CALTRANS CLIMATE CHANGE VULNERABILITY ASSESSMENTS

2019

District 3

Technical Report

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ACRONYMS AND ABBREVIATIONS

ADAP	Adaptation Decision-Making Assessment Process
ARCCA	Alliance of Regional Collaborations for Climate Adaptation
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
CMIP	Coupled Model Intercomparison Project
CRC	Climate Readiness Collaborative
DWR	California Department of Water Resources
EPA	US Environmental Protection Agency
FHWA	US Federal Highway Administration
GCM	Global Climate Model
GHG	Greenhouse Gas
GIS	Geographic Information System
IPCC	Intergovernmental Panel on Climate Change
LGC	Local Government Commission
LOCA	Localized Constructed Analogues
MACA	Multivariate Adaptive Constructed Analogs
NOAA	National Oceanic and Atmospheric Administration
NRA	California Natural Resources Agency
OPC	California Ocean Protection Council
RCP	Representative Concentration Pathway
SACOG	Sacramento Area Council of Governments
Scripps	The Scripps Institution of Oceanography
SHS	State Highway System
SRES	Special Report Emissions Scenarios
USFS	US Forest Service

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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 State Highway System (SHS) in Caltrans District 3. 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 climate change on California's natural resources and infrastructure. 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 study has three objectives:

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

The Caltrans study focuses on the 12 Caltrans districts, each facing its own set of challenges regarding future climate conditions and potential weather-related disruptions. The District 3 report is one of 12 district reports that are in various stages of development.

1.1. Purpose of Report

The *District 3 Technical Report* is one of two documents that describe the work completed for the District 3 vulnerability assessment, the other being the *District 3 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 3.

This *Technical Report* provides a more in-depth discussion, primarily for District 3 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, precipitation). Each section presents:

- How that climate stressor is changing,
- The data used to assess SHS vulnerabilities from that stressor,
- The approach in identifying and where necessary developing the data,
- Maps of the portion of district SHS exposed to that stressor,

- And centerline mileage of the 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 development of the District 3 *Technical* and *Summary Report*s were placed in a single database and provided to Caltrans. Caltrans will be able to use this data in their own mapping efforts and technical analyses. This database is expected to be a valuable resource for ongoing resiliency planning efforts. The contents of the District 3 database will also be available to the public in an online interactive mapping tool.[1]

1.2. District 3 Characteristics

Caltrans District 3 covers a portion of central California in the northern Central Valley. The district is made up of 11 counties: Sacramento, El Dorado, Placer, Yuba, Sutter, Yolo, Glenn, Colusa, Butte, Sierra, and Nevada Counties. The area is geographically diverse and includes the Sacramento metropolitan area, agricultural land, low-lying portions of the delta, river valleys and canyons, foothills, the Sierra Nevada mountains, and a portion of the Lake Tahoe Basin.[2]

The district maintains and operates approximately 1,500 centerline miles of SHS.[3] The primary north-south routes of the highway network are Interstate (I) 5 and State Routes (SR) 99, 70, and 149. SR-99 has been identified as the "Farm to Market" corridor of the region, as it connects agricultural areas south of Bakersfield to the Sacramento area. SR-70 and SR-149 are "focus routes," meaning they are high priority routes for goods movement and link rural and urban areas. The primary east-west routes are I-80, US Route (US) 50, and SR-20. I-80 has been targeted as part of a national freight corridor coordination effort, given the high truck volumes on the corridor and difficult winter driving conditions. District 3 is also home to the Port of West Sacramento, which specializes in agricultural and construction cargo.[4] The existing SHS in District 3 is key to moving agricultural goods between rural and urban areas. It supports freight transportation of goods to the port for movement to the Bay Area and international markets, or over the Sierra Nevada mountains for transport east.

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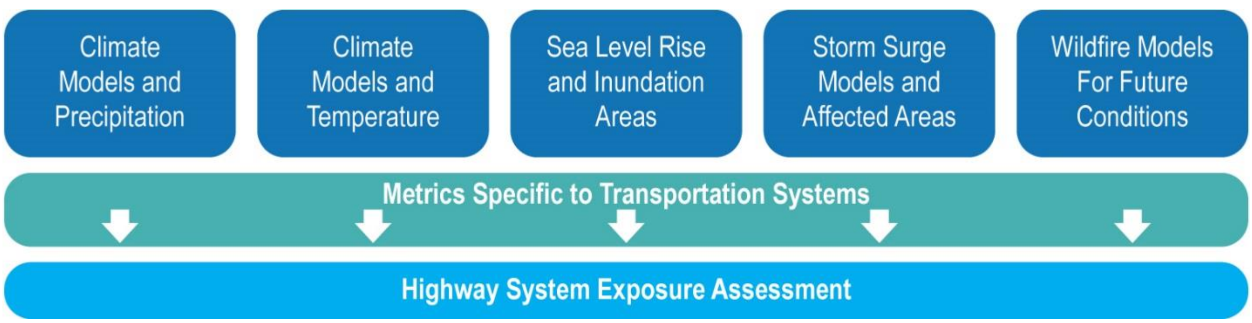
[1] "Vulnerability Assessment," Caltrans, last accessed June 12, 2019, http://www.dot.ca.gov/transplanning/ocp/vulnerability-assessment.html
[2] Caltrans, "Caltrans District 3 Freight Planning Fact Sheet," 2015, http://www.dot.ca.gov/dist3/departments/planning/Systemplanning/D3GMfactsheet.pdf
[3] "District 3 – Marysville/Sacramento," Caltrans, last accessed June 12, 2019, http://www.dot.ca.gov/d3/
[4] Caltrans, "Caltrans District 3 Freight Planning Fact Sheet," 2015, http://www.dot.ca.gov/dist3/departments/planning/Systemplanning/D3GMfactsheet.pdf

