CALTRANS CLIMATE CHANGE VULNERABILITY ASSESSMENTS

July 2018

District 2
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 2. 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 are invested in defining the implications of climate change and many of California's academic institutions are engaged in developing resources for decision-makers. Caltrans initiated the current study to better understand the vulnerability of California's 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 2 report is one of 12 district reports that are in various stages of development.

1.1. Purpose of Report

The *District 2 Technical Report* is one of two documents developed to describe the work completed for the District 2 vulnerability assessment, the other being the *District 2 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 2.

This *Technical Report* is intended to provide a more in-depth discussion, primarily for District 2 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.

All data used in the developed of the District 2 Technical and Summary Reports was collected into a single database and provided to Caltrans. Caltrans will be able to use this data in their own mapping efforts and analyses, and is expected to be a valuable resource for ongoing resiliency planning efforts. The contents of the District 2 database will also be available to the public in an online interactive mapping tool. The tool currently holds the data for District 4; data for District 2 and other districts will be added as it becomes available.[1]

1.2. District 2 Characteristics

District 2 is in the northeast corner of the state and is bordered by Oregon and Nevada, and Caltrans Districts 1 and 3. It encompasses Lassen, Modoc, Plumas, Shasta, Siskiyou, Tehama and Trinity Counties, making it the second largest district in the state. District 2 is largely rural, with a population of 13 people per square mile (compared with the statewide average of 255) and it includes large areas of undeveloped land—each of the seven counties in the district is at least 40% forested. The majority of land (75%) is held in public ownership, with the US Forest Service being the largest land holder and the Bureau of Land Management the second largest. Uses of federal land include wildlife preservation, nature conservation, cattle grazing, recreation, and natural resource development.

The district maintains 1,750 center-line miles, or more than 4,000 lane-miles of highway. The most important of these is Interstate 5 (I-5) which connects Redding and the north of the state to all major population centers of the west coast, including Sacramento, Stockton, San Diego, and Los Angeles. I-5 is a lifeline route that connects many local communities within the region, serves as a primary commuter link for many workers in the area, and provides access to major recreational opportunities in the district. In addition, I-5 is noted in the California Freight Mobility Plan as the main north-south interstate highway that crosses the length of the state and passes through the heart of the Northern California region. This route serves large volumes of truck freight on the west coast between Mexico and Canada. Freight in District 2 supports the primary economic drivers of the district, such as logging, manufacturing, and agriculture. Other economic drivers in District 2 are less reliant on freight, but directly tied to the local geography and environment, such as outdoor recreation and tourism.

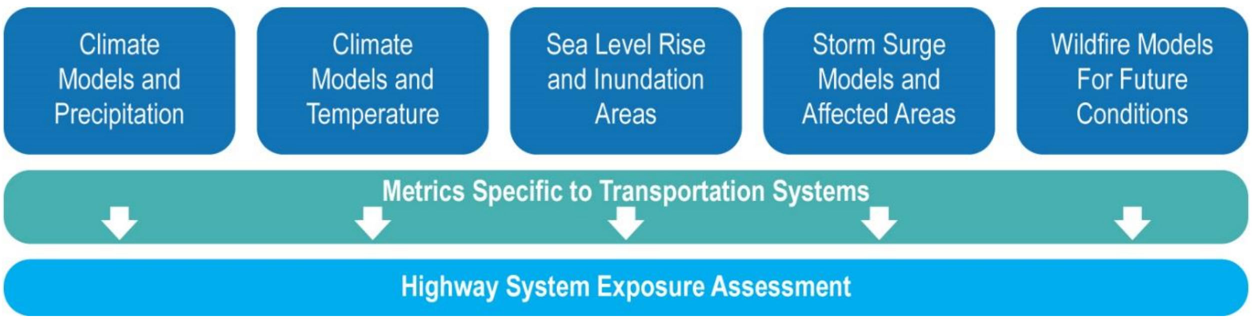
[1] "Caltrans Climate Change Vulnerability Assessment Map." Caltrans. http://caltrans.maps.arcgis.com/apps/webappviewer/index.html?id=517eecf1b5a542e5b0e25f337f87f5bb 2017.

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

Climate and extreme weather conditions in District 2 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 2 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.

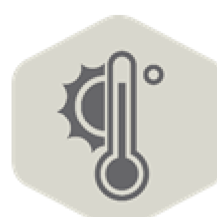
Figure 1 illustrates the general process for deciding which metrics should be included in the overall SHS vulnerability assessment. First, Caltrans and the project study team considered which climate stressors affect transportation systems. Then, Caltrans and the project study team decided on a relevant 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 2 infrastructure, with the potential for impacts to become more severe in the future. In 2017 alone, damage in District 2 was estimated at $85 million, with 110 damage assessments prepared, and 22 Emergency Directors Order Contracts applied in five of the District 2 counties. The following are summaries of the climate/extreme weather conditions that currently affect the District 2 State Highway System and for which future projections were evaluated for this assessment.

- **Temperature** –District 2 has a Mediterranean-like climate, characterized by hot, dry summers and cold, wet winters. Temperatures in lower-lying areas can be very hot, like in the City of Redding where the average temperature in July is 82 °F, with a maximum temperature of 114 °F recorded in August 2017.[2] As temperatures rise from higher GHG concentrations in the atmosphere, the average and maximum temperatures in District 2 are expected to increase. More frequent extreme heat events could affect District 2 maintenance needs, cause material damage, and cause changes in maintenance schedule during high heat to protect worker safety.



[2] Caltrans District 4 Map Viewer, http://www.sfgate.com/news/article/West-Coast-heat-wave-Seattle-Redding-record-temps-11727677.php, 2018

- **Precipitation and Flooding** – Precipitation is expected to be more volatile on the west coast due to increased energy and moisture in the atmosphere. Increases in heavy precipitation events combined with other changes in land use and/or land cover can increase the risk of flash flooding. The effects of flash flooding have already been significant in District 2, especially during the winter of 2016 – 2017 where rainstorms and mudslides caused road closures and damage in the district. Examples include:
  - Highway 3 in Trinity County experienced road collapse and failure from soaking rains and resultant slope failure, as shown on Figure 2. The road was closed for two weeks.
  - State Route 70 incurred significant storm damage related to precipitation, river flooding, and mudslides, requiring ongoing repair. Road sections included:
    (1) Rising floodwaters of the North Fork of the Feather River caused roadway damage and triggered landslides.
    (2) The valley portion of State Route 70 was shut down because of the Oroville Dam (located in District 3) spillway incident, a result of a steady barrage of storms in early 2017 causing serious damage to the Lake Oroville spillways.
    (3) Slope failure occurred in Plumas County at an area known as the “Gauntlet”. Images of this slope failure are shown in Figure 3.
  - State Route 96 in Siskiyou County is being repaired along a stretch of roadway because of major winter storm damage (see Figure 4). The stretch of State Route 96 that begins 23 miles north of Somes Bar, following the Klamath River and ending at Interstate 5 in Siskiyou County, was severely affected by the weather when more than 60 inches of rain fell in the area. Caltrans crews from the Seiad Valley and Yreka Maintenance Stations woke up every day to face multiple slides and slip-outs on SR-96, causing major damage and traffic delays. They experienced flooding, slide removal involving rock and mud, large boulder removal including blasting operations, slip outs where 200 feet of the roadway was gone, emergency hazard tree removal, plugged culverts from flash flooding and fire burn scars, and snow removal.
  - Similarly, rock slides in January and December 2016 caused the closure of State Route 299 at Big French Creek, which connects Humboldt, Trinity, and Shasta Counties (see Section 7 for a detailed discussion and presentation of the Big French Creek slide). Both weather and the dynamic nature of the slide have created multiple challenges for Caltrans District 2.

FIGURE 2: HIGHWAY 3 IN TRINITY COUNTY ROAD AND SLOPE FAILURE FROM INCREASED PRECIPITATION

FIGURE 3: PLUMAS STATE ROUTE 70 STORM DAMAGE IN AN AREA KNOWN AS THE “GAUNTLET”

FIGURE 4: STATE ROUTE 96 STORM DAMAGE IN SISKIYOU COUNTY

- **Wildfire** – Higher temperatures and extended periods of drought in California are expected to influence the risk of wildfire over time. Decreased precipitation creates drier conditions and can increase wildfire risk. Wildfires in District 2 could cause traffic, road blocks, or detours on the District 2 State Highway System. For example, on August 30, 2017 the Helena Fire broke out near Junction City in Trinity County and spread quickly. State Route 299 was closed over a good portion of the Labor Day weekend. Caltrans maintenance crews performed resultant guardrail and road repairs. This incident is also discussed in detail in Section 8.1.1.
- **Combined Effects** – There are also areas where the combined effects of these stressors may have an impact on the State Highway System. This includes:
    - **Landslides because of Wildfire and/or Precipitation** – Wildfires can burn areas that are then more susceptible to landslide events from precipitation. Specifically, wildfires can affect soils, making them less permeable (hydrophobic) and flash flooding can result since the land is limited in its ability to control rainwater flows. Land stripped of vegetation is also more susceptible to shallow landslides during precipitation events.

      Increased precipitation can also oversaturate a slope and its underlying soils, creating failure in the form of mudslides and landslides. These types of events occurred across the state, including District 2, during the 2016 to 2017 winter storm events.

      For example, a stretch of State Route 96 23 miles north of Somes Bar, along the Klamath River and ending at I-5 in Siskiyou County, was severely affected by the combined effects of wildfire and precipitation (see Figure 5 and Figure 6). More than 60 inches of rain fell in an area with fire burn scars in a relatively short period, resulting in flooding, rock/mud slides, and flash flooding.

This study examined the potential effects of these stressors on Caltrans District 2 by using the best available data at the state and regional level.

FIGURE 5: LANDSLIDE ALONG STATE ROUTE 96 NORTH OF SOMES BAR

FIGURE 6: EROSION ON SR 96 NORTH OF SOMES BAR

3. ASSESSMENT APPROACH

3.1. General Description of Approach and Review

The material presented in the District 2 Summary Report was reviewed by internal District 2 staff including representatives of Maintenance and Operations, System Planning, Project Management, Tribal Liaison, Traffic Safety, Regional Planning, Engineering, and others.

The development of this report also required extensive coordination with Caltrans District 2, and included:

- Coordination on previous work sponsored and completed by District 2 staff to identify available data, findings, and lessons learned.
- Working in partnership with District 2 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.
    - District 2 staff review of vulnerability assessment material.
    - Collection of District 2 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 2 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 2 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.[3]
- **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.[4]
- **Executive Order B-30-15** (2015) requires the consideration of climate change in all state investment decisions through: full life cycle cost accounting, the prioritization of adaptation actions that also mitigate greenhouse gases, the consideration of the state's most vulnerable populations, the prioritization of natural infrastructure solutions, and the use of flexible approaches where possible.[5]
- **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.[6]
- **Senate Bill 246** (2015) establishes the Integrated Climate Adaptation and Resiliency Program to coordinate with regional and local efforts with state adaptation strategies.[7]
- **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.[8]

These policies are among the factors State agencies consider when addressing climate change. Conducting an assessment such as this one for District 2 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.

