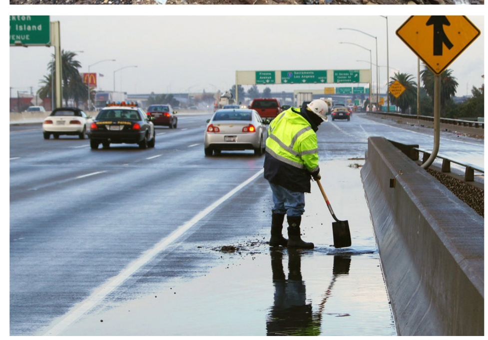
CALTRANS CLIMATE CHANGE VULNERABILITY ASSESSMENTS

2019



District 10

Technical Report

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ACRONYMS AND ABBREVIATIONS

ADAP	Adaptation Decision-Making Assessment Process
CalFire	California Department of Forestry and Fire Protection
Caltrans	California Department of Transportation
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
FHWA	Federal Highway Administration
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
USDAFS	US Department of Agriculture Forest Service
VHT	Vehicle Hours Traveled

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1. INTRODUCTION

This report, developed for the California Department of Transportation (Caltrans), summarizes a vulnerability assessment conducted for the portion of the State Highway System (SHS) located in Caltrans District 10. Although the SHS can be vulnerable to many different types of disruptions, this assessment specifically examined SHS vulnerabilities from long-term changes in climate.

Climate change and extreme weather events have received increasing attention worldwide as one of the greatest challenges facing modern society. Many state agencies—such as the California Coastal Commission (CCC), the California Energy Commission (CEC), and the California Department of Water Resources (DWR)—have developed approaches for understanding and assessing the potential impacts of a changing climate on California's natural resources and built environment. State agencies are invested in defining the implications of climate change and many of California's academic institutions are engaged in developing resources for decision makers.

Caltrans initiated the current study to better understand the vulnerability of California's SHS and other Caltrans assets to future changes in climate. The vulnerability study had three objectives:

- Understand the types of weather-related events and longer-term climate change that will likely occur with greater frequency and intensity in future years.
- Conduct a vulnerability assessment of Caltrans assets likely vulnerable to various climate-influenced natural hazards.
- Develop a method to prioritize candidate projects that recognizes climate change concerns and limited financial resources.

The Caltrans study focuses on all 12 Caltrans districts, each facing its own set of challenges regarding future climate conditions and potential weather-related disruptions. The District 10 report is one of the district reports that are currently in various stages of development.

1.1. Purpose of Report

The *District 10 Technical Report* is one of two documents that describe the work completed for the District 10 vulnerability assessment, the other being the *District 10 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 the effects of climate change might affect the SHS in District 10.

This *Technical Report* provides a more in-depth discussion, primarily for District 10 staff. It provides background on the methodology used to develop material for both reports and general information on how to replicate these methods, if desired. The report is divided into sections by climate stressor (e.g., wildfire, temperature, and precipitation). Each section discusses:

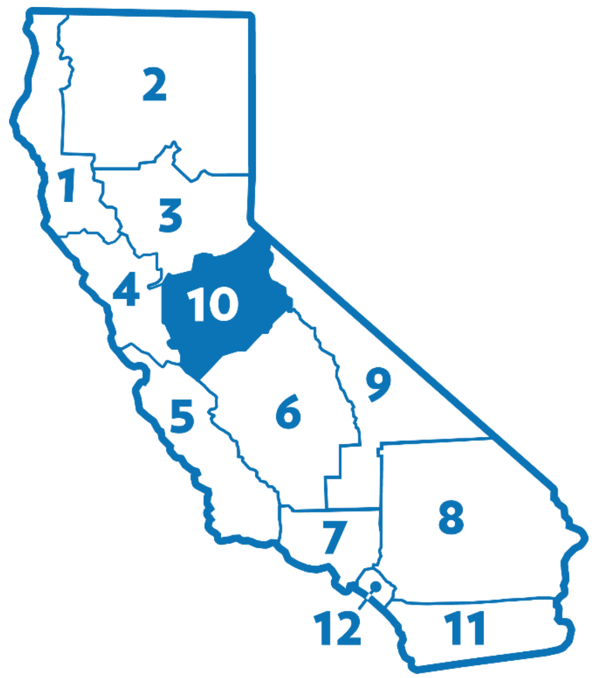
- How that climate stressor is changing
- The data used to assess SHS vulnerabilities associated with that stressor
- The approach in identifying and where necessary developing the data

- Maps of the portion of district SHS exposed to that stressor
- Mileage of exposed SHS.

Finally, this *Technical Report* outlines a recommended framework for prioritizing a list of project candidates for more detailed assessments that might be considered by Caltrans in the future. This framework was developed by examining decision support frameworks used by other transportation agencies and those formulated from research and climate adaptation pilot applications.

The data used in the District 10 *Technical* and *Summary Reports* were placed in a single database and provided to Caltrans. Caltrans will be able to use this data in its own mapping efforts and technical analyses. This database is expected to be a valuable resource for ongoing resiliency planning efforts. The contents of the District 10 database will also be available to the public in an on-line, interactive mapping tool. The tool currently holds the data for Districts 2, 4 and 6; data for District 10 and other districts will be added as it becomes available.[1]

1.2. District 10 Characteristics



District 10 encompasses eight counties---Alpine, Amador, Calaveras, Mariposa, Merced, San Joaquin, Stanislaus and Tuolumne Counties. The district is very diverse with three urban counties (San Joaquin, Stanislaus, and Merced) in the San Joaquin Valley and five rural counties (Amador, Calaveras, Tuolumne, Mariposa, and Alpine) in the Central Sierra Nevada. The cities of Stockton, Modesto and Merced are the three largest cities having a combined population of approximately 603,000. Because the district borders the East Bay, many parts of the district face increasing levels of congestion on the SHS due to heavy commuter traffic. For example, the District System Management Plan notes that 25% of all workers in District 10 work outside of the county where they reside and 15% of all workers that live in District 10 work outside of the district. Travel times for these commuters average about one hour.[2]

Over 90% of District 10's population resides in the three urban counties, resulting in very distinctive travel patterns throughout the district. The volume of interregional commuting is expected to grow to 120,000 commuters by 2022, with most of this occurring in the urban counties. The five mountain counties are also growing, primarily in the foothill communities of the Central Sierra mountains. The district's proximity to Yosemite National Park, which is one of the most popular national parks in the nation, also results in large recreational volumes on the SHS.

[1] Caltrans. "Caltrans Climate Change Vulnerability Assessment Map." 2017. Last accessed July 10, 2019, http://caltrans.maps.arcgis.com/apps/webappviewer/index.html?id=517eecf1b5a542e5b0e25f337f87f5bb

[2] California District 10. District 10 Highway System Management Plan. June 15, 2015. Last accessed June 30, 2019, http://www.dot.ca.gov/dist10/docs/Final_2015_DSMP.pdf

The economy of District 10 is very diverse. The district includes agricultural land that places it in the top 10 highest-earning agricultural regions in the country, which has resulted in high freight usage on the SHS. The urban counties in the district have typical suburban economies, with emphasis on retail, service, and office employment. Given the proximity to popular recreational travel destinations, the economies of several of the district's eastern counties heavily depend on tourism.

The average household income and governmental budgets within District 10 are below what is found elsewhere in California. The mountain counties have a higher-than-average percentage of middle-class household incomes; the San Joaquin Valley communities have numbers of both extremely poor and poor households that exceed the state average. As noted in the District 10 System Management Plan, this has resulted in less local governmental spending on transportation improvements and a much greater reliance on funds from the State Transportation Improvement Program (STIP) and the State Highway Operation and Protection Program (SHOPP) for roadway improvements.

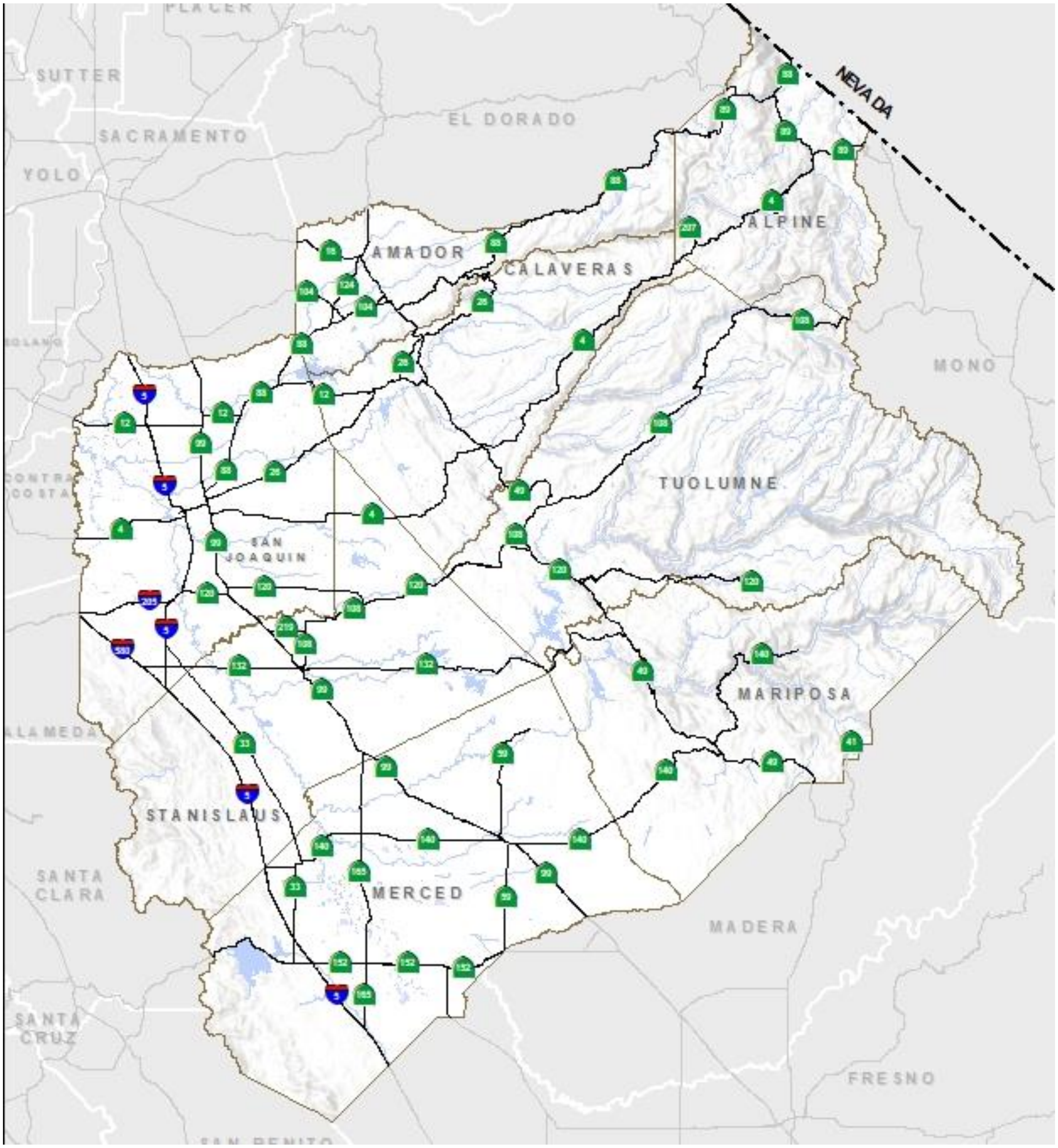
The district includes 3,547 state highway lane-miles, 854 bridge structures, 715 acres of landscape areas, 11,000 culverts, 3 rest areas, and 24 maintenance stations. The SHS includes four Sierra Nevada passes. The entire road network serves 29 cities, the Port of Stockton, and numerous recreational sites (see Figure 1). There are 19 airports and numerous transit rail authorities in the district as well.

The freeway corridors that connect to the Bay Area experience the largest share of traffic volumes. The western interstate and State Route (SR) 99 corridors, for example, carry the largest interregional commuting travel in the district (most of the district's urban areas cluster along Interstate 5 (I-5) and SR 99). To serve this travel market the district has incorporated managed lanes and ramp metering projects into the capital investment program. Several of the state routes within the district are included in the Interregional Road System (IRRS), facilities aimed at providing interconnections at either expressway or freeway standards. I-5, I-580, SR 99, and SR 152 are included in the IRRS plan as strategic interregional corridors, meaning they are high priority routes for goods movement and that they link rural and urban areas.

Freight movement is an important characteristic of the district's transportation system. The Union Pacific (UP) and Burlington Northern & Santa Fe (BNSF) Railroads have intermodal yards in Stockton and Lathrop. The Port of Stockton has both truck and rail access. A distinctive characteristic of District 10's SHS is the large truck volumes found on the network. This is due to (1) interstate and international movement of goods moving through the district, (2) truck movements supporting local commerce that continue to increase given the proximity to the Bay Area, and (3) the movement of trucks involved with transporting farm goods to market. Given the heavy agricultural focus of District 10 counties, it is not surprising that the number of trucks using the SHS is one of the highest in the state. For example, I-5 in San Joaquin County experiences a 20 percent or greater truck share, with 80 percent of that number having five axles or greater. Both I-5 and SR 99 provide access to major rail and marine intermodal terminals where agricultural products are transferred to other modes for long-distance transport.

In the eastern, more tourism-oriented portions of the district, the SHS tends to consist of two-lane roads with expressways connecting to the more urban western part of the district. Because of the recreational nature of the travel, these roads experience distinctive, directional peak demands (e.g., Friday afternoons and Monday mornings).

FIGURE 1: DISTRICT 10 STATE HIGHWAY SYSTEM

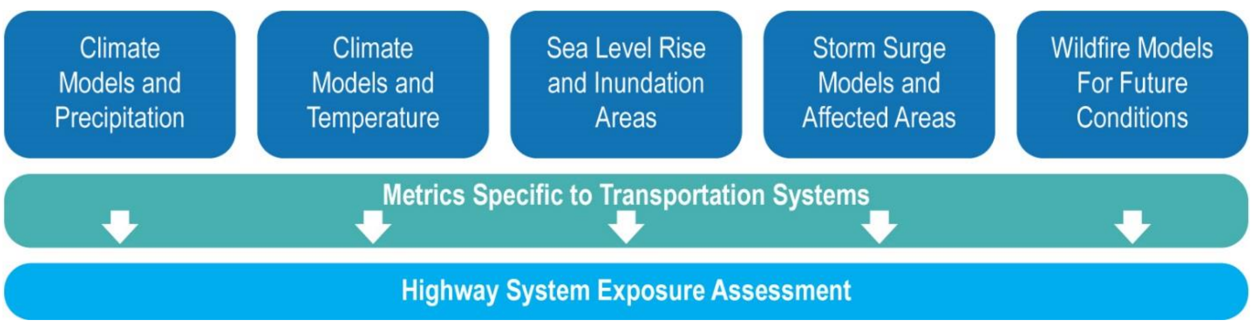


2. POTENTIAL EFFECTS OF CLIMATE CHANGE ON THE STATE HIGHWAY SYSTEM IN DISTRICT 10

Climate and extreme weather conditions in District 10 are changing as global greenhouse gas (GHG) emissions lead to higher temperatures and changes in precipitation patterns. These changing conditions are expected to affect the SHS in District 10 as well as other Caltrans assets throughout the state. These impacts might appear in a variety of ways, but most likely each will increase District 10 infrastructure's exposure to environmental stresses that exceed their original design factors. A range of climate stressors were considered in this study as well as how they align with Caltrans design criteria and other metrics specific to transportation systems.

Figure 2 illustrates the general process for deciding which metrics to include in the Caltrans statewide SHS vulnerability assessment (note: this approach was used for all districts and thus sea level rise and storm surge[3] are included in the figure even though such threats are not present in some districts). Caltrans and climate change specialists on the consultant team first considered which climate stressors affect transportation systems. Then, a relevant metric relating to the climate stressor's impact on transportation assets was identified. For example, precipitation data was formatted to show the 100-year storm depth given that the 100-year storm is a criterion used in the design of Caltrans assets.

FIGURE 2: CONSIDERATIONS FOR THE STATE HIGHWAY ASSESSMENT



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

Extreme weather events already disrupt and damage District 10 infrastructure. The following examples include weather-related issues and events that Caltrans District 10 has addressed in the past, and which may become more prevalent as climate continues to change.[4]

- **Temperature –** On January 17, 2014, Governor Jerry Brown declared a drought state-of-emergency. Since October of 2011, California had experienced years of high temperatures and lower-than-average rainfall.[5] These trends continued until the winter of 2016/2017 when an unusually wet winter caused flooding across the state.[6] In April 2017, Governor Brown declared an end to the drought.

  Between 2011 and 2017, California experienced its driest and warmest year (2014), its second driest and warmest year (2015), and unprecedented low Sierra Nevada snowpack levels (2013 – 2015).[7] Recent studies have suggested that climate change is at least partially responsible for the lack of precipitation in the winters from 2013 to 2015[8] and that this event may be an example of future dry spells as droughts are exacerbated by increased consecutive high-heat days.[9]

  One of the greatest impacts to Caltrans during this period was a massive tree die-off resulting from the drought. An estimated 102 million trees died in California because of the drought, contributing to wildfire risk across the state and raising concerns about damage from falling trees. As part of the Governor's proclamation, Caltrans was required to "identify areas of the State that represent high hazard zones for wildfire and falling trees" and "remove dead or dying trees in those high hazard zones." In response, Caltrans District 10 began efforts to remove stands of dead and dying trees surrounding the SHS. Particularly following the Detwiler Fire in July of 2017, which impacted SR 49, SR 140, SR 132, and SR 120, District 10 crews removed 780 trees. District 10 crews also removed trees after the Donnell Fire in August 2018, which occurred in the Stanislaus National Forest.

- **Precipitation** – Projecting changes in precipitation for California is complicated as California lies between two climatic zones---the temperate and subtropic zones. These zones are expected to become wetter and drier, respectively.[10] Most climate forecasts for the state suggest that it will be hotter and more drought-prone, with infrequent, heavy storm events. However, new research from the University of California, Riverside projects a wetter future.[11] Despite the

[4] Louise Bedsworth, Dan Cayan, Guido Franco, Leah Fisher, and Sonya Ziaja. "California's Fourth Climate Change Assessment, Statewide Summary Report." Governor's Office of Planning and Research, Scripps Institution of Oceanography, California Energy Commission, California Public Utilities Commission. Publication number: SUMCCCA4-2018-013. (2018).
[5] "California Drought 2011 to 2016." Climate Signals. December 4, 2018. Last accessed July 18, 2019. http://www.climatesignals.org/headlines/events/california-drought-2012-2016
[6] Louise Bedsworth, et al. op cit.
[7] "California Drought 2011 to 2016." op cit.
[8] Ibid.
[9] Louise Bedsworth et al. op cit.
[10] Robert Allen and Rainer Luptowitz, "El Niño-Like Teleconnection Increases California Precipitation in Response to Warming," Nature Communications volume 8, Article number: 16055 (2017). Last accessed July 10, 2019, https://www.nature.com/articles/ncomms16055
[11] Ibid.

uncertainty inherent in projections, scientists agree that California will have more volatile precipitation and more extreme events due to a warmer atmosphere heavy with water vapor. [12]

District 10 has already experienced several intense storms in recent years, which have caused damage to the SHS. In March 2018, the Moccasin Storm damaged roads and caused road closures in several counties. Within five hours of the beginning of the storm, eight to 10 inches of rain had fallen. The event caused erosion and washouts on SR 49 in Tuolumne and Mariposa Counties, and on SR 132 in Mariposa County. The intensity of the rain caused the steep slopes surrounding the roads to slide, overwhelming the drainage system which was unable to support and divert the flow of water. This storm resulted in road closures along SR 49 and SR 132.

District 10 has relied on Director's Orders emergency repair efforts to respond to these events. District 10 has also increased monitoring efforts in areas along SHS roads that are considered particularly susceptible to damage.

FIGURE 3: EXAMPLE OF LANDSLIDE REPAIR WORK ON SR 26

[12] Suraj Polade, Alexander Gershunov, Dan Cayan, Michael Dettinger, & David Pierce, "Precipitation in a Warming World: Assessing Projected Hydro-Climate Changes in California And Other Mediterranean Climate Regions," Scientific Reports volume 7, Article number: 10783. (2017) https://www.nature.com/articles/s41598-017-11285-y

- **Wildfire** – As temperatures increase, and prolonged droughts occur, so too historically does the area burned by wildfires increase. The recently released Fourth National Assessment of Climate Change reported that climate change has increased the areas burned by wildfire in the West by roughly double what it would have been between 1984 and 2015 under past conditions. The report also noted that the increase in area burned over the last century is more attributable to climate factors than other contributing conditions.[13]

  Due to longer and hotter dry seasons, fires in District 10 have moved to the tree canopy and spread quickly. This has resulted in several devastating wildfires in recent years. In June of 2015, the Washington Fire, initiated by a lightning strike, grew from 350 acres on June 18th to over 16,000 acres by June 25th. Due to the fire, portions of SR 4, SR 88, and SR 89 were closed for nine consecutive days. In burning many acres of vegetation, the fire made the hillsides susceptible to erosion.

