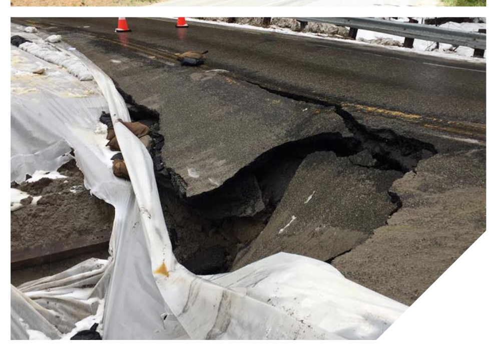
CALTRANS CLIMATE CHANGE VULNERABILITY ASSESSMENTS

July 2018

District 6
Technical Report



CONTENTS

TABLES

FIGURES

ACRONYMS AND ABBREVIATIONS

ADAP	Adaptation Decision-Making Assessment Process
CalFire	California Department of Forestry and Fire Protection
Caltrans	California Department of Transportation
CAP	Climate Action Plan/Planning
CCC	California Coastal Commission
CEC	California Energy Commission
CGS	California Geological Survey
DWR	California Department of Water Resources
EPA	Environmental Protection Agency
GCM	Global Climate Model
GHG	Greenhouse Gas
GIS	Geographic Information System
IPCC	Intergovernmental Panel on Climate Change
LOCA	Localized Constructed Analogues
NRA	Natural Resources Agency
RCP	Representative Concentration Pathway
Scripps	The Scripps Institution of Oceanography
SHS	State Highway System
SRES	Special Report Emissions Scenarios
USFS	US Forest Service
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 (SHS) in Caltrans District 6. 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 6 report is one of 12 district reports that are in various stages of development.

1.1. Purpose of Report

The *District 6 Technical Report* is one of two documents developed to describe the work completed for the District 6 vulnerability assessment, the other being the *District 6 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 6.

This *Technical Report* is intended to provide a more in-depth discussion, primarily for District 6 staff. It provides background on the methodology used to develop material for both reports and general information on how to replicate those methods, if desired. The report is divided into sections by climate stressor (e.g. wildfire, temperature, precipitation) and each section presents:

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

- And where applicable, mileage of exposed SHS.

Finally, this *Technical Report* outlines a recommended framework for prioritizing 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 6 Characteristics

Caltrans District 6 lies in the San Joaquin Valley, which is in the southern portion of the Central Valley.[1] The district is predominately rural and agricultural, with urban areas focused along the eastern portion of the valley. The district includes two of the nine largest cities in California – Fresno and Bakersfield. The eastern portion of District 6 lies in the Sierra Nevada mountain range and is heavily forested.

District 6 is headquartered in the City of Fresno and serves Fresno, Madera, Tulare, and Kings counties, and most of Kern County.[2] District 6 is responsible for 476 miles of freeway and 1,554 miles of rural and urban highway. It maintains the largest portion of lane miles (with a combined length of 5,810) in the entire State Highway System. Thirty-three state highways are wholly or partially located within the district.

Interstate 5 and State Route 99 run the length of District 6—they are the main north-south arteries for not just the Central Valley, but for the entire state. These two routes carry a significant amount of truck traffic that is vital to the agricultural base of the region. A series of east-west highways (SR 140, SR 152, SR 180, SR 198, and SR 46) connect I-5 to SR 99 and form the backbone of a grid system of roads connecting the valley's farming communities.

[1] The northern portion of the Central Valley is known as the Sacramento River Valley. Please note that neither the Central Valley nor the San Joaquin Valleys are wholly synonymous with District 6 geography.

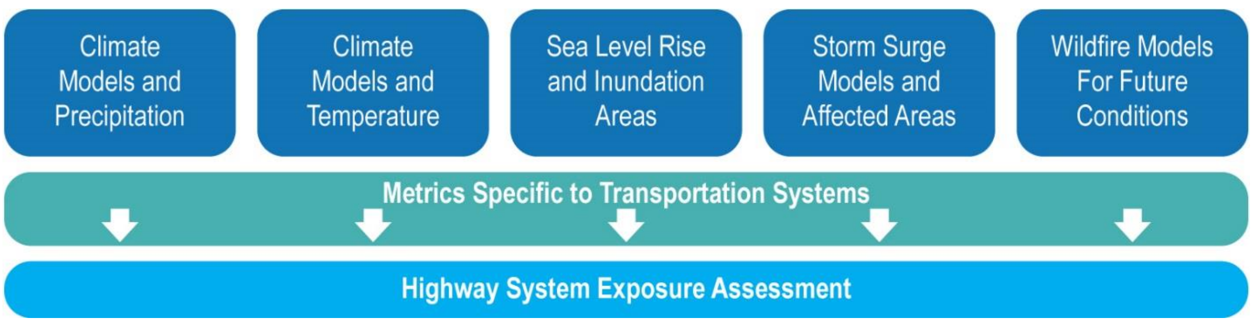
[2] The portion of Kern County that lies on the eastern slope of the Sierra Nevada Mountains is in District 9.

2. POTENTIAL EFFECTS FROM CLIMATE CHANGE ON THE STATE HIGHWAY SYSTEM IN DISTRICT 6

Climate and extreme weather conditions in District 6 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 6 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 considered a range of climate stressors and how they tie into Caltrans design criteria/other metrics specific to transportation systems.

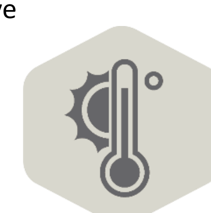
Figure 1 illustrates the general process for deciding which metrics should be included in the overall SHS vulnerability assessment. First, Caltrans and the project study team considered which climate stressors affect transportation systems. Then, Caltrans and the project study team decided on a relevant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

FIGURE 1: CONSIDERATIONS FOR THE STATE HIGHWAY ASSESSMENT



Extreme weather events already disrupt and damage District 6 infrastructure, with the potential for impacts to become more severe in the future. The following are summaries of the climate/extreme weather conditions that currently affect the District 6 State Highway System and for which future projections were evaluated for this assessment:

- **Temperature** – The San Joaquin Valley has a Mediterranean climate, with hot, dry summers and cool rainy winters. In recent years, the summers in District 6 have been hotter and longer and the winters have been drier. The Fresno area experienced three heat waves during the summer of 2017, with each spell of triple-digit temperatures lasting longer than a week.[3] These extended periods of high temperatures quickly melted the winter snowpack from the Sierra Nevada mountains, filling reservoirs, flooding the Kings River and at Pine Flat Dam. Higher temperatures and longer heat spells can also increase the buckling and rutting of roads, the warping of rails, and health risks for maintenance and construction crews working during the day.



[3] Anderson, Barbara and Konstantinovic, Aleksandra, "As Fresno area sets a record for heat, schools take it easy with students", http://www.fresnobee.com/news/local/article169798137.html, August 28, 2017.

- **Precipitation** – Climate change can cause large fluctuations in precipitation, with dry years becoming dryer and wet years becoming wetter. This effect has been clearly demonstrated in District 6 in recent years.

  2012, 2013, and 2014 was California's driest three-year period in 119 years of records. In January 2014, Governor Jerry Brown declared the drought as a State of Emergency for most of the State that lasted until April 2017, but the drought continues in Fresno, Kings, Tulare, and Tuolumne counties – three out of the four of which lie in District 6. Groundwater supplies remain diminished in these counties and will take more time to fully replenish. During the drought, groundwater pumping for various uses resulted in land subsidence in the San Joaquin Valley, and may have permanently decreased aquifer capacities.[4] Uneven subsidence rates throughout District 6 could cause roads and irrigation canals to buckle and break requiring increased maintenance and repair.

  Heavy rains in the winter of 2016-2017 resulted in numerous impacts to the transportation system and to local communities. Road closures especially affected visitors traveling to Yosemite National Park, when Highway 41 was closed in two places at the same time (near Fish Camp and at Big Oak Flat Road) in March 2017. The 2016-2017 winter also brought historic levels of snowfall to the Sierra Nevada Mountains, which then melted at high rates during the following summer.[5] In June 2017, outflows from Pine Flat Lake in Tulare County were increased to make room for more snowmelt, which caused related flooding downstream in Kingsburg. The Department of Water Resources (DWR) reported the total precipitation falling in the San Joaquin area was approximately 178 percent of an average water year, with runoff in the region at a level around 258 percent of average.[6] Intense storms or winter storm/summer thaw events likes these are a concern, as they may cause flooding of roadways and damage transportation infrastructure.

- **Wildfire** – The northeastern side of District 6 lies at the foothills of Sierra National Forest and Sequoia National Forest, where wildfires are a regular concern. Higher temperatures, changing precipitation patterns, and extended periods of drought are expected to influence the risk of wildfire over time. In August 2017, the Railroad fire burned over 12,000 acres between Sugar Pine and Fish Camp near Yosemite, requiring the closure of Highway 41 and blocking access to campgrounds. Wildfires can also increase the incidences of road closures even after the fire is extinguished, as damaged trees could fall and result in road blocks or driver safety threats. Additionally, smoke from ongoing fires can decrease visibility for drivers and raise health concerns for responding highway maintenance crews.

- **Combined Effects** –
  - **Wildfire and Flooding** – In areas recently effected by wildfires, falling rocks, mud, and trees damaged by fire can wash down steep banks during periods of

[4] "Current Land Subsidence in the San Joaquin Valley", U.S. Geological Survey, California Water Science Center, https://ca.water.usgs.gov/projects/central-valley/land-subsidence-san-joaquin-valley.html.

[5] Serna, Joseph, "The Kings River flooded from snowmelt that couldn't be measured or predicted", http://www.latimes.com/local/lanow/la-me-ln-kings-river-flooding-snowpack-20170626-story.html, June 26, 2017.

[6] "Hydrologic Conditions in California (09/30/2017), California Data Exchange Center, http://cdec.water.ca.gov/cgi-progs/reports/EXECSUM.

rain. These debris can cause road blocks and require detours on the District 6 State Highway System.

This study examined the potential effects of these stressors on Caltrans District 6 assets by using the best available data at the state and regional level.

3. ASSESSMENT APPROACH

3.1. General Description of Approach and Review

The material presented in this report was developed in coordination with various District 6 partners including:

- Bike Bakersfield
- California Environmental Justice Coalition
- California Walks
- Centro de Familia
- Clinica Sierra Vista
- Fresno Area Express
- Fresno County Bicycle Coalition
- Fresno County Rural Transit Agency
- Fresno Council of Governments
- Kern Council of Governments
- Kern Transit
- Kings County Association of Governments
- Kings Area Rural Transit
- Kings Transit Authority
- Leadership Council for Justice and Accountability
- Madera Area Express
- Madera County Transportation Commission
- North Fork Rancheria of Mono Indians of California
- Picayune Rancheria of Chukchansi Indians
- San Joaquin Valley Air Quality Management District
- San Joaquin Valley Latino Environmental Enhancement and Policy Project
- Table Mountain Rancheria
- Tejon Indian Tribe
- Tulare County Association of Governments
- Tulare County Area Transit
- Tule River Indian Tribe of the Tule River Reservation
- Visalia Transit

The development of this report also required extensive coordination with Caltrans District 6, and included:

- Coordination on previous work sponsored and completed by District 6 staff to identify available data, findings, and lessons learned.
- Working in partnership with District 6 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 District 6 photos, background information, and report inputs.

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 6 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 6 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.[7]
- **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.[8]
- **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

[7] “Assembly Bill 32 Overview,” https://www.arb.ca.gov/cc/ab32/ab32.htm, August 5, 2014
[8] “Executive Order S-13-08,” https://www.gov.ca.gov/news.php?id=11036, 2008

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.[9]

- **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.[10]
- **Senate Bill 246** (2015) establishes the Integrated Climate Adaptation and Resiliency Program to coordinate with regional and local efforts with state adaptation strategies.[11]
- **Assembly Bill 2800** (2016) requires that state agencies account for climate impacts during planning, design, building, operations, maintenance, and investments in infrastructure. It also requires the formation of a Climate-Safe Infrastructure Working Group represented by engineers with relevant experience from multiple state agencies, including the Department of Transportation.[12]

These policies are among the factors State agencies consider when addressing climate change. Conducting an assessment such as this one for District 6 is a key step towards preserving Caltrans infrastructure against future extreme weather conditions and addressing the requirements of the relevant state policies above, such as Executive Order B-30-15, Assembly Bill 1482, and Assembly Bill 2800. Other policies, such as Executive Order S-13-08, stimulate the creation of climate data that can be used by state agencies in their own adaptation planning efforts. It is important for Caltrans staff to be aware of the policy requirements defining climate change response and how this assessment may be used to indicate compliance, where applicable.