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3 "Assembly Bill 32 Overview," https://www.arb.ca.gov/cc/ab32/ab32.htm, August 5, 2014
4 "Executive Order S-13-08," https://www.gov.ca.gov/news.php?id=11036, 2008
5 "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
6 "Assembly Bill No. 1482," https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201520160AB1482, October 8, 2015
7 "Senate Bill No.246," https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB246, 2015
8 "Assembly Bill No. 2800," http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160AB2800, September 24, 2016

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

Global Climate Models (GCMs)

GCMs have been developed worldwide by many academic or research institutions to represent the physical processes that interact to cause climate change, and to project future changes to GHG emission levels.[9] 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.[10] 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.

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

- 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.[11]

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."[12] 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.[13] 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.[14] 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

[11] 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
[12] "LOCA Downscaled Climate Projections," Cal-Adapt 2.0, http://cal-adapt.org/, 2018
[13] Pierce et al.,"Statistical Downscaling Using Localized Constructed Analogs," http://journals.ametsoc.org/doi/abs/10.1175/JHM-D-14-0082.1 , 2014
[14] Cal-Adapt 2.0, http://cal-adapt.org/, 2018 (and http://www.water.ca.gov/climatechange/docs/2015/Perspectives_Guidance_Climate_Change_Analysis.pdf)

Data from these models are available on Cal-Adapt 2.0, California's Climate Change Research Center.[15] The Cal-Adapt 2.0 data is some of the best available data in California on climate change and, for this reason, selections of data from Cal-Adapt and the GCMs above were utilized in this study.

3.3. Other District 2 Efforts to Address Climate Change

In addition to and concurrent with the statewide efforts, there are regional efforts underway within District 2 relating to climate change planning and preparedness.

Several counties within the District have adopted Climate Action Plans, largely designed to mitigate greenhouse gas emissions, reduce the impacts of climate change to local communities, and build resilience to climate change. Some examples include:

- **Shasta County** – The Shasta County Air Quality Management District initiated the Regional Climate Action Planning (RCAP) process, with the primary goals of contributing to the State's climate protection efforts and providing California Environmental Quality Act (CEQA) review. The Air Quality Management District works to streamline development projects that have direct benefits within the region's four jurisdictions: (1) the City of Anderson, (2) the City of Redding, (3) the City of Shasta Lake, and (4) the unincorporated areas of Shasta County. To facilitate these objectives, Shasta County worked with the four jurisdictions to prepare community-specific, independent Climate Action Plans that contain GHG emission inventories and forecasts, emission reduction measures, and implementation and monitoring programs. The Climate Action Plans[16] provide a summary of jurisdictional GHG inventories and describe how each jurisdiction would achieve GHG reductions through local actions that contribute to the statewide GHG emissions reduction target defined in AB 32, CEQA guidelines, and other State guidance. The RCAP document serves as a collection of the individual Climate Action Plans and demonstrates the region's commitment to the State's GHG reduction efforts. The plan also references the California Climate Change Adaptation Policy Guide and notes that GHG reductions should occur in tandem with adaptation planning.

- **Trinity County** - In 2011, the Model Forest Policy Program, the Cumberland River Compact, and The Watershed Research and Training Center created a Climate Adaptation Plan for Trinity County.[17] Development of the plan was based on the critical need for local community resilience against the impacts of climate change by protecting forest and water resources. This Climate Adaptation Plan for Trinity County leads the community toward climate resilience with an adaptation plan that addresses local climate risks and fits the local conditions and culture.

- **Siskiyou County** – Like the plan developed for Trinity County, the Model Forest Policy Program also prepared a Climate Adaptation Plan for the communities within Siskiyou County.[18] The

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

[16] Shasta Regional Climate Action Plan. November 2012 https://www.co.shasta.ca.us/index/drm_index/aq_index/programs/RCAP/Draft_RCAP.aspx

[17] Forest and Water Resources Climate Adaptation Plan: Trinity County, CA. http://www.mfpp.org/wp-content/uploads/2012/03/Trinity-County_CA_Forest-and-Water_Climate-Adaptation-Plan_2011.pdf , 2011

[18] Renew Siskiyou – A Roadmap to Resilience. http://mtshastaca.gov/wp/wp-content/uploads/2017/04/Siskiyou-Forest-Water-Climate-Adaptation-Plan-Final-2014_Fnl.pdf , 2014

overarching purpose of the plan is to build local community resilience against the impacts of climate change by protecting forest and water resources.

- **Lassen Volcanic National Park** – Lassen Volcanic National Park is a part of the National Park Service Climate Friendly Parks program, which provides parks with resources to address climate change impacts and promote sustainable practices. The Climate Friendly Parks program focuses on the following goals: park GHG emissions measurement, climate change education, and assisting parks in developing strategies to reduce emissions and anticipate future climate impacts.[19] Becoming a Climate Friendly Park requires the completion of a GHG inventory, a training to educate park staff and stakeholders on the impacts of climate change, and the completion of an Action Plan to outline the park's sustainability and climate change goals. Lassen Volcanic National Park has completed a Climate Action Plan focused on sustainability planning.

- **Active Transit in Redding** - A quarter of the district's population resides within the City of Redding. While automobiles are the predominant mode of travel in District 2, the district recognizes the importance of bicycle, pedestrian, and other active transit—both for public health and GHG mitigation. The Caltrans District 2 Cycling Guide provides key information related to bicycle use in the District 2 area and specifically for the City of Redding. Redding is home to the Sundial Bridge, a glass-decked, suspension pedestrian bridge reaching 217 feet into the sky and spanning 710 feet across the Sacramento River to form a working sundial. The bridge is a gathering place for locals and travelers, and provides an easily accessible entry point for Redding's extensive trail system.

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 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).

[19] Climate Friendly Parks Program. National Park Service. 2018. https://www.nps.gov/subjects/climatechange/cfpprogram.htm

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 7) that was supplied to Caltrans after the study was completed. Limited metadata on each dataset was also provided in the form of an Excel table that described each dataset and its characteristics (see Figure 8). This GIS data will be useful to Caltrans for future climate adaptation planning activities.

FIGURE 7: SCREENSHOT OF GIS DATABASE

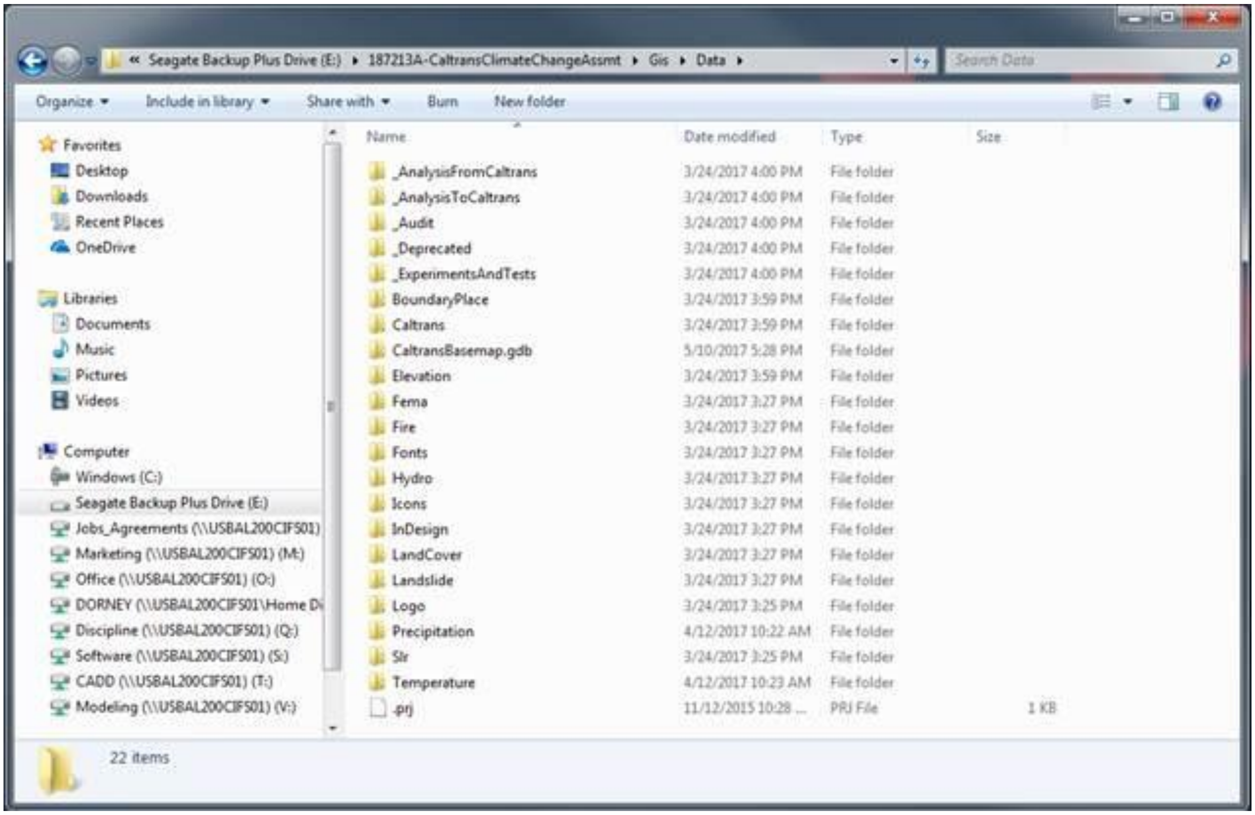
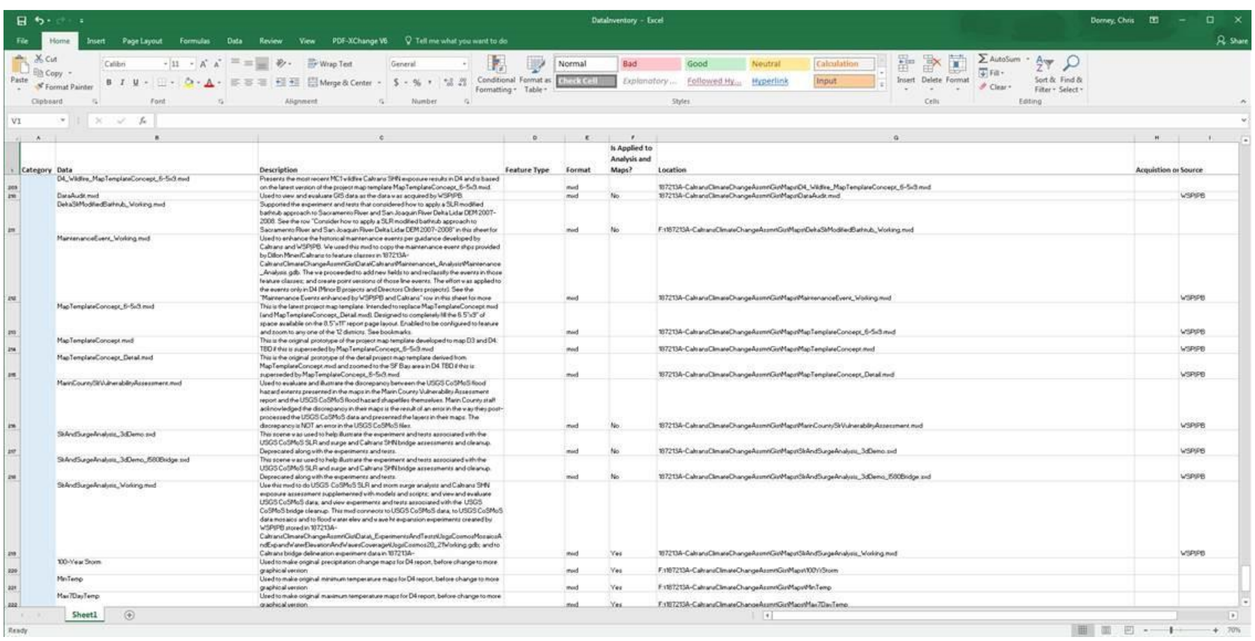


FIGURE 8: SCREENSHOT OF SPREADSHEET PROVIDED



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.[20] The potential effects of extreme temperatures on District 2 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.