  In July, 2018, the Ferguson Fire, which grew to 42,017 acres over the course of two weeks, resulted in the closure of SR 140 and many local roads. More information about the impacts of the Ferguson Fire are included in Section 9 of this report.

  In addition to damage repair and the need for extra staffing, these disasters generally result in road closures for extended periods of time, interrupting the movement of people and goods. This is particularly serious in the mountain counties where no alternate routes often exist, resulting in significant economic impacts to the region and extreme danger to residents if evacuation routes become unusable.

  Wildfires and drought also cause changes in wildlife migration and concentration patterns. This affects the ability of agencies to predict wildlife incident areas and create connectivity for new migration patterns.

- **Wildfire & Flooding --** The combination of wildfires followed by intense precipitation and flooding has the potential to exacerbate impacts to the SHS. For example, the Detwiler Fire in July 2017 is speculated to have made the slip-outs and washouts that occurred during the Moccasin Storm in 2018 much worse than might have been expected. The Detwiler Fire torched over 80,000 acres and destroyed 63 homes before it was contained in early August 2017. The fire impacted SR 49, SR 140, SR 132, and SR 120. The vegetation burned could have served to soak up the heavy rainfall from the Moccasin Storm and helped to stabilize slopes and sediments adjacent to SR 49, in particular. In response, District 10 has adopted preventive measures to reduce the risk of wildfires, such as ditch cleaning and ongoing tree removal along the SHS.

[13] Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.). *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*. U.S. Global Change Research Program (USGCRP). Washington, DC, 1515 pp. doi: 10.7930/NCA4. (2018).. Last accessed July 17, 2019. https://nca2018.globalchange.gov/chapter/25/

FIGURE 4: DAMAGE FROM THE DETWILER FIRE

- **Sea Level Rise and Storm Surge –** Projected sea level rise in San Joaquin County is expected to place several thousand Stockton residents and properties at risk of flooding. According to research conducted by Climate Central, roughly 55,000 Stockton residents live in properties at elevations that are lower than the historic tides and storm records in the San Francisco Bay.[14] Of the vulnerable communities in Stockton and Sacramento, 60 percent of the residents are low income and live in ethnic minority communities, raising environmental justice concerns as sea levels continue to rise.

  While there have yet to be instances in District 10 where sea level rise has caused damage to the SHS, there are 254 miles of the state highway between Stockton and Sacramento that sit below the three-foot high tide line. In the future, these roadways will be increasingly vulnerable to sea level rise, storm surge, and flooding.[15]

[14] "Sacramento and Stockton Face Biggest Sea Level Rise Threat in California." Climate Central. Last accessed July 10, 2019. https://www.climatecentral.org/pdfs/SLR-CA-SS-PressRelease.pdf
[15] Ibid.

3. ASSESSMENT APPROACH

3.1. Collaboration and Coordination in the Assessment Approach

The Caltrans SHS vulnerability study has been based on research and the work of multiple agencies and academic institutions across California. The databases and tools developed by these other agencies were used throughout the District 10 study. Importantly, Caltrans District 10 staff helped in the preparation of this report in several ways:

- Met to discuss the methodology for undertaking the study, reviewed desired project deliverables, and identified District contacts.
- Provided reports and studies sponsored by or completed by District 10 staff.
- Identified available data on the SHS and noted the climate-related concerns in the district through the collection of photos showing recent events, and the identification of available summary information on the impacts to highway network.
- Reviewed the report and provided feedback on its findings and lessons learned.

The vulnerability study has also included coordination with the California organizations responsible for climate modeling and data development. These agencies and research institutions will be discussed in the following section and referenced in the respective sections on each climate stressor – temperature, precipitation, sea level rise, storm surge, and wildfire.

3.2. Adaptation State-of-the-Practice in California

California has been at 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 (GHG) mitigation strategies and that consider climate change in state decision making. California agencies have also been pivotal in creating climate change datasets that can be used to consider regional impacts. At a more local level, efforts to plan for and adapt to climate change are underway in communities across California. These practices are key to the development of climate change vulnerability assessments in California. 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 vulnerability assessment.

3.2.1. Policies

Various state policies have directly addressed GHG mitigation and climate adaptation planning. These policies require state agencies to consider the effects of climate change 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 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 future policy.[16]

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

- **Executive Order S-13-08** (2008) directed state agencies to plan for sea level rise (SLR) and climate impacts through the coordination of the State Climate Adaptation Strategy.[17]
- **Executive Order B-30-15** (2015) required 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.[18]
- **Assembly Bill 1482** (2015) required 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.[19]
- **Senate Bill 246** (2015) established the Integrated Climate Adaptation and Resiliency Program to coordinate regional and local efforts with state adaptation strategies.[20]
- **Assembly Bill 2800** (2016) required that state agencies account for climate impacts during the planning, design, building, operations, and maintenance activities associated with infrastructure investments. It also required the formation of a Climate-Safe Infrastructure Working Group represented by engineers with relevant experience from multiple state agencies, including Caltrans.[21]

These policies represent the type of factors state agencies should consider when addressing climate change. Conducting an assessment such as the one for District 10 is a key step towards protecting Caltrans infrastructure against future extreme weather conditions and addressing the requirements of the relevant state policies above. 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.

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 on how state agencies can implement the policy was released in 2017, entitled *Planning and Investing for a Resilient California*. This guidance helps 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 state agencies, which allows consistent communication among agency staff on the effects of climate change.

[17] Adaptation Clearinghouse. "California Executive Order S-13-08 Requiring State Adaptation Strategy." Last accessed July 19, 2019. https://www.adaptationclearinghouse.org/resources/california-executive-order-s-13-08-requiring-state-adaptation-strategy.html

[18] Office of Governor Edmund Brown. "Governor Brown Establishes Most Ambitious Greenhouse Gas Reduction Target in North America." April 29, 2015. Last accessed July 15, 2019. https://www.gov.ca.gov/news.php?id=18938

[19] California Legislative Information. "Assembly Bill No. 1482." October 8, 2015. Last accessed October 18, 2019, https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201520160AB1482

[20] California Legislative Information. "Senate Bill No.246." 2015. Last accessed July 17, 2019, https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB246

[21] California Legislative Information. "Assembly Bill No. 2800." September 24, 2016. Last accessed July 17, 2019, http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160AB2800

3.2.2. Research and Tool Development

California has been on the forefront of climate change research nationally and internationally. For example, Executive Order S-03-05 directs state agencies to develop and regularly update guidance on climate change. These research efforts are encompassed in the California Climate Change Assessment, which is in its fourth edition (Fourth Climate Change Assessment). To understand the research and datasets from the Fourth Climate Change Assessment, which are utilized in the District 10 vulnerability assessment, some background is needed on Global Climate Models and emissions scenarios.

Global Climate Models (GCMs)

GCMs have been developed worldwide by many research institutions to represent the physical processes that cause climate change. Once validated, these models are then used to project future changes to GHG emission levels.[22] These models reflect the different estimates of GHG emissions or atmospheric concentrations of these gases.

The Intergovernmental Panel on Climate Change (IPCC) is the leading international body recognized for its work in quantifying the potential effects of climate change. 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 used worldwide. However, the State of California has identified a subset of these GCMs that are most applicable to California as outlined in the California Fourth Climate Change Assessment section discussed below.

Emissions Scenarios

Two commonly cited sets of emissions data are developed by the IPCC:

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

RCPs represent the most recent generation of GHG scenarios produced by the IPCC and were used in this study. The scenarios use three metrics to estimate future emissions: radiative forcing, emission rates, and emission concentrations.[23] Four RCPs were developed to reflect assumptions on emissions growth, and the resulting concentrations of GHGs in the atmosphere. The RCPs are applied in GCMs to forecast future conditions and enable a comparison of one scenario 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 policies on reducing GHG emissions or changing socio-economic conditions). The RCPs developed for this purpose include:

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[22] Intergovernmental Panel on Climate Change (IPCC). "What is a GCM?" June 18, 2013. Last accessed July 17, 2019, http://www.ipcc-data.org/guidelines/pages/gcm_guide.html

[23] IPCC. "Representative Concentration Pathways," Last accessed July 17, 2019, http://sedac.ipcc-data.org/ddc/ar5_scenario_process/RCPs.html

- RCP 2.6 assumes that global annual GHG emissions will peak in the next few years and then begin to decline substantially (due to human action to reduce such emissions).
- 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.[24]

California Fourth Climate Change Assessment and Modeling Future Climate Conditions

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

Model downscaling is a statistical technique that refines the results of global models 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."[25] This effort was undertaken by Scripps and provides a finer grid system than is found in other techniques. It enables an assessment of changes in a more localized way than was previously available, given that past models summarized changes with lower resolution.[26] Out of the 32 LOCA-downscaled GCMs for California, 10 models were chosen by the state as being most relevant for state agency assessments and planning decisions.[27] 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

[24] M. Meinshausen, et al. "The RCP Greenhouse Gas Concentrations and their Extensions from 1765 to 2300 (open access)." Climatic Change, 109 (1-2): 213–241 (2011)
[25] Cal-Adapt. "LOCA Downscaled Climate Projections." 2.0. 2018. Last accessed July 17, 2019, http://cal-adapt.org/
[26] Pierce et. al. "Statistical Downscaling Using Localized Constructed Analogs." 2014. Last accessed July 17, 2019, http://journals.ametsoc.org/doi/abs/10.1175/JHM-D-14-0082.1
[27] Cal-Adapt. 2018. op cit.

Data from these models are available on Cal-Adapt 2.0, California's Climate Change Research Center.[28] The Cal-Adapt 2.0 data are some of the best available data in California on climate change and, for this reason, selected of data from Cal-Adapt and the GCMs above were utilized in this study.

3.3. Other Efforts in District 10 to Address Climate Change

In addition to the work completed and in progress by Caltrans, regional efforts are underway or have been undertaken in District 10 relating to climate change planning and preparedness. Some examples of these efforts include:

Amador-Calaveras Consensus Group[29] -- A community-based group, the Amador-Calaveras Consensus Group focuses on protecting communities from wildfires in part by creating fire-safe communities. Members include state and federal agencies, business owners, nonprofit organizations, elected officials, and private individuals. The Group emphasizes fire prevention and adaptation strategies in the upper Mokelumne River and Calaveras River watersheds east of Highway 49.

Climate Change and Health Profile Report San Joaquin County[30] -- The California Department of Public Health has developed county-specific reports on climate change and health impacts. This report examined likely climate change health-related impacts in San Joaquin County using climate projections for the Northern Central Valley Region. Projections for temperature showed an increase in average temperature of 4°F to 6°F in 2050 and between 8°F and 12°F by 2100. A July increase in average temperature of 6°F to 7°F is expected in 2050 and 12°F to 15°F by 2100. The report noted the increased likelihood of heat waves and wildfire risks. Two to three more heat waves per year are expected by 2050 with five to eight more by 2100. By 2085, the northern and eastern portions of the region will experience an increase in wildfire risk, more than four times the current levels in some areas.

Mariposa County Hazard Mitigation Plan[31] -- The Mariposa County Hazard Mitigation Plan is illustrative of the types of plans counties develop in anticipation of disruptions due to local hazards. Twenty-eight different types of hazards were identified by the planning committee, who shortened the list to the five they considered most important---floods, landslides, wildfires, winter storms, and solid waste and hazardous materials (earthquakes and extended power loss were also identified as major concerns but were subsumed in these categories). The plan noted that Mariposa County has experienced major floods and estimated a 37 percent probability that floods causing more than $10,000 in damage would occur in an average year in the future. Similarly, the plan estimated that the probability of a future winter storm/rain-induced landslide at 70 percent per year.

Sacramento-San Joaquin Delta Conservancy[32] -- The Conservancy is the primary state agency addressing potential climate change impacts in the Delta. The Conservancy has adopted a position that the economic and environmental health of the Delta region is directly linked to the Delta's vulnerability to potential climate change impacts. It has placed particular attention on risks associated with sea level

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

[29] Amador-Calaveras Consensus Group. N.d. Last accessed July 17, 2019, http://acconsensus.org/about/

[30] California Department of Public Health. *Climate Change and Health Profile Report San Joaquin County*. Feb 2017. Last accessed July 17, 2019, https://www.cdph.ca.gov/Programs/OHE/CDPH%20Document%20Library/CHPRs/CHPR077SanJoaquin_County2-23-17.pdf

[31] Mariposa County. "Mariposa County Local Hazard Mitigation Plan." 2015. Last accessed July 17, 2019, http://www.mariposacounty.org/DocumentCenter/View/67481/FINAL-Mariposa-LHMP-Update_February-2015

[32] Sacramento-San Juaquin Delta Conservancy. "Climate Change." 2015. Last accessed July 17, 2019, http://deltaconservancy.ca.gov/climate-change-1/

rise. The Conservancy has encouraged programs and funding for projects that promote infrastructure resiliency in anticipation of climate change risks.

San Joaquin Council of Governments Climate Change Planning/Assessment Work – SJCOG has adopted the following resilience goals:

- Maintain a multi-modal transportation network to deliver services throughout the county, with a focus on vulnerable populations in floodplains and low-income peoples with limited bus service.
- Create and maintain redundancy in the system to allow for evacuations/rerouting.
- Ensure operation of routes supporting evacuation, staging areas, emergency response.

The COG is conducting a Climate Adaptation and Resiliency Study that will initially identify the top five vulnerable assets in the region and resilience gaps in other local plans based on an assessment of existing asset conditions and of future climate scenarios. Phase 2 of the study will:

- Develop a plan to address the asset vulnerabilities identified in Phase 1
- Deliver data evaluation tools and adaptation planning implementation guide
- Focus on disadvantaged communities
- Strengthen local partnerships and collaboration, create shared understanding on climate risks and adaptation needs
- Expand SJCOG role as source of technical assistance for member agencies and public
- Ensure local jurisdictions have the tools they need to consider climate impacts

Sierra Nevada Recreation and Infrastructure Vulnerability Assessment and Adaptation Strategy Partnership[33] – The purpose of this partnership is to "synthesize the best available science to assess climate change vulnerability and develop adaptation strategies for recreation and infrastructure resources on National Forests in the Sierra Nevada Mountain Range to understand and mitigate potentially adverse effects of climate change." The steps in the assessment include:

- Develop a framework and tools for managers to incorporate the best available science plus existing/complementary assessments.
- Define priority regional- and forest-level climate change vulnerabilities.
- Produce a spatially explicit, peer-reviewed vulnerability assessment.

There are two main partners in this collaboration—the US Forest Service and the University of Washington School of Environmental and Forest Sciences.

Sustainable Communities Coalition in Stanislaus County[34] -- The Coalition has convened groups in San Joaquin and Stanislaus Counties to advocate for land use, housing, and transportation policies leading to more sustainable communities. The Coalition is interested, in particular, in environmental justice for

[33] Sierra Nevada Recreation And Infrastructure Vulnerability Assessment And Adaptation Strategy Partnership. Website, last accessed July 18 2019. http://www.adaptationpartners.org/sierrarecinfra/

[34] The Sustainable Communities Coalition in Stanislaus County. N.d. Last accessed July 17, 2019, https://ejstockton.org/community/

low income and minority populations as it relates to decisions affecting the built environment. Its efforts have included obtaining funding, technical expertise, and exchanging strategies and best practices on a range of issues, including climate change and the need for equitable adaptation strategies. The Coalition has worked with county and local governments to develop their Sustainable Communities Strategy and in two cases in amending the Stanislaus General Plan to be more sensitive to equity issues.

Tuolumne County General Plan, Climate Change[35] -- The latest update of the Tuolumne County General Plan included adaptation strategies for providing a more resilient county. Some examples of proposed strategies included: (1) identify critical infrastructure vulnerable to extreme heat events, (2) develop outreach programs for outdoor workers to prevent heat-related illness, (3) explore options to incorporate cool pavement technology, 4) establish an Excessive Heat Emergency Response Plan, and (5) identify critical infrastructure vulnerable to wildfire.

3.4. General Methodology

The adaptation planning methodology used in this study varied by climate change stressor. Given that each stressor is analyzed with a different set of models, emissions scenarios, and assumptions, this leads to stressor-specific data and information on which to develop an understanding of potential future climate conditions. The methods employed are further described the following stressor sections; 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. The year 2085 is the center point of this time range and the last year in which statistically-derived projections can defensibly be made. The 2025 and 2055 out-years follow the same logic but applied to each of the prior 30-year periods (2010 to 2039 and 2040 to 2069, respectively).

3.4.2. Geographic Information Systems (GIS) and Geospatial Data

Developing an understanding of Caltrans assets exposed to sea level rise and projected changes in temperature, precipitation, and wildfire required complex geospatial analyses. The geospatial analyses were performed using Environmental Systems Research Institute Esri GIS software (a screenshot of the GIS database is shown in Figure 5). The general approach for each stressor's geospatial analysis included:

Obtain/conduct stressor mapping: The first step in each GIS analysis was to obtain or create maps showing the presence and/or value of a given hazard at various future time periods, under different

[35] Tuolumne County. "Climate Change, Chapter 18." Tuolumne County General Plan. 2015. Last accessed July 17, 2019, https://www.tuolumnecounty.ca.gov/DocumentCenter/View/11956/Chapter-18-Climate-Change-Final

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.

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

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

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

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

4. TEMPERATURE

Temperature rise is an 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.[36] The potential effects of extreme temperatures on District 10 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.

Design

- Pavement design includes an assessment of temperature in determining the most appropriate pavement 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.

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.
- Temperatures over 115-130 °F in enclosures can result in higher failure rates in signal controllers, loops, weigh-in-motion sites, and the like.
- Right-of-way landscaping and vegetation must survive higher temperatures and drought.
- 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 that changing temperatures might have on Caltrans activities. Instead, it was decided to take a close look at one of the ways in which rising temperatures 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 relies, in part, on the following two temperature variables:

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

[36] Reidmiller et al. op cit.

These climate metrics are critical to determine the extreme temperatures a roadway may experience over time. This is important to understand, because a binder must maintain pavement integrity under both extreme cold conditions (which leads to contraction) and high heat (which leads to expansion).

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

The Localized Constructed Analogues (LOCA) climate data developed by Scripps was used for the analysis of temperature,[37] which had a spatial resolution of 1/16th of a degree or approximately three and a half to four miles.[38] 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.