2. POTENTIAL EFFECTS FROM CLIMATE CHANGE ON THE STATE HIGHWAY SYSTEM IN DISTRICT 3

Climate and extreme weather conditions in District 3 are changing as rising greenhouse gas (GHG) emissions lead to higher mean and maximum temperatures in California. These changing conditions are anticipated to affect the SHS and other Caltrans assets in District 3. These impacts could appear in a variety of ways and might increase the district infrastructure's exposure to environmental factors that exceed the original design considerations. The project study team, made up of WSP climate and sustainability subject matter experts, considered a range of climate stressors and how they align with Caltrans design criteria/other metrics specific to transportation systems.

Figure 2-1 illustrates the general process for deciding which metrics should be included in the overall SHS vulnerability assessment. First, Caltrans and the project study team considered which climate stressors affect transportation systems. Then, Caltrans and the project study team decided on a relevant metric that the climate stressor data could inform. For example, precipitation data was formatted to show the 100-year storm depth, as the 100-year storm is a criterion used in the design of many Caltrans assets.

FIGURE 2-1: CONSIDERATIONS FOR THE STATE HIGHWAY ASSESSMENT



Extreme weather events already disrupt and damage District 3 infrastructure. The following examples include issues and events that District 3 has addressed in the past through Director's Orders (orders for emergency funds to respond to an event). They provide examples of the types of impacts weather events have on the SHS and how the district responds. These types of impacts may become more prevalent as mean global temperatures rise, drought periods become longer and more severe, precipitation becomes more volatile and larger, wildfires become larger and more frequent, and sea level rises.[5]

- **Temperature –**

  In April of 2017, Governor Jerry Brown declared an end to a five-and-a-half-year drought. Between 2011 and 2017, California experienced its driest and warmest year (2014) since records began, thee second driest and warmest year (2015), and unprecedented low levels of Sierra

[5] Louise Bedsworth et al. (California Governor's Office of Planning and Research, Scripps Institution of Oceanography, California Energy Commission, California Public Utilities Commission), "Statewide Summary Report," *California's Fourth Climate Change Assessment,* Publication number: SUMCCCA4-2018-013, 2018, http://www.climateassessment.ca.gov/state/docs/20190116-StatewideSummary.pdf

Nevada snowpack (2013 – 2015).[6] Recent studies that incorporate projected higher temperatures suggest that droughts like this may become more common if current trends continue.[7]

One of the greatest drought impacts on Caltrans was the resulting massive tree die-off. The Governor proclaimed a state of emergency and required Caltrans and other agencies 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."[8] In response, from 2015 to 2018, Caltrans District 3 removed dead trees within 100 feet of highway centerlines along SR-20, SR-50, SR-80 and US-89 in Nevada, El Dorado, and Placer Counties. The program felled over 5,500 trees for an estimated cost of over ten million dollars. See Figure 2-2 for images of tree mortality along SR-20.

FIGURE 2-2: TREE MORTALITY ON SR-20

- **Precipitation** –

  The winter of 2016/2017 was unusually wet and is an example of the increased precipitation volatility projected for California. In District 3 that year, there was a spike in Director's Orders, mostly in response to rain or snow events. These included a 50-foot slip out (movement of soil or rocks adjacent to a road that affects the road) on Route 128 in Yolo County, embankment failures and slip outs on Route 49 following severe storms, a major slip out on Route 50 near Bridal Veil Falls (which shut down both westbound lanes), and cracking caused by saturated soils on Route 220 in Sacramento County. The 2019 fiscal year so far has also been characterized by higher than average Director's Orders in response to heavy precipitation. Over $7,000,000 has been allocated to respond to drainage damages, slip outs, and stormwater management.

[6] Climate Signals (beta), "California Drought 2011 to 2016," December 4, 2018, http://www.climatesignals.org/headlines/events/california-drought-2012-2016

[7] Louise Bedsworth et. al. (California Governor's Office of Planning and Research, Scripps Institution of Oceanography, California Energy Commission, California Public Utilities Commission), "Statewide Summary Report." *California's Fourth Climate Change Assessment*, SUMCCCA4-2018-013, 2018, http://www.climateassessment.ca.gov/state/docs/20180827-StatewideSummary.pdf

[8] Executive Department, State of California, "Proclamation of a State of Emergency," October 30, 2015, https://www.ca.gov/archive/gov39/wp-content/uploads/2017/09/10.30.15_Tree_Mortality_State_of_Emergency.pdf

FIGURE 2-3: ROUTE 49 SLIP OUT IN SIERRA COUNTY

- **Wildfire** –

  Wildfire extent and severity increase as temperatures rise. The recently released California Fourth National Assessment of Climate Change reported that climate change factors alone roughly doubled the area burned by wildfire in the West between 1984 and 2015.[9] District 3 has been affected by several wildfires in recent years—most notably, the Camp Fire. Given its significance and devastation, the Camp Fire and Caltrans' response are highlighted in the District 3 Summary Report.