4.1.1. 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.

4.1.2. 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

[20] 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,[21] which has a spatial resolution of 1/16 of a degree or approximately three and a half to four miles.[22] 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.

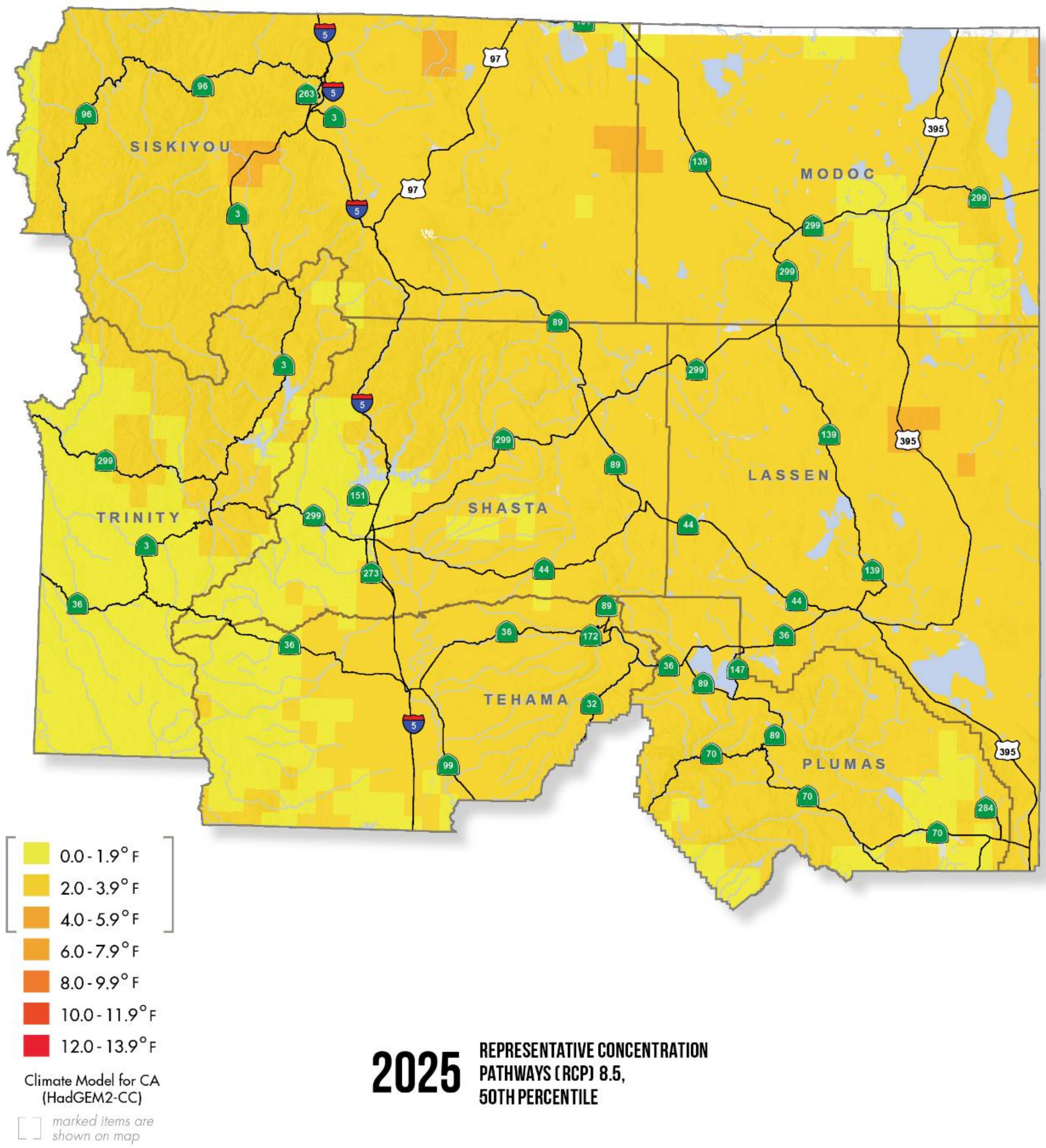
The maps shown are for the model that represents the median change across the state, among all California-approved climate models for RCP 8.5 (data for RCP 4.5 was analyzed, but for brevity is not shown here). The maps highlight the temperature change expected for both the maximum and minimum metrics. 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 provided in Figure 9 through Figure 14 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.

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

FIGURE 9: CHANGE IN THE ABSOLUTE MINIMUM AIR TEMPERATURE 2025

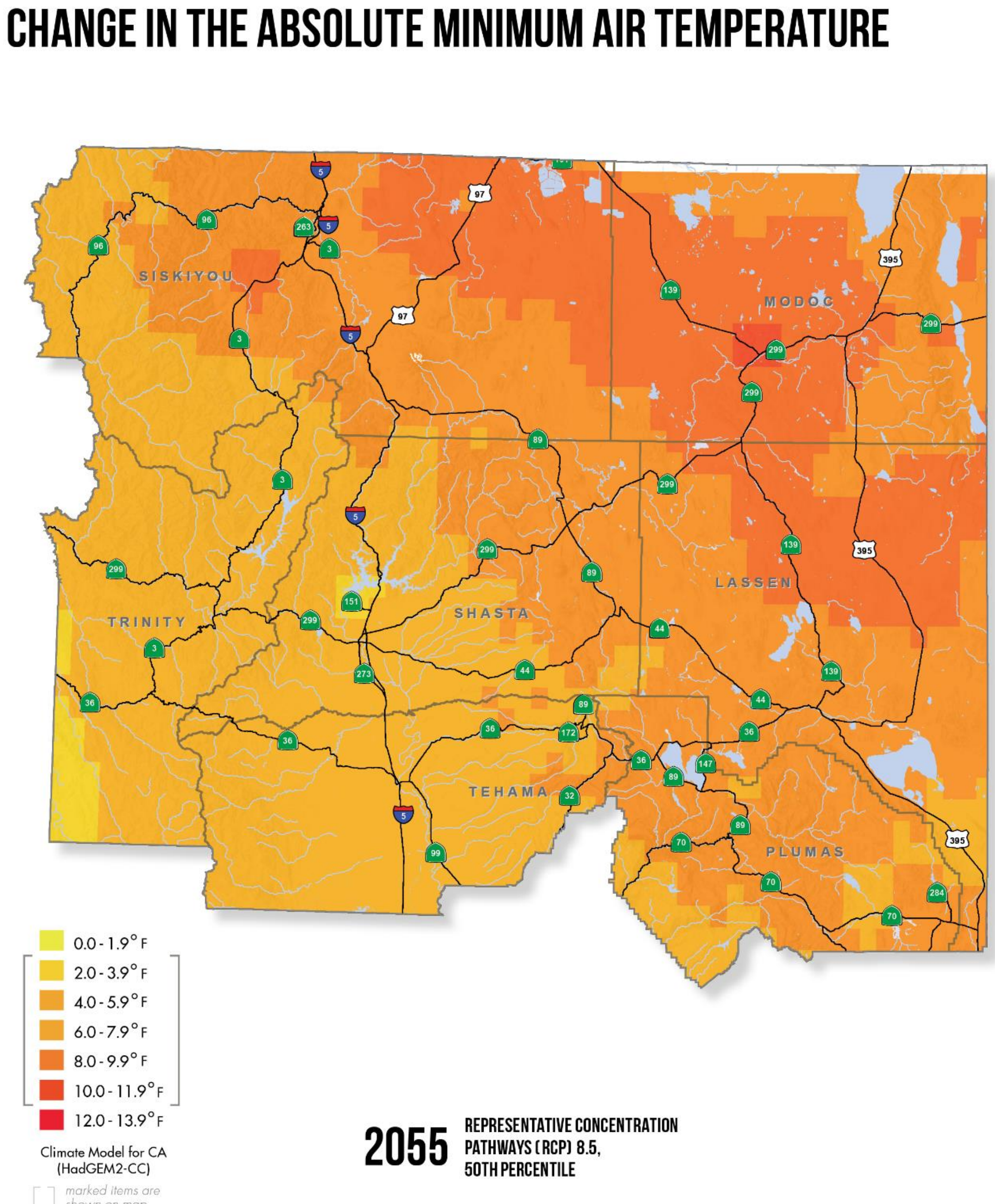
CHANGE IN THE ABSOLUTE MINIMUM AIR TEMPERATURE



Future Change in the Absolute Minimum Air Temperature within District 2, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 2. 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 ABSOLUTE MINIMUM AIR TEMPERATURE 2055