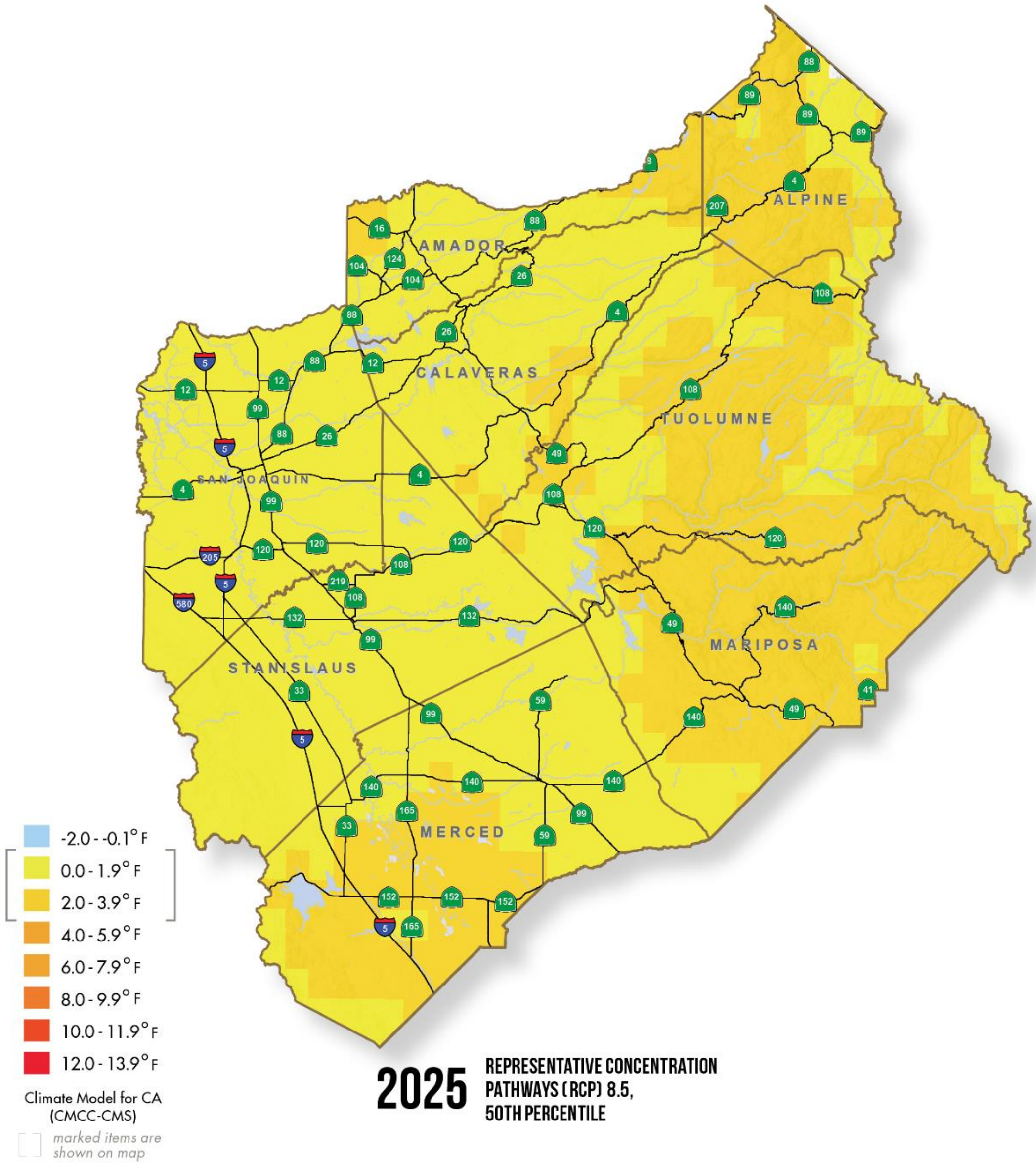
The maps shown on the next pages are for the model that represents the median change across the state among all California-approved climate models for RCP 8.5 (data for RCP 4.5 was analyzed, but for brevity is not shown here). The maps highlight the temperature change expected for both the maximum and 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 depending on the area of the district.

The projected change shown on the maps in the following pages can be added to Caltrans' current source of historical temperature data to determine final pavement design values 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 temperatures and help inform decisions on how to provide the best pavement quality for California SHS users.

[37] A more detailed description of the LOCA data set and downscaling techniques can be found at the start of this report.
[38] Cal-Adapt." LOCA Downscaled Climate Projections." 2.0. 2018. Last accessed July 17, 2019, http://cal-adapt.org/

FIGURE 5: CHANGE IN THE ABSOLUTE MINIMUM AIR TEMPERATURE 2025

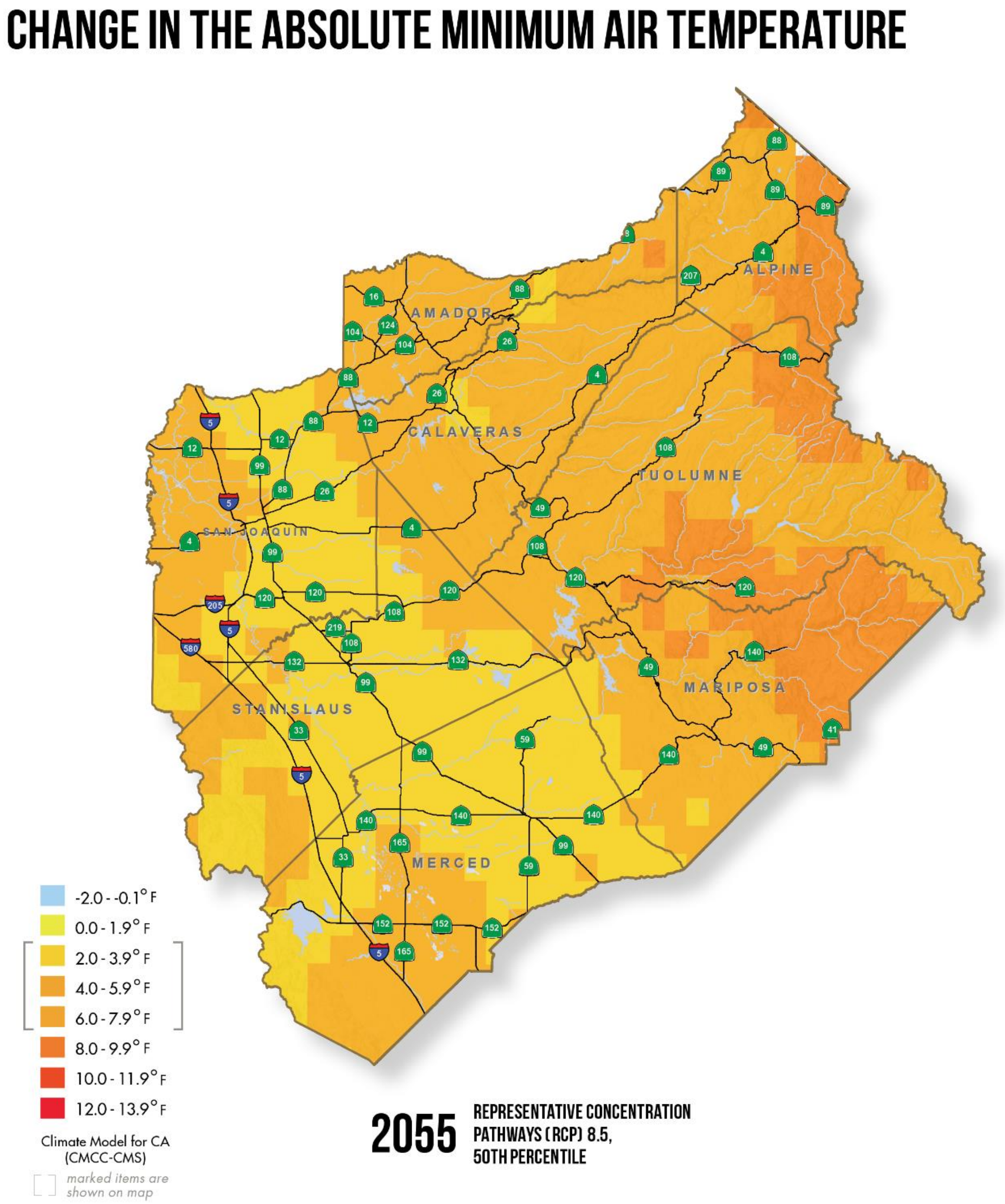
CHANGE IN THE ABSOLUTE MINIMUM AIR TEMPERATURE



Future Change in the Absolute Minimum Air Temperature within District 10, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 10. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown was generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

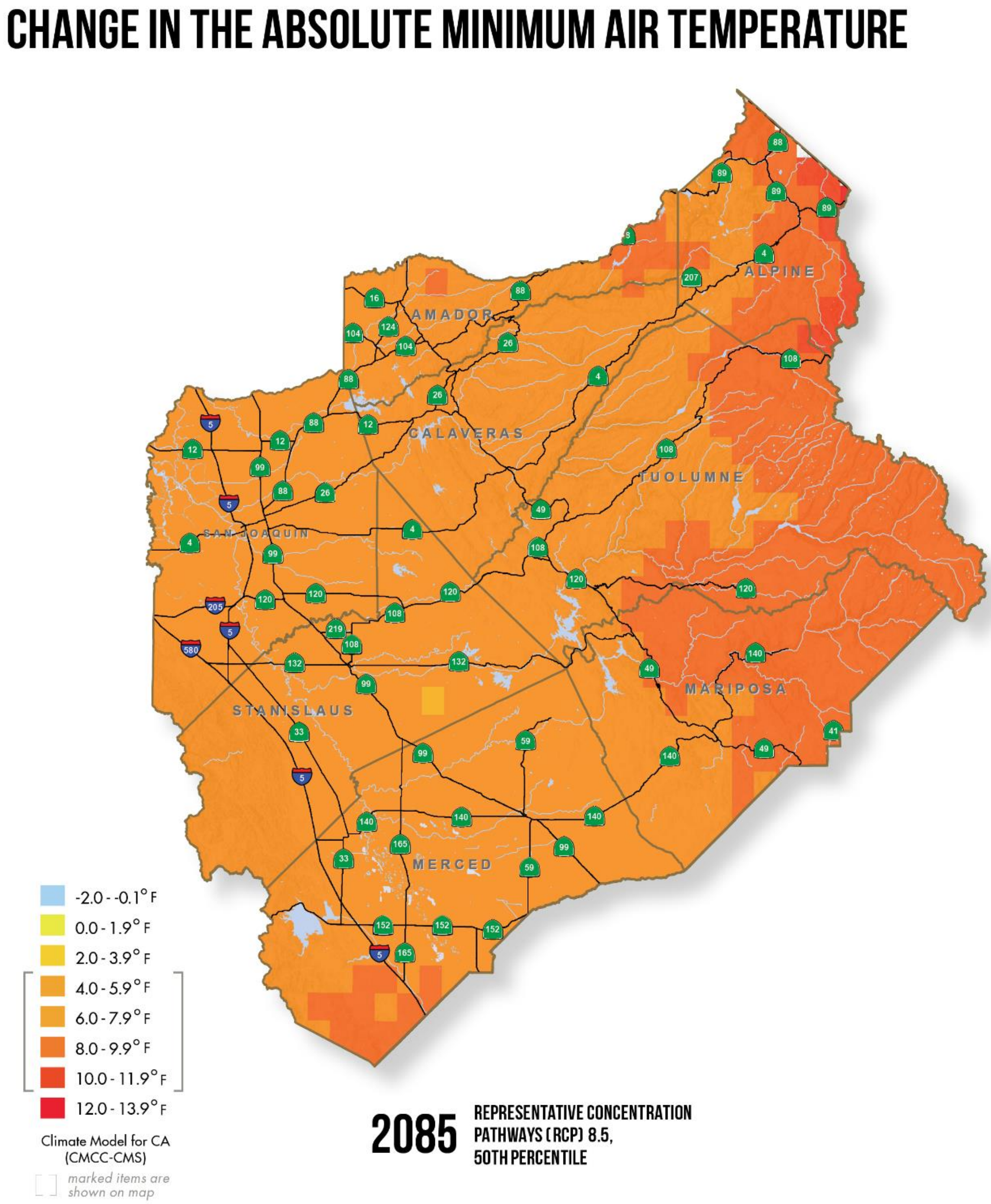
FIGURE 6: CHANGE IN THE ABSOLUTE MINIMUM AIR TEMPERATURE 2055



Future Change in the Absolute Minimum Air Temperature within District 10, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 10. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown was generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

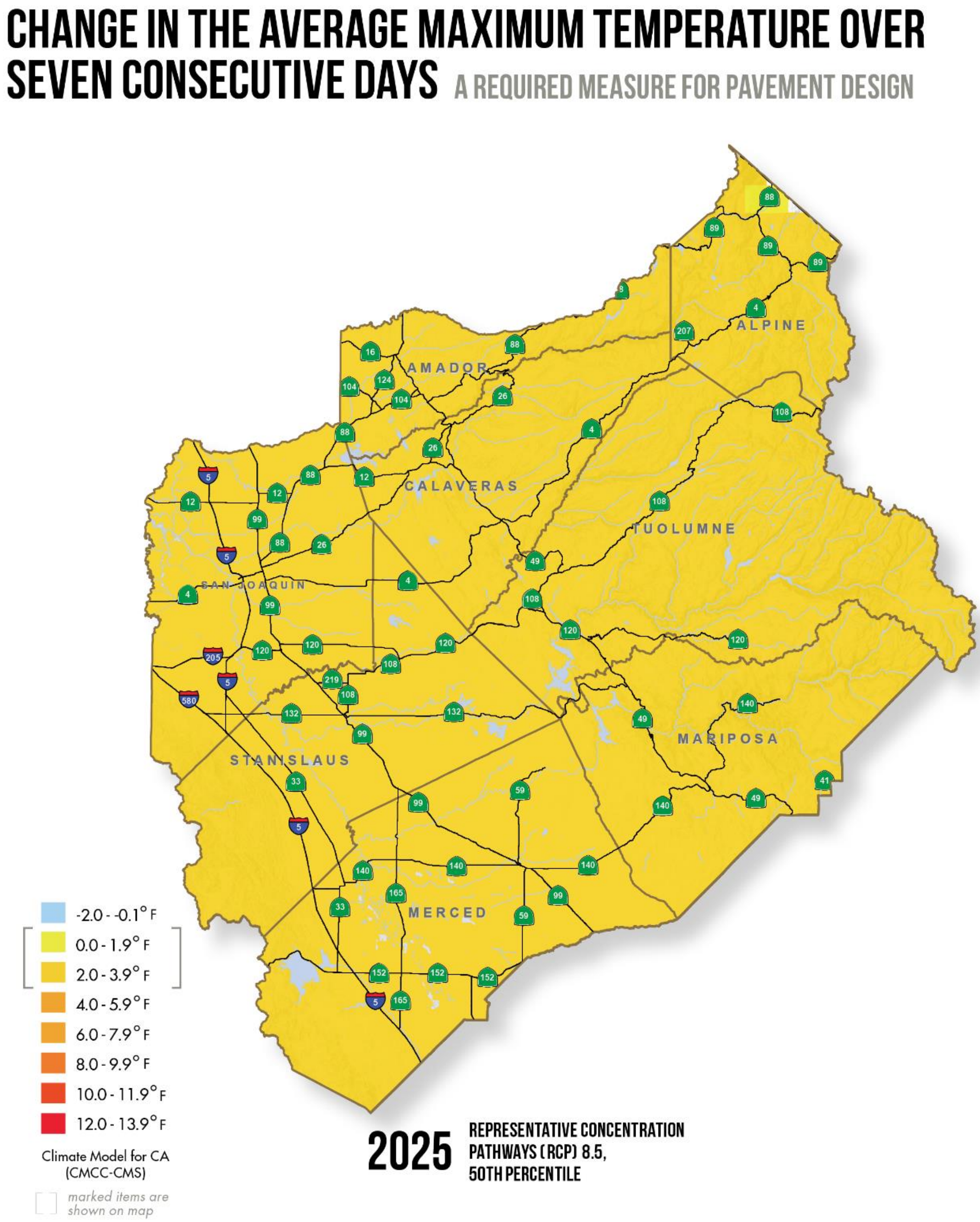
FIGURE 7: CHANGE IN THE ABSOLUTE MINIMUM AIR TEMPERATURE 2085



Future Change in the Absolute Minimum Air Temperature within District 10, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 10. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown was generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

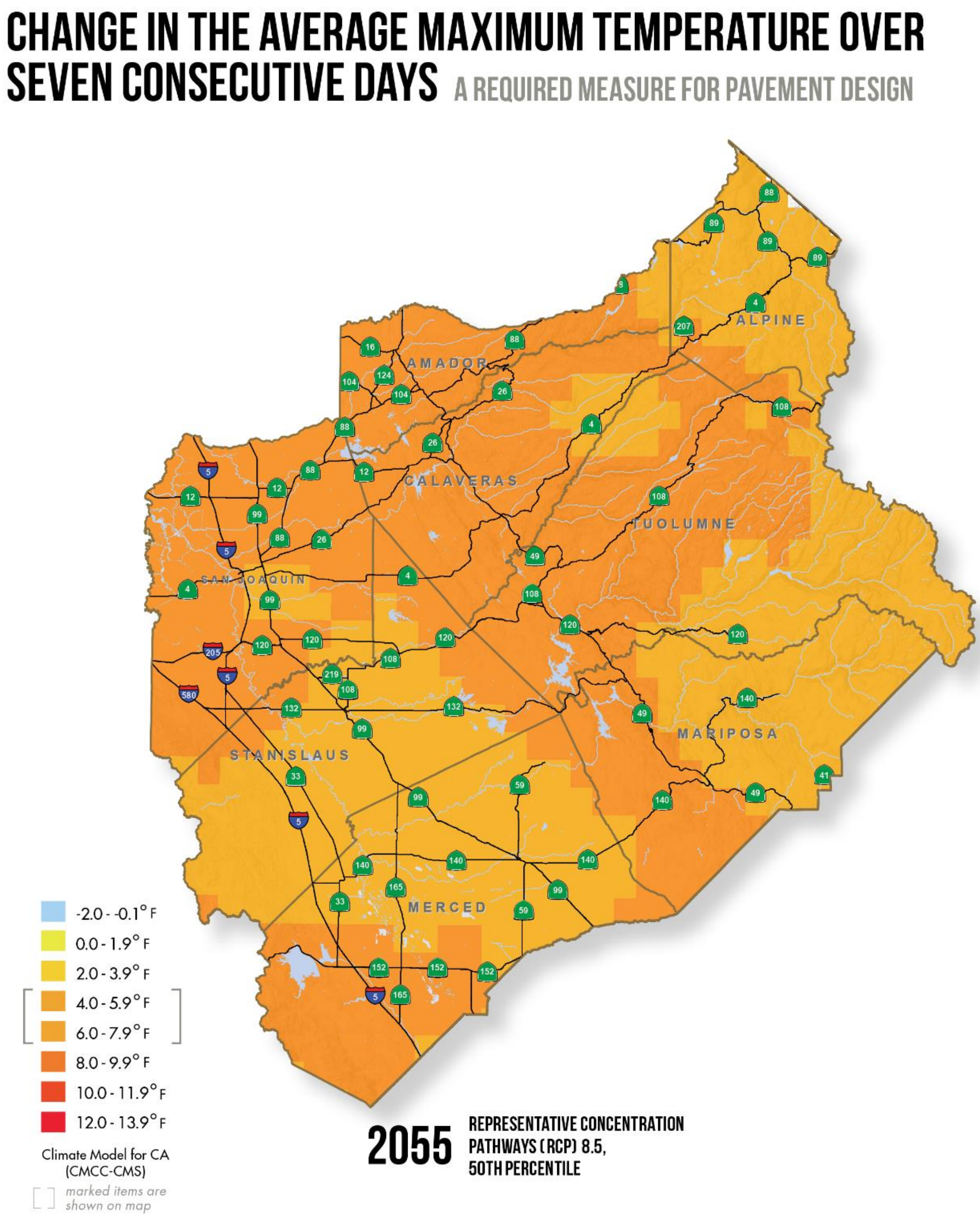
FIGURE 8: CHANGE IN THE AVERAGE MAXIMUM TEMPERATURE OVER SEVEN CONSECUTIVE DAYS 2025



Future Change in the Average Maximum Temperature over Seven Consecutive Days within District 10, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 10. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown was generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

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

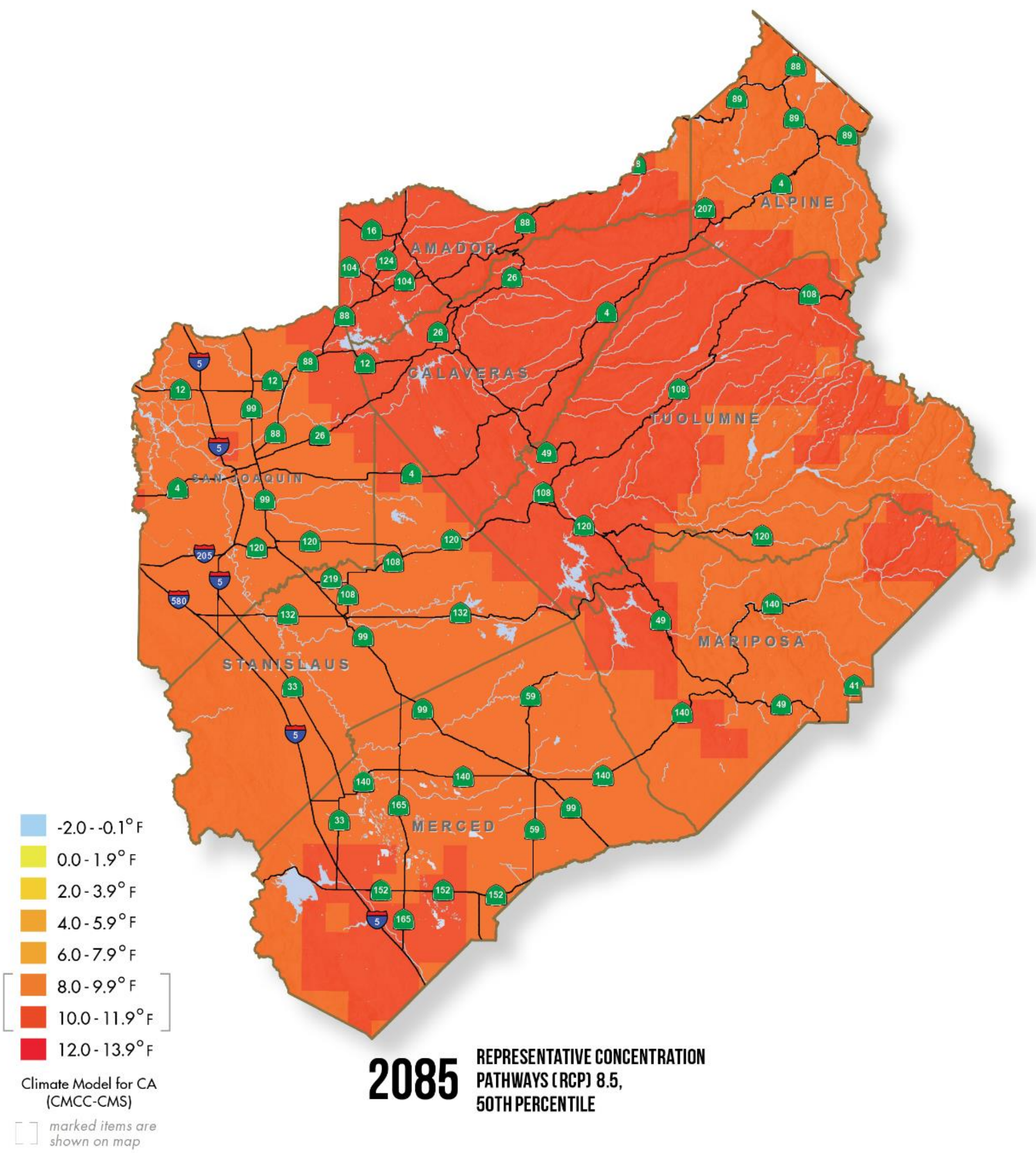


Future Change in the Average Maximum Temperature over Seven Consecutive Days within District 10, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 10. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown was generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

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

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 10, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 10. 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

According to the U.S. National Climate Assessment, the Southwest region of the United States is expected to experience less precipitation overall in the future,[39] but with the potential for heavier individual events, and with more precipitation falling as rain. This section of the report focuses on how these heavy precipitation events may change and become more frequent over time in District 10. Current transportation design utilizes “return period storm events” as a variable in the design of assets such as bridges, culverts, roadways, etc. A return period storm event is the historical intensity of storms based on how often such level of storms have occurred in the past. A 100-year storm event is one that has the intensity of a storm that statistically occurs once every 100 years. 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.[40] This metric was analyzed to determine how 100-year storm rainfall is expected to change.