  District 3 mitigates wildfire risk in many ways. A district landscape specialist prepares site-specific fire risk plans which provide details on fire risk and vegetation control. District 3 performs annual inspections of fire suppression equipment to ensure its suitability for effective response. When response is necessary, District 3 employs additional traffic signals, detour signage, and other tools to help emergency vehicles and drivers to navigate hazardous areas. The district also prepares for subsequent flooding and landslides with debris control and slope stabilization strategies.

  Of particular concern to District 3 is the disproportionate impacts wildfires have on disadvantaged and low-income communities. Many wildfires occur in rural areas having higher-than-state-average low-income households. Providing transportation options for these households to evacuate when wildfires threaten, as well as providing resources for recovery in these areas, is a challenge to government agencies at all levels.

[9] P. Gonzalez et. al., "Southwest," *In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II, U.S. Global Change Research Program*, pp. 1101–1184. doi: 10.7930/NCA4.2018.CH25, 2018, https://nca2018.globalchange.gov/chapter/25/

- **Sea Level Rise and Storm Surge –**

  To date, there have been no major events in District 3 where sea level rise and storm surge are *known* causes. However, evidence suggests that there is reasons for concern. One major concern is that sea level rise in the Sacramento-San Joaquin Delta could result in upstream impacts in the Sacramento area. However, the SHS itself is relatively isolated from SLR and storm surge except for a few locations along I-5 south of Hood-Franklin. In these very limited areas, rising sea levels could have possible impacts relating to bridge scour given changing river flow characteristics, potential increased corrosion due to higher salinity farther upstream from the brackish delta water, roadway flooding, washout and slip outs, culvert failures, and the like. The District 3 Hydraulics and Stormwater team regularly assess the need for debris basins, debris racks, debris nets, and establishment of a bulking factor for sizing the cross-drainage structures to ensure that culverts are functioning correctly given changing flows.

  Another concern would be other areas in the district affected by SLR and/or storm surge that could indirectly affect the SHS. For example, a recent analysis completed by Climate Central found that there are approximately 3,000 acres in Sacramento under three feet of elevation at the local high tide line that could be flooded by that level of sea level and storm surge. Three feet of sea level rise could affect over 22,000 people and 10,000 homes, and likely cause the SHS to be used in major evacuations and for recovery efforts.[10]

[10] Climate Central, "Sea Level Rise and Coastal Flood Exposure: Summary for Sacramento, CA," Surging Seas Risk Finder, July 21, 2016, http://ssrf.climatecentral.org.s3-website-us-east1.amazonaws.com/Buffer2/states/CA/downloads/pdf_reports/Town/CA_Sacramento-report.pdf

3. ASSESSMENT APPROACH

California has been on the forefront of climate change policy, planning, and research across the nation. State officials have been instrumental in developing and implementing policies that foster effective greenhouse gas (GHG) mitigation strategies and the consideration of climate change in State decision-making. California agencies have also been pivotal in creating climate change data sets that can be used to consider regional impacts across the state. At a more local level, efforts to plan for and adapt to climate change are underway in communities throughout California and in District 3. These practices are key to the development of climate change vulnerability assessments in California and were found to be very helpful in the development of the District 3 report. The sections below provide some background on the current state-of-the-practice in adaptation planning and how specific analysis methods were considered/applied in the District 3 vulnerability assessment.

The Caltrans SHS vulnerability assessment methods used and described in the following pages included coordination with California organizations responsible for climate model and data development. These agencies and research institutions listed in Appendix A.

3.1. Policies

Various state policies have directly addressed GHG mitigation and climate adaptation planning (in other words, State policy recognizes both topics as part of its policy approach toward climate change). These policies require State agencies to consider the effects of climate in their investment and design decisions, among other considerations. State adaptation policies that are relevant to Caltrans include:

Assembly Bill 32 (2006) or the “California Global Warming Solution Act” was marked as being the first California law to require a reduction in emitted GHGs. The law was the first of its kind in the country and set the stage for further policy in the future.[11]

Executive Order S-13-08 (2008) directs State agencies to plan for sea level rise (SLR) and climate impacts through the coordination of the State Climate Adaptation Strategy.[12]

Executive Order B-30-15 (2015) requires the consideration of climate change in all State investment decisions through: full life cycle cost accounting, the prioritization of adaptation actions that also mitigate greenhouse gases, the consideration of the State’s most vulnerable populations, the prioritization of natural infrastructure solutions, and the use of flexible approaches where possible.[13]

Assembly Bill 1482 (2015) requires all State agencies and departments to prepare for climate change impacts through (among others) continued collection of climate data, considerations of climate in State investments, and the promotion of reliable transportation strategies.[14]

[11] California Air Resources Board (CARB). “Assembly Bill 32 Overview.” August 5, 2014. https://www.arb.ca.gov/cc/ab32/ab32.htm
[12] California Legislative Information. “Executive Order S-13-08.” 2008. https://www.gov.ca.gov/news.php?id=11036
[13] Office of Governor Edmund Brown. “Governor Brown Establishes Most Ambitious Greenhouse Gas Reduction Target in North America.” April 29, 2015. https://www.gov.ca.gov/news.php?id=18938
[14] California Legislative Information. “Assembly Bill No. 1482.” October 8, 2015. https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201520160AB1482

Senate Bill 246 (2015) establishes the Integrated Climate Adaptation and Resiliency Program to coordinate with regional and local efforts with State adaptation strategies.[15]

Assembly Bill 2800 (2016) requires that State agencies account for climate impacts during planning, design, building, operations, maintenance, and investments in infrastructure. It also requires the formation of a Climate-Safe Infrastructure Working Group represented by engineers with relevant experience from multiple State agencies, including the Department of Transportation.[16]

These policies represent the types of factors State agencies should consider when addressing climate change. Conducting an assessment such as this one for District 3 is a key step towards protecting Caltrans infrastructure against future extreme weather conditions and addressing the requirements of the relevant State policies above, such as Executive Order B-30-15, Assembly Bill 1482, and Assembly Bill 2800. Other policies, such as Executive Order S-13-08, stimulate the creation of climate data that can be used by State agencies in their own adaptation planning efforts.

