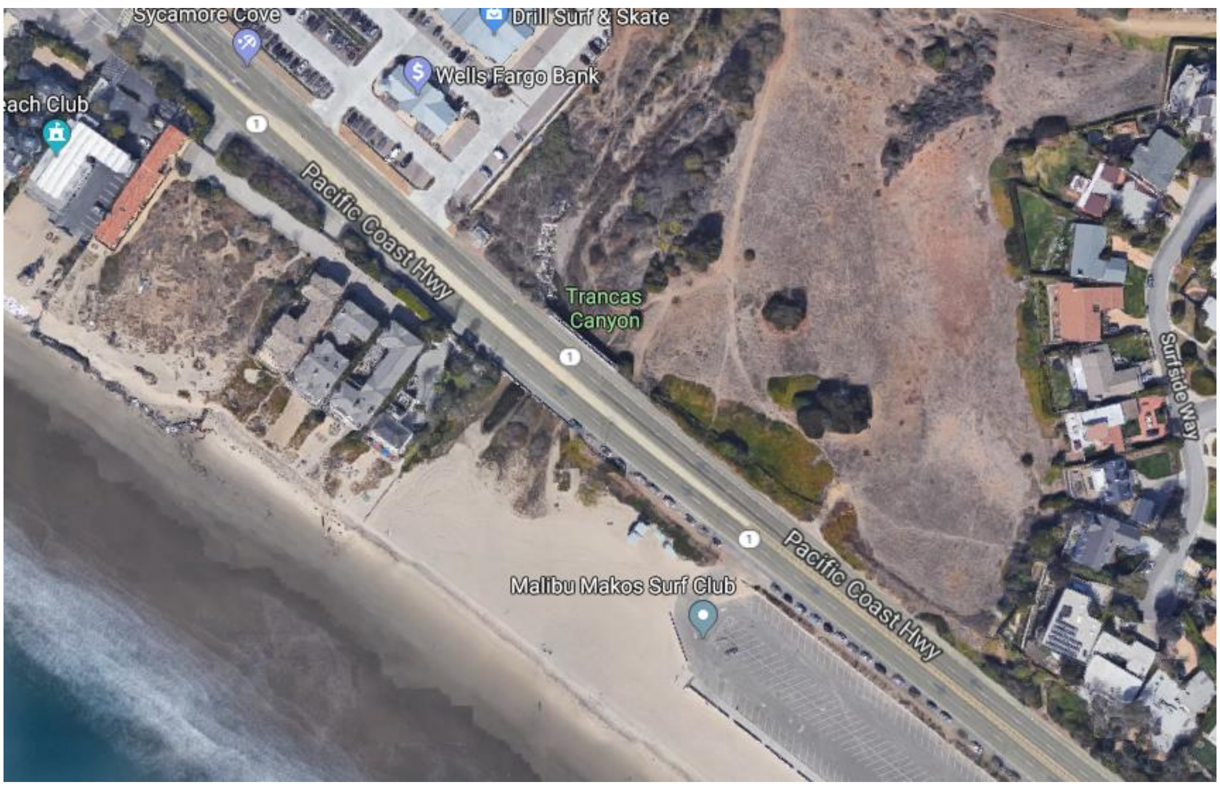
CLIFF RETREAT DATA ARE FROM THE US GEOLOGICAL SURVEY, COASTAL STORM MODELING SYSTEM (COSMOS). THIS DATA APPLIES THE "DO NOT HOLD THE LINE" MANAGEMENT OPTION, WHICH ASSUMES THAT CLIFF RETREAT CONTINUES UNIMPEDED. SEE [Our Coast, Our Future] AND THE [USGS CoSMoS] WEBPAGE FOR MORE INFORMATION ON THE MODEL.

10. LOCALIZED ASSESSMENT OF EXTREME WEATHER IMPACTS

An example event was chosen from District 7 to highlight how climate change may affect highway infrastructure in the district. This example is a recent event on the Pacific Coast Highway that illustrates how the highway is currently vulnerable to tidal influences and heavy rain events. Effects like those presented in this example may be exacerbated due to sea level rise, surge, and flood events, and become a more common risk for Caltrans District 7 infrastructure.