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 was compiled as a part of the California Fourth Climate Assessment.

Precipitation data are traditionally used at the project level by applying statistical analyses of historical rainfall, most often through the National Oceanic and Atmospheric Administration (NOAA) Atlas 14.[41] 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. Future precipitation was analyzed through a broad range of potential effects predicted by a set, or sometimes referred to as an ensemble, of models.

Of interest to the analysis was determining how a 100-year event may change over time for the purposes of analyzing the vulnerabilities of the SHS to 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. Climate change specialists from the consultant team worked with researchers from Scripps to estimate extreme precipitation changes over time. There are several methodological challenges with using downscaled GCM projections to derive estimations of future extreme precipitation events, addressable through vetted and available methods. Because of these challenges, the common approach

[39] Jerry Melillo, Terese (T.C.) Richmond, and Gary W. Yohe, (eds), “Climate Change Impacts in the United States: The Third National Climate Assessment.” U.S. Global Change Research Program, 841 pp. doi:10.7930/J0Z31WJ2. (2014).
[40] Caltrans. “Highway Design Manual.” Sacramento, CA. July 2, 2018. Last accessed July 17, 2019, http://www.dot.ca.gov/hq/oppd/hdm/hdmtoc.htm
[41] National Oceanic and Atmospheric Administration (NOAA), “Hydro Meteorological Design Studies Center,” December 3, 2015. Last accessed July 17, 2019, http://nws.noaa.gov/oh/hdsc/index.html

is to compare forecasts across multiple models to conduct a robust assessment of how changing precipitation conditions may impact the highway system. Precipitation forecasts were used across the set of 10 international GCMs identified by the State as having the best applicability for California.

The data were only available for the RCP 4.5 and 8.5 emissions scenarios. The data were analyzed for three time periods to determine how precipitation may change through the end of century. The years shown in the following figures represent the mid-points of the same 30-year statistical analysis periods used for the temperature metrics. The precipitation forecasts were analyzed to understand two important points:

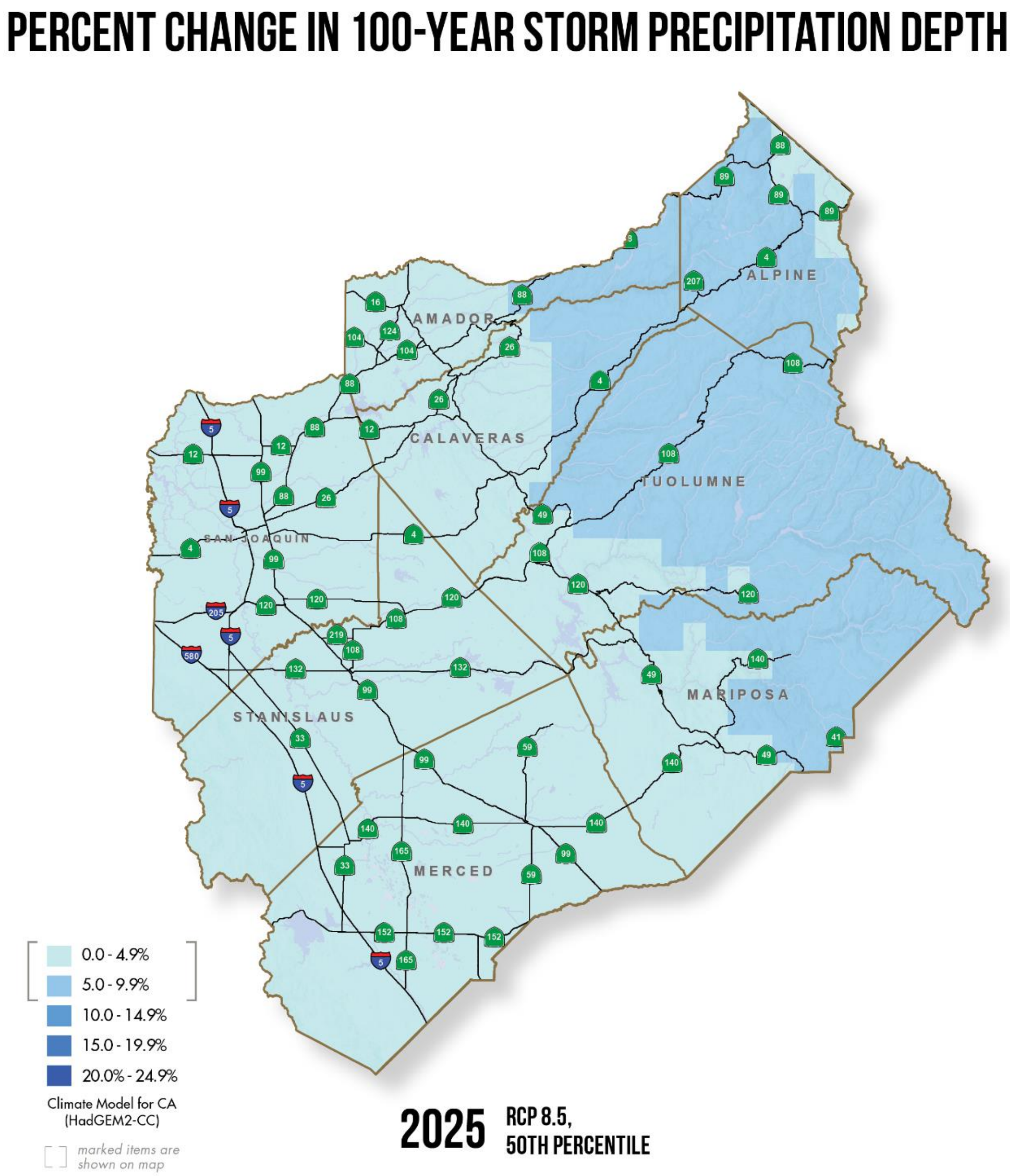
- Were there indications of change in return period storms across the models that should be considered in decision-making when considering estimates for future precipitation?
- What was the magnitude of change for a 100-year return-period storm that should be considered as a part of facility design looking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

The results of this assessment are shown in the District 10 figures on the following pages. 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 the change in 100-year storm depth is positive throughout District 10 indicating heavier rainfall during storm events.

Indications of increased precipitation in District 10 means that Caltrans must assume higher rainfall and associated flooding, and plan improvements to the SHS accordingly. This situation can be exacerbated by increased development, which reduces the natural absorption capacity of the land in drainage areas. Complex conditions like these require a longer-term view for design and flood response for facilities in these areas to ensure that they remain operational to the end of their design lives. Improving long-term resiliency will require that Caltrans conduct a comprehensive assessment of future conditions and incorporate new values for precipitation in design.

At first glance, the precipitation increases may appear to conflict with the wildfire analysis, which shows that wildfire events are expected to increase due to drier conditions. However, precipitation conditions in California are expected to change so that there are more frequent drought periods, but heavier, intermittent rainfall. In addition, low moisture levels in forests are the direct result of not only summer temps but frequent warm rainfall events melting the snowpack that would normally persist at higher elevations into mid-summer and inducing higher than normal stream flows. Heavy storm events could have serious implications to the SHS. Understanding these implications will help Caltrans engineers and designers implement designs that are more adaptive to the changing environment. That said, a hydrological analysis of flood flows is necessary to determine how this data will affect specific bridges and culverts.

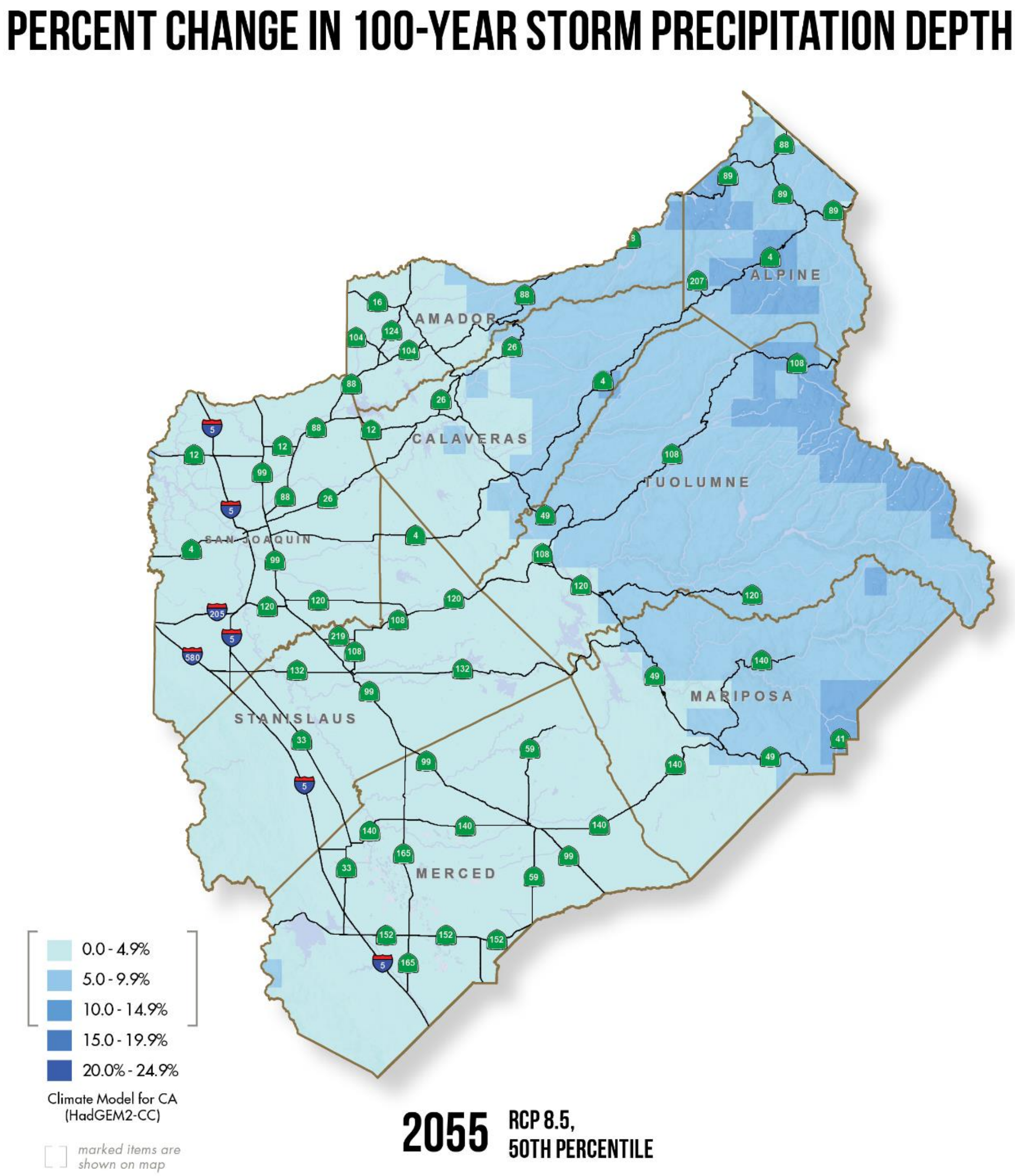
FIGURE 11: PERCENT CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH 2025



Future Percent Change in 100-year Storm Precipitation Depth within District 10, Based on the RCP 8.5 Emissions Scenario

Caltrans Transpotation Asset Vulnerability Study, District 10. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown were generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

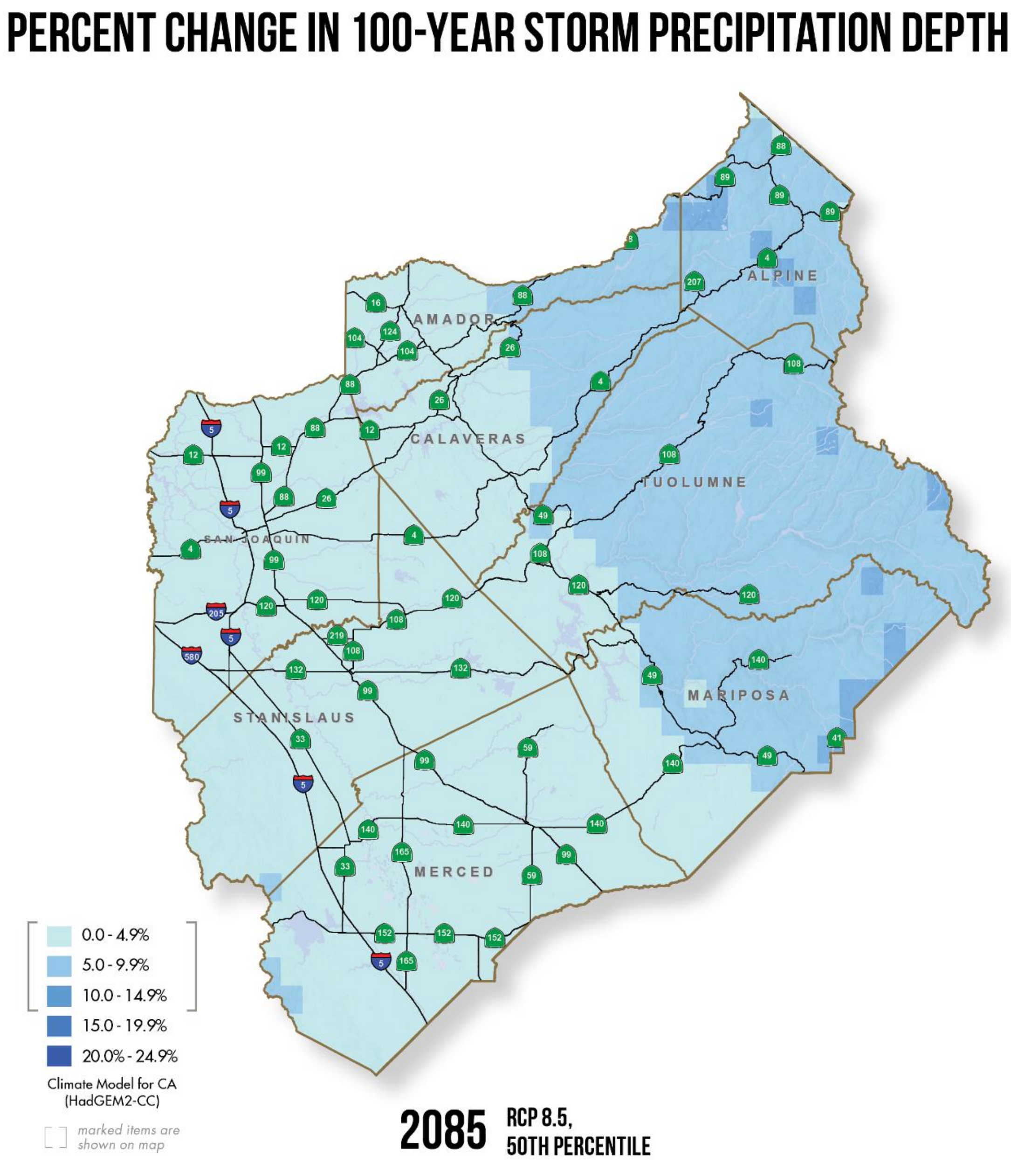
FIGURE 12: PERCENT CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH 2055



Future Percent Change in 100-year Storm Precipitation Depth within District 10, Based on the RCP 8.5 Emissions Scenario

Caltrans Transpotation Asset Vulnerability Study, District 10. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown were generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

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



Future Percent Change in 100-year Storm Precipitation Depth within District 10, Based on the RCP 8.5 Emissions Scenario

Caltrans Transpotation Asset Vulnerability Study, District 10. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown were generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

6. WILDFIRE

Increasing temperatures, changing precipitation patterns, and resulting changes to land cover are expected to affect wildfire frequency and intensity. Infrastructure, including the presence of utility infrastructure or other potential sources of fire (mechanical, open fire, accidental or intentional), may also influence the occurrence of wildfires. Wildfire is a direct concern for driver safety, system operations, and damage to 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 throughout California. These devastating fires caused property damage, loss of life, and damage to roadways. The wildfires often stripped the land of protective cover and damaged the soils, such that subsequent rain storms led to disastrous mudslides. The costs to Caltrans for repairing such damage can extend over months for individual events and could require years of investment to maintain the viability of the SHS for its users. The conditions that contributed to these impacts, notably a wet rainy season followed by very dry conditions and heavy winds, are likely to occur again in the future as climate conditions change and storm events become more dynamic.

The information gathered and assessed to develop wildfire vulnerability data for District 10 included research on the effect of climate change on wildfire recurrence. This is of interest to several agencies, including the U.S. Department of Agriculture Forest Service (USDAFS), Bureau of Land Management (BLM), Environmental Protection Agency (EPA) and California Department of Forestry and Fire Protection (CalFire), who have developed their own models to understand the trends of future wildfires throughout the U.S. 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, USDAFS
- **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 USDAFS. 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 USDAFS 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 includes climate, vegetation, population density, and fire history. This model then incorporates 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/USDAFS and UC Merced used the LOCA climate data set developed by Scripps, while the University of Idaho used an alternative downscaling method, the Multivariate Adaptive Constructed Analogs (MACA).

For purposes of this report, these three available climate models will be noted hereafter as:

- MC2 - EPA
- MC2 - University of Idaho
- UC Merced/Westerling

6.2. Global Climate Models Applied

A series of GCM outputs were used to generate projections of future wildfire conditions. The four recommended GCMs from Cal-Adapt for wildfire outputs (CAN ESM2, CNRM-CM5, HAD-GEM2-ES, MIROC5) were used in the analyses. 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 provide 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 1/24th degree square, to match the grid cells generated by MACA downscaling.

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

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

- Very Low 0-5%,
- Low 5-15%,
- Medium 15-50%,
- High 50-100%,
- Very High 100%.[42]

[42] >100% means fires are burning portions of each cell more than once in the same time period.

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 results across all models were examined 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, a score was assigned for each cell where there was 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.

Table 3 and Table 2 summarize the results of the analysis by providing centerline miles of the District 10 SHS that are exposed to Medium to Very High wildfire risk, by classification, county, and RCP. Note that under RCP 4.5, the total mileage of highway exposed steadily increases from beginning to end of century. Under RCP 8.5, the *total* mileage of the District 10 SHS exposed to wildfire does not change over time. This is because every possible location where there is a wildfire risk in District 10 is now in the Medium or above classification. However, there are portions of the system exposed to Medium wildfire concern at the beginning of the century that will be exposed to Very High wildfire concern by the end of century. The levels of concern still change over time, even when the mileage totals do not.