One of the most important climate adaptation policies out of those listed above is Executive Order B-30-15. Guidance specific to the Executive Order and how State agencies can begin to implement was released in 2017, titled *Planning and Investing for a Resilient California*. This guidance will help State agencies develop methodologies in completing vulnerability assessments specific to their focus areas and in making adaptive planning decisions. *Planning and Investing for a Resilient California* created a framework to be followed by other State agencies, which allows consistent communication among agency staff communicating on the effects of climate change.[17]

3.2. Research

California has sponsored cutting edge research on climate change nationally and internationally. For example, Executive Order S-03-05, directs that State agencies develop and regularly update guidance on climate change. These research efforts are encompassed in the *California Climate Change Assessments*, the most recent of which is the fourth edition (*California's Fourth Climate Change Assessment*). To understand the research and datasets from the *Assessment*, which are utilized in this District 3 vulnerability assessment, some background is needed on Global Climate Models (GCMs) and greenhouse gas concentrations.

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 used to project future changes to GHG emission levels.[18] 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 their

[15] California Legislative Information. "Senate Bill No.246." 2015. https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB246
[16] California Legislative Information. "Assembly Bill No. 2800." September 24, 2016. http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160AB2800
[17] Governor's Office of Planning and Research, "Planning and Investing for a Resilient California: a Guidebook for State Agencies," March 13th, 2018, http://opr.ca.gov/planning/icarp/resilient-ca.html
[18] "What is a GCM?" Intergovernmental Panel on Climate Change, June 18, 2013, http://www.ipcc-data.org/guidelines/pages/gcm_guide.html

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 the 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 for use in California as outlined in the *California's Fourth Climate Change Assessment* section discussed below.

Emissions Scenarios and Greenhouse Gas Concentrations

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

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

RCPs represent the most recent generation of GHG concentration scenarios produced by the IPCC and were used in this report. These scenarios use three main metrics to estimate future emissions: radiative forcing, emission rates, and emission concentrations.[19] Four RCPs were developed to reflect assumptions on emissions growth, and the resulting concentrations of GHG in the atmosphere. The RCPs are applied in GCMs to forecast future conditions and enable a comparison of one against another. Generally, the RCPs are based on assumptions for GHG emissions growth and an identified point at which they would be expected to begin declining (assuming varying reduction policies or changing socioeconomic conditions). The RCPs developed for this purpose include:

- 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 emissions).
- RCP 4.5 assumes that global annual GHG emissions will peak around 2040 and then begin to decline.
- RCP 6.0 assumes that emissions will peak near the year 2080 and then start to decline.
- RCP 8.5 assumes that high GHG emissions will continue through the end of the century, and extended outlooks for RCP 8.5 assume constant emissions after 2100 as well.[20]

California's Fourth Climate Change Assessment

The *California's 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 California Department of Water Resources (DWR) and the California Natural Resources Agency (NRA), as well as academic

[19] "Definition of Terms Used Within the DDC Pages," Data Distribution Center, Intergovernmental Panel on Climate Change, last accessed June 11, 2019, https://www.ipcc-data.org/guidelines/pages/glossary/glossary_r.html

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

institutions such as the Scripps Institution of Oceanography (Scripps) and the University of California-Merced.[21]

Model downscaling is a statistical technique that refines the results of GCMs to a regional level. The model downscaling used in the *California's Fourth Climate Change Assessment* is a technique called Localized Constructed Analogs (LOCA), which "uses past history to add improved fine scale detail to GCMs."[22] This effort was undertaken by Scripps and provides a finer grid system/spatial resolution than is found in other techniques. It enables the assessment of changes in a more localized way than was previously available, given that past models summarized changes with lower resolution.[23] LOCA data is provided in 1/16th degree, or 3.7 mi/6 km grid cells, as compared to GCM grid cells, which can span hundreds of miles across one such cell.[24] Figure 3-1 shows the difference in resolution between GCM data and downscaled GCM data using the LOCA technique. The leftmost image (from the GCM) provides an example of "grid cells" that are easily visible; in the rightmost image (downscaled) these grid cells are so small they are impossible to distinguish individually from this scale.