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

3.2.2. 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 6 vulnerability assessment, some background is needed on Global Climate Models and emissions scenarios.

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[9] "Governor Brown Establishes Most Ambitious Greenhouse Gas Reduction Target in North America," Office of Governor Edmund Brown, https://www.gov.ca.gov/news.php?id=18938, April 29, 2015

[10] "Assembly Bill No. 1482," https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201520160AB1482, October 8, 2015

[11] "Senate Bill No.246," https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB246, 2015

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

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.[13] 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 emissions may change given international policies. The IPCC also summarizes scenarios of atmospheric concentrations of GHG emissions to the end of the century.

There are dozens of climate models worldwide, but there are a set of GCMs that have been identified for use in California, as outlined in the California 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.[14] 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.
- RCP4.5 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.[15]

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[13] "What is a GCM?" Intergovernmental Panel on Climate Change, http://www.ipcc-data.org/guidelines/pages/gcm_guide.html, June 18, 2013
[14] Wayne, G.P., "A Guide to the IPCC's New RCP Emissions Pathways," https://skepticalscience.com/rcp.php, August 30, 2013
[15] 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

California Fourth Climate Change Assessment

The California Fourth Climate Change Assessment is an inter-agency research and "model downscaling" effort for multiple climate stressors. The Fourth Climate Change Assessment is being led by the California Energy Commission (CEC), but other contributors include agencies such as the Department of Water Resources (DWR) and the Natural Resources Agency (NRA), as well as academic institutions such as the Scripps Institution of Oceanography (Scripps) and the University of California, Merced.

Model downscaling is a statistical technique that refines the results of GCMs to a regional level. The model downscaling used in the Fourth Climate Change Assessment is a technique called Localized Constructed Analogs (LOCA), which "uses past history to add improved fine scale detail to GCMs."[16] 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.[17] 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.[18] 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.[19] 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 6 Efforts to Address Climate Change

In addition to and concurrent with the statewide efforts, there are regional efforts underway within District 6 related to climate change planning, research, and modeling.

[16] "LOCA Downscaled Climate Projections," Cal-Adapt 2.0, http://cal-adapt.org/, 2018
[17] Pierce et al.,"Statistical Downscaling Using Localized Constructed Analogs," http://journals.ametsoc.org/doi/abs/10.1175/JHM-D-14-0082.1 , 2014
[18] "LOCA Downscaled Climate Projections," Cal-Adapt 2.0, http://beta.cal-adapt.org/data/loca/, 2017 (and http://www.water.ca.gov/climatechange/docs/2015/Perspectives_Guidance_Climate_Change_Analysis.pdf)
[19] For more information, visit http://cal-adapt.org/

3.3.1. Climate Action Plans

Many cities and counties in District 6 have adopted Climate Action Plans (CAPs) designed to mitigate GHG emissions and reduce the effects of climate change to their communities. The cities of Madera, Merced, Avenal, and Hanford have all adopted CAPs, as has Tulare County.[20] A recent General Plan Update workshop in Kern County showed public interest in a CAP.[21] The City of Fresno has its own action-oriented plan called Fresno Green, which consists of 25 different strategies to reduce pollution and transform Fresno into a sustainable city.[22] While these strategies are still primarily focused on GHG mitigation, reports and studies are also addressing the need for climate adaptation.[23]

3.3.2. Sierra CAMP

The Sierra Climate Adaptation and Mitigation Partnership (Sierra CAMP) is a regional collaborative focused on promoting climate adaptation and mitigation strategies across the Sierra Nevada region and building connections with urban areas. [24] Sierra CAMP is one of five across the state that make up the Alliance for Regional Collaboratives for Climate Adaptation (ARCCA). The partnership spans from the Sierra foothills to the Nevada border, encompassing rural District 6 communities in the Sierra foothills. See Figure 2 for the full range of the Sierra Nevada in relation to District 6 headquarters in Fresno and other District 6 counties. This collaborative includes both public and private members such as the US Forest Service, the Sierra Nevada Alliance, Tahoe Mountain Sports, and Ski California, who are focused on engaging other Sierra stakeholders in a discussion about climate change issues in the Sierra and catalyzing climate action in the region.

[20] Climate Action Plan. *County of Tulare.* 2010. http://generalplan.co.tulare.ca.us/documents/GeneralPlan2010/ClimateActionPlan.pdf
[21] General plan update workshop summary of comments. May 25, 2017. https://www.kerncounty.com/planning/pdfs/GPupdate/gpu_pc052517_sum_comments.pdf
[22] The City of Fresno's Strategy for Achieving Sustainability. *City of Fresno.* 2007. http://toolkit.valleyblueprint.org/sites/default/files/fresnogreenpacketfinal50608_0.pdf
[23] "Central Valley Regional Adaptation Efforts to Climate Change Impacts." *California Legislature Senate Committee on Environmental Quality.* 2015. http://senv.senate.ca.gov/sites/senv.senate.ca.gov/files/cv_background_paper_final.pdf
[24]Sierra Camp, http://www.sbcsierracamp.org/sierracamp/ , n.d.

FIGURE 2: SIERRA CAMP BOUNDARIES

3.3.3. Disadvantaged Populations and Environmental Justice

The San Joaquin Valley is one of the most disadvantaged and pollution burdened regions identified by CalEnviroscreen 3.0.[25] Many communities in the San Joaquin Valley still do not have safe drinking water due to nitrate pollution from agricultural runoff. Poorer areas in the San Joaquin Valley suffer from poor air quality and are more likely to be located next to hazardous facilities.[26] Climate change may disproportionately affect these communities who are already suffering from environmental impacts, and they may lack the resources to respond to additional stressors. In response, the San Joaquin Valley is home to environmental justice organizations that are focused on creating a cleaner and safer California for everyone. Some of these organizations include the California Environmental Justice Alliance, Center on Race, Poverty, and the Environment, United Farm Workers of America, and Voices from the Valley (see the link for more resources).[27]

3.3.4. Central Valley Hydrologic Model

The Central Valley is known for its agricultural importance to California and the rest of the nation, generating around 8% of U.S. agricultural output on just 1% of U.S. farmland.[28] The valley also provides key habitats for ducks, geese, shorebirds, and other birds that rely on wetlands for migration and survival.[29] Due to the competing demands for water and its limited supply, the region has been the subject of numerous studies and modeling to determine how water flows and uses will change over time. The US Geological Survey (USGS) developed the Central Valley Hydrologic Model (CVHM) to understand how water use, precipitation, and land use changes will affect surface and groundwater flows in the Central Valley.[30] The model's simulations based on a warmer, drier California find that stream flows are expected to decline by up to 40%, which will increase groundwater demand across the region. The effects of increased groundwater draw-down include increased streamflow infiltration, reduced outflow to the Delta, and increased subsidence rates. [31] The USGS and Central Valley stakeholders are continuing to explore future changes to the regional hydrologic system, which may have significant effects on the nearby communities and natural habitats.

3.3.5. The Central Valley Flood Protection Plan

In the past, the Central Valley was largely wetland. Now, only 10% of historic wetland remains[32] and the area is low-lying and flood prone. The Central Valley Flood Protection Plan is updated every five years to enhance flood risk management in the Central Valley and develop strategies for reducing risk that

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[25] https://oehha.maps.arcgis.com/apps/webappviewer/index.html?id=4560cfbce7c745c299b2d0cbb07044f5

[26] "Central Valley Regional Adaptation Efforts to Climate Change Impacts." *California Legislature Senate Committee on Environmental Quality.* 2015. http://senv.senate.ca.gov/sites/senv.senate.ca.gov/files/cv_background_paper_final.pdf

[27] "Organizations." *Voices from the Valley*, accessed on October 25th 2017, http://www.voicesfromthevalley.org/organizations/

[28] "California's Central Valley." U.S. Geological Survey. March 20th, 2017. https://ca.water.usgs.gov/projects/central-valley/about-central-valley.html

[29] "Save California's Last Wetlands." Central Valley Joint Venture Conserving Bird Habitat. https://www.waterboards.ca.gov/rwqcb5/board_decisions/tentative_orders/1504/2_5_wetlands/3_wet_savecalastwetlands.pdf

[30] "Central Valley Hydrologic Model." US Geological Survey. Last modified March 20, 2017. https://ca.water.usgs.gov/projects/central-valley/central-valley-hydrologic-model.html

[31] "Conjunctive Use in Response to Potential Climate Changes in the Central Valley, California." US Geological Survey. Last modified March 20, 2017. https://ca.water.usgs.gov/projects/central-valley/climate.html

[32] "Save California's Last Wetlands." Central Valley Joint Venture Conserving Bird Habitat. https://www.waterboards.ca.gov/rwqcb5/board_decisions/tentative_orders/1504/2_5_wetlands/3_wet_savecalastwetlands.pdf

provide multiple benefits, including transportation system protection.[33] The most recent update was released in 2017 and includes climate change considerations, such as: more frequent extreme precipitation, changes in flood magnitudes and frequencies, the effects of sea level rise, and increased land subsidence.[34]

3.3.6. Subsidence

The San Joaquin Valley is sinking five centimeters per month in some locations, in large part due to groundwater depletion from agriculture draw down combined with hydro compaction.[35] Though groundwater pumping rates have slowed in the region since the 1970's, droughts (such as the 2011 to 2017 drought) typically result in an increase in groundwater use.[36] Two main subsidence bowls have been mapped in the San Joaquin Valley, one in the north that sank 37 inches from 2006 to 2010, and one in the south that sank 24 inches in the same time period.[37] If droughts become more frequent and groundwater depletion continues as a result, land subsidence will continue. Impacts to infrastructure (such as the State Highway System) may occur where it crosses subsiding areas, especially if the depths or rates of subsidence are uneven across the landscape.[38] Subsidence in the San Joaquin and greater Central Valley area is being watched carefully by both researchers and infrastructure managers. For example, the California High-Speed Rail Authority is preparing for potential subsidence by using ballast, as opposed to "highway-like" concrete slabs, to support track in subsidence prone areas. This design will be easier to maintain and fix if the land sinks, saving time and costs in the future. [39] Subsidence will be an ongoing issue for the region that will undoubtedly affect infrastructure planning, management, and maintenance for Caltrans and other infrastructure owners.

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 100-year precipitation event) are typically calculated over 30-year time periods centered on the year of

[33] "Central Valley Flood Protection Plan Update." CA Department of Water Resources. August 2017. http://www.water.ca.gov/cvfmp/docs/2017/2017CVFPPUpdate-Final-20170828.pdf

[34] Ibid.

[35] Galloway, Devin, David R Jones, and Steven E Ingebritsen. "Land subsidence in the United States." U.S. Geological Survey. 1999.

[36] "Ground water in the Central Valley, California." U.S. Geological Survey. December 30th, 2015. http://pubs.usgs.gov/pp/1401a/report.pdf

[37] "Progress Report: Subsidence in the Central Valley, California." NASA. December 30th, 2015. http://water.ca.gov/groundwater/docs/NASA_REPORT.pdf

[38] "Land Subsidence: Cause and Effect." U.S. Geological Survey. Last modified October 16th, 2017. https://ca.water.usgs.gov/land_subsidence/california-subsidence-cause-effect.html

[39] "No end in sight as repair work on California's sinking land costs billions." The Guardian. December 27th, 2015. https://www.theguardian.com/us-news/2015/dec/27/california-central-valley-land-sinking-subsidence-drought

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 (see screenshot in Figure 3) that was supplied to Caltrans after the study was completed (see Figure 3). Limited metadata on each dataset was also provided in the form of an Excel table that described each dataset and its characteristics (see Figure 4). This GIS data will be useful to Caltrans for future climate adaptation planning activities.