The figures on the following pages show the mapped projections for RCP 8.5 only. Red highlights show portions of the Caltrans SHS that are likely to be exposed to wildfire (in the medium, high, or very high concern classifications). These maps can be compared to Table 3 to see how the risk classifications change over time by county. For example, approximately 37 miles are expected to be exposed to Medium wildfire concern areas in Tuolumne County in the year 2025. By 2085, this decreases to about 17 miles. This change can be observed in the mapped results, as the yellow medium concern areas are slowly replaced by red high/very high concern areas.

TABLE 2: CENTERLINE MILES OF HIGHWAY EXPOSED TO MEDIUM TO VERY HIGH WILDFIRE CONCERN UNDER THE RCP 4.5 SCENARIO

District 10	2025			2055			2085		
	Med	High	Very High	Med	High	Very High	Med	High	Very High
Alpine	1.5	23.0	58.2	0.0	22.4	60.3	0.0	29.9	52.8
Amador	8.2	109.8	5.1	12.3	110.8	0.0	0.0	123.1	0.0
Calaveras	14.3	127.0	5.4	6.6	138.6	1.9	6.6	139.8	0.8
Mariposa	36.2	80.7	0.0	12.6	102.7	0.0	9.7	107.3	0.0
Merced	45.1	4.7	0.0	53.6	2.1	0.0	59.0	4.7	0.0
San Joaquin	18.8	19.1	0.0	24.5	13.4	0.0	21.6	17.5	0.0
Stanislaus	41.7	12.9	0.0	53.2	1.4	0.0	46.7	7.9	0.0
Tuolumne	37.1	90.0	24.2	26.6	119.9	9.7	17.1	135.7	3.4
District 10 Totals by Level of Concern and Year	**202.8**	**467.3**	**92.9**	**189.4**	**511.2**	**71.9**	**160.7**	**565.8**	57.0
District 10 Total by Year	**762.9**			**772.6**			**783.5**		

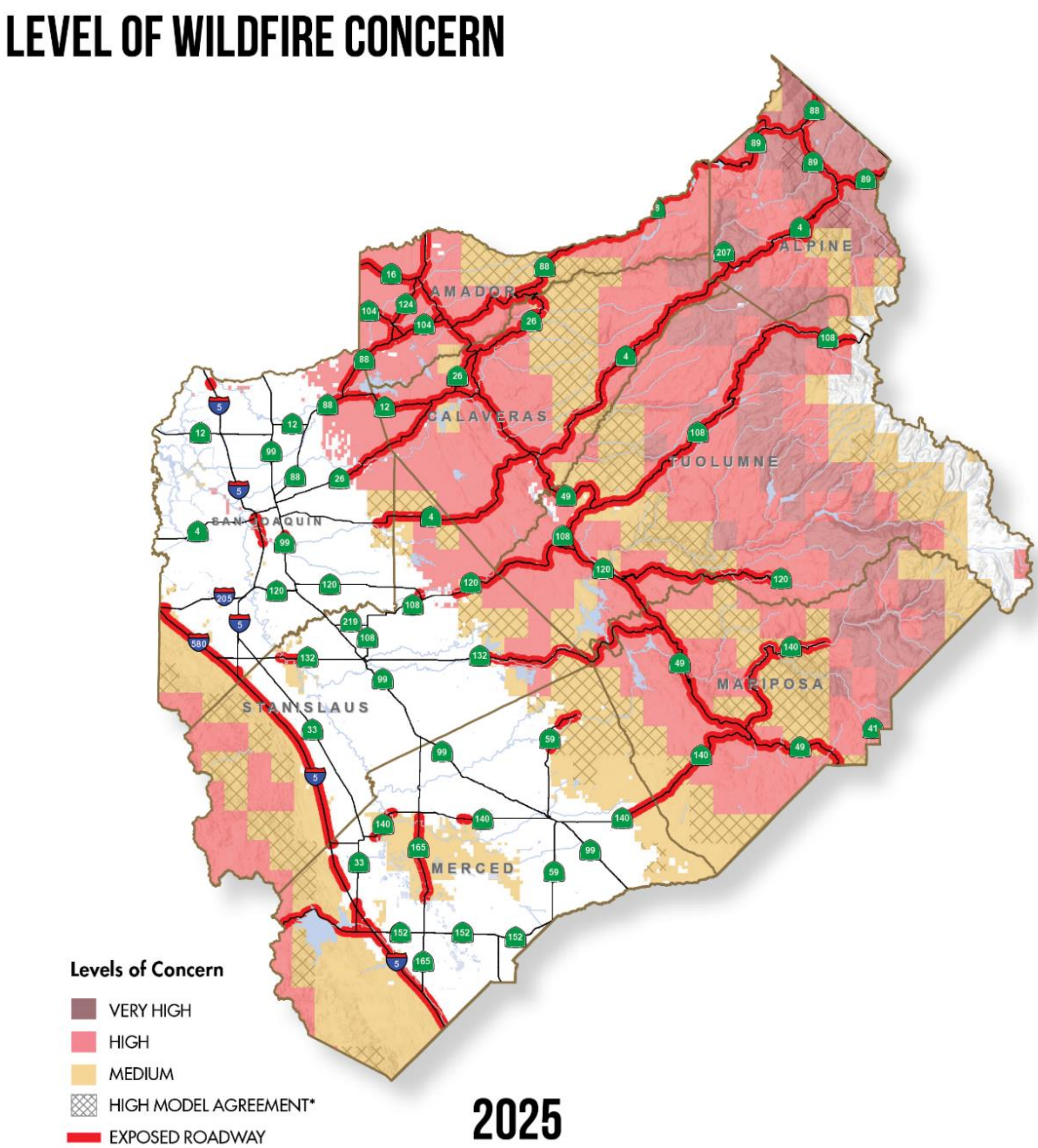
NOTE: PART OF MARIPOSA COUNTY LIES IN DISTRICT 6. THESE MILEAGE TOTALS ARE NOT INCLUDED HERE.

TABLE 3: CENTERLINE MILES OF HIGHWAY EXPOSED TO MEDIUM TO VERY HIGH WILDFIRE CONCERN UNDER THE RCP 8.5 SCENARIO

District 10	2025			2055			2085		
	Med	High	Very High	Med	High	Very High	Med	High	Very High
Alpine	1.5	23.0	58.2	0.0	22.4	60.3	0.0	35.9	46.8
Amador	8.2	109.8	5.1	12.1	111.0	0.0	0.0	122.9	0.2
Calaveras	17.4	124.3	5.4	5.2	141.2	0.8	7.5	139.6	0.0
Mariposa	48.8	68.1	0.0	3.8	113.1	0.0	2.3	114.6	0.0
Merced	61.6	2.1	0.0	57.6	6.1	0.0	52.6	11.1	0.0
San Joaquin	20.1	19.1	0.0	18.2	20.9	0.0	13.8	25.4	0.0
Stanislaus	45.5	11.3	0.0	28.4	28.4	0.0	36.9	20.0	0.0
Tuolumne	40.7	87.0	24.2	14.8	138.0	3.4	5.7	150.5	0.0
District 10 Totals by Level of Concern and Year	**243.9**	**444.7**	**92.9**	**140.2**	**581.1**	**64.5**	**118.9**	**619.9**	**47.0**
District 10 Total by Year	**781.5**			**785.8**			**785.8**		

NOTE: PART OF MARIPOSA COUNTY LIES IN DISTRICT 6. THESE MILEAGE TOTALS ARE NOT INCLUDED HERE.

FIGURE 14: INCREASE IN WILDFIRE EXPOSURE 2025

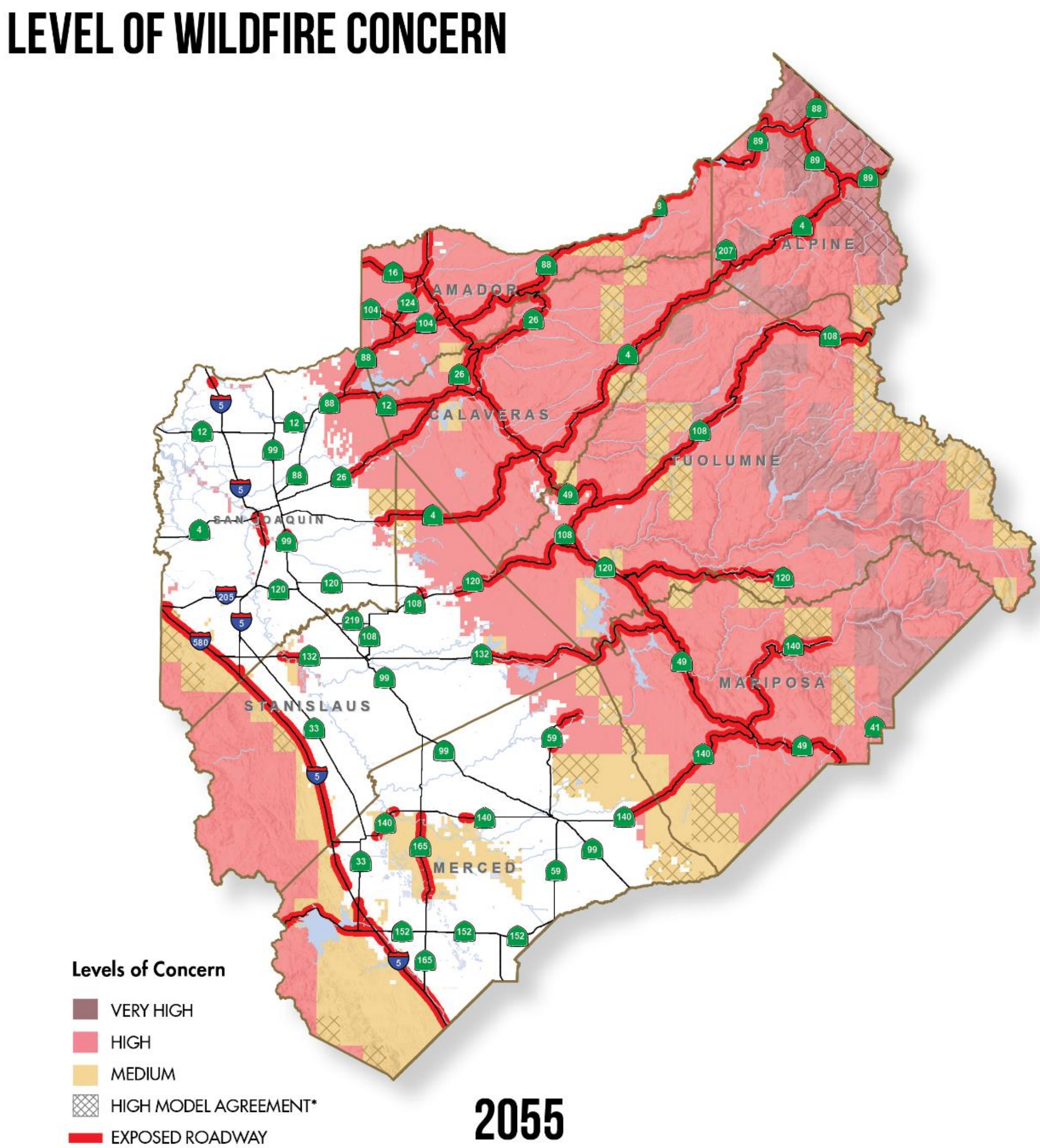


Future Level of Wildfire Concern for the Caltrans State Highway System within District 10, Based on the RCP 8.5 Emissions Scenario

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 5 or more of the 9 models fall under the same cumulative % burn classification as the one shown on the map.

FIGURE 15: INCREASE IN WILDFIRE EXPOSURE 2055

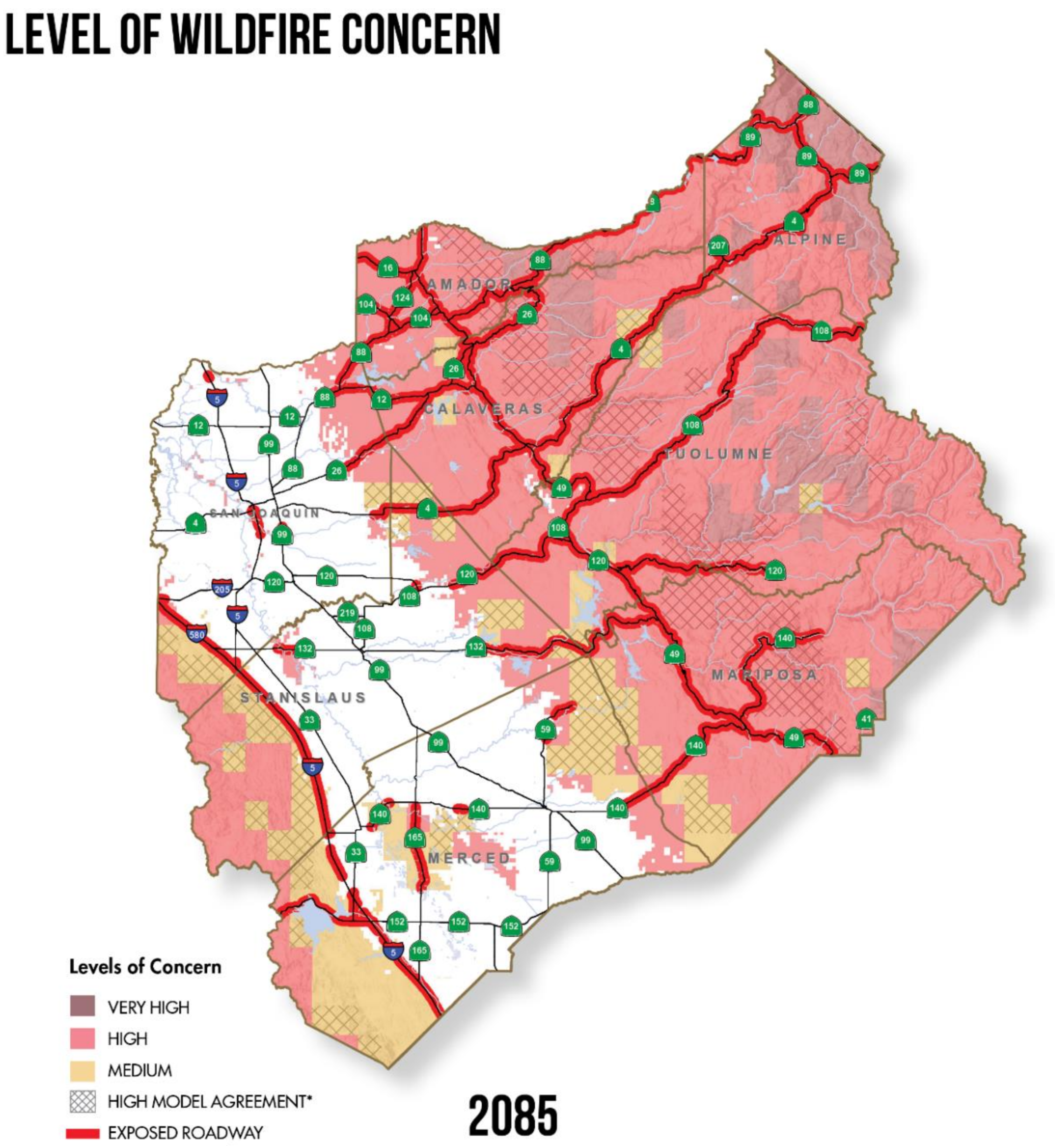


Future Level of Wildfire Concern for the Caltrans State Highway System within District 10, Based on the RCP 8.5 Emissions Scenario

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 5 or more of the 9 models fall under the same cumulative % burn classification as the one shown on the map.

FIGURE 16: INCREASE IN WILDFIRE EXPOSURE 2085



Future Level of Wildfire Concern for the Caltrans State Highway System within District 10, 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 5 or more of the 9 models fall under the same cumulative % burn classification as the one shown on the map.

7. SEA LEVEL RISE IN THE DELTA

Before it became the focus for residential and commercial development, the Sacramento-San Joaquin River Delta (the Delta) was a dynamic area, continually shifting due to the influence of the river and tides. It was a reedy freshwater marsh with riparian forest lining its stream channels and it was populated by fish, deer, elk, and waterfowl.[43] Since then, the Delta has changed. Starting with the Gold Rush and continuing today, human agriculture and habitation have altered the area forever. Stretches of land were cleared for crops, and levees to protect those crops were constructed from peat and muck in the late 1800s. Water from the Delta was systematically diverted for irrigation and household use, and today more than half of the water that once flowed through the Delta is diverted for human purposes.[44] Flooding was and still is relatively common in the Delta, and about 100 levee failures have occurred since 1890. These failures furthered attempts to use engineered strategies to protect the area, including additional levee construction. Today, the Delta is made up of about 55 islands, predominantly used for agriculture, which are protected by over 1,000 miles of levees.[45] The short-term benefits of the engineered solutions may be outweighed by the long-term challenges they have caused—soil erosion, settling, and oxidation[46] have resulted in land subsidence throughout the Delta. Historically, delta islands were slightly above or near sea level—now large areas are up to 15 feet below it.[47]

As subsidence continues and sea levels rise, flooding in the Delta, and its potentially devastating impacts, have become a major concern. The levees have promoted agriculture, community-building, and infrastructure development in flood-prone areas, and they are aging---in some cases, outdated. Their heights may not provide adequate protection against higher flood levels. This all becomes especially problematic given the subsidence of delta islands, which is expected to continue without proper mitigation. Subsidence reduces levee heights and may increase the floodplain size and water depth during flood events.[48] The flood-prone areas of the Delta are largely reliant on the levee system for flood protection, but recent estimates find that protection is adequate for only about half of the Delta.[49]

The lack of available inventory data on the levee system leads to uncertainty about the adequacy of these levees to provide protection, and this is exacerbated by the complexities of levee ownership and responsibility. The State of California is responsible for maintaining and regulating only a third of Delta levees, while the remaining are split among 70 local reclamation districts.[50] The U.S. Army Corps of Engineers, in partnership with the Department of Water Resources, conducts periodic inspections of

[43] U.S. Geological Survey. "Sacramento-San Joaquin Delta." N.d. Last accessed July 17, 2019, https://pubs.usgs.gov/circ/circ1182/pdf/11Delta.pdf
[44] Delta Stewardship Council. Delta Plan Executive Summary. 2013. Last accessed July 17, 2019, http://deltacouncil.ca.gov/sites/default/files/documents/files/Delta_Plan_Executive_Summary_2013.pdf.
[45] Ibid.
[46] Exposure to oxygen accelerates the decay of organic matter and peat soil, leading to soil loss and subsidence.
[47] Delta Plan Executive Summary. Delta Stewardship Council. 2013. Last accessed July 17, 2019, http://deltacouncil.ca.gov/sites/default/files/documents/files/Delta_Plan_Executive_Summary_2013.pdf.
[48] U.S. Geological Survey. op cit.
[49] Delta Stewardship Council. op cit.
[50] Ibid.

district levees as part of the Corps' Levee Safety Program.[51] But of the 6,500 miles of levees in the Central Valley, only 1,760 are in the Corps' program.[52] And out of 27 recent levee inspections in the Delta, 24 received a rating of "unacceptable." [53] In addition to age and subsidence, levees can be affected by burrowing mammals and crabs, which undermine the levees structure. If levee failure occurred due to flooding from storm events, sea level rise, or of some combination, the effects could be significant throughout the Delta.

A Climate Central analysis found that sea level rise impacts and overtopping levees could be particularly severe not just for the Delta, but also for the cities of Sacramento and Stockton. These cities are highly populated urban areas, with some portions only a foot above sea level.[54] The study found that in Sacramento, 22,808 people live in areas that would be at risk with three feet of sea level rise—14,628 of these people were identified as being in high-vulnerability populations (low income and ethnic minorities). Also at risk in Sacramento are 86 road miles and 10,600 homes.[55] The numbers are higher in Stockton, with 54,986 people vulnerable to sea level rise—32,699 of whom are in high-vulnerability populations.[56] In Stockton, $5.1 billion in property, 168 road miles, and 32 EPA-listed contaminated sites would also be at risk.[57] These statistics are in part based on the assumption that levees and other barriers do not provide adequate protection which, as noted, is a significant unknown.

The levee system is also important to the SHS, which traverses the Delta and connects Sacramento, Stockton, and other neighboring cities. The SHS sits atop levees in parts of the Delta and is elevated on viaducts in others, but there is a significant network that extends through low-lying farmland and suburban neighborhoods. These areas could be increasingly vulnerable to flooding and its associated damage, especially considering the potential for subsidence and sea level rise. Portions of SR 160, SR 12, SR 4, and I-5, among others, traverse levee-protected areas. These routes are critical for transporting agricultural products and providing Bay Area access for residents and other travelers. Given the high level of importance of the SHS in and around the Delta, Caltrans has included the potential for sea level rise in the District 10 vulnerability assessment. This assessment will help Caltrans identify which routes may be vulnerable to inundation, scour, erosion, or other effects due to higher water levels.