FIGURE 3-1: LOCA DOWNSCALING RESOLUTION

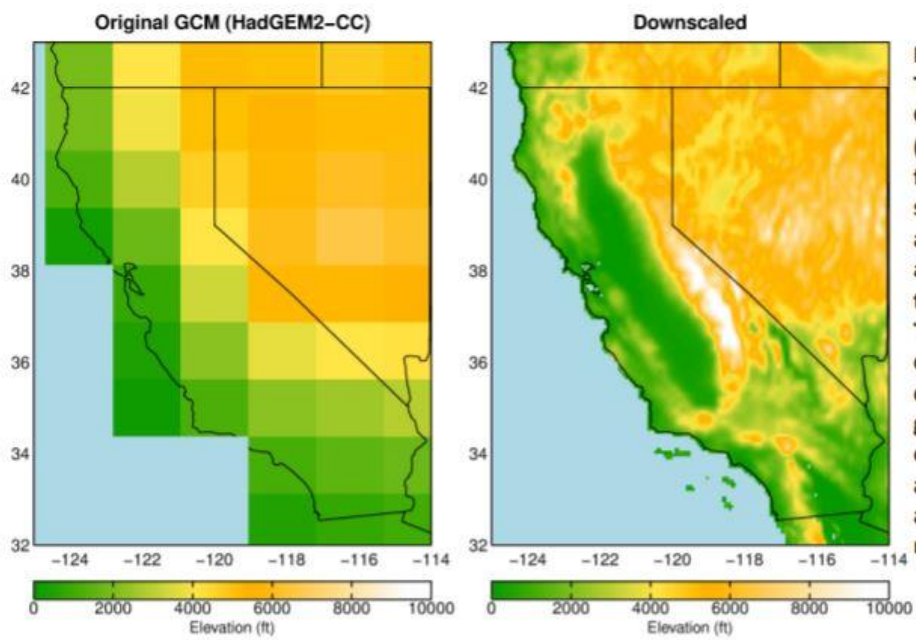


Figure 1. Left: Topography in a typical Global Climate Model (GCM). Major land features of California, such as the Sierra Nevada and Central Valley, are almost entirely absent in the global models. Right: Topography after downscaling to the 1/16th degree (6 km, or 3.7 mile) grid. At this scale not only the Central Valley and Sierra Nevada, but also details of the coastal ranges are captured.

SOURCE: DAVID PIERCE ET AL.

Out of the 32 LOCA downscaled GCMs for California, 10 models were chosen by State scientists and practitioners as being most relevant for California. This effort was led by DWR and its intent was to

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[21] "California's Fourth Climate Change Assessment," State of California website (CA.gov), last accessed June 5th, 2019, http://www.climateassessment.ca.gov/

[22] "LOCA Downscaled Climate Projections," Cal-Adapt 2.0, 2018, http://cal-adapt.org/

[23] David Pierce et al., "Statistical Downscaling Using Localized Constructed Analogs," 2014, http://journals.ametsoc.org/doi/abs/10.1175/JHM-D-14-0082.1

[24] David Pierce et al., "Creating Climate Change Projections to Support the California 4th Climate Assessment," Division of Climate, Atmospheric Sciences, and Physical Oceanography Scripps Institution of Oceanography, June 13, 2016, http://loca.ucsd.edu/~pierce/IEPR_Clim_proj_using_LOCA_and_VIC_2016-06-13b.pdf

understand which models to use in State agency assessments and planning decisions. More information on the selection process and the stakeholders involved can be found in the 2015 "Perspectives and Guidance for Climate Change Analysis" document developed by DWR and their Technical Advisory Group.[25] The 10 representative GCMs for California are:

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

Data from these models are available on the Cal-Adapt 2.0, California's Climate Change Research Center website.[26] The Cal-Adapt 2.0 data are some of the best available data in California on climate change and, for this reason, selections of data from Cal-Adapt and the GCMs above were utilized in this study.

3.3. Other Efforts in District 3 to Address Climate Change

Caltrans recognizes that outside of its own and statewide efforts, there are also regional efforts underway in District 3 to mitigate and address the effects of climate change. Ongoing coordination with local governments and stakeholders will be critical to ensure that analyses and adaptations are developed in awareness of one another. Regional coordination will be especially important to combat stressors like rising seas and temperature rise that will affect everyone and necessitate a collective response. Several regional stakeholders and projects that are instrumental to addressing impacts of climate change in District 3 include the following:

- **Local Government Commission:**

  The Local Government Commission (LGC) is a Sacramento-based nonprofit organization that facilitates communication among California leadership to support resilient, sustainable, and healthy communities. One of the LGC's major focus areas is to address the impacts of a changing climate through exchanging ideas and best practices. They host the biennial California Adaptation Forum that brings together key stakeholders addressing climate change across the state to foster knowledge exchange and influence partnerships. LGC also hosts the CivicSpark program, an AmeriCorps program dedicated to building capacity for local governments to address climate

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

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

change, and the Capital Region Climate Readiness Collaborative (CRC). For more information on the CRC, see below.[27]

- **Capital Region Climate Readiness Collaborative (CRC):**

The CRC is a program of the Local Government Commission and a member of the Alliance of Regional Collaboratives for Climate Adaptation (ARCCA). The CRC is a multidisciplinary collaborative focused on building climate resilience in California's Capital region, which includes Yolo, Sacramento, Sutter, Yuba, Placer and El Dorado Counties. The CRC is focused on achieving a common understanding of regional climate vulnerabilities and issues, identifying local strategies to address climate impacts, providing a voice for the Capital Region and its stakeholders, and communicating climate change issues across the state and nation. They provide resources to their members and the public, such as fact sheets on climate change impacts and responses, a monthly newsletter on news updates and resources in the Capital Region and beyond, and quarterly meetings open to the public.[28]