FIGURE 3: SCREENSHOT OF GIS DATABASE

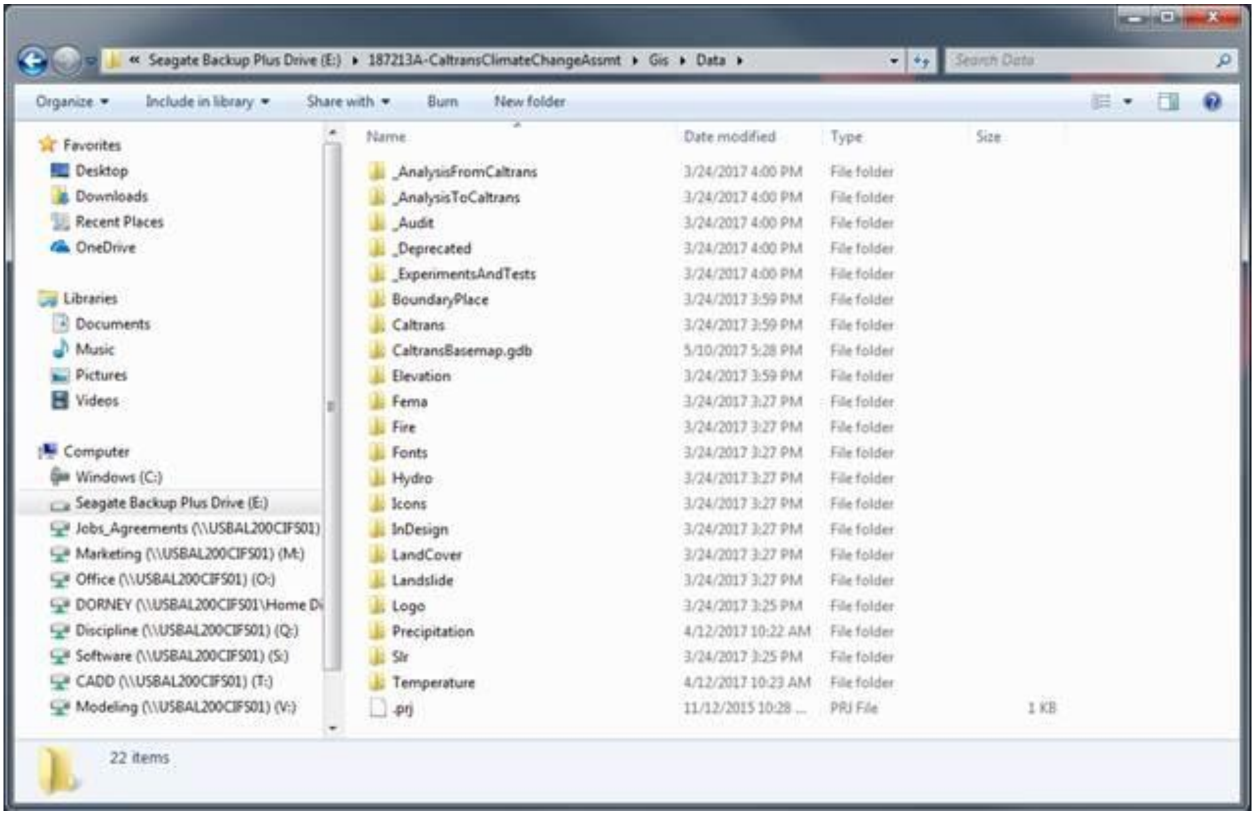
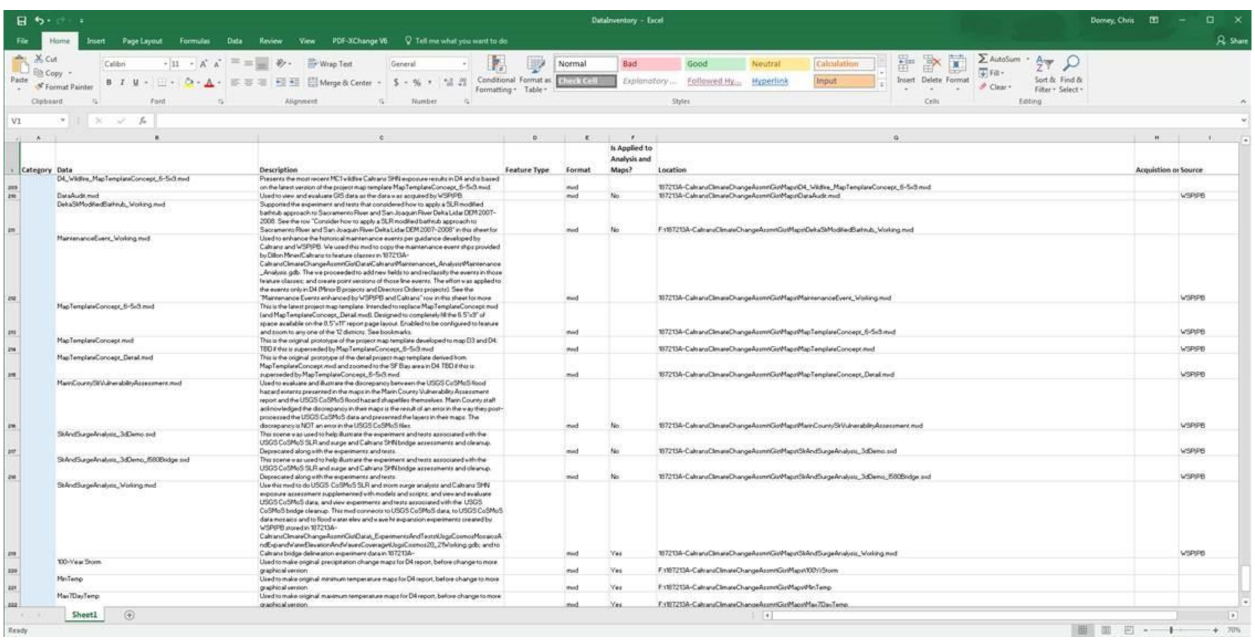


FIGURE 4: SCREENSHOT OF SPREADSHEET PROVIDED



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.[40] The potential effects of extreme temperatures on District 6 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:

- **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 design may need to shift over time. Asphalt pavements are typically put in place for a period of

[40] U.S. National Climate Assessment, http://nca2014.globalchange.gov/report/our-changing-climate/extreme-weather

approximately 20 years, so their design lives closely match the 30-year analysis periods used in this report. Because of their relatively short design lives, asphalt overlays of different specifications can be used as climate conditions change.

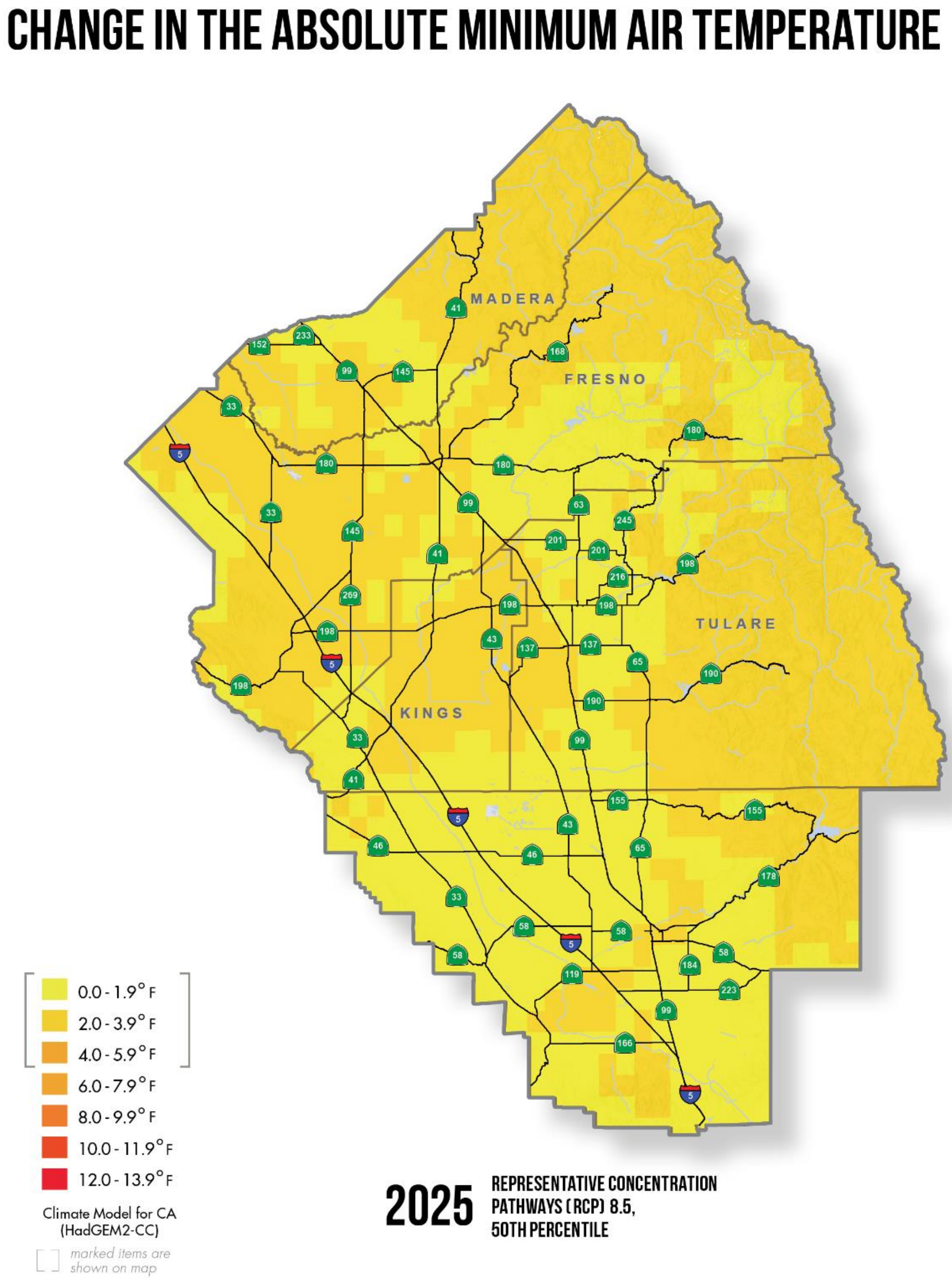
The project study team used the LOCA climate data developed by Scripps for this analysis of temperature,[41] which has a spatial resolution of 1/16 of a degree or approximately three and a half to four miles.[42] This data set was queried to determine the annual lowest temperature and the average seven-day 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, 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 in the following pages can be added to Caltrans' current source of historical temperature data to determine final pavement design value for the future. This summarized data can be used by Caltrans to identify how pavement design practices may need to shift over time given the expected changes in temperature in the future and help inform decisions on how to provide the best pavement quality for California State Highway System users.