In this example, the damage occurred to Trancas Creek Bridge, which crosses Trancas Canyon in Malibu. See Figure 27 for an aerial view of the bridge. In August of 2017 the bridge was scoured by a heavy rain event, which caused the bridge footings to be exposed. Caltrans District 7 responded by replacing the existing bridge scour monitors with new tilt sensors, water level sensors, sonar, and a wireless camera on the bridge piers. These improvements were made to monitor any changes to the bridge while Caltrans addressed bridge erosion and scour.[55]

FIGURE 27: TRANCAS CREEK BRIDGE ON THE PACIFIC COAST HIGHWAY



After a bridge inspection, the Trancas Creek Bridge was determined to be scour critical and have structural deficiencies. Caltrans District 7 staff proposed to replace the bridge with a wider one, that can better accommodate bicyclists and pedestrians. District 7 staff are considering two alternatives, with the

[55] Caltrans, "Mitigated Negative Declaration/Finding of No Significant Impact and Section 4(f) Evaluation," EA: 07-29140/EFIS #: 0712000094 (June 2017), http://www.dot.ca.gov/d7/env-docs/docs/Trancas%20Creek%20Bridge%20Replacement%20Project%20-%20MND_FONSI%20-%20FINAL.pdf

preferred being a longer bridge replacement option that would have a wider opening, allowing for more room for flow under the bridge, as well as a 10-foot-wide foot path. The trail would connect the nearby beach with the Trancas Lagoon, which is scheduled for restoration by the Santa Monica Mountains Resource Conservation District and the National Park Service.[56] The other option would raise the bridge 2.5 feet above the existing height, but not have as wide of an opening for a foot path. Both options will include rock slope protection to preserve abutments from future scour.[57]

Using the CoSMoS model paired with future projections of sea level rise, we can begin to understand how the Trancas Creek Bridge could be affected by rising seas and storm surge. With an annual storm, it would take a long time for the Trancas Creek Bridge to be affected by sea level rise. Using the CoSMoS model, the bridge would not be affected by higher water levels until local sea level rise reached almost six feet, which is not projected to occur until the end of century for the highest scenarios. When adding a 100-year storm into consideration, high waters could reach the bridge by under one foot of sea level rise. Caltrans has included considerations of the tides and sea level rise on the new structure, and plans to complete a wave run-up study during the next stages of project development.[58] As Caltrans moves forward with building new shoreline structures and rehabilitating older ones, it is important to continue to address the effects of future sea level rise and storm surge on each project.

[56] Jimy Tallal, "Lagoon restoration sought at Trancas Creek," *The Malibu Times,* August 21, 2013, http://www.malibutimes.com/news/local/article_1aa978cc-0a21-11e3-9d79-0019bb2963f4.html,

[57] Caltrans, "Mitigated Negative Declaration/Finding of No Significant Impact and Section 4(f) Evaluation," EA: 07-29140/EFIS #: 0712000094 (June 2017), http://www.dot.ca.gov/d7/env-docs/docs/Trancas%20Creek%20Bridge%20Replacement%20Project%20-%20MND_FONSI%20-%20FINAL.pdf

[58] Ibid.

11. INCORPORATING CLIMATE CHANGE INTO DECISION-MAKING

11.1. Risk-Based Design and Decision Making

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),[59] 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 28.

The first five steps of the ADAP process cover the characteristics of the project and the context. The District 7 Vulnerability Assessment has worked through these first steps at a high level 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:

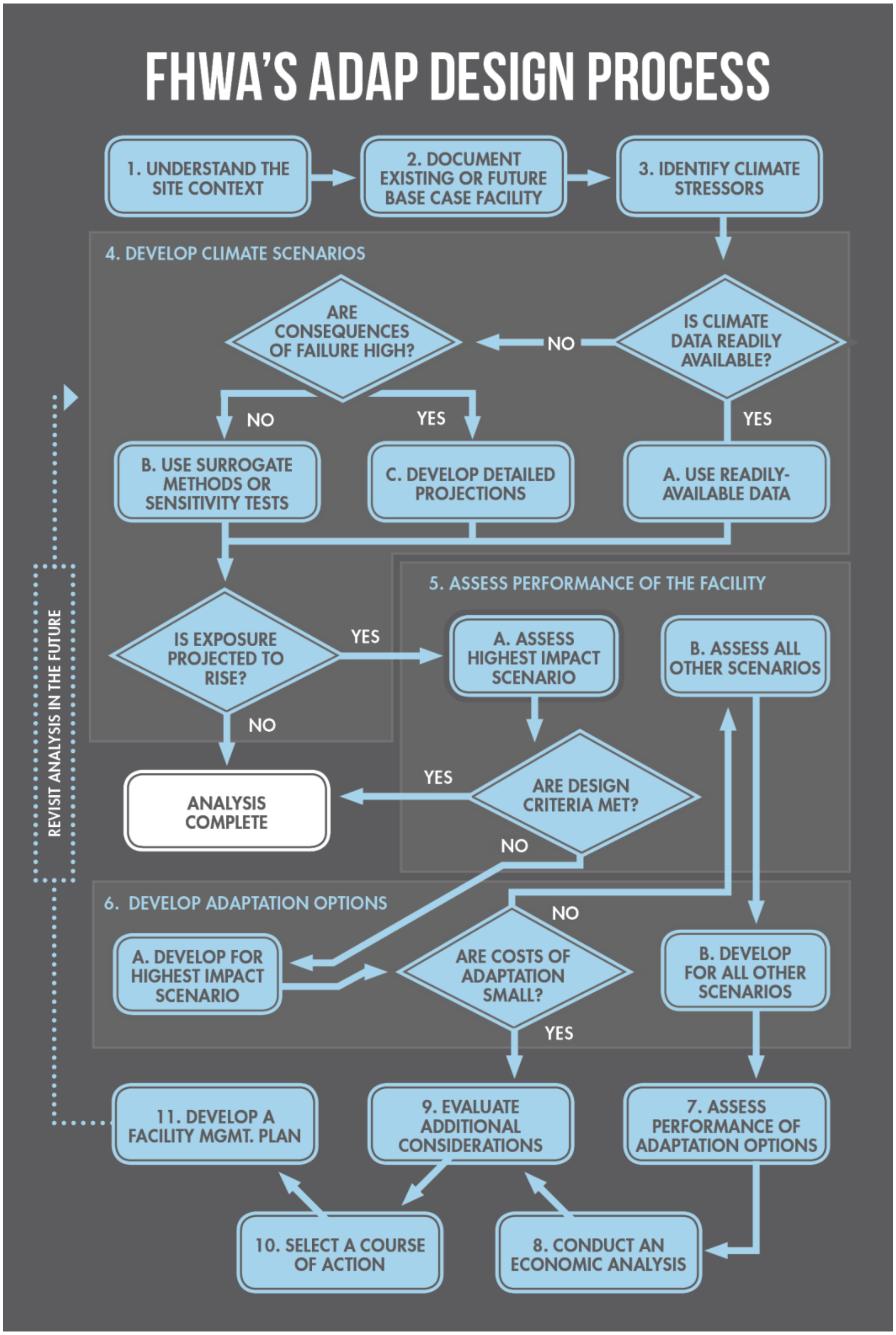
- full life cycle cost accounting

[59] "Adaptation Decision-Making Assessment Process," Federal Highway Administration, last modified January 12, 2018, https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/teacr/adap/index.cfm

- 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 selected and a facility management plan can be implemented.

FIGURE 28: FHWA'S ADAPTATION DECISION-MAKING PROCESS



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

11.1.1. Las Tunas Beach Rehabilitation Project

Between 2014 and 2016, Caltrans planned and implemented the Las Tunas Beach Rehabilitation Project. The goal of this project was to repair and expand a rock slope protection revetment along the oceanfront roadway embankment between State Route 1 / Pacific Coast Highway (PCH) and Las Tunas State Beach (PM 41.8/42.1).

The project area lies within the City of Malibu in the County of Los Angeles, as shown on Figure 29. This figure provides a before and after aerial view of the project area. The original embankment within the project limits was 1,660 feet long, approximately 20 feet high, and up to 40 feet wide. Caltrans constructed a full bank and shore Rock Slope Protection (RSP), with an embedded toe and RSP fabric with anchor ties, to stabilize the embankment and prevent further undermining of the roadway.