This analysis used sea level models developed by Climate Central, which identify potential flooding conditions if levees and flood control barriers[58] do remain resilient, and the expected conditions if they do not. The results of this analysis for 1.64, 3.28, and 5.74 feet of sea level rise (0.5, 1.00, and 1.75 meters respectively) are shown below. Two types of inundation are presented, "sea level rise inundation," which assumes that levees and other barriers are both high and strong enough to effectively stop the flow of water, and "levee protected areas," which identifies land areas at risk if

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[51] U.S. Army Corps of Engineers. "Levee Safety Program." N.d. Last accessed July 17, 2019, https://www.spk.usace.army.mil/Missions/Civil-Works/Levee-Safety-Program/

[52] U.S. Army Corps of Engineers, "Corps Releases Inspection Ratings for Seven Delta Levee Systems." June 26, 2013. Last accessed July 17, 2019, https://www.spk.usace.army.mil/Media/News-Releases/Article/479329/corps-releases-inspection-ratings-for-seven-delta-levee-systems/

[53] National Levee Database. US Army Corps of Engineers. December 18, 2018. Last accessed July 17, 2019, https://levees.sec.usace.army.mil/

[54] Climate Central. "Sacramento and Stockton Face Biggest Sea Level Rise Threat in California."op cit.

[55] Ibid.

[56] These values include areas that are currently flood protected by levees. Excluding these areas, the estimates for Stockton are: 10,334 people in the path of sea level rise, 5,469 of which are high vulnerability.

[57] Climate Central. "Sea level rise and coastal flood exposure: Summary for Stockton, CA."
Surging Seas Risk Finder file created July 21, 2016. Last accessed July 17, 2019,
http://ssrf.climatecentral.org.s3-website-us-east-1.amazonaws.com/Buffer2/states/CA/downloads/pdf_reports/Town/CA_Stockton-report.pdf

[58] Barriers are not exclusively levees, but "walls, dams, ridges, or other features that protect or isolate some areas, e.g., block hydrologic connectivity." See http://sealevel.climatecentral.org/ for more information.

levees and other barriers were to fail. Flooding risks posed to the SHS are highlighted for regular inundation extents and are summarized below.

7.1. Sea Level Rise Inundation in District 10

Table 4 summarizes the centerline mileage of the SHS in District 10 that sea level rise could inundate or otherwise impact (e.g., through erosion or washouts). This data assumes that levee protection is adequate to protect against higher water levels. The mileage summary includes bridges on the SHS that may be overtopped or otherwise exposed to conditions that could affect their long-term viability, including increased scour and erosion, and a higher water table. These areas may require additional analysis to determine whether the bridges are at risk.

TABLE 4: CENTERLINE MILES OF STATE HIGHWAY SYSTEM INUNDATED BY DELTA SEA LEVEL RISE

	Sea Level Rise Height			
District 10 County	**0 ft**	**1.74 ft (0.50 m)**	**3.28 ft (1.00 m)**	**5.74 ft (1.75 m)**
San Joaquin	0	0.27	0.30	13.88

NOTE: SOME MILEAGE SUMMARIZED FOR DISTRICT 10 INCLUDES PORTIONS OF THE NETWORK THAT OVERLAP WITH OTHER DISTRICT BOUNDARIES.

If all levees and flood control structures provide adequate flood protection, only small segments of Interstate 5 and SR-12 could experience isolated impacts from sea level rise of 1.74 and 3.28 feet. These areas are mainly bridges where the SHS crosses waterways. The OPC's "likely range" projections show a 66% chance of 1.74 feet of sea level rise happening by 2060. Using more conservative estimates, 1.74 feet of sea level rise could happen sooner—sometime between 2040 and 2050. At 5.74 feet of sea level elevation, large segments of I-5 through San Joaquin County are modeled to flood.

If certain levees and flood barriers failed or provided inadequate protection, sea level rise could also flood large portions of SR 4 and SR 12. It is important to note that this analysis scenario assumes that ALL levees and flood barriers fail, which is highly unlikely. However, it is also important to identify the worse-case scenario so actions can be taken to identify and mitigate potential risks and adequately protect the SHS. Table 5 provides a summary of this analysis, including conditions under zero feet of sea level rise, which identifies the mileage of SHS in District 10 that is currently protected by levees and other barriers.

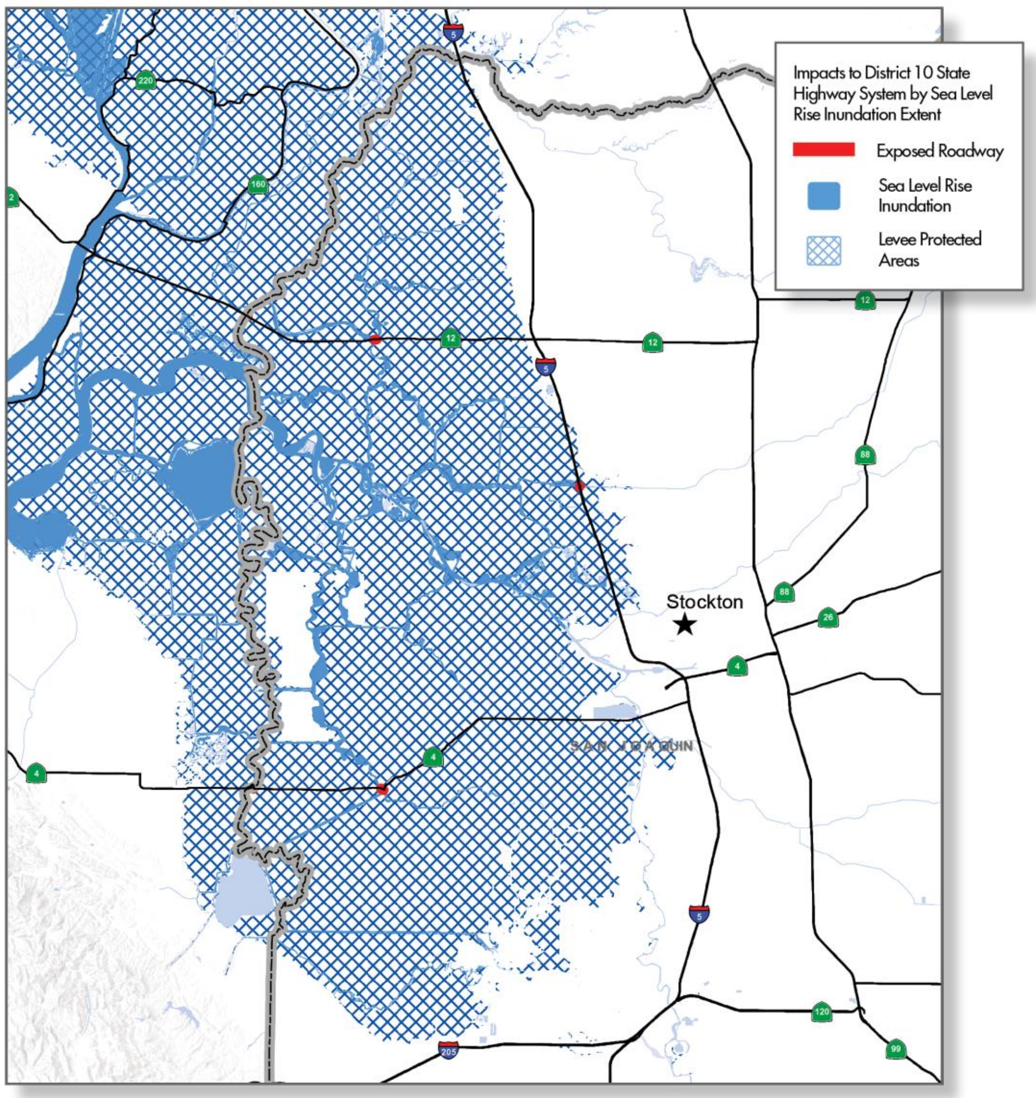
TABLE 5: CENTERLINE MILES OF STATE HIGHWAY SYSTEM VULNERABLE TO INUNDATION IN LEVEE PROTECTED AREAS

	Sea Level Rise Height			
District 10 Counties	**0 ft (0 m)**	**1.64 ft (0.50 m)**	**3.28 ft (1.00 m)**	**5.74 ft (1.75 m)**
San Joaquin	23.1	31.6	35.3	40.5

NOTE: SOME MILEAGE SUMMARIZED FOR DISTRICT 10 INCLUDES PORTIONS OF THE NETWORK THAT OVERLAP WITH OTHER DISTRICT BOUNDARIES. MILES OF EXPOSURE UNDER 0 FT OF SEA LEVEL RISE REPRESENT PARTS OF THE SHS THAT ARE CURRENTLY PROTECTED BY LEVEES/BARRIERS.

FIGURE 17: INUNDATION FROM SEA LEVEL RISE OF 1.64 FEET (0.50 METERS)

SEA LEVEL RISE INUNDATION IN THE DELTA



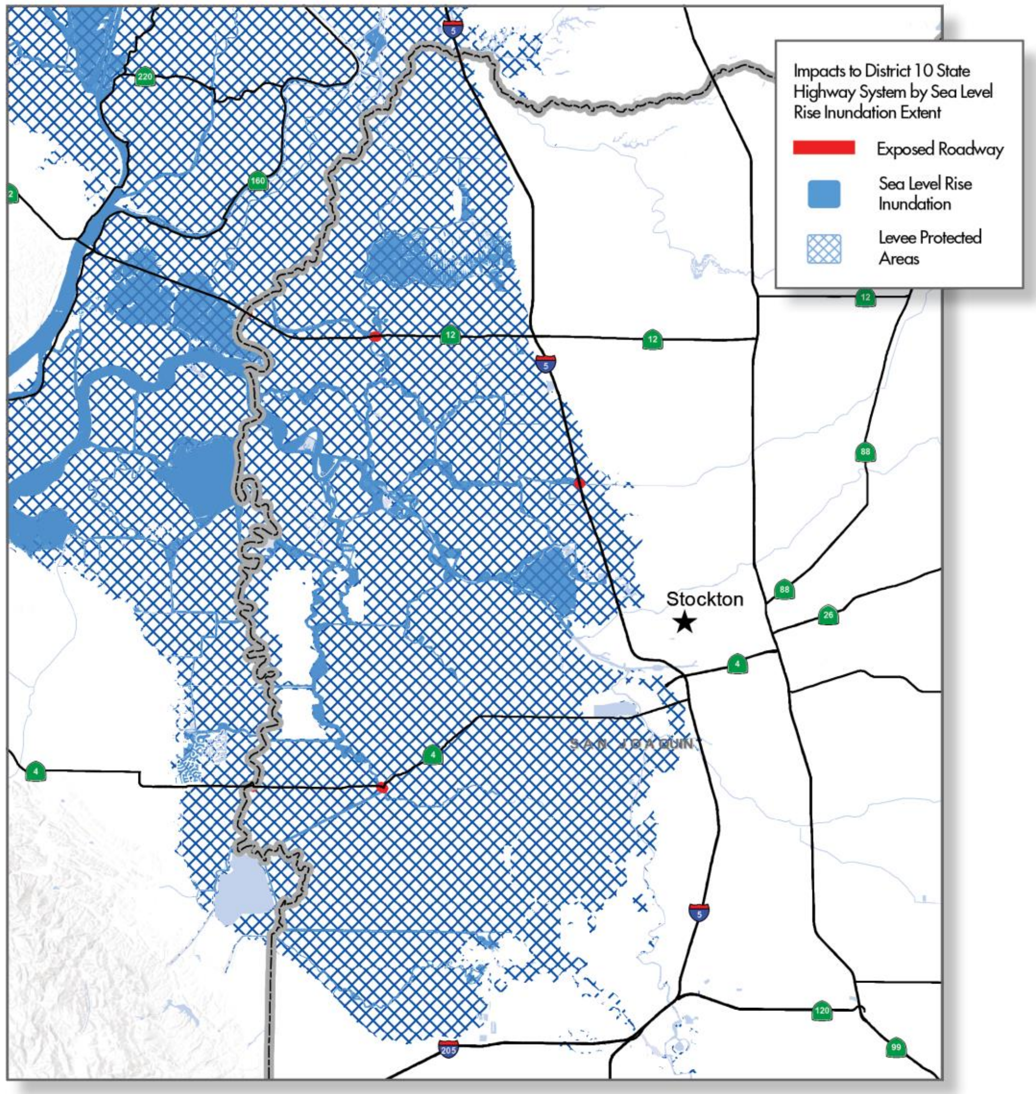
1.64 FT (0.5 M)

Sea Level Rise Inundation of the Caltrans State Highway System in District 10

Delta sea level rise data was provided by Climate Central. Shapefiles represent inundation at the National Oceanic and Atmospheric Administration (NOAA) mean high higher water (MHHW) tidal datum for the Sacramento-San Joaquin River Delta. The following increments of sea level rise were provided: 0.0, 0.25, 0.5, 0.75, 1.0, 1.25, 1.5, 1.75, 2, and 5 meters. Levees and other flood control structures, including those that are unmapped that are captured in elevation data, are included in this data and are assumed to provide flood protection. With respect to levees, the "sea level rise inundation extents" show where flooding may occur assuming levees are high and strong enough to provide adequate flood protection. The "levee protected areas" mapping indicates areas that may be inundated if levees failed. These areas are provided in the data to demonstrate the full potential flooding extent if these levees or other barriers were to fail. Data limitations, such as an incomplete inventory of levees and their heights, make assessing adequate protection by levees difficult. See the Surging Seas Risk Zone Map for more information.See the Surging Seas Risk Zone Map for more information.

FIGURE 18: INUNDATION FROM SEA LEVEL RISE OF 3.28 FEET (1.00 METER)

SEA LEVEL RISE INUNDATION IN THE DELTA



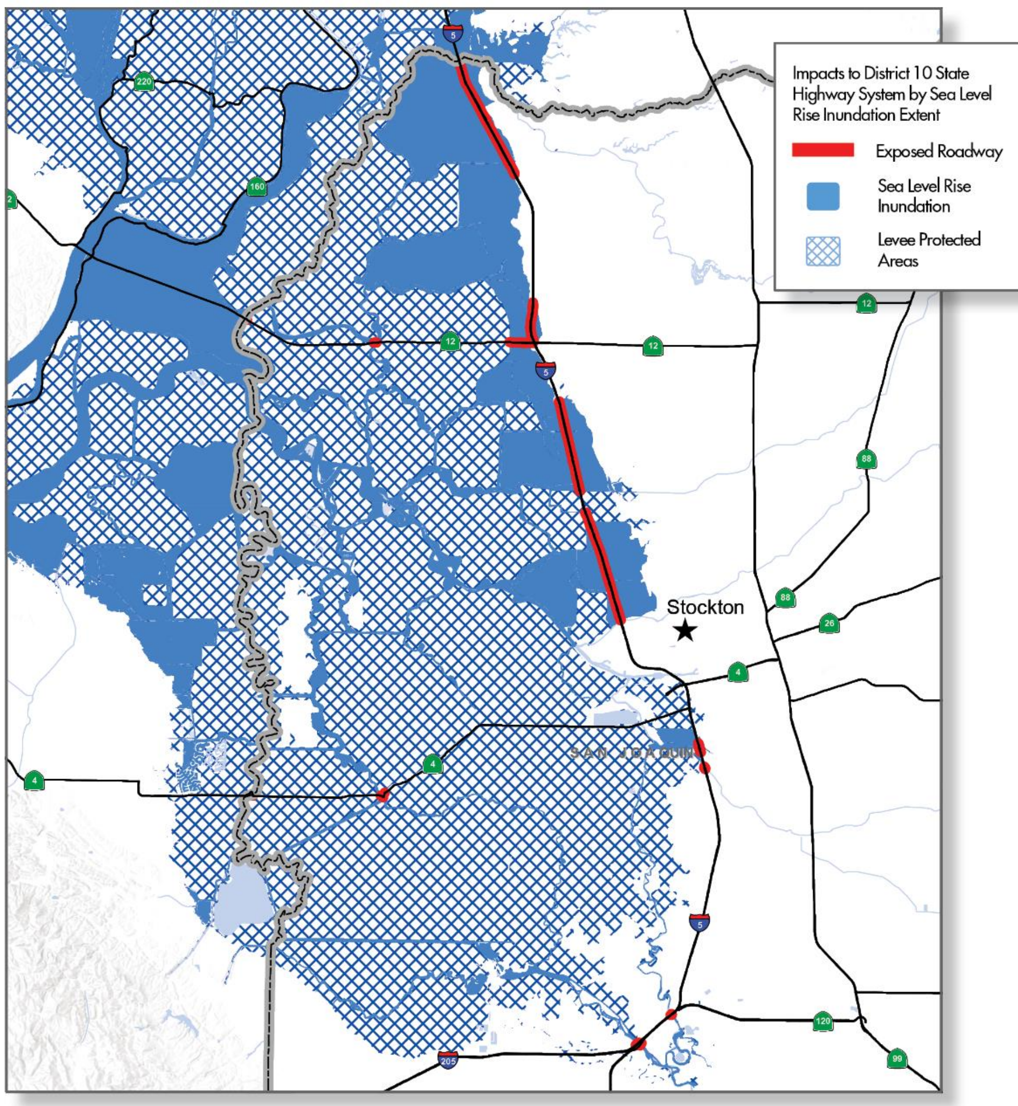
3.28 FT (1.00 M)

Sea Level Rise Inundation of the Caltrans State Highway System in District 10

Delta sea level rise data was provided by Climate Central. Shapefiles represent inundation at the National Oceanic and Atmospheric Administration (NOAA) mean high higher water (MHHW) tidal datum for the Sacramento-San Joaquin River Delta. The following increments of sea level rise were provided: 0.0, 0.25, 0.5, 0.75, 1.0, 1.25, 1.5, 1.75, 2, and 5 meters. Levees and other flood control structures, including those that are unmapped that are captured in elevation data, are included in this data and are assumed to provide flood protection. With respect to levees, the "sea level rise inundation extents" show where flooding may occur assuming levees are high and strong enough to provide adequate flood protection. The "levee protected areas" mapping indicates areas that may be inundated if levees failed. These areas are provided in the data to demonstrate the full potential flooding extent if these levees or other barriers were to fail. Data limitations, such as an incomplete inventory of levees and their heights, make assessing adequate protection by levees difficult. See the Surging Seas Risk Zone Map for more information.See the Surging Seas Risk Zone Map for more information.

FIGURE 19: INUNDATION FROM SEA LEVEL RISE OF 5.74 FEET (1.75 METERS)

SEA LEVEL RISE INUNDATION IN THE DELTA



5.74 FT (1.75 M)

Sea Level Rise Inundation of the Caltrans State Highway System in District 10

Delta sea level rise data was provided by Climate Central. Shapefiles represent inundation at the National Oceanic and Atmospheric Administration (NOAA) mean high higher water (MHHW) tidal datum for the Sacramento-San Joaquin River Delta. The following increments of sea level rise were provided: 0.0, 0.25, 0.5, 0.75, 1.0, 1.25, 1.5, 1.75, 2, and 5 meters. Levees and other flood control structures, including those that are unmapped that are captured in elevation data, are included in this data and are assumed to provide flood protection. With respect to levees, the "sea level rise inundation extents" show where flooding may occur assuming levees are high and strong enough to provide adequate flood protection. The "levee protected areas" mapping indicates areas that may be inundated if levees failed. These areas are provided in the data to demonstrate the full potential flooding extent if these levees or other barriers were to fail. Data limitations, such as an incomplete inventory of levees and their heights, make assessing adequate protection by levees difficult. See the Surging Seas Risk Zone Map for more information.See the **Surging Seas** Risk Zone Map for more information.

7.2. Projections of Sea Level Rise for San Francisco

Sea level rise estimates, focused at locations where tidal data is regularly collected, have been developed for California by various agencies and research institutions. For the Delta, the San Francisco gauge was the closest tide gauge used for analysis. Figure 20 presents the estimates recently developed for the San Francisco gauge by a scientific panel for the 2018 update of the State of California Sea-Level Rise Guidance, an effort led by the Ocean Protection Council (OPC).[59] These projections were developed for gauges along the California coast based on global and local factors that drive sea level rise, including thermal expansion of ocean water, glacial ice melt, and the expected amount of vertical land movement.