[41] A more detailed description of the LOCA data set and downscaling techniques can be found at the start of this report.
[42] "LOCA Downscaled Climate Projections," http://beta.cal-adapt.org/data/loca/, 2017

FIGURE 5: CHANGE IN THE ABSOLUTE MINIMUM AIR TEMPERATURE 2025

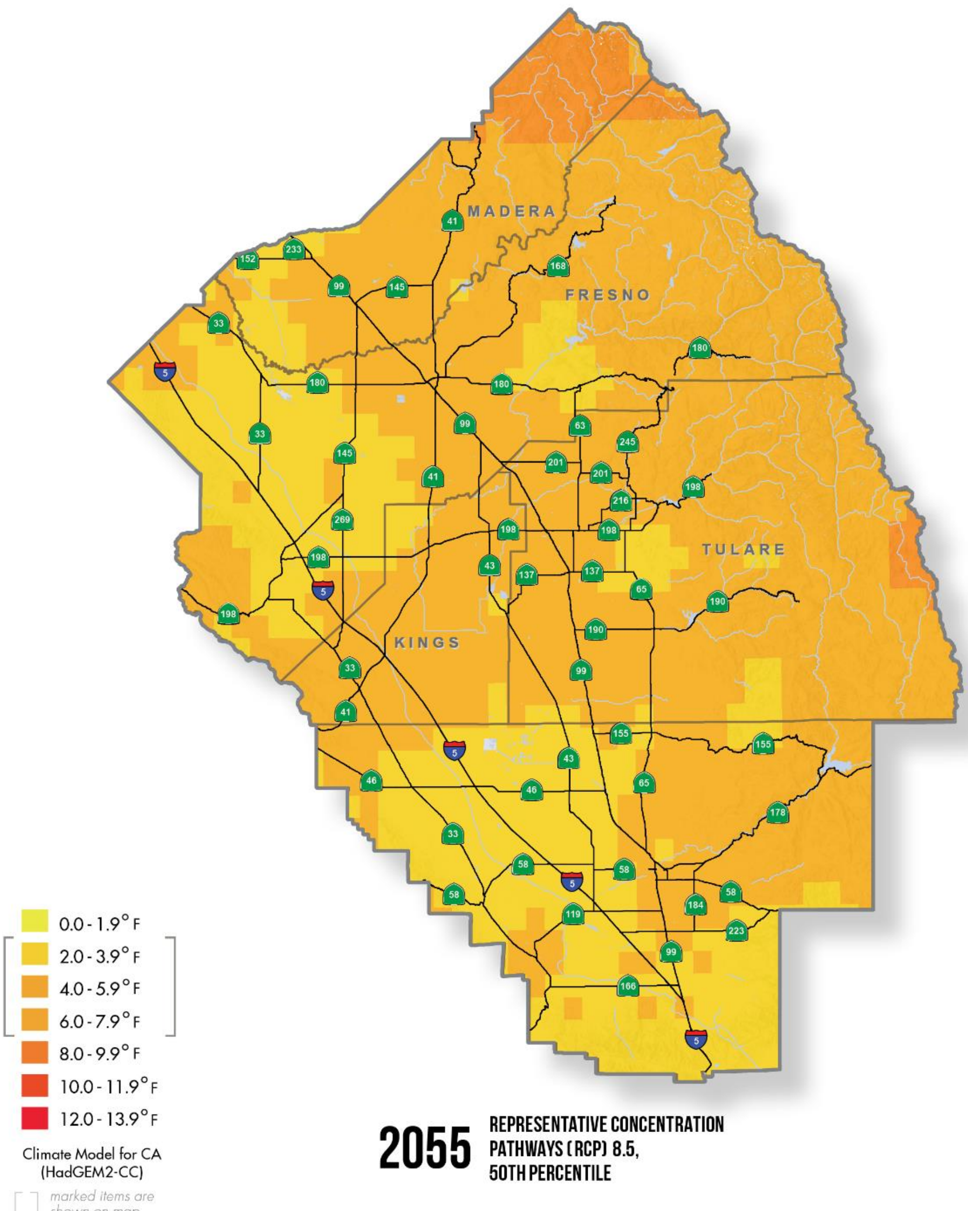


Future Change in the Absolute Minimum Air Temperature within District 6, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 6. 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 THE ABSOLUTE MINIMUM AIR TEMPERATURE 2055

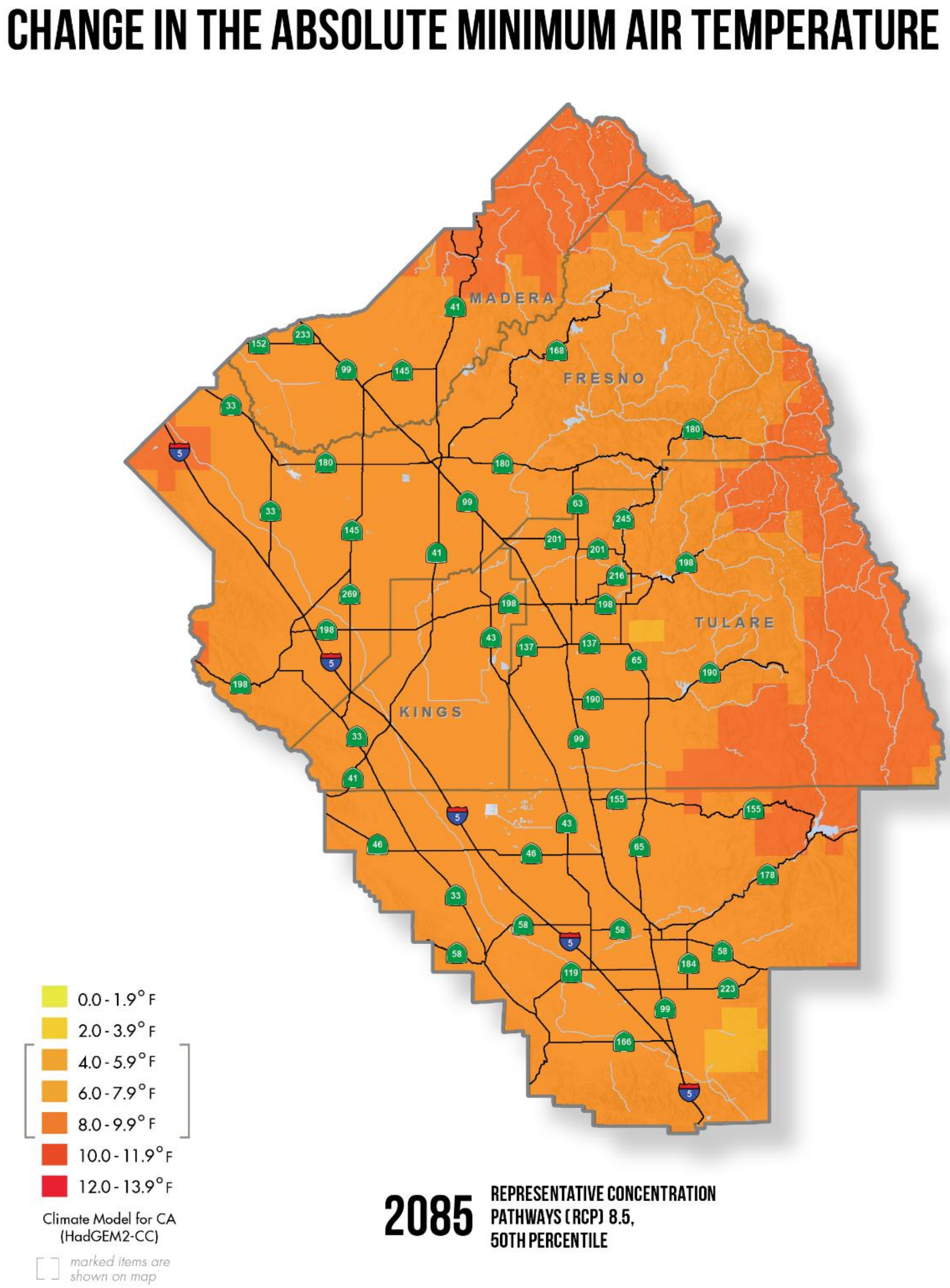
CHANGE IN THE ABSOLUTE MINIMUM AIR TEMPERATURE



Future Change in the Absolute Minimum Air Temperature within District 6, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 6. 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.

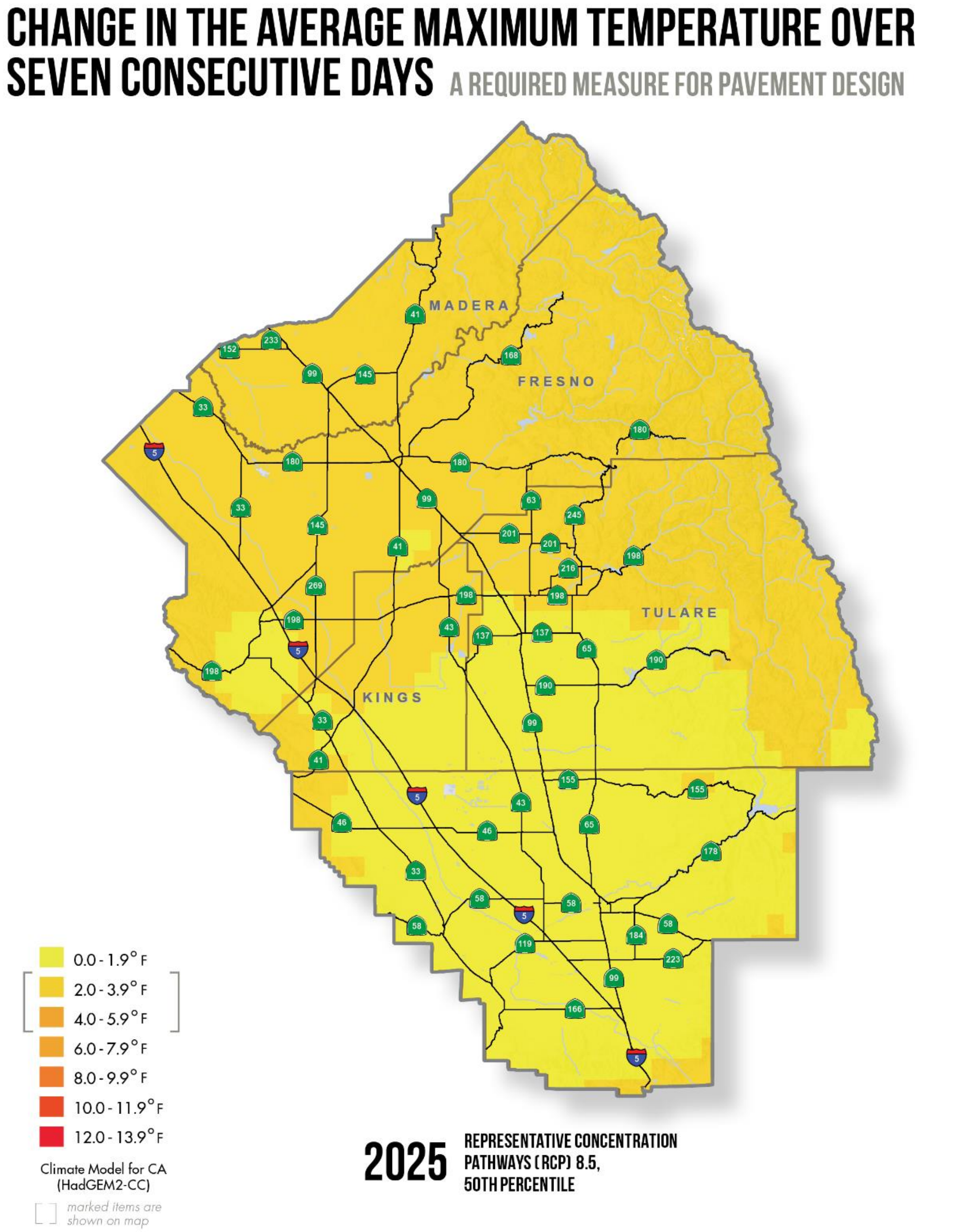
FIGURE 7: CHANGE IN THE ABSOLUTE MINIMUM AIR TEMPERATURE 2085



Future Change in the Absolute Minimum Air Temperature within District 6, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 6. 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 THE AVERAGE MAXIMUM TEMPERATURE OVER SEVEN CONSECUTIVE DAYS 2025