Prior to project implementation, the California Coastal Commission required a wave run-up study to obtain the Coastal Development Permit for this project, which was conducted by Caltrans in 2014.[60] Using current engineering standards and practices for the analysis and design of coastal structures, the technical analyses were conducted to provide a sound understanding of the beach and coastal characteristics near the project site. The technical studies included determining the design water level, SLR effects, wave transformation, wave run-up on coastal structures, short/long-term beach evolution, potential tsunami impacts, and coastal structure susceptibility. The studies were also supported by on-site investigations for summer and winter beach conditions and topographic data collected at Las Tunas beach. Important findings and conclusions determined through the wave run-up study included:

- The SLR projections used for the study to the target year 2100 ranged between 1.38 to 5.48 feet due to uncertainties in predictions. The large uncertainties led to diverse design water depths for the Las Tunas Beach coastal region. The highest SLR projection was used in determining the adequacy of the revetment for protecting the highway.
- Near-shore design wave heights were modeled and estimated between 6.2 and 9.3 feet for the highest 2100 SLR water depth scenario, at six beach profile locations. Wave run-up height estimates were also calculated for coastal structures. The design maximum wave run-up calculated was 32.22 feet for the 2100 SLR scenario.
- Based on the analysis of historical and current beach surveys, aerial imagery, and a numerical model (called SBEACH), the beach profiles demonstrate a long-term erosion trend. Among the profiles, Station 774+01 showed the highest beach recession rates and depths, and is considered the most degradational beach section within the study area.
- No severe tsunami hazards have been observed at Las Tunas Beach based on the historical tsunami investigation from the National Centers for Environmental Information (NCEI, formerly NGDC) database. Nevertheless, tsunami forecast model results and the inundation map derived by numerical modeling suggests that impacts resulting from future tsunamis on the project site are smaller than impacts from the design waves. The degradational trend of the beach has affected all properties along this portion of the coast.

[60] Caltrans, "Las Tunas Beach Wave Run-Up Study – Final," Caltrans, (July 11, 2014):54-164, http://www.dot.ca.gov/hq//esc/oe/project_ads_addenda/07/07-316604/supplemental_info/07-316604-eIH.pdf

- The size and weight of the RSP to withstand the design waves was determined using FHWA and Caltrans design guidelines. The project is adequate to withstand the expected wave uprush at the 100-year recurrence interval.

- The revetment is as far landward as possible and replaced the revetment that previously protected the PCH. The footprint of the new revetment is similar to the historic revetment footprint and does not extend past the rocks that are already found on the beach.

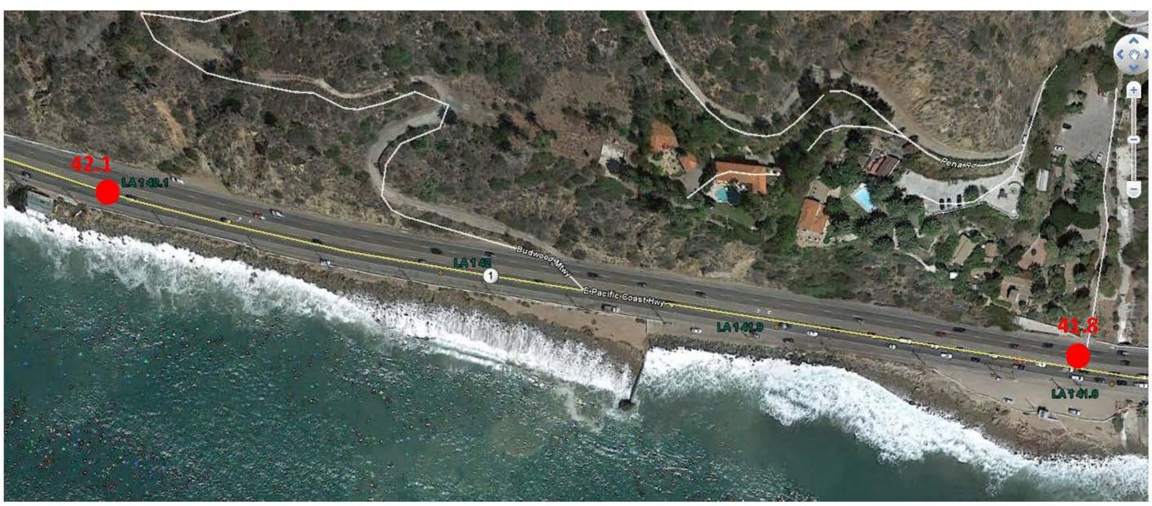
- The existing cement groin keeps sediment from being transported littorally from west to east along the Las Tunas Beach coast.