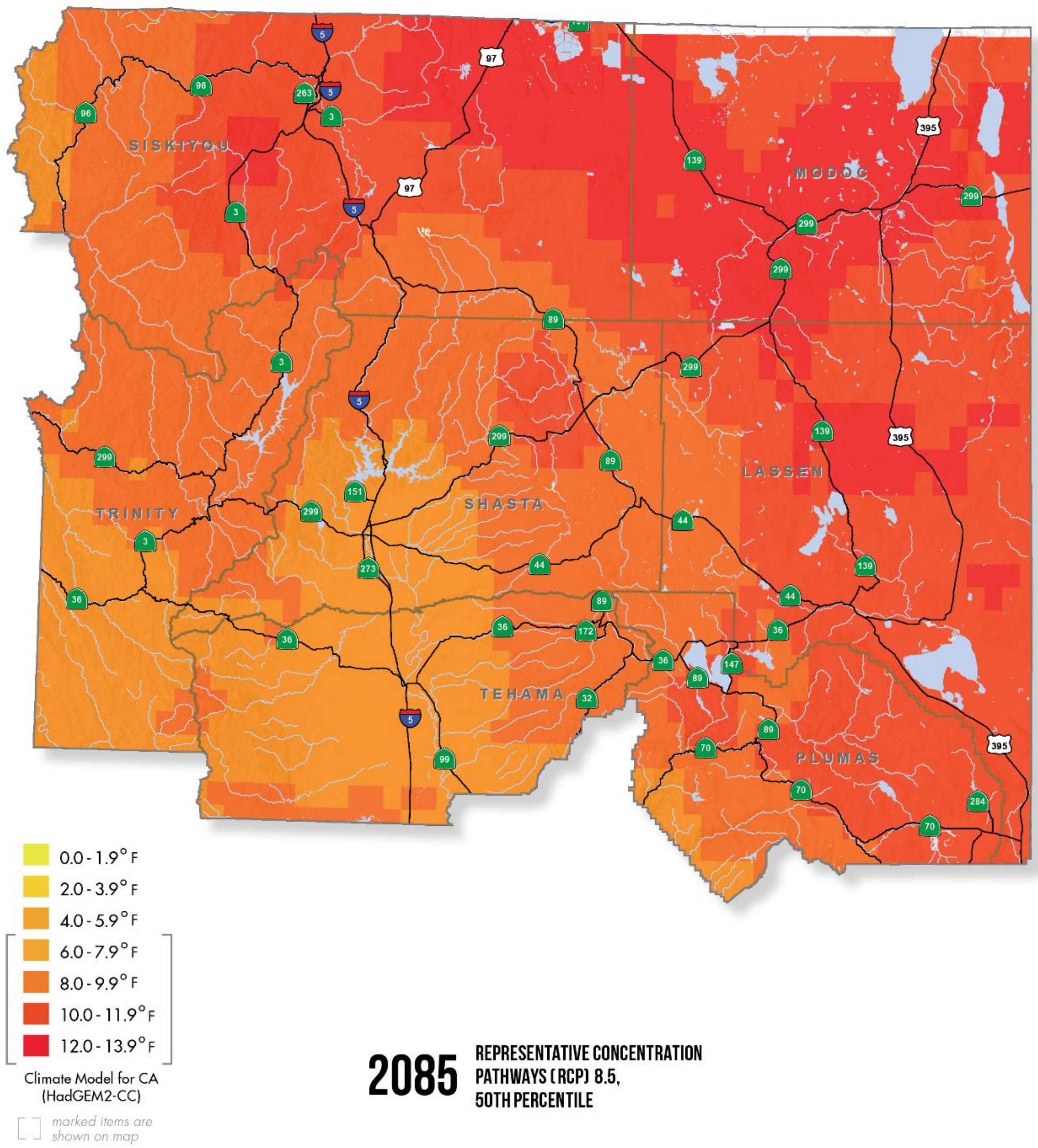


Future Change in the Absolute Minimum Air Temperature within District 2, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 2. 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 11: CHANGE IN THE ABSOLUTE MINIMUM AIR TEMPERATURE 2085

CHANGE IN THE ABSOLUTE MINIMUM AIR TEMPERATURE

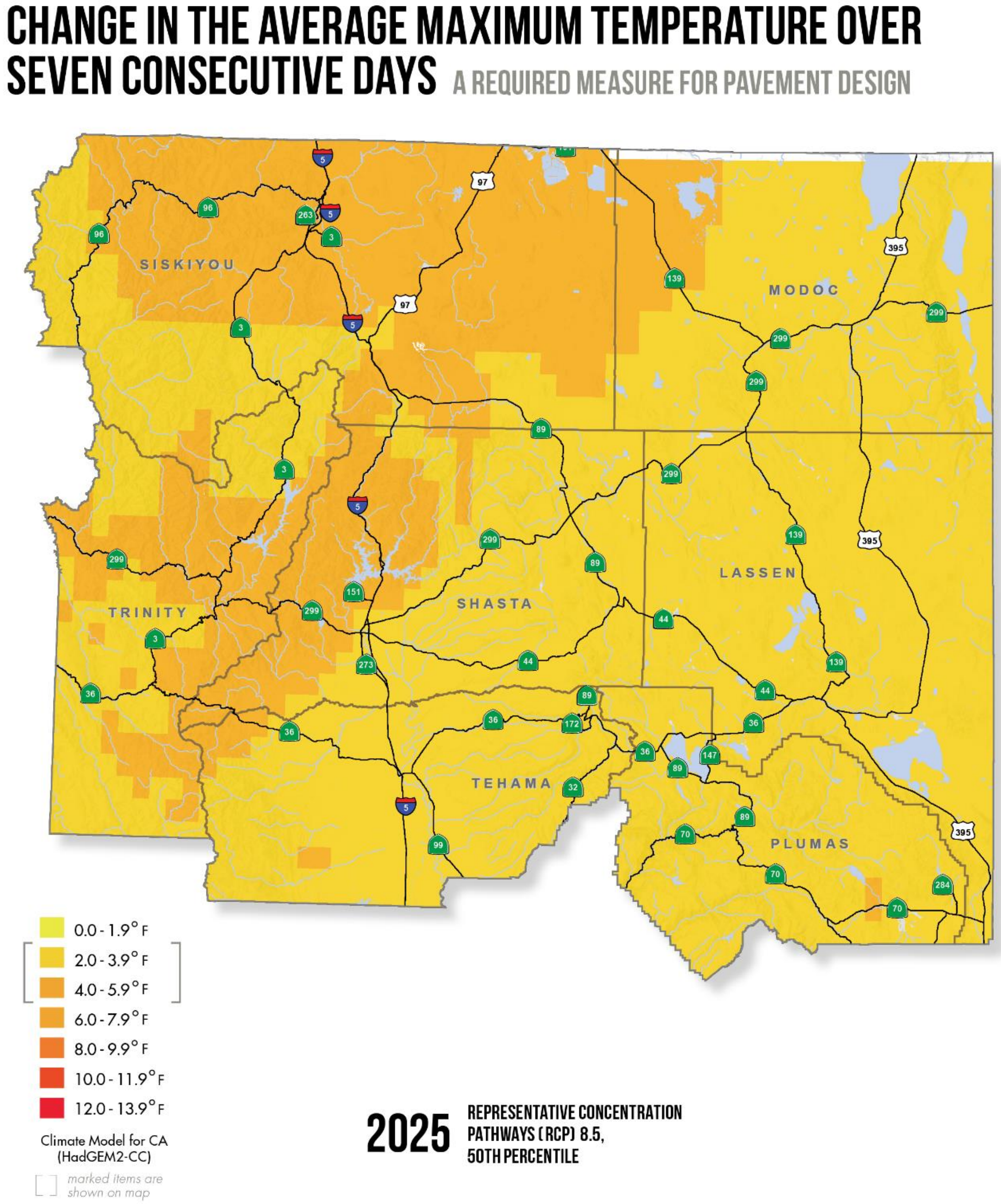


2085 REPRESENTATIVE CONCENTRATION PATHWAYS (RCP) 8.5, 50TH PERCENTILE

Future Change in the Absolute Minimum Air Temperature within District 2, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 2. 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: CHANGE IN THE AVERAGE MAXIMUM TEMPERATURE OVER SEVEN CONSECUTIVE DAYS 2025

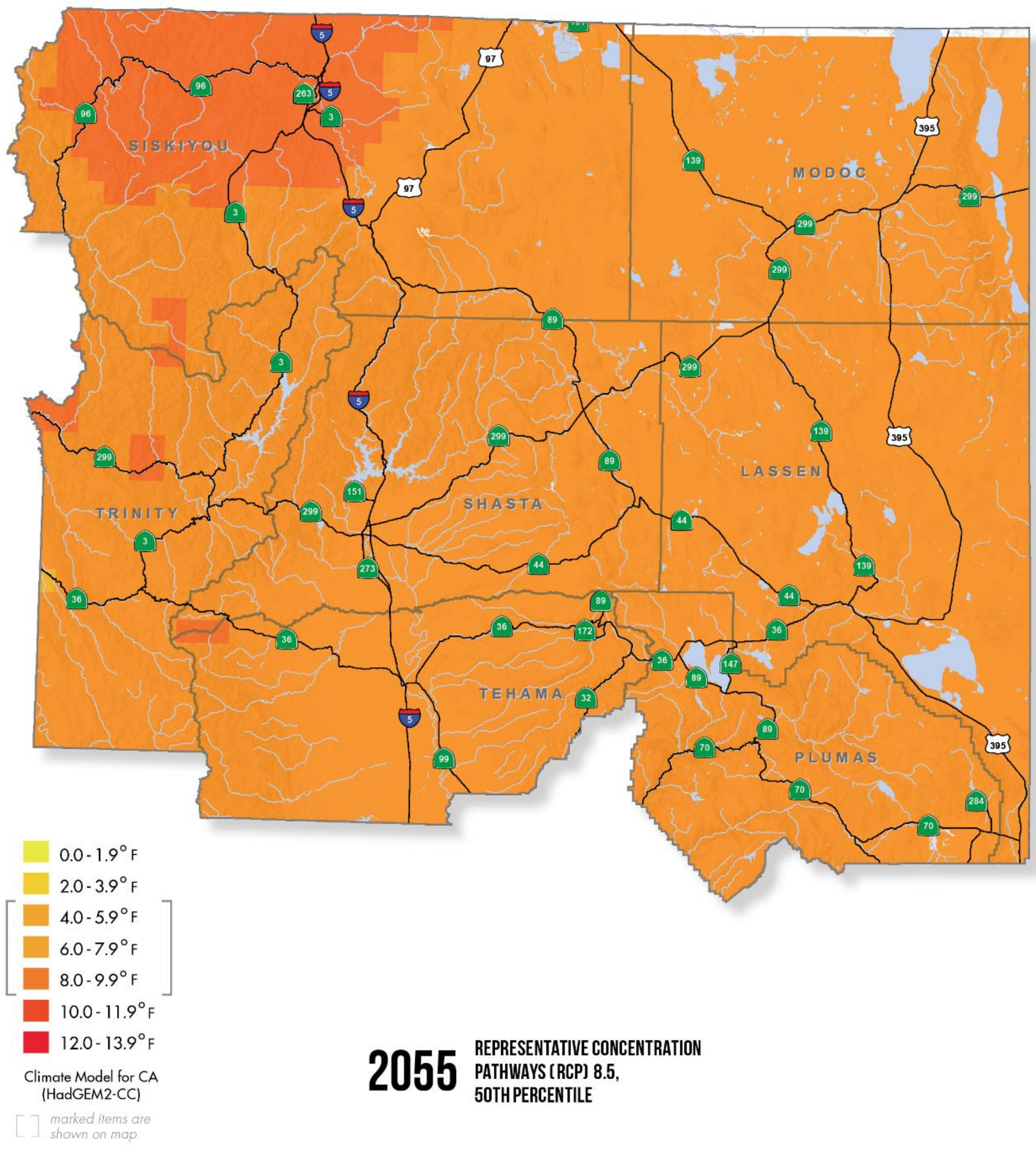


Future Change in the Average Maximum Temperature over Seven Consecutive Days within District 2, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 2. 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: 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