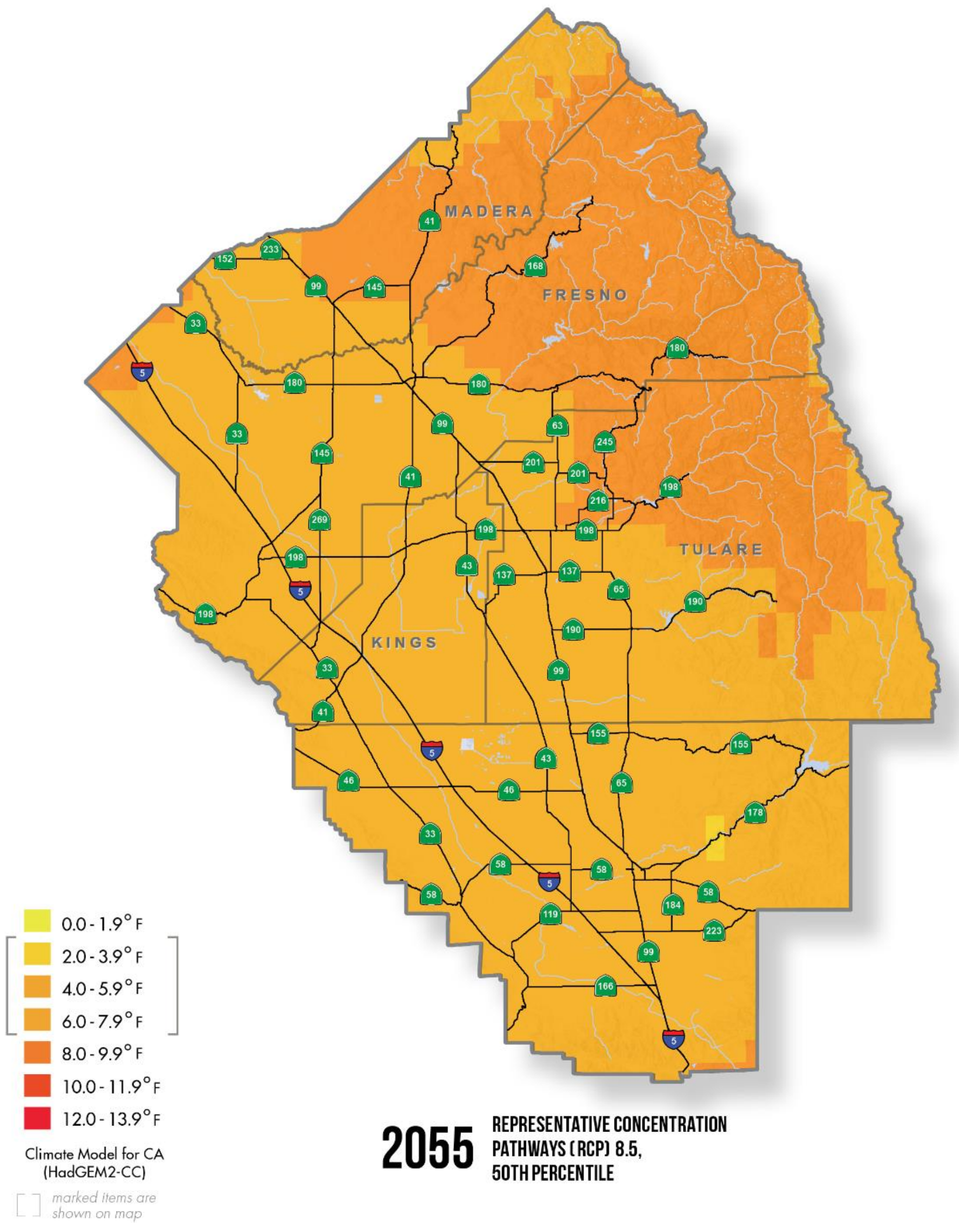


Future Change in the Average Maximum Temperature over Seven Consecutive Days within District 6, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 6. 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 9: CHANGE IN THE AVERAGE MAXIMUM TEMPERATURE OVER SEVEN CONSECUTIVE DAYS 2055

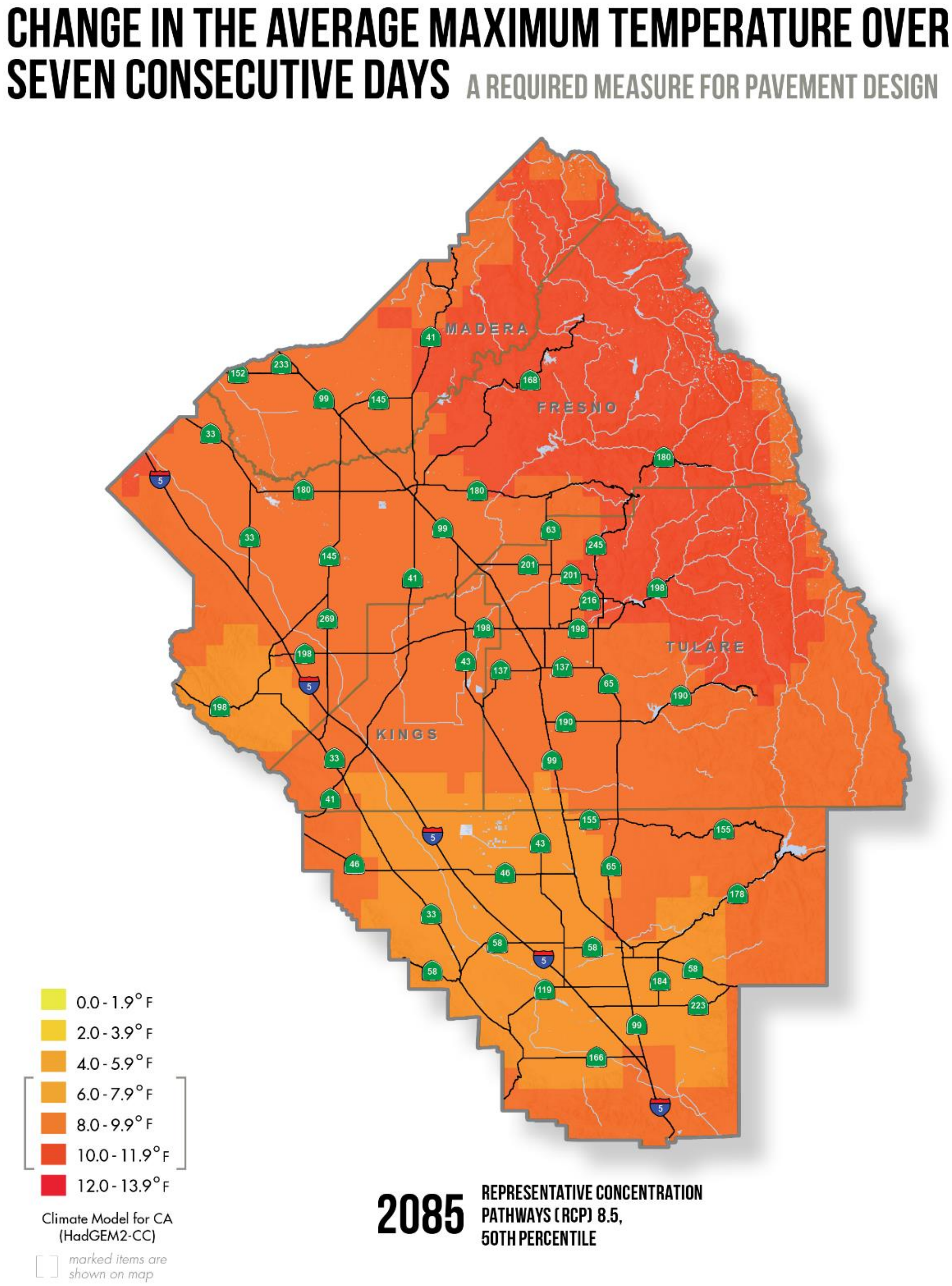
CHANGE IN THE AVERAGE MAXIMUM TEMPERATURE OVER SEVEN CONSECUTIVE DAYS A REQUIRED MEASURE FOR PAVEMENT DESIGN



Future Change in the Average Maximum Temperature over Seven Consecutive Days within District 6, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 6. 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 10: CHANGE IN THE AVERAGE MAXIMUM TEMPERATURE OVER SEVEN CONSECUTIVE DAYS 2085



Future Change in the Average Maximum Temperature over Seven Consecutive Days within District 6, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 6. 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[43], but with the potential for heavier individual events, with more precipitation falling as rainfall. These conditions were experienced in District 6 during the 2016–2017 winter, where heavy precipitation caused $85 million in damages to District 6 assets in 2017 alone. 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.[44] 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.[45] 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 Scripps Institution for Oceanography is working to better understand future precipitation projections and this research is being compiled as a part of California 4th Climate Assessment.

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 SHS 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 8.5 emissions scenarios and was analyzed for three time periods to determine how precipitation may change through the end of century. The years shown in the

[43] 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.

[44] http://www.dot.ca.gov/hq/oppd/hdm/hdmtoc.htm

[45] http://nws.noaa.gov/oh/hdsc/index.html

following figures represent the mid-points of the same 30-year statistical analysis periods as used for the temperature metrics.

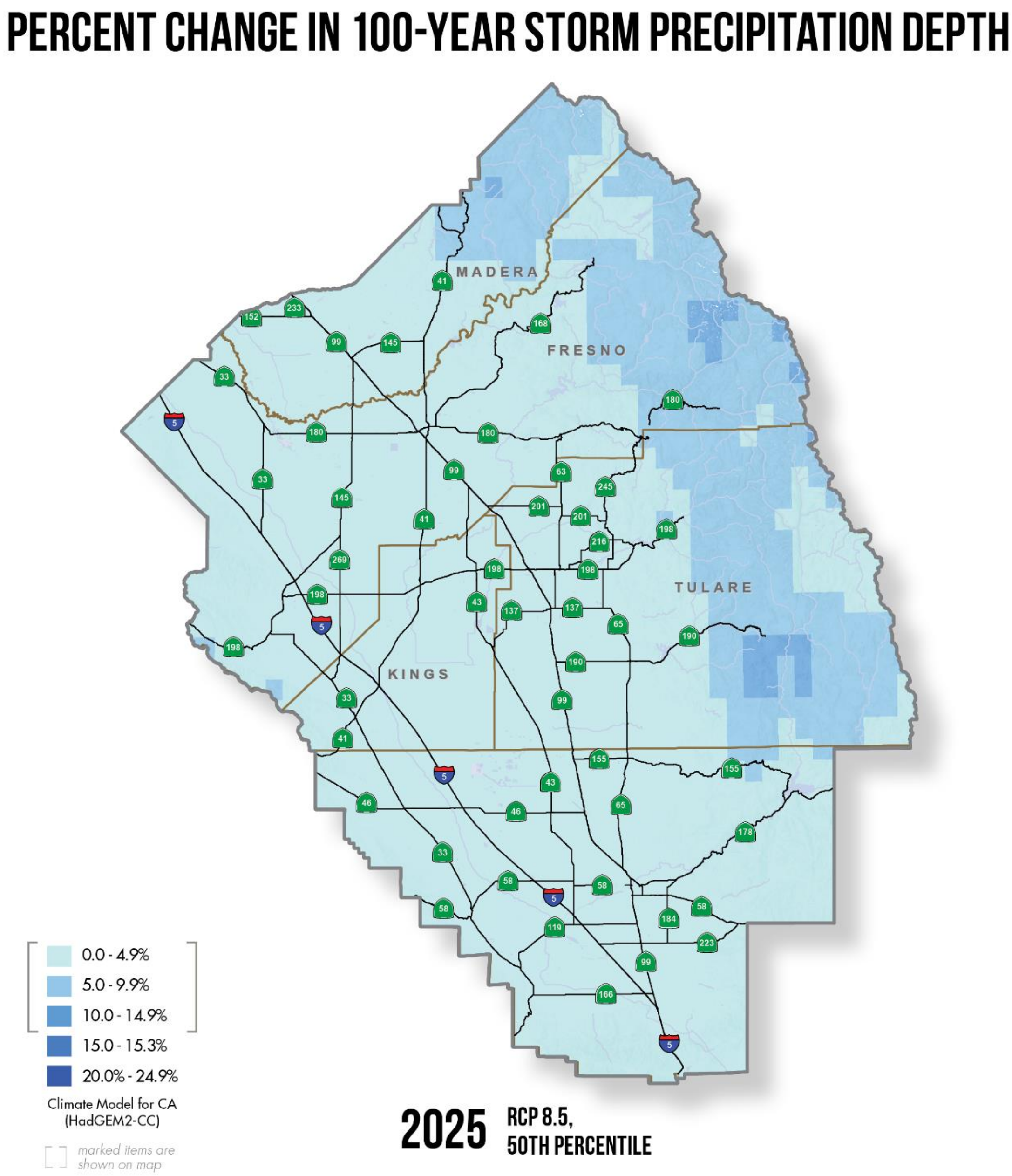
The project study team analyzed the models to understand two important points:

- 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 6 maps on the following pages, which depict the percentage change in the 100-year storm rainfall event predicted for the three analysis periods and the RCP 8.5 emissions scenario (the RCP 4.5 results are not shown). The median model for the state was used in this mapping. Note that the change in 100-year storm depth is positive throughout District 6, 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 SHS and understanding those implications may help Caltrans engineers and designers implement an adaptive design solution. That said, a hydrological analysis of flood flows is necessary to determine how this data will affect specific bridges and culverts.