- **Delta Stewardship Council**

The Delta Stewardship Council was created to advance the State's goals for the Delta, including creating a more reliable water supply and protecting the Delta ecosystem. As a part of reaching this goal, the Council has created the Delta Plan, which is a long-term management plan for the Delta. The plan identifies policies and recommendations to protect and improve the Delta, some of which relate to climate change and sea level rise impacts. For example, the plan includes recommendations to restore tule habitat, which would reduce GHG emissions. The plan also recommends reducing Delta flood risk and lessening drought impacts by increasing water storage. The Delta Plan also acknowledges the need to consider long-term sea level rise in Delta planning and notes that coordination with Caltrans will be key to understand flood risk from sea level rise to the SHS (see recommendation DP R6 of the Delta Plan).[29]

- **Sacramento Area Council of Governments:**

The Sacramento Area Council of Governments (SACOG) is an association of local governments in the Sacramento region, covering El Dorado, Placer, Sacramento, Sutter, Yolo, and Yuba Counties. SACOG provides transportation planning and funding for the region and addresses other regional issues such as those related to land use, air quality, and affordable housing.[30] SACOG has also been working to identify and address climate change impacts to their network. In 2015, SACOG released a Sacramento Region Transportation Climate Adaptation Plan, which summarized potential climate stressors that may pose risks to the region. These stressors included temperature rise, heavy rain events, wildfires and landslides, and drought.[31] Today, SACOG is undertaking another assessment focused on identifying the vulnerability and criticality of the region's transportation network.

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[27] For more on LGC, visit: https://www.lgc.org/

[28] For more on CRC, visit: http://climatereadiness.info/

[29] Delta Stewardship Council, "Delta Plan Executive Summary," Last amended April 26, 2018, http://deltacouncil.ca.gov/sites/default/files/documents/files/Delta_Plan_Executive_Summary_2013.pdf.

[30] For more on SACOG, visit: https://www.sacog.org/

[31] Sacramento Area Council of Governments & CivicSpark, "Sacramento Region Climate Adaptation Plan," 2015, http://www.sacog.org/sites/main/files/file-attachments/fullplanwithappendices.pdf

- **California Tahoe Conservancy:**

The California Tahoe Conservancy (Conservancy) was formed to sustain a healthy balance between the natural environment and human use in the Lake Tahoe Basin. As one of their recent efforts, the Conservancy is collaboratively leading the development of the Lake Tahoe Climate Adaptation Action Plan (CAAP). The CAAP uses downscaled climate change projections to examine the impacts of temperature, precipitation, snowpack, drought, soil moisture, and seasonal runoff on the Basin's key socio-ecological resources and ecosystem services, specifically lakes and streams, meadows and riparian areas, forests, biodiversity, cultural landscapes, transportation, water and energy infrastructure, recreation and tourism, and public health and safety. This will result in an integrated social-ecological vulnerability assessment.

For the corresponding interagency action plan, California agencies and other partners will (and State of Nevada agencies and cooperators may) use the vulnerability assessment to identify gaps, weaknesses, and opportunities in their climate adaptation work. Participants will subsequently identify specific actions that they themselves commit to implementing. The participants would then implement the actions for which they have or share responsibility.

Ultimately, the CAAP will inform and increase the awareness of public agencies, stakeholders, and Basin communities regarding the impacts and implications of climate change, and the actions that partners are taking to adapt to these. The Conservancy hopes to align public and private efforts to integrate resilience into the Basin's planning and investment programs.

- **Sacramento County and Butte County Climate Action Plans:**

Butte County completed its Climate Action Plan (CAP) in 2014, which includes a GHG emissions inventory and sets targets for emissions reductions based on that inventory. The CAP is focused on ensuring the county protects its natural resources, remains resilient against future environmental and economic conditions, and improves its transportation system.[32]

Sacramento County is currently developing its CAP, which will include strategies for the reduction of GHG emissions and preparation for the effects of future climate change. The development of GHG mitigation strategies will be consistent with a traditional CAP, by first creating an inventory of emissions and forecasting growth, then identifying measures to cut those emissions. The climate adaptation planning process will focus on first identifying risks, their impacts, and their probabilities, then prioritizing adaptation needs and relevant strategies.[33]

3.4 General Methodology

The adaptation planning methodology used in this study varied by climate change stressor. Given that each uses 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 defined in each stressor section; however, there are some general practices that apply across all analysis approaches.

[32] Butte County, "Butte County Climate Action Plan," 2014, https://www.buttecounty.net/dds/Planning/General-Plan/CAP
[33] Sacramento County, "Climate Action Plan," N.d. http://www.per.saccounty.net/PlansandProjectsIn-Progress/Pages/CAP.aspx

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.[34] The 2025 and 2055 out-years follow the same logic but applied to each of the prior 30-year periods (2010 to 2039 and 2040 to 2069, respectively).

3.4.2 Geographic Information Systems (GIS) and Geospatial Data

Developing an understanding of Caltrans assets exposed to sea level rise, storm surge, and projected changes in temperature, precipitation, and wildfire required complex geospatial analyses. The geospatial analyses were performed using Environmental Systems Research Institute (Esri) geographic information systems (GIS) software. 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 climate scenarios. For example, extreme temperature maps were created for temperature metrics important to pavement binder grade specifications; maps of extreme (100-year) precipitation depths were developed to show changes in rainfall; burn counts were compiled to produce maps indicating future wildfire frequency; and sea level rise, storm surge, and cliff retreat maps were made to understand the impacts of future tidal flooding[35] and erosion.