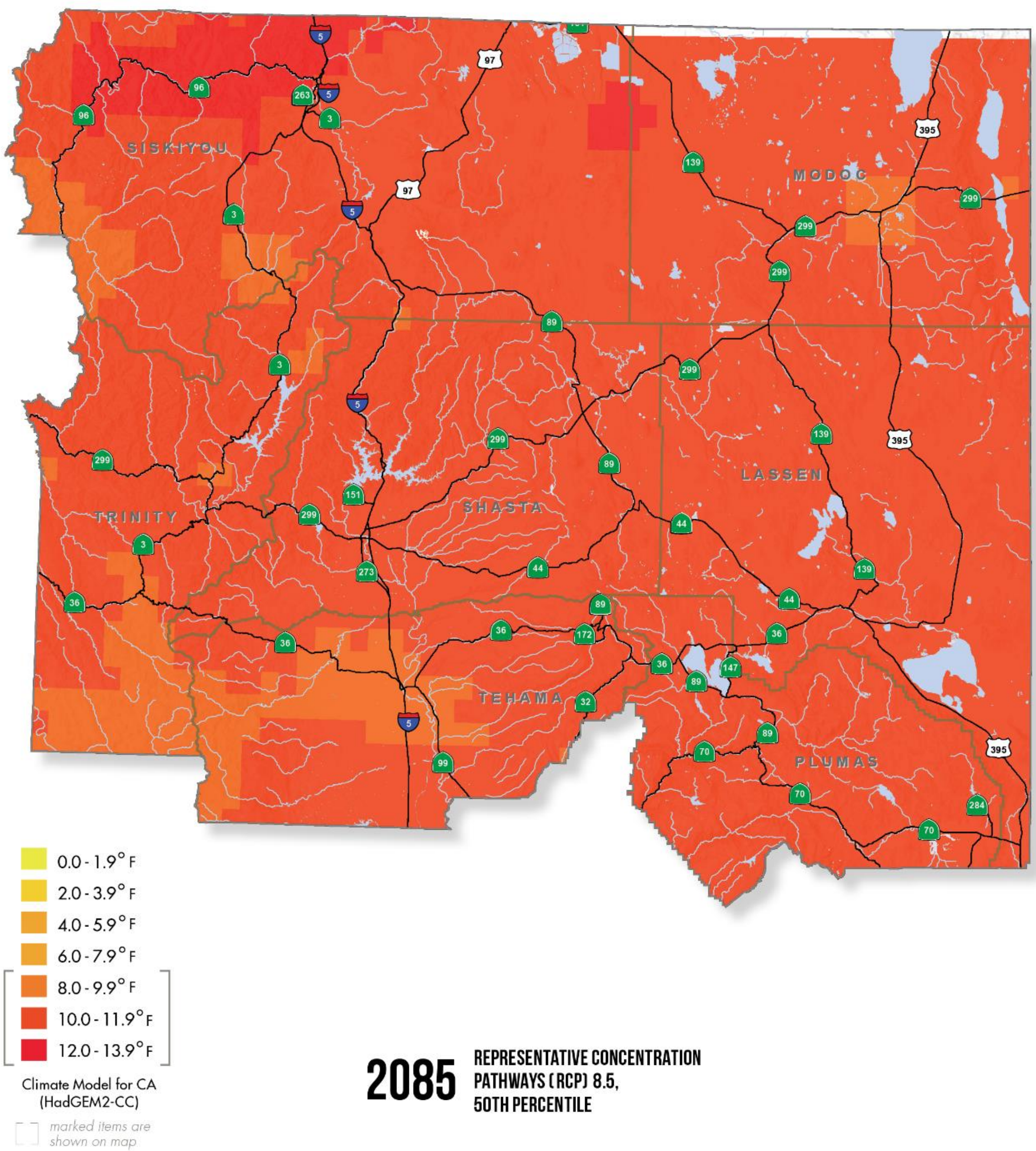


Future Change in the Average Maximum Temperature over Seven Consecutive Days within District 2, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 2. 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 14: CHANGE IN THE AVERAGE MAXIMUM TEMPERATURE OVER SEVEN CONSECUTIVE DAYS 2085

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



2085 REPRESENTATIVE CONCENTRATION PATHWAYS (RCP) 8.5, 50TH PERCENTILE

Future Change in the Average Maximum Temperature over Seven Consecutive Days within District 2, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 2. 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[23], but with the potential for heavier individual events, with more precipitation falling as rainfall. These conditions were experienced in District 2 during the 2016–2017 winter, where heavy precipitation caused $85 million in damages to District 2 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.[24] 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.[25] 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

[23] 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.
[24] http://www.dot.ca.gov/hq/oppd/hdm/hdmtoc.htm
[25] 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.

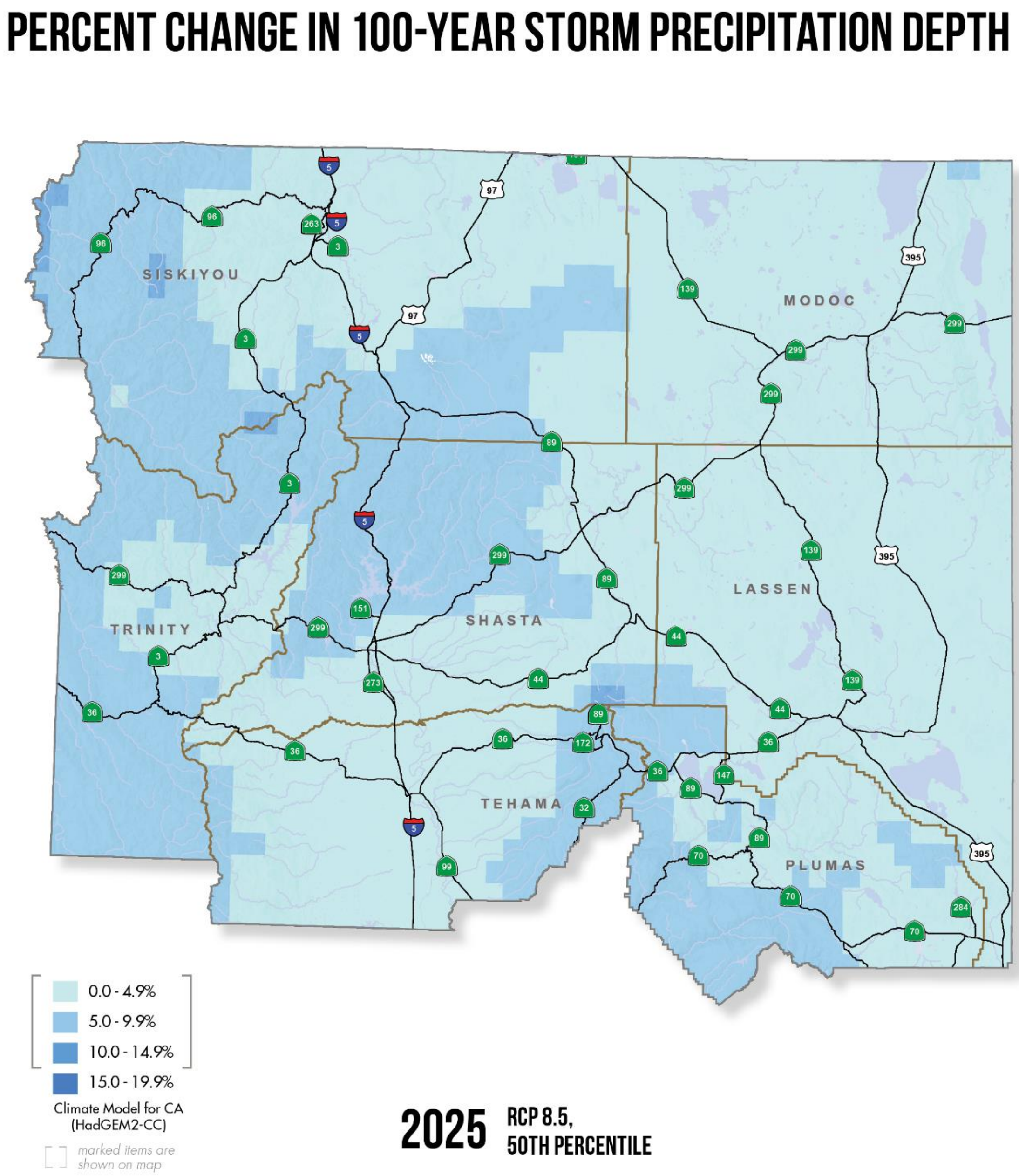
The project study team analyzed the models to understand two important points:

- 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 2 maps from Figure 15 to Figure 21. The three maps depict the percentage change in the 100-year storm rainfall event predicted for the three analysis periods, and for the RCP 8.5 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 2, 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.

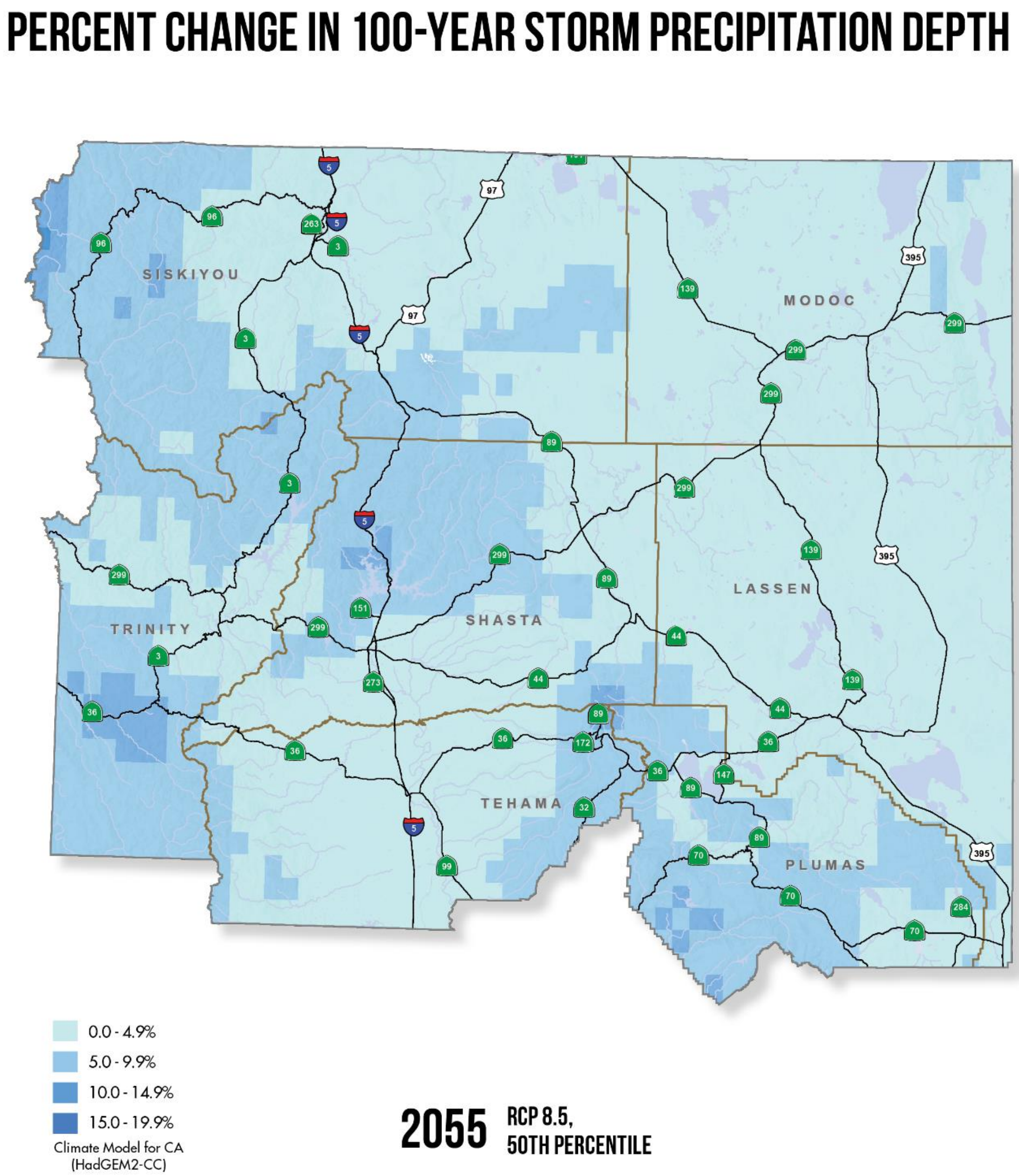
FIGURE 15: PERCENT CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH 2025



Future Percent Change in 100-year Storm Precipitation Depth within District 2, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 2. 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.