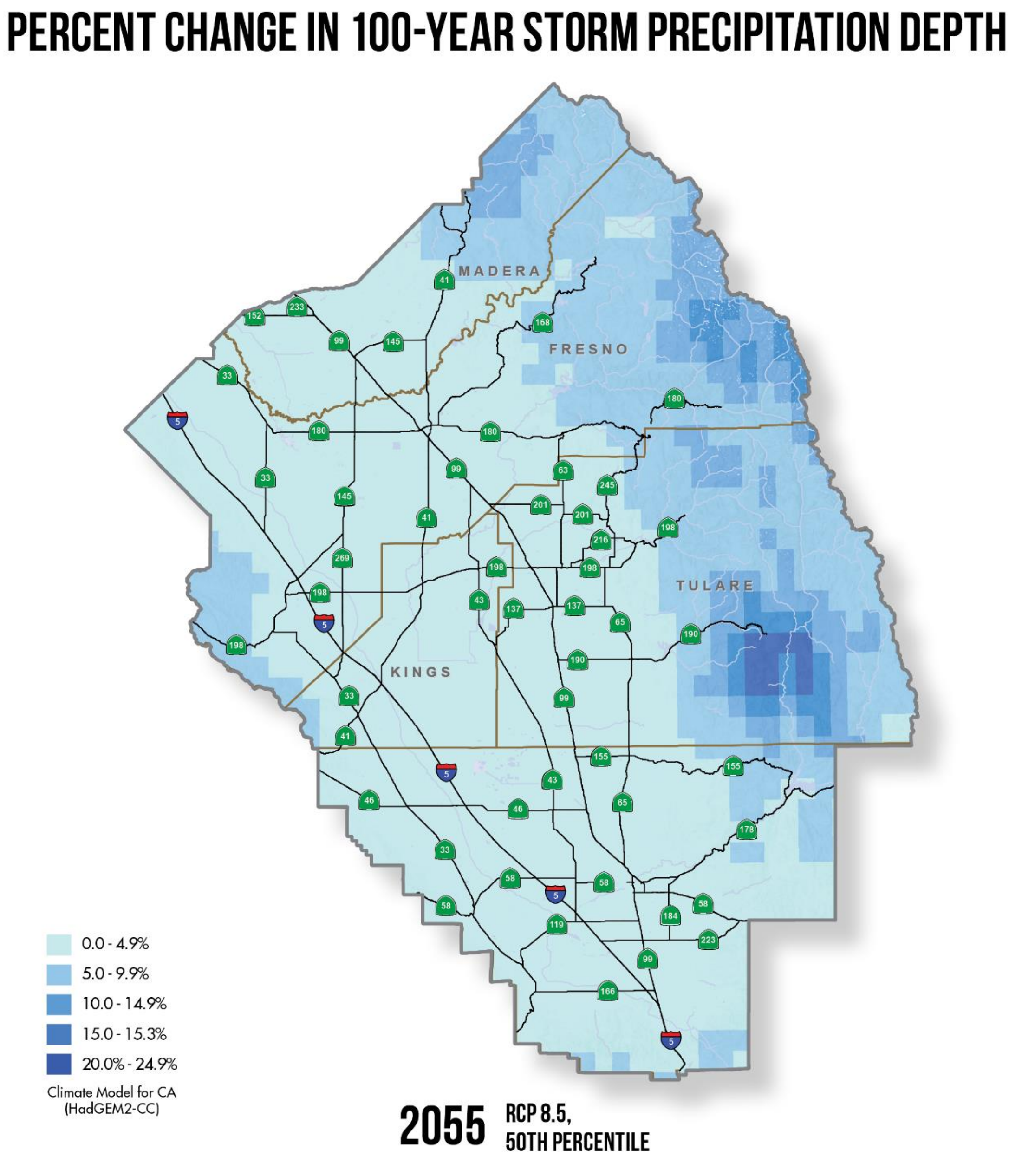
FIGURE 11: PERCENT CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH 2025



Future Percent Change in 100-year Storm Precipitation Depth within District 6, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 6. 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.

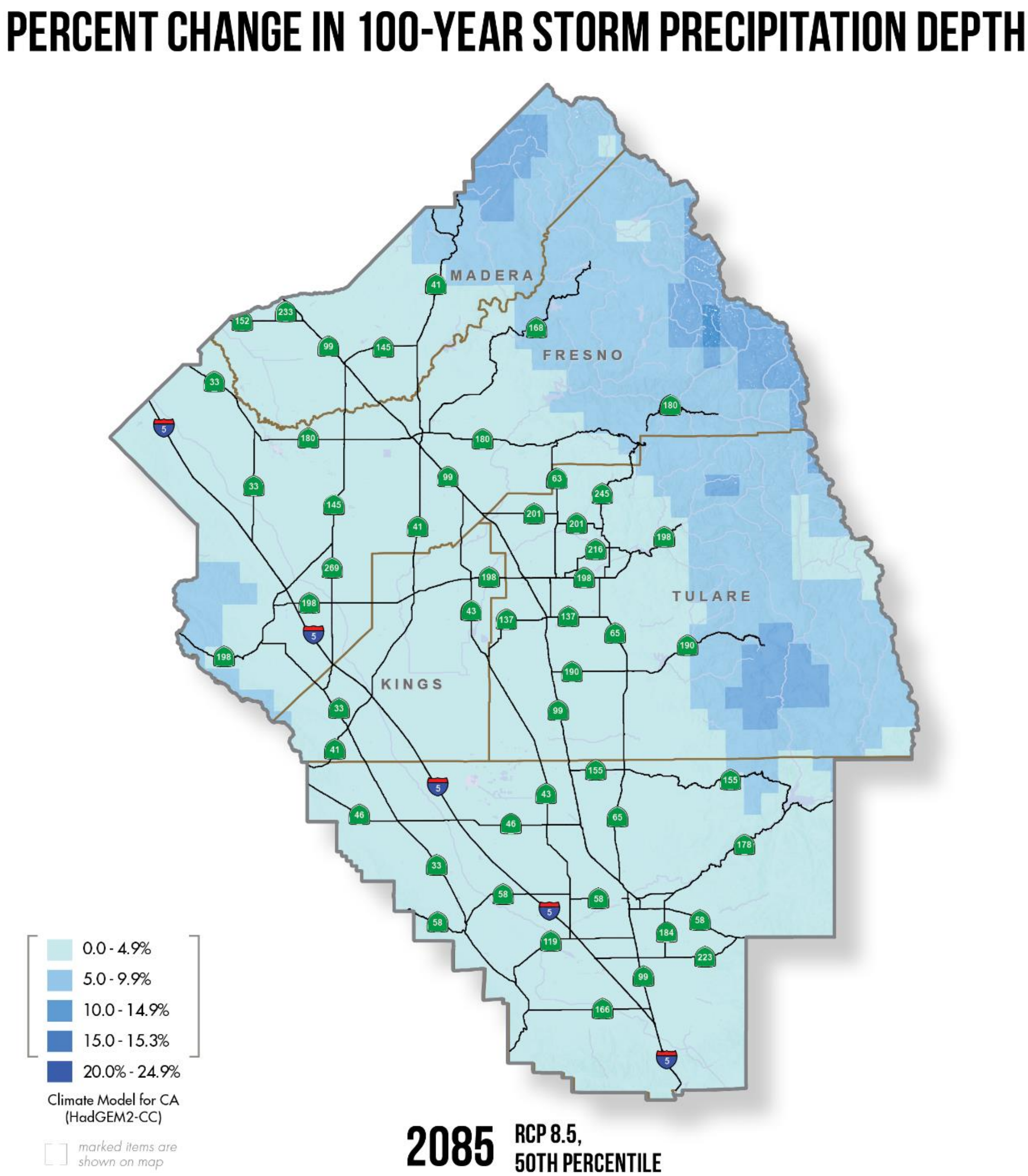
FIGURE 12: PERCENT CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH 2055



Future Percent Change in 100-year Storm Precipitation Depth within District 6, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 6. 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 13: PERCENT CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH 2085



Future Percent Change in 100-year Storm Precipitation Depth within District 6, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 6. 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.

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

6.1. Ongoing Wildfire Modeling Efforts

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

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

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 felt 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%+.

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.

Figure 14, Figure 15, and Figure 16 on the following pages show the results of this analysis, using the classification scheme explained above. These figures show projections for RCP 8.5 only and red highlights show portions of the Caltrans SHS that are likely to be most exposed to wildfire. Table 2 summarizes the miles of District 6 State Highway System that are exposed to wildfire risk, by level of concern and District 6 county.

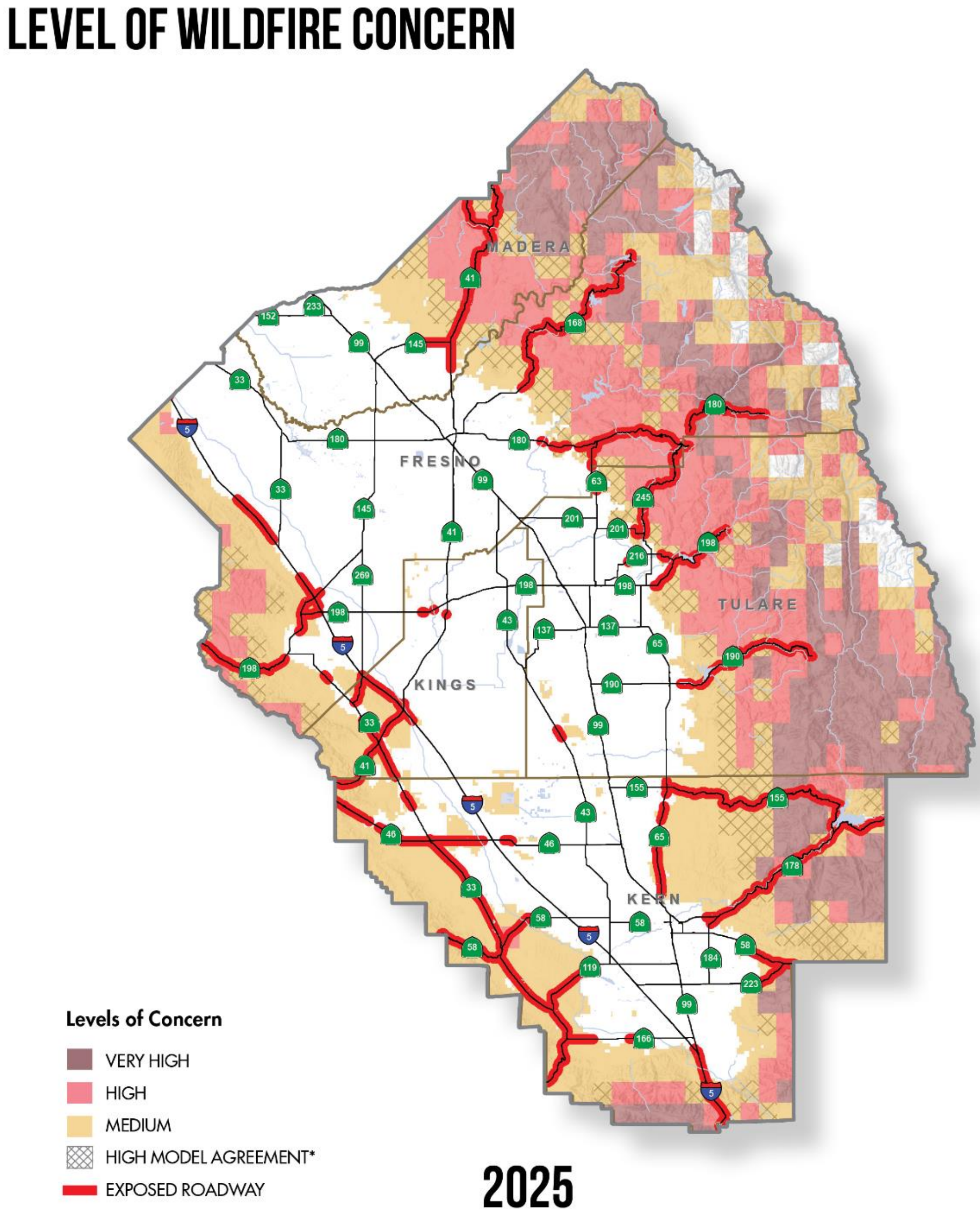
TABLE 2: MILES OF STATE HIGHWAY SYSTEM EXPOSED TO WILDFIRE FOR THE RCP 8.5 SCENARIO