- Beach nourishment may slow the erosion of the beach, but this section of the coast is subject to erosion due to limited sediment delivery and high wave action. The erosion of this beach has been artificially slowed through the addition of beach nourishment sand and groins along Las Tunas Beach.

The project was completed in June 2016, and while RSP and coastal hardening strategies like this are a typical approach to mitigating wave run-up and coastal erosion impacts, Caltrans recognizes the limitations of armoring. Caltrans hopes to implement a variety of solutions moving forward (such as natural infrastructure solutions) so long as strategies are effective and affordable. Figure 29 through Figure 31 provide before and after imagery of the completed project. Figure 32 illustrates beach access after the project was completed and Figure 33 is a photo of new ADA-compliant parking at the beach.

FIGURE 29: BEFORE AND AFTER PHOTO OVERVIEW OF LAS TUNAS PROJECT LIMITS

BEFORE



Google Earth image taken from <u>2010</u> of the project limits (PM 41.8-42.1) along PCH.

AFTER

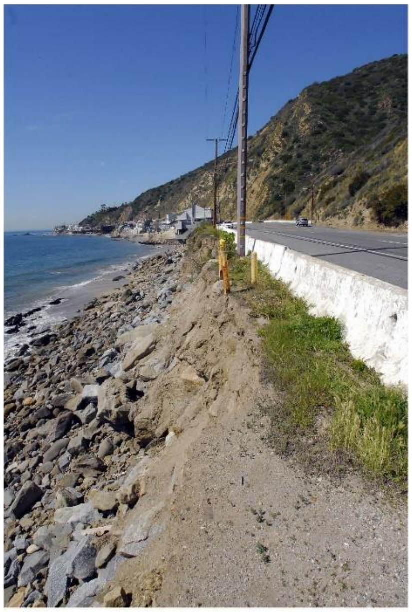
Las Tunas Post Construction Photo Exhibit: ACOE SPL-2013-00415-SJH

6/15/16 Aerial looking southbound on PCH.

FIGURE 30: BEFORE AND AFTER SOUTHBOUND AND NORTHBOUND PROJECT PHOTOS

6/15/2016 Before photo looking southbound.

6/15/2016 After photo looking southbound.



3/10/2011 Before photo looking northbound.

6/15/2016 After photo looking northbound.

FIGURE 31: AERIAL VIEWS OF COMPLETED LAS TUNAS PROJECT

6/15/2016 Aerial of completed project looking north.

10/1/2004 Aerial of project location looking east at lifeguard tower.

6/15/2016 Aerial of southbound completed project just west of beach access #3.

FIGURE 32: BEACH ACCESS PHOTOS

6/15/2016 Photos of all 3 Beach Access Points. Beach Access Point #1 is furthest south and #3 is at the northern tip of the project.

FIGURE 33: NEW ADA-COMPLIANT PARKING SPACE

6/15/2016 New ADA compliant parking space.

11.2. Project Prioritization

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. 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.

Some guiding principles for the development of the prioritization method included the following:

- It should be straightforward in application, easily discernable, understandable 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 (SLR, 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?