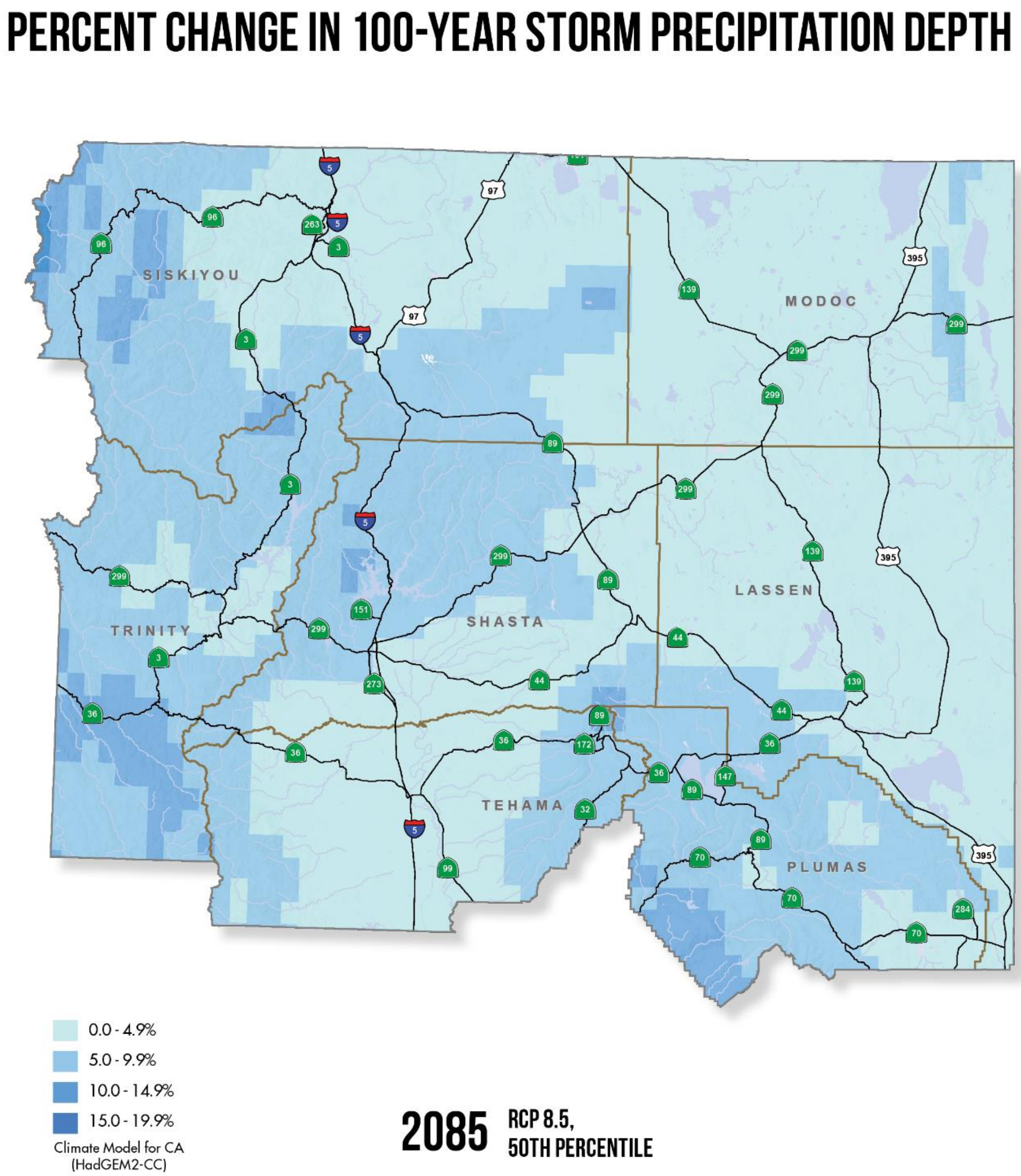
FIGURE 16: PERCENT CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH 2055



Future Percent Change in 100-year Storm Precipitation Depth within District 2, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 2. 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 17: PERCENT CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH 2085



Future Percent Change in 100-year Storm Precipitation Depth within District 2, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 2. 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 visibility and the 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 2 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 18 through Figure 20 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 2 State Highway System that are exposed to wildfire risk, by level of concern and District 2 county.

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

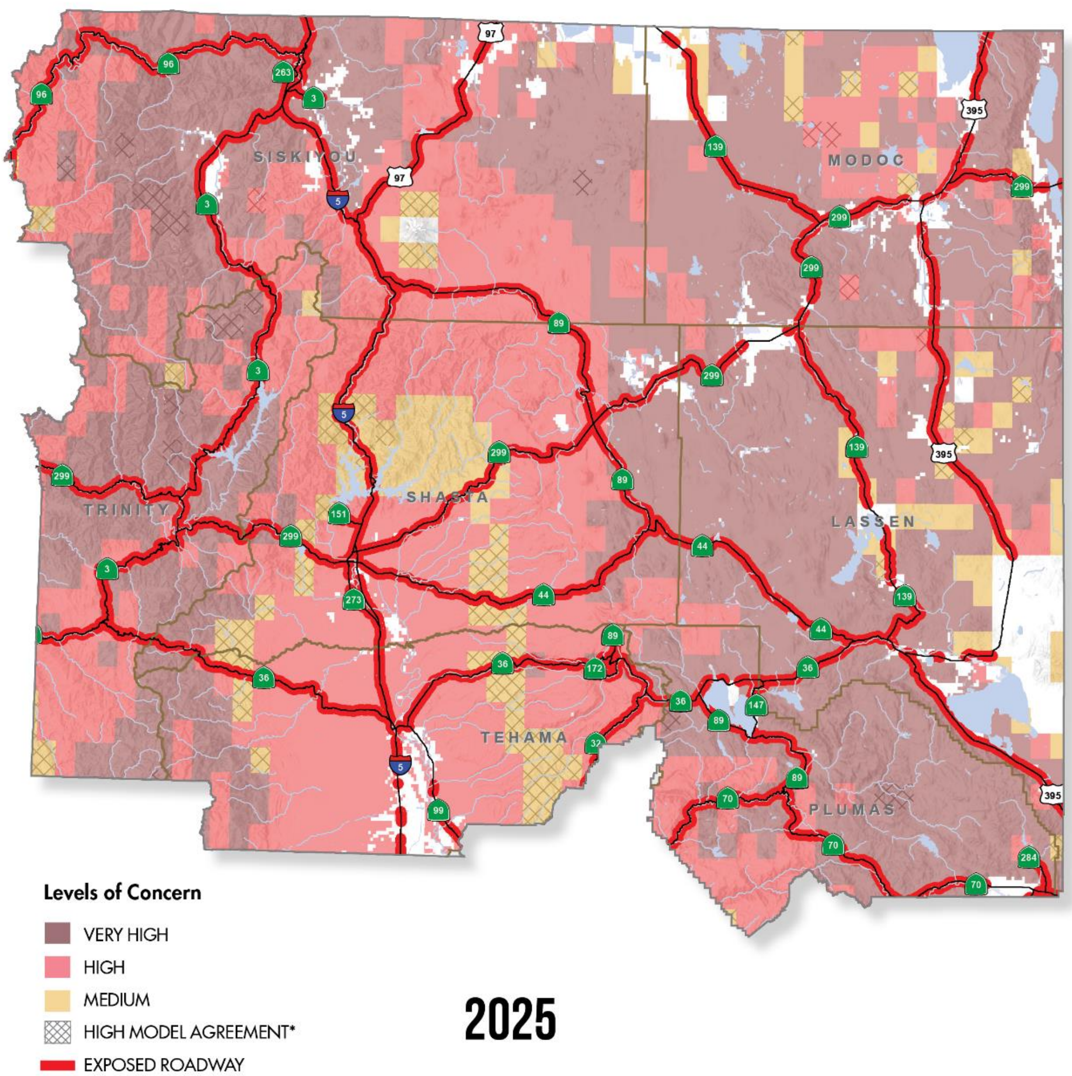
	Year		
District 2 Counties	**2025**	**2055**	**2085**
Lassen	246.0	257.6	261.9
Modoc	130.2	130.2	130.2
Plumas	157.9	160.9	167.0
Shasta	294.2	294.2	294.2
Siskiyou	332.1	332.1	332.1
Tehama	175.4	175.4	175.4
Trinity	200.0	200.0	200.0

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

	Year		
District 2 Counties	**2025**	**2055**	**2085**
Lassen	251.2	264.7	261.9
Modoc	130.2	131.7	130.2
Plumas	167.0	167.0	167.0
Shasta	293.3	294.2	294.2
Siskiyou	332.1	332.1	332.1
Tehama	175.4	175.4	175.4
Trinity	200.0	200.0	200.0