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

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

Identify the segments of the SHS that are vulnerable to climate change stressors: The final step in the geospatial analyses involved running the segments of roadway exposed to a stressor through Caltrans' linear referencing system. This step was performed by Caltrans and provided an output GIS file indicating the centerline miles of roadway affected by a given stressor. Using GIS, this data can then be

[34] To date, model projections are rarely provided beyond 2100 given increased uncertainty in results.
[35] Tidal flooding (sometimes referred to as temporary nuisance flooding) occurs in low-lying coastal areas during especially high tide events.

summarized in many ways (e.g. by district, county, municipality, route number, or some combination thereof) to provide useful statistics to Caltrans planners.

Upon completion of the geospatial analyses, GIS data for each step was saved to a database that was supplied to Caltrans after the study was completed. Limited metadata on each dataset 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 a direct outcome of increased concentrations of GHGs in the atmosphere. Temperatures in the west are projected to continue rising and heat waves are expected to become more frequent.[36] The potential effects of extreme temperatures on District 3 assets will vary by asset type and will depend on the specifications followed in the original design of the facility. For example, the following have been identified in other studies in the United States as potential impacts of increasing temperatures.

4.1. Design

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

4.2. Operations and Maintenance

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

Resources available for this study did not allow for a detailed assessment of all the impacts temperature changes 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 is reliant, in part, on the following two temperature variables:

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

These climate metrics are critical to 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 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

[36] U.S. National Climate Assessment, U.S. Global Change Research Program, 2014, http://nca2014.globalchange.gov/report/our-changing-climate/extreme-weather

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.

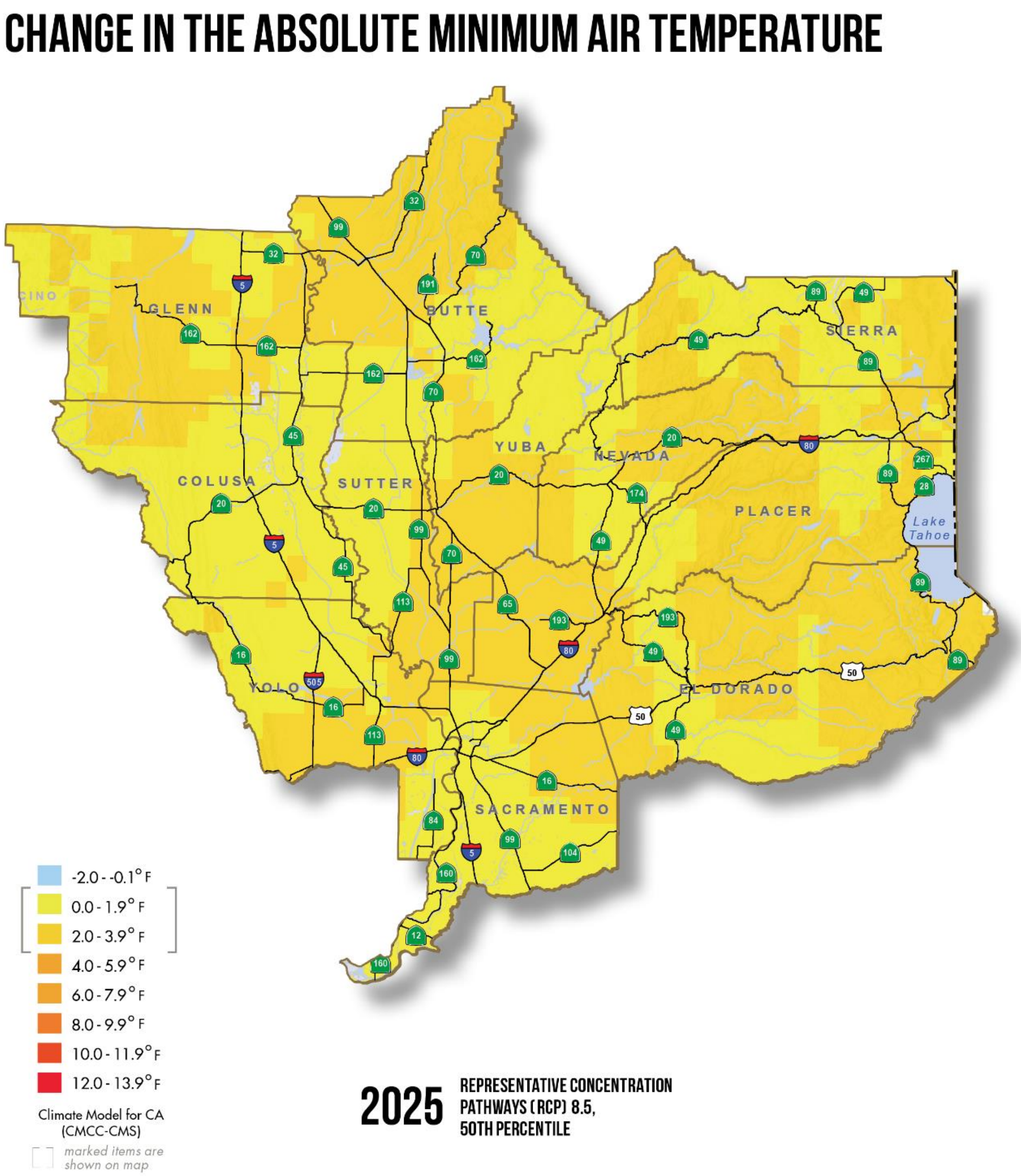
The LOCA climate data developed by Scripps and researchers that contributed to *California's Fourth Climate Change Assessment* were used for the analysis of temperature, which has a spatial resolution of 1/16th of a degree or approximately three-and-a-half to four miles.[37] This dataset was queried 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. These years are the same 30-year statistical analysis periods explained in the 3.4.1 Time Periods Section. To reiterate, these time periods are: 1) 2010 to 2039, where the mid-point year is 2025, 2) 2040 to 2069, where the mid-point year is 2055, and 3) 2070 to 2099, where the mid-point year is 2085.