	Year		
District 6 Counties	**2025**	**2055**	**2085**
Fresno	172.2	172.2	172.2
Kern	285.2	277.3	285.2
Kings	39.8	39.8	39.8
Madera	57.3	57.3	57.3
Tulare	85.0	85.0	85.0

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

	Year		
District 6 Counties	**2025**	**2055**	**2085**
Fresno	155.4	156.1	172.2
Kern	206.1	182.4	285.2
Kings	14.1	8.3	39.8
Madera	51.7	57.3	57.3
Tulare	68.7	80.3	85.0

FIGURE 14: INCREASE IN WILDFIRE EXPOSURE 2025

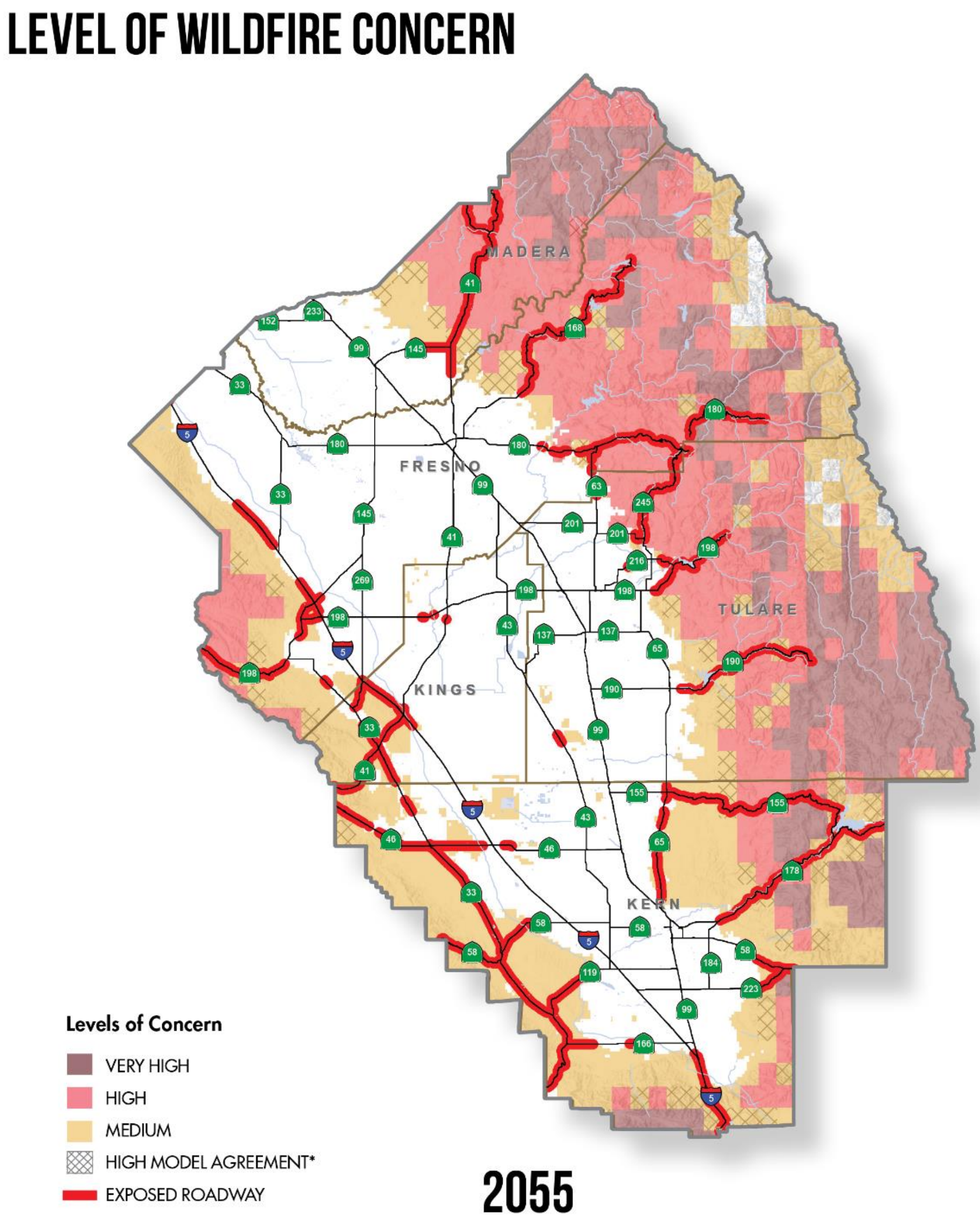


Future Level of Wildfire Concern for the Caltrans State Highway System within District 6, Based on the RCP 8.5 Emissions Scenario

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 15: INCREASE IN WILDFIRE EXPOSURE 2055

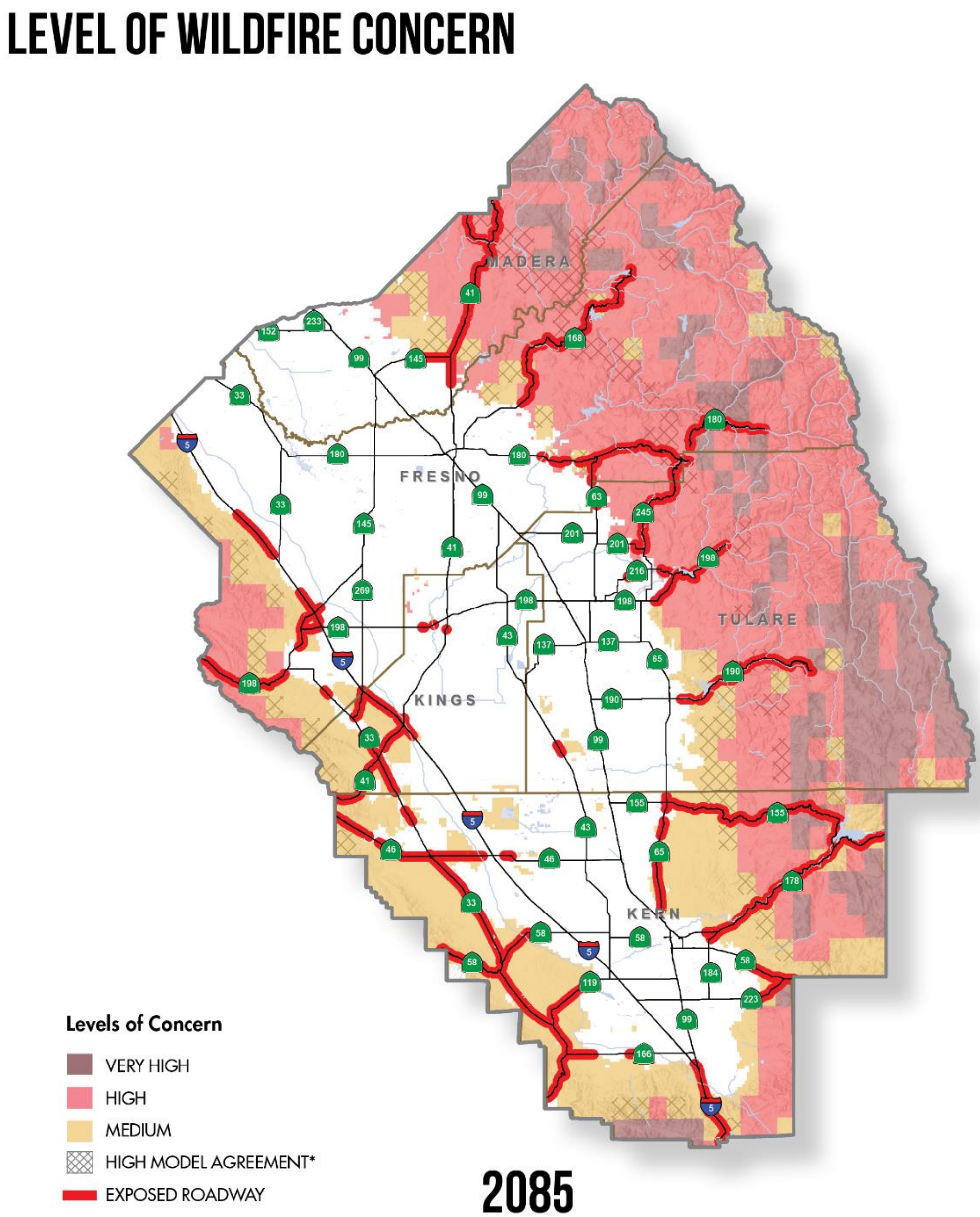


Future Level of Wildfire Concern for the Caltrans State Highway System within District 6, Based on the RCP 8.5 Emissions Scenario

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 16: INCREASE IN WILDFIRE EXPOSURE 2085



Future Level of Wildfire Concern for the Caltrans State Highway System within District 6, 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. LOCALIZED ASSESSMENT OF EXTREME WEATHER IMPACTS

To highlight how climate change may impact facilities in District 6, an example from a recent event on a Caltrans managed roadway has been highlighted to illustrate how the roadway is currently vulnerable to landslides and erosion, and how the facility could face increased vulnerability due to climate change. Highway 41 is one of three roadways that enter Yosemite Valley, the others being Big Oak Flat Road and Highway 140. Alternate route and detour options are very limited in this area and at one point following heavy precipitation events in 2017, both Highway 41 and Big Oak Flat were closed at the same time due to storm damage.[46] Highway 41 was closed at Fish Camp near Summerdale Campground due to a February 9 washout that eroded the southbound shoulder of the highway. Caltrans workers responding to the washout noted that the northbound lane was also sinking and eventually a five-foot hole in the roadway opened. [47] Rain water had eroded the roadbed under part of Highway 41, which needed to be excavated and rebuilt.[48] Repairs to this section of roadway cost over one million dollars to reopen the highway for use. [49]

Highway 41 passes through rural and forested areas in Madera County on the way to Yosemite Valley, so it is exposed to potential wildfires. Based on the climate emissions scenarios analyzed for this assessment, by 2025, large portions of Highway 41 are expected to lie in areas that are high-risk for wildfires. Wildfires along Highway 41 could have a variety of impacts, including loss of forest cover leading to faster water runoff and less infiltration during storm events. Increased flows and looser soils from vegetation loss could lead to increased landslide risk. The washout and erosion of Highway 41 was caused by a reactivated underground spring following heavy rain events. Highway 41 was restored following the event, but future extreme precipitation events could lead to similar impacts in this area. These impacts could be even more severe in periods following a wildfire. The 100-year storm depths are expected to increase in the northern segment of Highway 41 by about 5 to 10%, by 2025.