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

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

Each of these values is presented below for both low (RCP 2.6) and high (RCP 8.5) emissions scenarios to show the full range of projections over time—note that the assumptions for global emissions associated with the RCP 8.6 scenario are considered "business-as-usual" that is, society continues a continuing trend of emitting GHGs into the atmosphere at alarming levels. The OPC guidance provides estimates derived for the RCP 8.5 scenario until 2050, and for both scenarios through 2100. Given the uncertainty inherent in any modeling result, the OPC recommends assessing a broad range of future projections through a scenario analysis before making investment decisions for projects. Guidance is provided for when it is best to consider certain projections for projects of varying risk aversion, since some projects have greater consequences and impacts if affected by sea level rise. The ranges include:

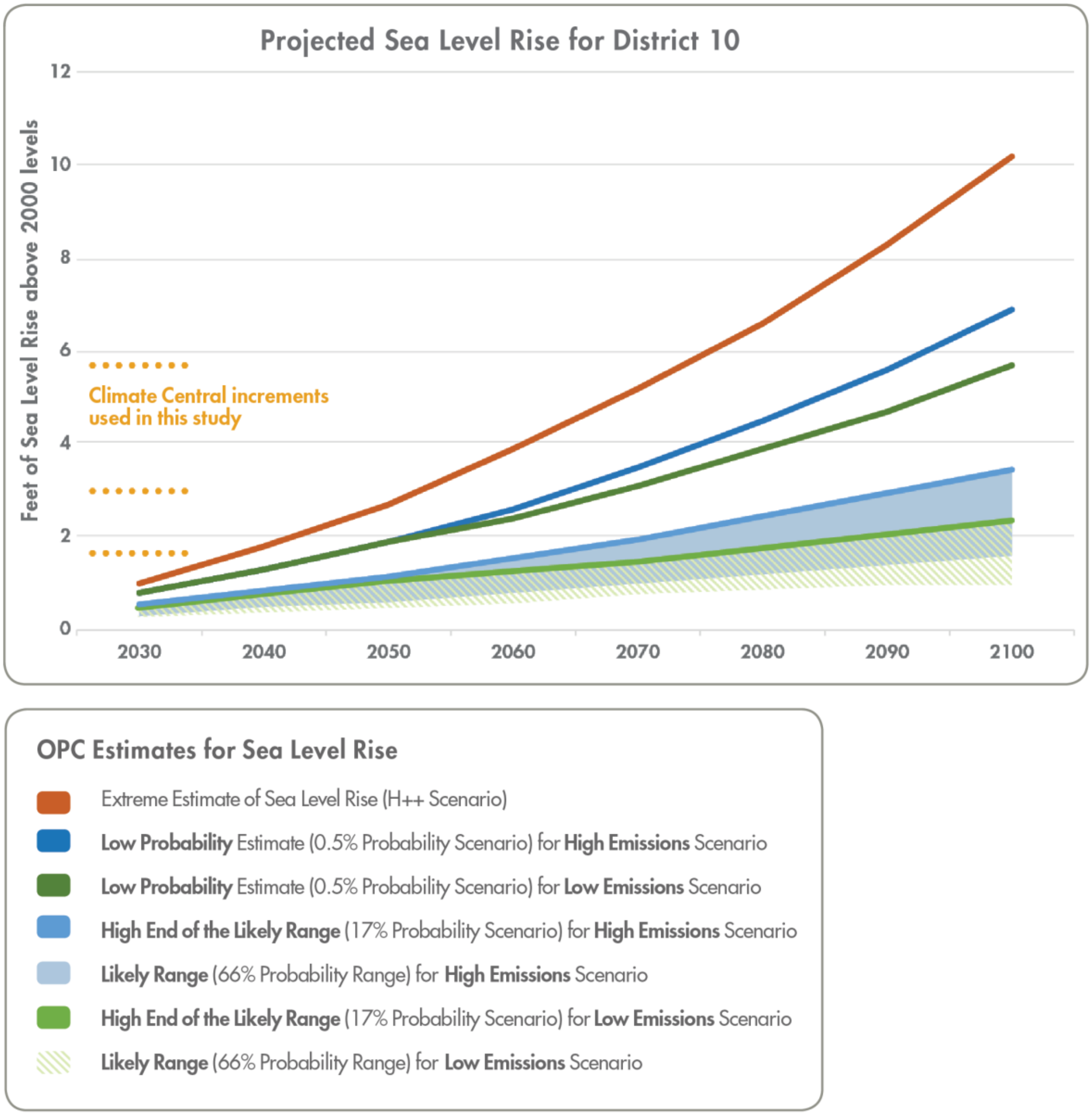
- For low-risk aversion decisions (for projects with few consequences, a short lifespan, or low cost), the OPC recommends using the likely (66%) probability sea level rise range estimate. This range is shown in light blue for the RCP 8.5 scenario and light green for RCP 2.6 in the graphic below.
- For medium to high-risk aversion decisions (for projects with higher potential risk, more significant consequences, a long lifespan, or high costs), the OPC recommends using the low (0.5%) probability scenario. This value is shown in dark green for RCP 2.6 and in dark blue for RCP 8.5 in the graphic below.
- For high-risk aversion decisions (for projects where risks are significant, and consequences could be catastrophic), the OPC recommends considering the extreme (H++) scenario. This projection is shown in dark orange in the graphic below.

[59] Ocean Protection Council. "State of California Sea Level Rise Guidance: 2018 Update." 2018. Last accessed July 17, 2019, http://www.opc.ca.gov/webmaster/ftp/pdf/agenda_items/20180314/Item3_Exhibit-A_OPC_SLR_Guidance-rd3.pdf

The OPC guidance was developed to help state and local governments understand the potential future risks associated with sea level rise and incorporate this understanding into work efforts, investment decisions, and policy mechanisms. The OPC recognizes that the science surrounding sea level rise projections is still improving and anticipates updating the guidance at least every five years to incorporate the best current information. Accordingly, Caltrans will always use the best-available sea level rise projections and associated guidance and incorporate them into its policies to help ensure the best capital investment decisions for its projects.

Identifying specific sea level rise height projections can be helpful when reviewing modeling results. Sea level rise heights of 1.64, 3.28, and 5.74 feet (0.5, 1.00, and 1.75 meters, respectively) are shown in Figure 20, which correspond to the Climate Central increments used in this sea level rise analysis. In referencing these specific heights, and the estimates for sea level rise in OPC's guidance document, Caltrans can identify the full range of projections to consider for its capital projects. For example, 3.28 feet of sea level rise is projected to occur around mid-century (2060) under the H++ scenario, or around 2130 under the high-emissions median scenario. Given the uncertainty regarding the rate of sea level rise, especially after mid-century, a wide range of projections needs to be considered. Caltrans plans to develop a policy for how best to incorporate these estimates and OPC guidance into its processes and procedures.

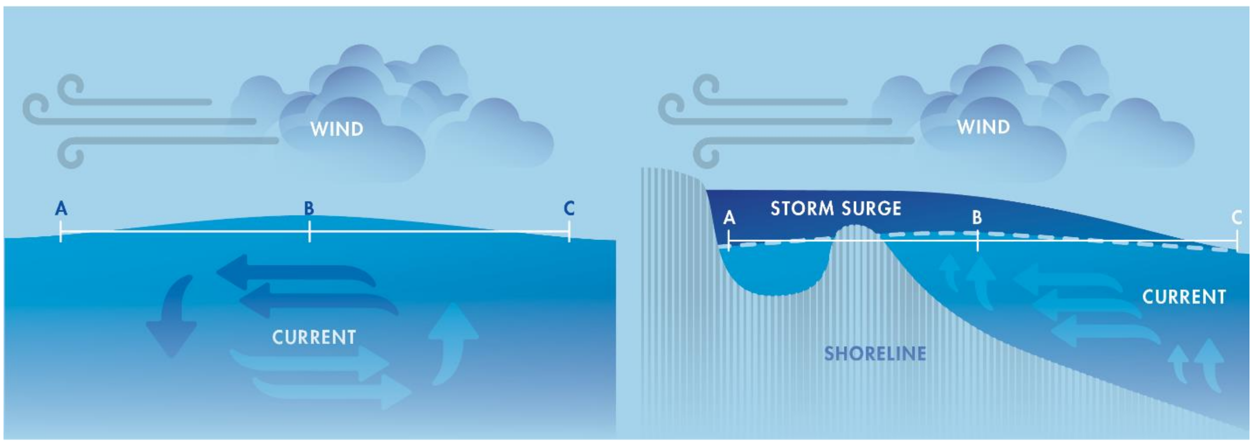
FIGURE 20: PROJECTED SEA LEVEL RISE FOR SAN FRANCISCO BAY



8. STORM SURGE IN THE DELTA

As seas rise and move inland over low-lying areas, there is a greater potential for storm surge due to meteorological events to become more devastating. Storm surge is defined as “an abnormal rise of water generated by a storm, over and above the predicted astronomical tide.”[60] Surges are caused primarily by strong winds during a storm event that cause “vertical circulation” by pushing water forward. In deep water the effect is minimal, but when the storm reaches shallower water or coastline, the disrupted circulation pushes water onshore.[61] Figure 21, developed by the National Oceanic and Atmospheric Administration (NOAA), shows how wind-driven events create a surge at the coastline and inland.

FIGURE 21: VERTICAL CIRCULATION DURING A STORM EVENT (NOAA)



Surge events are typically not as frequent or devastating for the West Coast as hurricanes and nor’easters are along the Gulf of Mexico and the Atlantic coast line but they can still raise sea levels during severe winter storms. Heavy rain during these events can also contribute to coast line flooding. Higher river levels can channel additional water into affected areas, where it flows into coastal waters. This type of combined water flow could significantly impact the Delta, where the San Joaquin and Sacramento Rivers meet and then flow through the Central Valley’s one natural outlet, the Carquinez Strait. Storm surge moving inland, combined with water flows moving seaward, could lead to even higher water levels in the Delta and San Francisco Bay.

An analysis of the potential effects of sea level rise, combined with storm surge in the Delta, was completed using data from the 3Di model developed by John Radke (et al.) of University of California, Berkeley.[62] 3Di is a three-dimensional hydrodynamic model that simulates water movement during flood events based on observed water levels from a past near-100-year storm event.[63] Three future water

[60] National Oceanic and Atmospheric Administration. “Introduction to Storm Surge.” N.d. Last accessed July 17, 2019, https://www.nhc.noaa.gov/surge/surge_intro.pdf

[61] Ibid.

[62] Cal-Adapt. “Sea Level Rise CalFloD-3D.” 2018. Last accessed July 17, 2019, http://cal-adapt.org/data/slr-calflod-3d/

[63] Radke, J. D., G. S. Biging, M. Schmidt-Poolman, H. Foster, E. Roe, Y. Ju, O. Hoes, T. Beach, A. Alruheil, L. Meier, W. Hsu, R. Neuhausler, W. Fourt, W. Lang, U. Garcia I. Reeves (University of California, Berkeley). 2016. Assessment of Bay Area Natural Gas Pipeline Vulnerability to Climate Change. California Energy Commission. Publication number: CEC-500-2017-008

levels associated with sea level rise were used as the baseline water elevation and combined with the identified storm event to determine future surge levels. The levels used were 1.64, 3.28, and 4.62 feet (or 0.50, 1.00, and 1.41 meters, respectively), and, except for the highest, they align with the sea level rise data used in the previous section. The different methodologies and inputs used in each model result in different outcomes for what parts of the SHS may be exposed, and when. The resulting flood impacts are identified in the sections below. This can be noted by comparing Table 4 and Table 5 in the previous section with the table below. The Climate Central (sea level rise) regular inundation data provides much higher estimates than the 3DI (surge) data, despite the expectation that the area exposed to sea level rise and storm surge should be greater. This is a product of working with two different models, each with their own methodologies and variables, which can create different results.

8.1. Storm Surge Flooding in District 10

Table 6 summarizes the centerline miles of the District 10 SHS that could be flooded by a 100-year storm event, given 1.74, 3.28, or 4.62 feet of sea level rise, as identified by the 3Di model. As with levee protected areas, current conditions are represented by the “no sea level rise” or zero feet of sea level rise. This summarizes the estimated mileage of SHS in District 10 that could flood under a 100-year storm event today.[64]

TABLE 6: CENTERLINE MILES OF STATE HIGHWAY SYSTEM FLOODED BY SEA LEVEL RISE AND SURGE

	Sea Level Rise Height			
District 10 County	**0 ft (0 m)**	**1.64 ft (0.50 m)**	**3.28 ft (1.00 m)**	**4.62 ft (1.41 m)**
San Joaquin	0.74	0.80	5.25	10.45

NOTE: SOME MILEAGE SUMMARIZED FOR DISTRICT 10 INCLUDES PARTS OF THE SHS IN SACRAMENTO COUNTY THAT OVERLAP WITH THE DISTRICT BOUNDARY. MILEAGE UNDER 0 FEET OF SEA LEVEL RISE REPRESENTS THE AREAS OF THE SHS THAT COULD FLOOD GIVEN A PRESENT DAY 100-YEAR STORM.

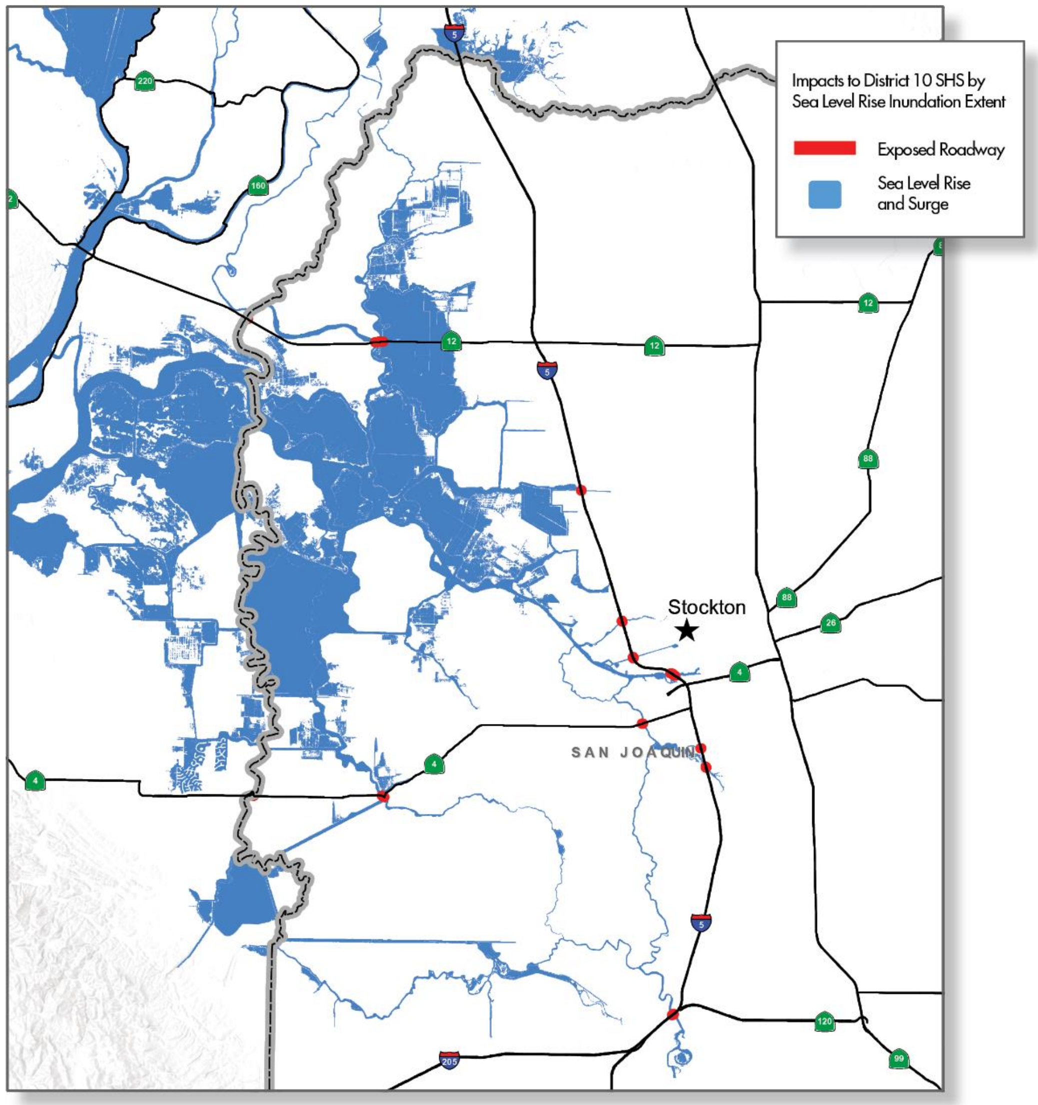
Assuming 1.74 feet of sea level rise and a 100-year storm the model projects that isolated sections on I-5 and State Routes 4, 12 and 120 may temporarily flood and/or suffer storm surge damage. With 3.28 feet of sea level rise, I-5 could flood along longer segments, with the same happening to SR 12. Under the highest sea level rise scenario modeled (4.62 feet), a much longer section of I-5 and SR 12 might flood or be otherwise impacted.

It should be noted that significant uncertainties inherent in flood modeling suggest some caution in accepting these projections as “ground truth.” Future research on the implications of long-term flooding in the Delta is necessary. However, for the purposes of identifying future areas of potential vulnerability, the information provided in Table 6 and the maps on the following pages provides a useful sense of what might be expected in District 10.

[64] 100-year storm water levels are based on one event in February 1998. Therefore, “zero meters” of sea level rise accounts for sea level rise that has occurred up to 1998.

FIGURE 22: FLOODING FROM SURGE AND SEA LEVEL RISE OF 1.64 FEET (0.50 METERS)

FLOODING FROM STORM SURGE IN THE DELTA



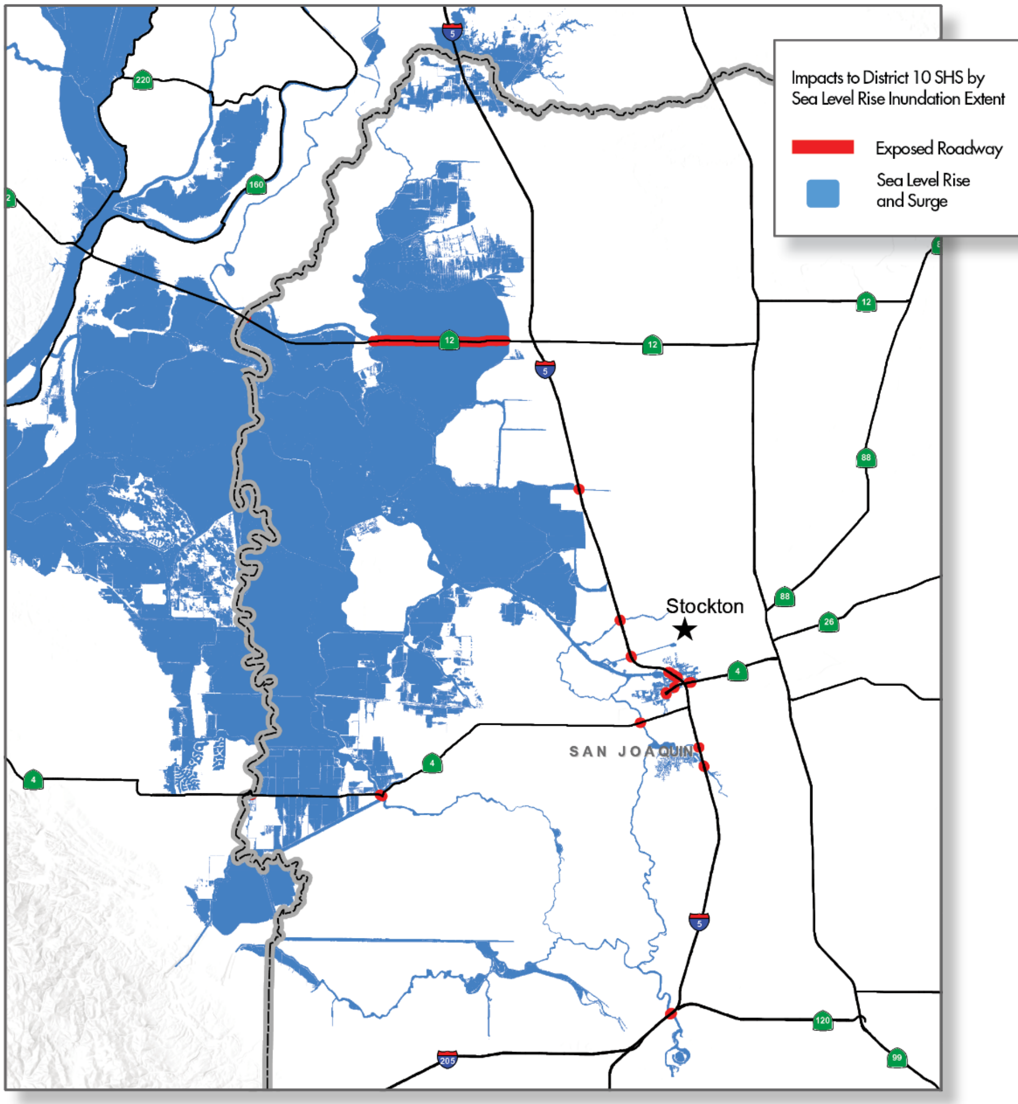
1.64 FT (0.5 M)

Flooding of the Caltrans State Highway System in District 10 given the 100-Year Storm Event and Sea Level Rise

Delta sea level rise and storm surge data are from the 3Di modeling conducted by Dr. John Radke's team at the University of California, Berkeley and featured on the Cal-Adapt website. 3Di is a three-dimensional hydrodynamic model that captures the dynamic effects of flooding from storm surge. The Sacramento-San Joaquin Delta data are based on a near 100-year storm event coupled with 0.0, 0.5, 1.0, and 1.41 meters of sea level rise. See Cal-Adapt for more information.