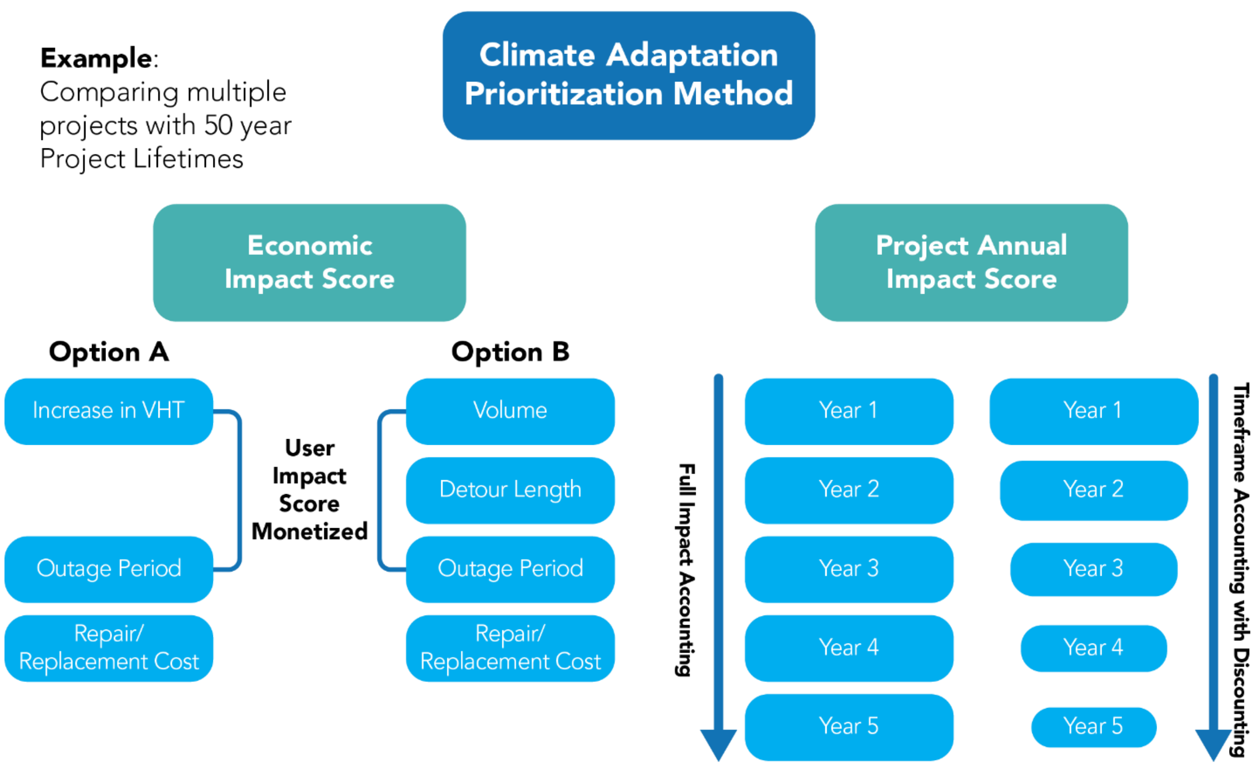
- System impacts (supplied by Caltrans planning staff) – the impacts of the loss of the facility on the broader system. This could be in terms of increase in Vehicle Hours Traveled (VHT) if using a traffic model, or an estimated value using volume and detour length as surrogates.
- Probability of occurrence (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 that can be used for prioritization. The left side (Economic Impact Score) shows two methods for determining costs to the system user. The right-side shows 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, at a minimum, of 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 State Highway System 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 in selecting projects. The identification of an annual cost metric, which includes discounting, enables a decision 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 impacts to the system, but 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 7. 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 7. The study distilled the larger context of climate change down to a more localized understanding of what such change might mean to District 7 functions and operations, District 7 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 (SLR, 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 State Highway System. 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 7 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 7 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.

The following section provides some context as to what the next steps for Caltrans and District 7 may be, to build upon this work and create a more resilient State Highway System.

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 State Highway System. 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 7.

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 7. 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. (See 11.1 Risk-Based Design).
- Acquisition of Improved Data for Improved Decision-Making
    - Determining potential impacts of precipitation on the state highway system will require additional system/environmental data to complete a system-wide assessment. This includes:
        - Improved topographic data across District 7 (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 state highway system 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 State Highway System. Much work remains to create a resilient State Highway System across California.

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14. GLOSSARY

100-year design standard: Design criteria for highway projects that address expected environmental 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 expected to occur due to the presence of greenhouse gas concentrations in the atmosphere. Examples include changing precipitation levels, higher temperatures, and sea level rise.

Downscaling: An approach to estimate climate predictions at a more localized level based on the outcomes of models that predict future climate conditions at a much larger scale of application.

Emissions Scenarios: Assumed future states of greenhouse gas concentrations in the atmosphere.

Exposure: The degree to which a facility or asset is exposed to climate stressors that might cause damage, disrupt facility operations, or otherwise affect asset condition.

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

Representative concentration pathways (RCP): Scenarios of future greenhouse gas emission concentrations based on assumed future greenhouse gas emissions given economic development, population growth, technology, and other variables.

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

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 (1% chance of occurring each year).

State Highway System: The designated highway network in California, which Caltrans is responsible for operating and maintaining.

Stressor: Climate conditions that could possibly apply stress to engineered facilities. Examples include temperature rise and precipitation change.

Vulnerability assessment: A study of those areas likely to be exposed to future climate and weather conditions that will add additional stress to assets, in some cases, levels of stress that might exceed the assumed conditions when the asset was originally designed.