[46] http://www.sierrastar.com/news/local/article134365769.html
[47] http://abc30.com/weather/highway-41-closed-near-yosemite-national-park-entrance/1765815/
[48] http://www.fresnobee.com/news/local/article134063094.html
[49] http://abc30.com/weather/highway-41-closed-near-yosemite-national-park-entrance/1765815/

FIGURE 17: HIGHWAY 41 WASHOUT

8. INCORPORATING CLIMATE CHANGE INTO DECISION-MAKING

8.1. Risk-Based Design

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

One outcome of the FHWA studies was a step-by-step method for completing facility (or asset) design, such that climate change was considered and inherent uncertainties in the timing and scale of climate change were included. This method, termed the Adaptation Decision-Making Assessment Process (ADAP),[50] 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 18.

The first five steps of the ADAP process cover the characteristics of the project and the context. The District 6 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:

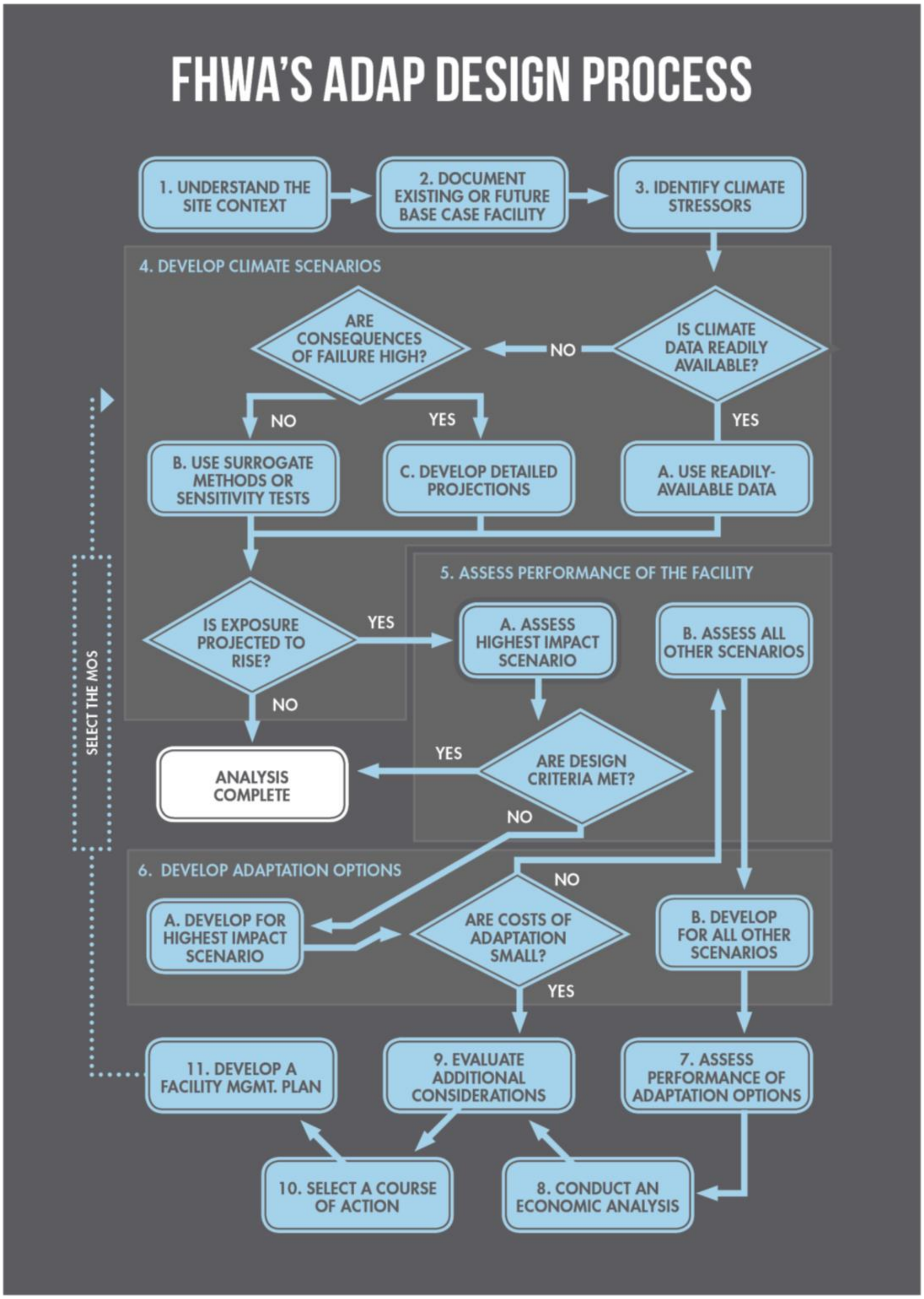
- full life cycle cost accounting

[50] 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 18: FHWA'S ADAPTATION DECISION-MAKING PROCESS



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

8.1.1. Drought-Stricken Tree Removal

From mid-2016 into 2017, Caltrans District 6 staff initiated an effort to remove stands of dead trees from District 6 SHS right-of-way. Millions of trees across the state died due to an unabated period of drought lasting multiple years, from late 2011 to 2017. This period of drought in California led it to be the driest it had ever been since the beginning of record keeping.[51] Trees died directly from the drought and due to associated pathogens/parasites such as the bark beetle. These parasitic beetles are native to the state, but are more successful in attacking California conifers when trees are weak and make better hosts.[52]

On October 30th of 2015, Governor Jerry Brown issued a State of Emergency in response to the massive tree die-off. This proclamation ordered state agencies to start removing the stands of dead trees to protect public health and safety. In response, and recognizing that these dead trees will act as fuel for wildfires or fall during a storm/high wind event, District 6 began issuing emergency bids to remove trees across its counties. District 6 staff removed:

- 4,473 trees along Route 155 in Kern County for over $4 million (final billing is in progress).
- 18,071 trees along Route 41 in Madera County for $8,275,000.
- 7,278 trees along Route 168 in Fresno County for $8,822,400.
- 4,064 trees in Tulare and Fresno Counties near Sequoia National Park for $3,757,762.
- 6,305 trees in Tulare and Fresno Counties near Sequoia National Park for $6,412,264.

Tree removal along Route 155 in Kern County was also done in response to the Cedar Fire, which had been burning adjacent to the roadway for several weeks. District staff were concerned that the stands of dead/diseased trees could further feed the flames, or that the dry fuel could lead to another wildfire event. This concern is held widely across the state by many - by Caltrans, other agencies, and local municipalities.

As drought events become more common in California due to future climate change, these tree removals may become a more regular practice for Caltrans staff and a point of further dialogue for statewide policy. Tree removal of this magnitude falls outside of regular District 6 maintenance activities, being done in this circumstance because of the statewide proclamation. These efforts provide an excellent example of preventative measures that can pre-emptively mitigate risk. This could be an operational/maintenance adaptation response deployed by Caltrans as climate changes.

[51] http://www.ppic.org/publication/californias-latest-drought/
[52] https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5384837.pdf

FIGURE 19: ROUTE 55 IN KERN COUNTY

FIGURE 20: ROUTE 168 IN FRESNO COUNTY

8.2. Project Prioritization

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

The prioritization method requires the following information:

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

    What are the levels for stressors (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?

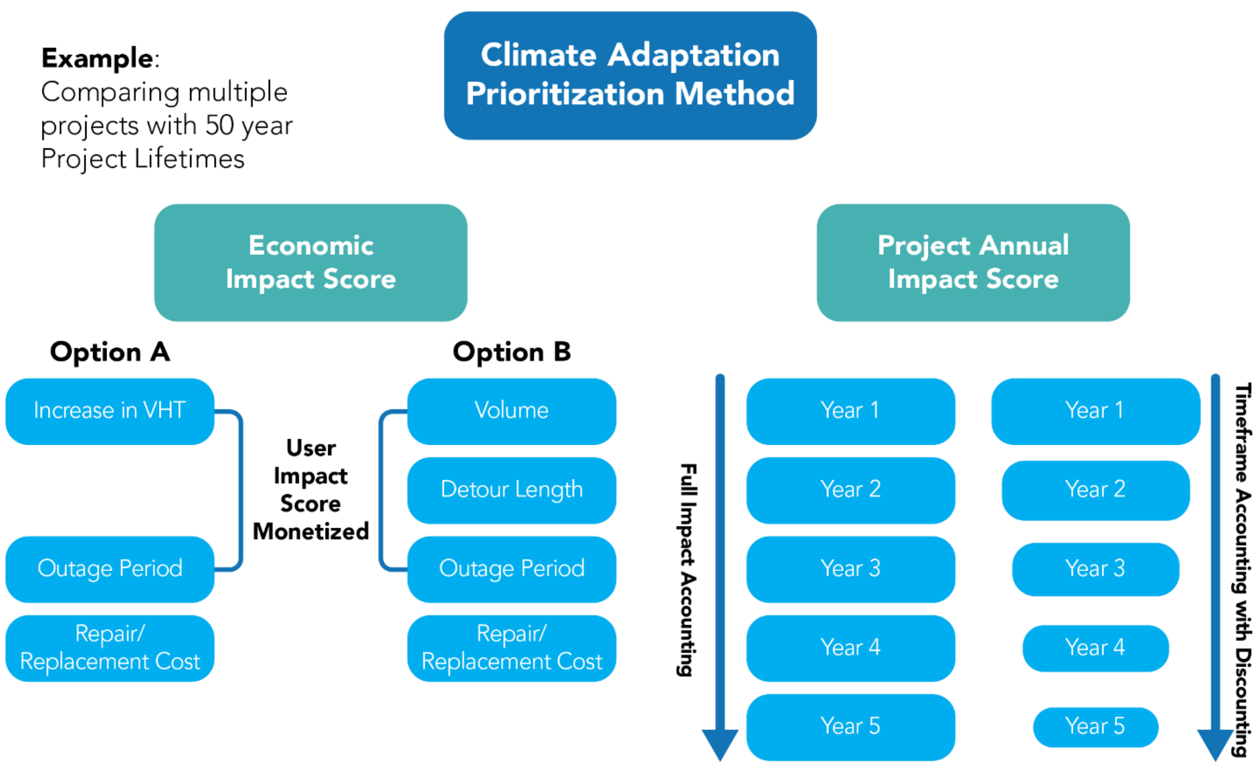
- System impacts (supplied by Caltrans planning staff) – the impacts of the loss of the facility on the broader system. This could be in terms of increase in Vehicle Hours Traveled (VHT) if using a traffic model, or an estimated value using volume and detour length as surrogates.
- Probability of occurrence (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 21 shows the general approach for the prioritization method.

FIGURE 21: APPROACH FOR PRIORITIZATION METHOD



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

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

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

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

Probabilities of an event occurring over each year would be used to summarize costs per year as well as a summarized cumulative total cost for the project over the lifetime. The resulting values would set the prioritization metric in terms of net present value for Caltrans to apply in selecting projects. The identification of an annual cost metric, which includes discounting, enables the important decision-making process on which project should advance given limited project resources. Table 4 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 4: 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.

9. 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 6. 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 6. The study distilled the larger context of climate change down to a more localized understanding of what such change might mean to District 6 functions and operations, District 6 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 6 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 6 and where project development efforts for projects in these areas should consider changing future environmental conditions. There are several steps that can be taken to transition from a traditional project development process based on historical environmental conditions to one that incorporates a greater consideration for facility and system resiliency. This process can incorporate the benefits associated with climate change adaptation strategies and use climate data as a primary decision factor. District 6 staff, with its recent history of assessing long-term risks associated with climate change, has the capacity to adopt such an approach and ensure that travelers in the region are provided with a resilient system over the coming years.

The following section provides some context as to what the next steps for Caltrans and District 6 may be, to build upon this work and create a more resilient State Highway System.

9.1. Next Steps

The work completed for this effort answers a few questions and raises many more. The scope of this work was focused on determining what is expected in the future and how that may affect the Caltrans SHS. This analysis has shown that climate data from many sources indicates an expanded set of future risks – from increased extreme precipitation, to higher temperatures, and an increase in wildfires – all concerns that will need to be considered by District 6.

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 6. 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 8.1 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 6 (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.

10. GLOSSARY

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

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

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

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

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

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

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

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

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

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

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