FIGURE 18: INCREASE IN WILDFIRE EXPOSURE 2025

LEVEL OF WILDFIRE CONCERN

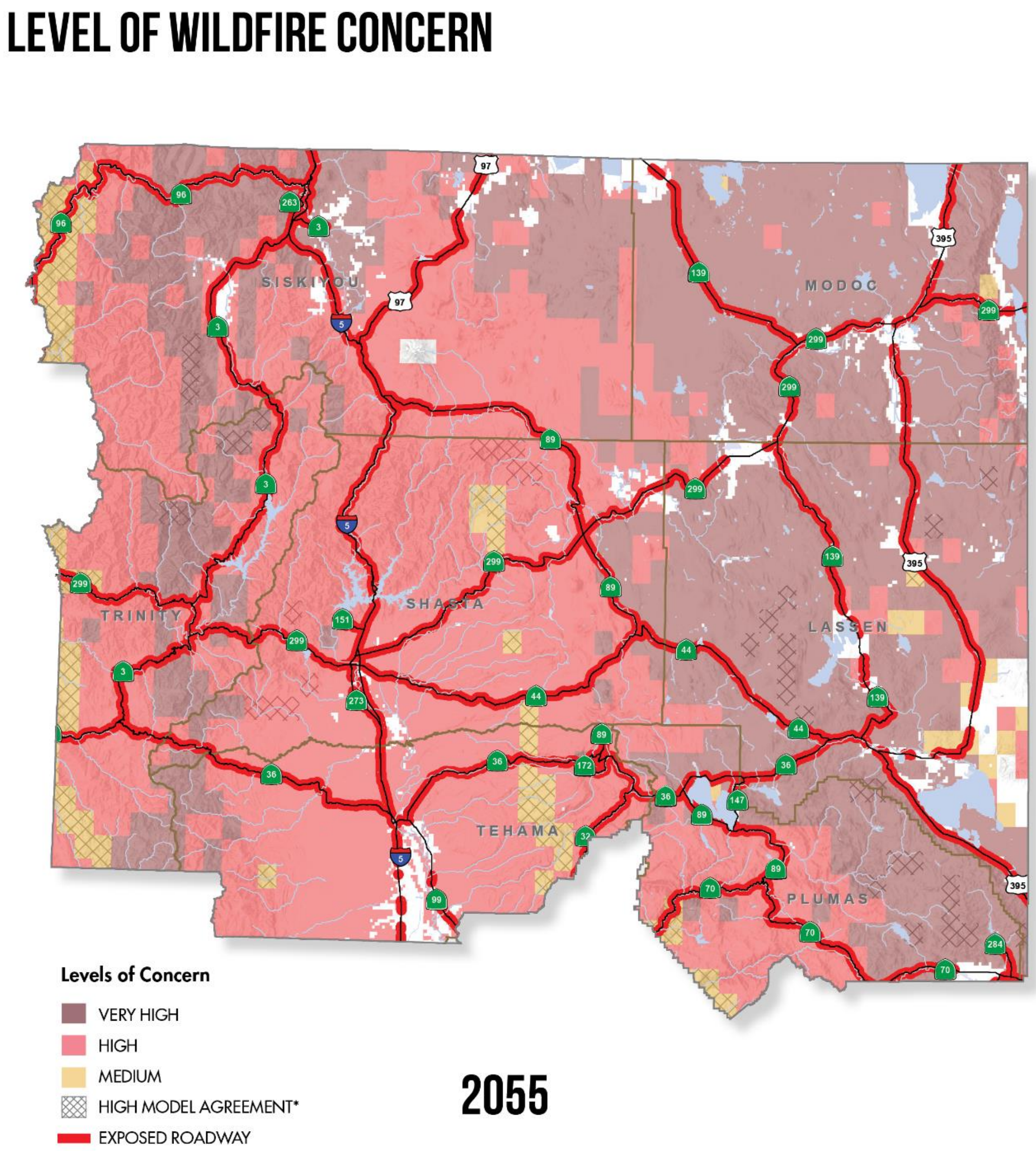


Future Level of Wildfire Concern for the Caltrans State Highway System within District 2, Based on the RCP 8.5 Emissions Scenario

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 19: INCREASE IN WILDFIRE EXPOSURE 2055

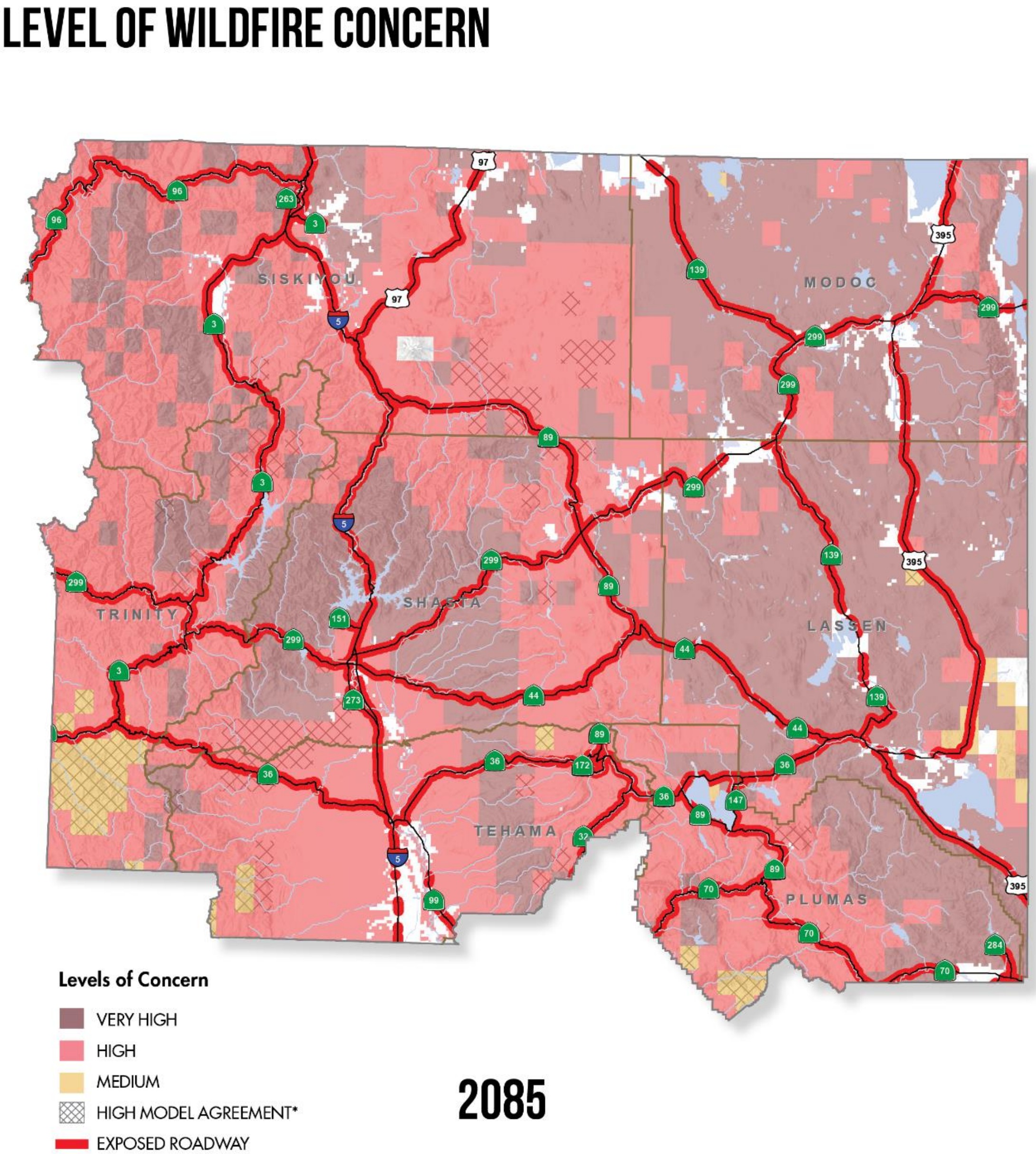


Future Level of Wildfire Concern for the Caltrans State Highway System within District 2, Based on the RCP 8.5 Emissions Scenario

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 20: INCREASE IN WILDFIRE EXPOSURE 2085



Future Level of Wildfire Concern for the Caltrans State Highway System within District 2, 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

An example Caltrans SHS location was selected to illustrate how extreme weather events have already damaged the SHS in District 2. Similar impacts may become more frequent in the future given changes in future climate. The location is State Route 299 PM 23.3 at the Big French Creek Slide in Trinity County, as shown on Figure 21. Inclement weather patterns forced continued road closures between 2016 - 2017. The weather and the dynamic nature of the landslide brought multiple challenges, and a need to adapt to changes quickly. Photographs of the slide area are provided in Figure 22. Key dates and events included:

- **January 16, 2016** – A series of rock slides occurred during heavy rains. An emergency project was initiated to clean debris from the roadway, monitor the slope, and provide traffic control through the end of the rainy season.
- **February 24, 2016** – After continued rock slides, a supplemental emergency project was approved to install cable anchored rock fall drapery over the slide area as weather permits.
- **July 11, 2016** – The necessary drilling data was gathered and analyzed. A "catchment" area at the bottom of the slope was excavated and a large wall was constructed between the catchment area and the highway to catch debris. A new emergency project was developed to design and construct this solution. Caltrans determined that the rock fall drapery would not be adequate and should no longer be pursued.
- **August 2016** – After obtaining necessary project clearances to excavate the catchment area and construct the debris wall, work began.
- **Early October 2016** – Early rains triggered additional rock slides.
- **December 9, 2016** – A large slide closed the highway during a heavy storm disrupting regular traffic and the lives of hundreds of residents, business owners, and truck drivers.
- **January 2017** – Caltrans received approval to construct a temporary detour near the Trinity River. Work commenced from the top to the bottom to remove approximately 200,000 cubic yards of material, providing a more stable slope (see Figure 23). Construction of the catchment area and debris wall was finalized. The highway then opened to normal traffic.

FIGURE 21: LOCATION OF BIG FRENCH CREEK SLIDE ON STATE ROUTE 299 IN TRINITY COUNTY

FIGURE 22: PHOTOGRAPH OF BIG FRENCH CREEK SLIDE

FIGURE 23: VIEW OF WORK ON THE SLIDE

A follow-up project is likely necessary to construct drainage settling basins, provide maintenance access, and perform other work to finalize the slide repair. The following discusses how evaluated factors affect this important stretch of highway.

Changes in Wildfire

The roadway is in the immediate vicinity of an area affected by wildfires. For example, a serious fire started on August 30, 2017 near the town of Helena, west of Weaverville, along Highway 299 and Junction City. Almost 22,000 acres were burned, resulting in unstable slopes and resultant slope failure. A timeline and discussion of this event is provided in Section 8.1.1. Wildfire is a concern for driver safety as well as Caltrans operations and infrastructure. Indirectly, wildfires can contribute to de-stabilization of slopes, resultant landslide and flooding exposure, and reduced driver visibility.

Changes in Extreme Rainfall[26]

This highway corridor is expected to experience higher percentage precipitation depths during extreme rainfall events. By the end of the century, precipitation could increase over the watershed by up to 10 to

[26] Note that detailed engineering analyses are required to determine whether the projected precipitation changes would be enough to cause these impacts.

14.9 percent under the RCP 8.5 scenario. This could lead to increased slope failure and flooding along the adjacent Trinity River that could exacerbate existing issues along State Route 299. Figure 24 shows the face of the Big French Creek Slide after heavy rains, illustrating how the protective slope cover has been compromised.

Changes in Temperature

Warmer temperatures may necessitate the changing of asphalt binder-grade specifications for this stretch of State Route 299. By the end of the century, mean absolute minimum temperatures may increase by upwards of 9°F while average maximum seven consecutive day temperatures may increase by upwards of 12°F under RCP 8.5.

FIGURE 24: FACE OF THE BIG FRENCH CREEK SLIDE COMPROMISED AFTER HEAVY RAINS

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),[27] 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 25: FHWA's Adaptation Decision-Making Process.