FIGURE 23: FLOODING FROM SURGE AND SEA LEVEL RISE OF 3.28 FEET (1.00 METER)

FLOODING FROM STORM SURGE IN THE DELTA



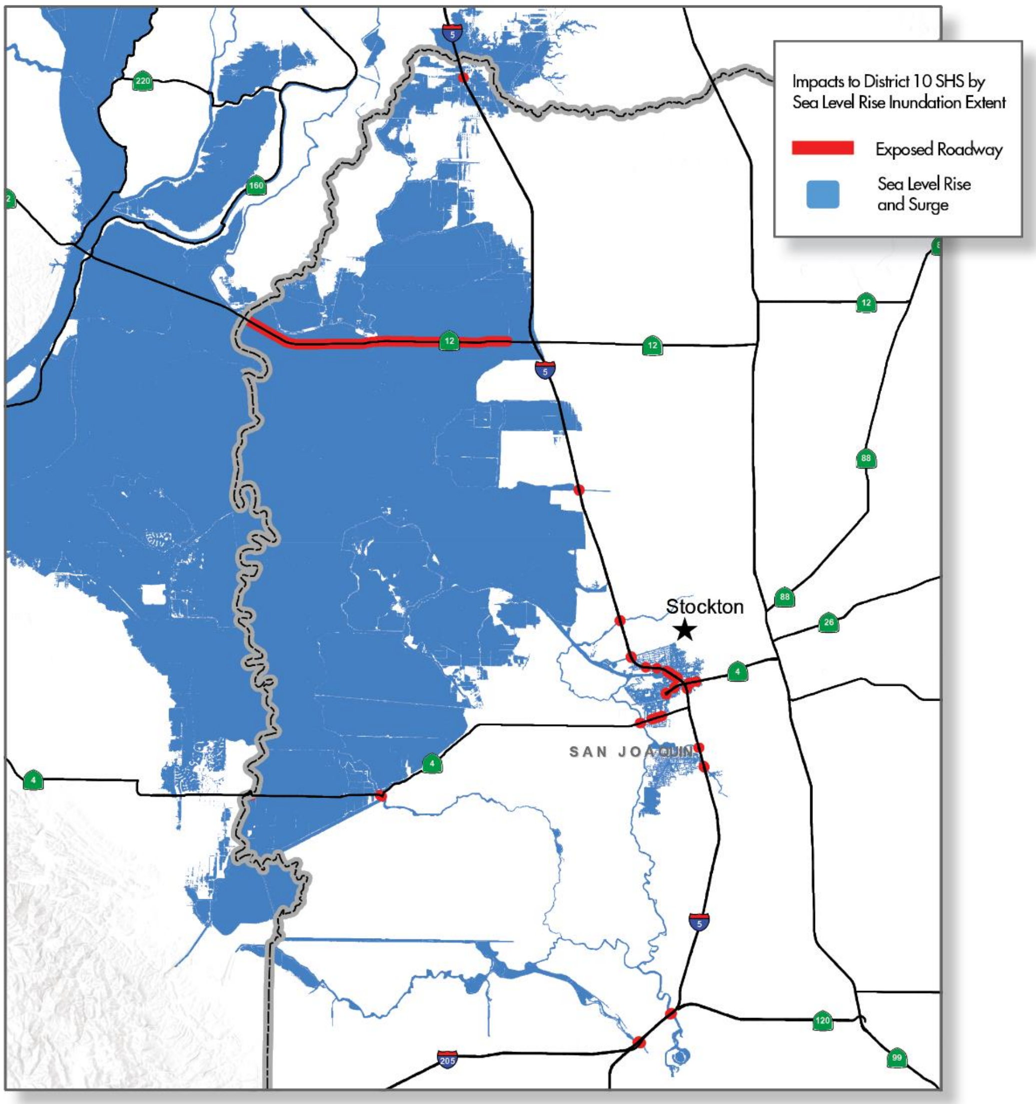
3.28 FT (1.00 M)

Flooding of the Caltrans State Highway System in District 10 given the 100-Year Storm Event and Sea Level Rise

Delta sea level rise and storm surge data are from the 3Di modeling conducted by Dr. John Radke's team at the University of California, Berkeley and featured on the Cal-Adapt website. 3Di is a three-dimensional hydrodynamic model that captures the dynamic effects of flooding from storm surge. The Sacramento-San Joaquin Delta data are based on a near 100-year storm event coupled with 0.0, 0.5, 1.0, and 1.41 meters of sea level rise. See Cal-Adapt for more information.

FIGURE 24: FLOODING FROM SURGE AND SEA LEVEL RISE OF 4.62 FEET (1.41 METERS)

FLOODING FROM STORM SURGE IN THE DELTA



4.63 FT (1.41M)

Flooding of the Caltrans State Highway System in District 10 given the 100-Year Storm Event and Sea Level Rise

Delta sea level rise and storm surge data are from the 3Di modeling conducted by Dr. John Radke's team at the University of California, Berkeley and featured on the [Cal-Adapt] website. 3Di is a three-dimensional hydrodynamic model that captures the dynamic effects of flooding from storm surge. The Sacramento-San Joaquin Delta data are based on a near 100-year storm event coupled with 0.0, 0.5, 1.0, and 1.41 meters of sea level rise. See [Cal-Adapt] for more information.

9. EMERGENCY RESPONSES IN DISTRICT 10

9.1. Ferguson Fire

The Ferguson Fire is a recent example of a wildfire that struck District 10 in California's famed Stanislaus National Forest and Yosemite Valley. The fire burned from July 13, 2018 until it was contained on August 19, 2018, scorching 96,901 acres of land, causing two fatalities and 19 injuries, and destroying 10 structures. It caused an estimated $171 million in damage. Even though the fire was declared contained on August 19th, hotspots continued to smolder within the fire's perimeter well into September.

Numerous communities were placed under mandatory evacuation and all but one entrance to Yosemite National Park were closed. Not only did the fire cause physical damage and result in fatalities and injuries, low-level smoke hampered visibility, grounding aircraft and making it difficult to traverse roads in the affected area. Several roads were closed for approximately one week. Most of these roads were local roads, but Highway 41 was heavily impacted with falling trees, branches, and rock slides. Critically, many of the local roads were the only access into and out of specific sites (e.g., campgrounds) and when threatening fires closed the roads for a limited time, evacuation became almost impossible.

The USA Today, reporting more broadly on all of the 2018 wildfires in the West, noted "battling wildfires year-round is now the norm."[65] This creates significant challenges not only to those firefighting, emergency management staff, and other public agencies that are on the front line, but also to Caltrans who not only has to be concerned about its own staff (and their families), but also how to keep SHS evacuation routes open as long as possible.

FIGURE 25: FERGUSON FIRE NEAR YOSEMITE NATIONAL PARK

PHOTO SOURCE: BLAKE SCOTT, US FOREST SERVICE INCIDENT WEBVIEWER, HTTPS://INCIWEB.NWCG.GOV/INCIDENT/PHOTOGRAPH/5927/14/80306

[65] Lindsay Schnell, USA TODAY, "Battling wildfires year-round is now the norm: How did we get here?" Aug. 8, 2018

9.2. District 10 Emergency Repair Coordination – SR 49 Repairs

District 10 continues to respond to extreme weather impacts and take steps to increase the resiliency of the SHS wherever possible. The following is one example of a collaborative emergency repair response to flood damage in District 10. In March 2018, an atmospheric river event resulted in heavy rains and flash floods. Several washouts and slip-outs occurred on District 10 highways. As a result of the slip-outs on SR 49 in Tuolumne County, hundreds of feet of slope were eroded along the roadway. In other locations, failed cut slopes deposited soil and rock debris on the roadway causing SR 49 to be closed. In response, the District 10 Maintenance Branch coordinated efforts with Caltrans' Headquarters Geotechnical Team, Construction Office, Environmental Office, and a contractor to promptly make the repairs. This group also worked together to address repairs in other locations impacted by the March 2018 event, including damaged culverts on SR 49 in Mariposa County. The emergency repair work in Tuolumne county on SR 49 was completed in May of 2018 and the roadway was reopened for traffic. The emergency repair work on SR 49 in Mariposa county was completed in early August 2018. The work consisted of rebuilding and repairing the failed slope areas and roadway sections, replacing existing damaged culverts and inlets, installing flume down drains at various locations, and overlaying the roadway with asphalt.

These examples of emergency repair work conducted by the District 10 Maintenance Engineering Branch and other offices under Director's Orders are illustrative of the types of actions that will likely occur more frequently in the future. Director's Orders require coordinated actions to ensure that the emergency contracts and subsequent repair work comply with environmental laws and regulations, permit requirements, and all other requirements that are standard for Caltrans projects. The collaborative and team-oriented approach to emergency repairs in District 10 is worth highlighting as it allows for rapid responses to emergencies on District 10-managed roadways.

Figure 26 displays the damage caused on SR 49 in Tuolumne County from the atmospheric rain event.

Figure 27 highlights the repaired road after the District 10-coordinated emergency repair effort.

FIGURE 26: DAMAGE ON SR 49 IN TUOLUMNE COUNTY, MARCH 2018

FIGURE 27: REPAIRED ROADWAY SR 49 IN TUOLUMNE COUNTY, MAY 2018

10. INCORPORATING CLIMATE CHANGE INTO DECISION-MAKING

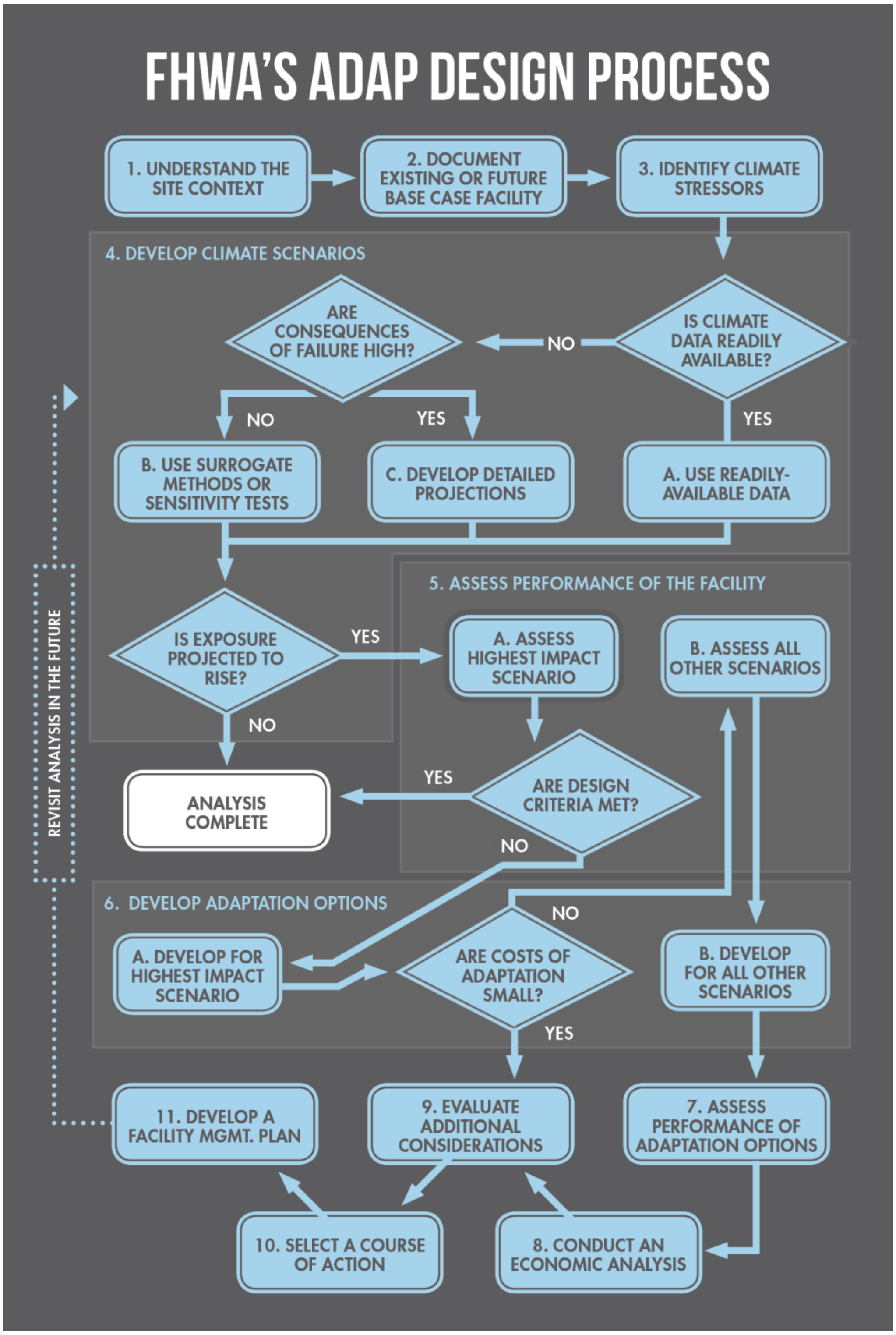
10.1. Risk-Based Design

A risk-based decision approach considers the broader implications of damage and economic loss due to future risks when determining project design. Climate change is a risk factor that is often omitted from design but is important for the functioning of an asset 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 projects to assess climate change and facility design – including the Gulf Coast II project (Mobile, AL) and the Transportation Engineering Approaches to Climate Resiliency (TEACR) study. Both assessed facilities of varying types, examined the impacts of different climate stressors, and then identified design responses that could make the facilities more resilient to these stresses.

One outcome of the FHWA studies was a step-by-step method for completing facility (or asset) design that considered climate change and the inherent uncertainties in the timing and scale of climate change impacts. This method, termed the Adaptation Decision-Making Assessment Process (ADAP),[66] provides facility designers with a recommended approach to designing a facility when considering possible climate change impacts. The key steps in ADAP are shown in Figure 28.

[66] Federal Highway Administration. "Adaptation Decision-Making Assessment Process (ADAP)." January 12, 2018. Last accessed July 17, 2019, https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/teacr/adap/index.cfm

FIGURE 28: 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

The first five steps of the ADAP process cover the characteristics of the project and the context. The District 10 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 such 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 not, other scenarios can be considered. 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. The 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
- Maladaptation,
- Vulnerable populations,
- Natural infrastructure,
- Adaptation options that also mitigate greenhouse gases, and
- Use of flexible approaches where necessary.

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

The District 10 vulnerability assessment is the first step in a multi-part effort to identify SHS exposure to climate change, to identify the consequences and impacts of climate change to the system, and to prioritize actions based upon those impacts. A final prioritization step will be key to identifying which assets are at the greatest risk and should be prioritized first for more detailed, ADAP-style assessments and risk-based design responses.

10.2. Prioritization of Adaptive Response Projects

The project prioritization approach outlined below is based on a review of methods used 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 an event occurring.
- The timeframe at which the events may occur, and the shifting of future risks associated with climate change.

The 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 and 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 these processes tend to be difficult to explain and are open to interpretation among professionals with varying perspectives.
- It should be focused on how transportation agencies 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 that is causing the 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 the larger loss or damage. These should include a few key pieces of information, including:
    - What are the levels for stressors (SLR, surge, wildfire, etc.) where damage and/or loss would occur?
    - 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) include the impacts of the loss of the facility on broader system performance. 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) indicates the probability of events occurring as estimated from the climate data for chosen climate scenarios. Estimates are made for each year out to the end of the facility design life.

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. Various approaches to calculating values for prioritization could be used. One could use indicators that reflect costs to system users. Another approach could be to use a full impact accounting that basically sums all costs to the end of the asset useful life. Annual discounting to reflect “true costs” or current year dollar equivalent values would also be important to calculate the final impact score for the asset.

The prioritization method needs 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 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 the increase in VHT associated with the loss of use of a facility.
- Utilize a traffic model to estimate the impacts on the broader SHS from damage/loss of a facility or facilities anticipated to occur 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. 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 selection of the most effective project given limited project resources.

Table 7 highlights how the method would be implemented, with the project selected in the out years selected by the calculated annual cost metric. The impacts noted in the time period beyond the selected year (shown in shaded color) would be expected to have been addressed by the adaptation strategy. Thus, in the table, Project 1 at year 5 has the highest annual cost associated with disruptions connected to an extreme weather event. The project with the next greatest annual cost is Project 2, where this cost is reached at year 15. The next project is Project 3 at year 35 and the final project is Project 4 at year 45.

TABLE 7: EXAMPLE PROJECT PRIORITIZATION

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

The project prioritization method outlined above requires the development of new approaches to determining how best to respond to climate change risks. It does not rely on existing methods as they do not reflect climate risk effectively. 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. 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.

11. CONCLUSIONS AND NEXT STEPS

This report represents an initial effort to identify areas of exposure to potential climate change stresses on the District 10 SHS. The report included 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 10. The report represented the larger context of climate change at a more localized understanding of what such change might mean to District 10 functions and operations, District 10 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 trends and conditions. 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 SHS. This is an important consideration given that transportation infrastructure investment decisions made today will have implications for decades to come given the long lifetimes for roadway facilities.

This report provides District 10 with information 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 10 and where project development efforts for projects in these areas should consider 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 change risks as a primary decision factor. District 10 staff, with its recent history of assessing long-term risks associated with extreme weather, 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 10 may be to build upon this work and create a more resilient SHS.

11.1. Next Steps

The work completed for this effort answers a few questions and raises many more. The scope of this work focused on determining what is expected in the future and how that may affect the 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 10.

There are a few steps that Caltrans should take to achieve a more resilient SHS in District 10. These include:

Policy Changes

- Agency leadership will need to provide guidance for incorporating findings from this assessment into decision making. Risk-based assessment is a new area 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, Environment, Design, Construction, Maintenance, and Operations.
- The changing elements of climate change require the consideration of the implications of these 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 10.1 Risk-Based Design).

Acquisition of Improved Data for Improved Decision Making

- Determining potential impacts of precipitation on the SHS will require additional system/environmental data to complete a system-wide assessment. This includes:
  - Improved topographic data across District 10 (and California).
  - Improved asset data – including accurate location of assets (bridges and culverts) and information on the waterway openings at these locations.
- The assessment of wildfire potential along the SHS is an ongoing effort. Follow up will be required to determine the results of new research and whether updated models indicate any additional areas of risk.
- The precipitation and temperature data presented in this report is based on 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 more precisely defines expected future changes for these stressors.
- There are efforts underway to refine the understanding of other stressors, including landslide potential. Further refinements of these efforts will require additional investment and coordination. 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 of many steps to address the implications of climate change to the SHS. Much work remains to create a resilient SHS across California.

12. WORKS CITED

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13. GLOSSARY

Median/50th percentile of model outputs: The 50th percentile of downscaled climate model outputs under a particular RCP for the climate metric as calculated over the State of California using the area weighted mean.

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

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

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

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

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

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

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

Inundation: Temporary or permanently flooding. For this report, flooding is typically used to define a temporary condition, where "permanent inundation" is used when sea level rise could lead to an area being primarily underwater.[67]

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

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

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

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

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

[67] Detailed, site-specific analyses would be needed to ultimately determine what would be permanently inundated.

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

Vulnerable populations: "Vulnerable populations include, but are not limited to women; racial or ethnic groups; low-income individuals and families; individuals who are incarcerated or have been incarcerated; individuals with disabilities; individuals with mental health conditions; children; youth and young adults; seniors; immigrants and refugees; individuals who are limited English proficient (LEP); and Lesbian, Gay, Bisexual, Transgender, Queer, and Questioning (LGBTQQ) communities, or combinations of these populations."[68]

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