The first five steps of the ADAP process cover the characteristics of the project and the context. The District 2 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:

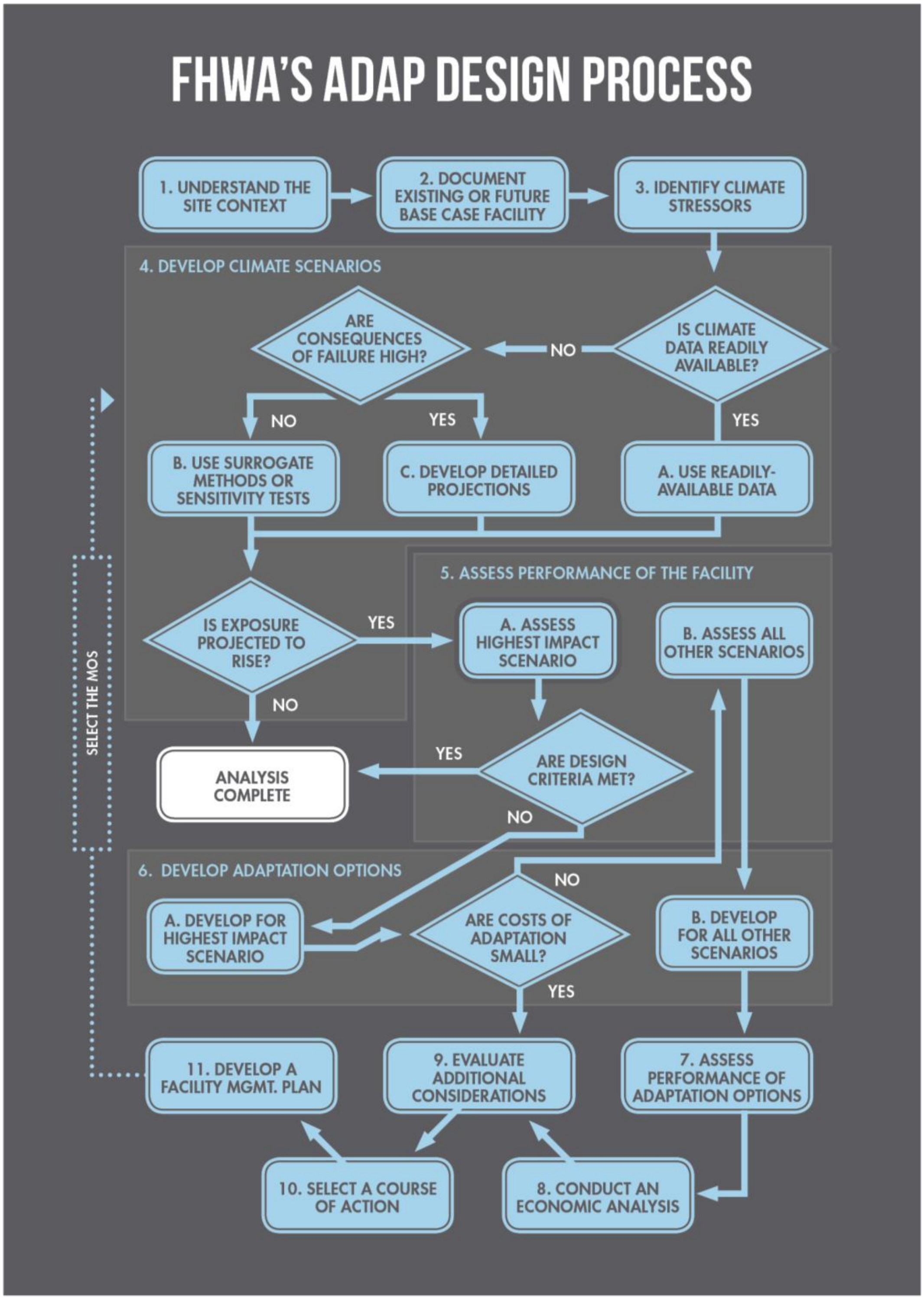
- full life cycle cost accounting

[27] 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 25: 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. Helena Fire along State Route 299 and Hydroseeding

The Helena wildfire from August – September 2017 burned vegetation along the slope adjacent to State Route 299 in Trinity County, resulting in potential slope instability near PM 45.0. Caltrans used hydroseeding via helicopter to reseed the impacted slope. This location and project provides an example of a Caltrans response to climate/weather related impacts in District 2.

As previously described, wildfire is an immediate concern for driver safety, system operations, and infrastructure. Indirectly, wildfires contribute to slope instability by burning off soil-stabilizing land cover/vegetation and reducing the capacity of the soils to absorb rainfall. Thus, after a wildfire, a burned slope is extremely vulnerable to slides during and after precipitation events. In this situation, Caltrans proactively used hydroseeding to begin immediate slope stabilization in anticipation of future precipitation events. While not an example of risk-based design, this is an example of how district staff can mitigate risk following a wildfire event as these events may become more frequent in the future.

Below is a timeline of events of the fire and Caltrans risk-based response actions:

- **August 30, 2017** - The Helena Fire started on August 30 at 5:10 p.m. near the town of Helena, west of Weaverville, along Highway 299 and Junction City. Almost 22,000 acres were burned. Over an estimated 70 homes and 60 outbuildings were confirmed destroyed, primarily in the area between Junction City and Helena. State Route 299 was closed within twenty minutes of the fire starting. Due to the early intensity, Caltrans maintenance crews were unable to get to the western edge of the fire on SR 299 until the following day.

- **August 30 - September 3, 2017** - State Route 299 was completely closed, encompassing a good portion of Labor Day weekend. After careful inspection and collaboration with fire, law enforcement, and other agencies, Caltrans maintenance crews began conducting single-time openings of the highway. Highway openings were scheduled every three to four hours, to allow some traffic through the area while leaving adequate time for crews to continue to work.

- **September 7, 2017** - The Helena Fire was 30 percent contained. The following roads remained closed: Canyon Creek Road, Upper Road, Lower Road, Valdor Road, and Powerhouse Road.

- **September 11, 2017** - The area opened to continuous traffic control, with construction crews working on an emergency contract in the area for guardrail and road repairs.

- **September 20, 2017** - The Helena Fire continued to burn near Junction City and Weaverville, CA. The Fork Fire was located north of Monument Peak and southwest of East Fork Lakes in the Trinity Alps Wilderness Helena Fire – Size: 18,392 acres.

  Crews took advantage of cool conditions to work on suppression on the edge of the fire east of the residences on Canyon Creek Road and continued to improve the line from the Hayfork Divide to Eagle Creek. Caltrans was hopeful that with the fair weather they would have the suppression line completed in the next several days. Rain-slicked roads and terrain can be hazardous, and carefully evaluated conditions before engaging.

- **September 29, 2017** - Firefighters made strides on containing the destructive Helena and Fork fires to 85% and Caltrans workers warned drivers to be aware of upcoming road closures. To complete emergency road repairs and damage caused by the flames, Caltrans District 2 closed

State Route 299 between Junction City and Helena in order to move large hazardous trees and rocks.

- **September 25 - October 7, 2017** - Rock scaling and hazardous tree removal required single-time openings in the area during the day, with traffic control overnight.

- **November 6, 2017** - Caltrans utilized hydroseeding by helicopter as part of erosion control management.

Photographs of the Helena fire and resultant hillside impacts are shown on Figure 26. Images of the hydroseeding work and new replacement Caltrans infrastructure following the fire are shown on Figure 27.

FIGURE 26: IMAGES OF THE HELENA WILDFIRE AND CALTRANS RESPONSE

FIGURE 27: IMAGES OF HYDRO SEEDING AND NEW INFRASTRUCTURE AFTER THE HELENA FIRE

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?

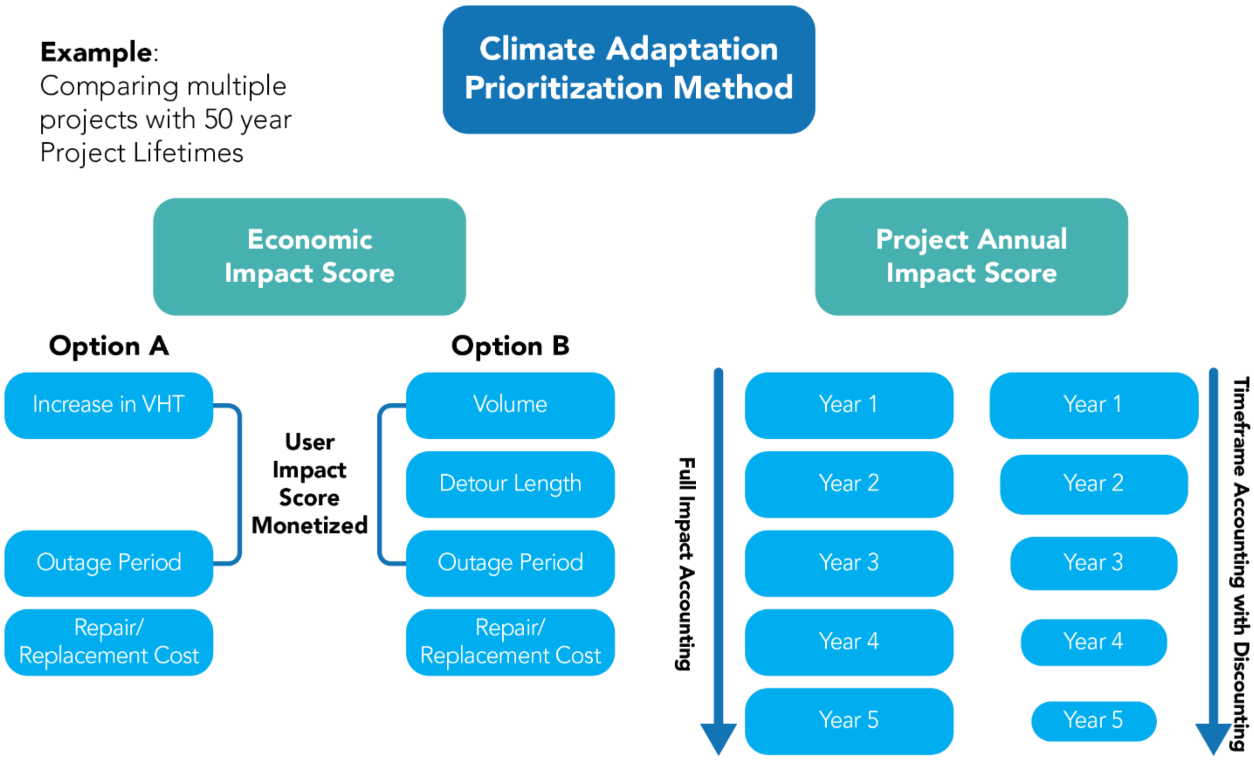
- System impacts (supplied by Caltrans planning staff) – the impacts of the loss of the facility on the broader system. This could be in terms of increase in Vehicle Hours Traveled (VHT) if using a traffic model, or an estimated value using volume and detour length as surrogates.
- Probability of occurrence (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 287 shows the general approach for the prioritization method.

FIGURE 28: 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 2. 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 2. The study distilled the larger context of climate change down to a more localized understanding of what such change might mean to District 2 functions and operations, District 2 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 2 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 2 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 2 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 2 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 2.

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 2. 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 2 (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.