The maps shown are for the temperature model (CMCC-CMS) 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 are not shown here). The maps highlight the temperature change expected for both the maximum and minimum metrics. Both temperature metrics increase over time with the maximum temperature changes generally being greater than the minimum changes. Some areas may experience change in the maximum temperature metric upwards of 13.9 °F by the end of the century. Finally, for both metrics, temperature changes are generally greater farther inland, due to the moderating influence of the Pacific Ocean.

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

[37] "LOCA Downscaled Climate Projections." Cal-Adapt 2.0. 2018. https://cal-adapt.org/data/loca/

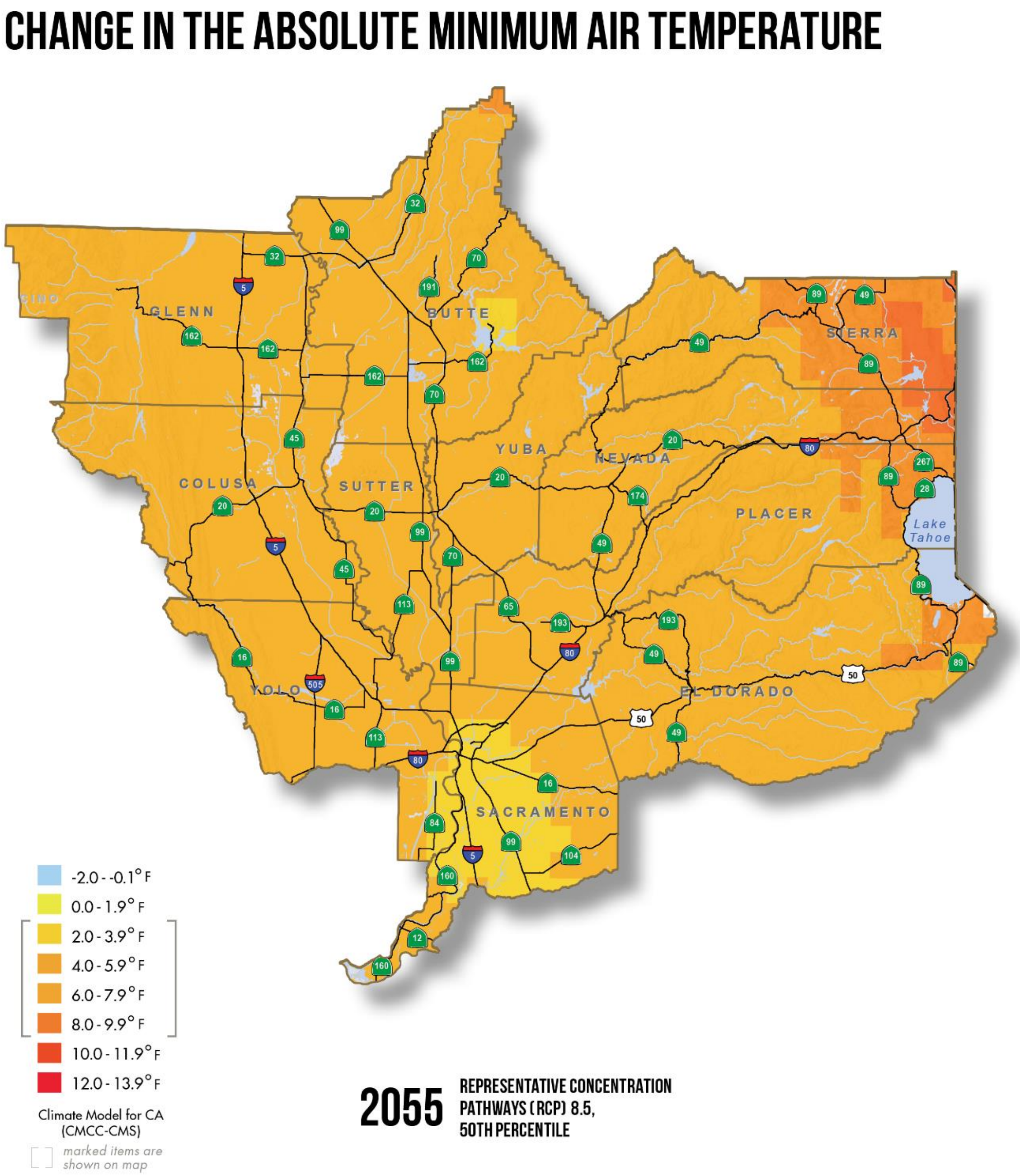
FIGURE 4-1: CHANGE IN THE ABSOLUTE MINIMUM AIR TEMPERATURE 2025



Future Change in the Absolute Minimum Air Temperature within District 3, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 3. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown was generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

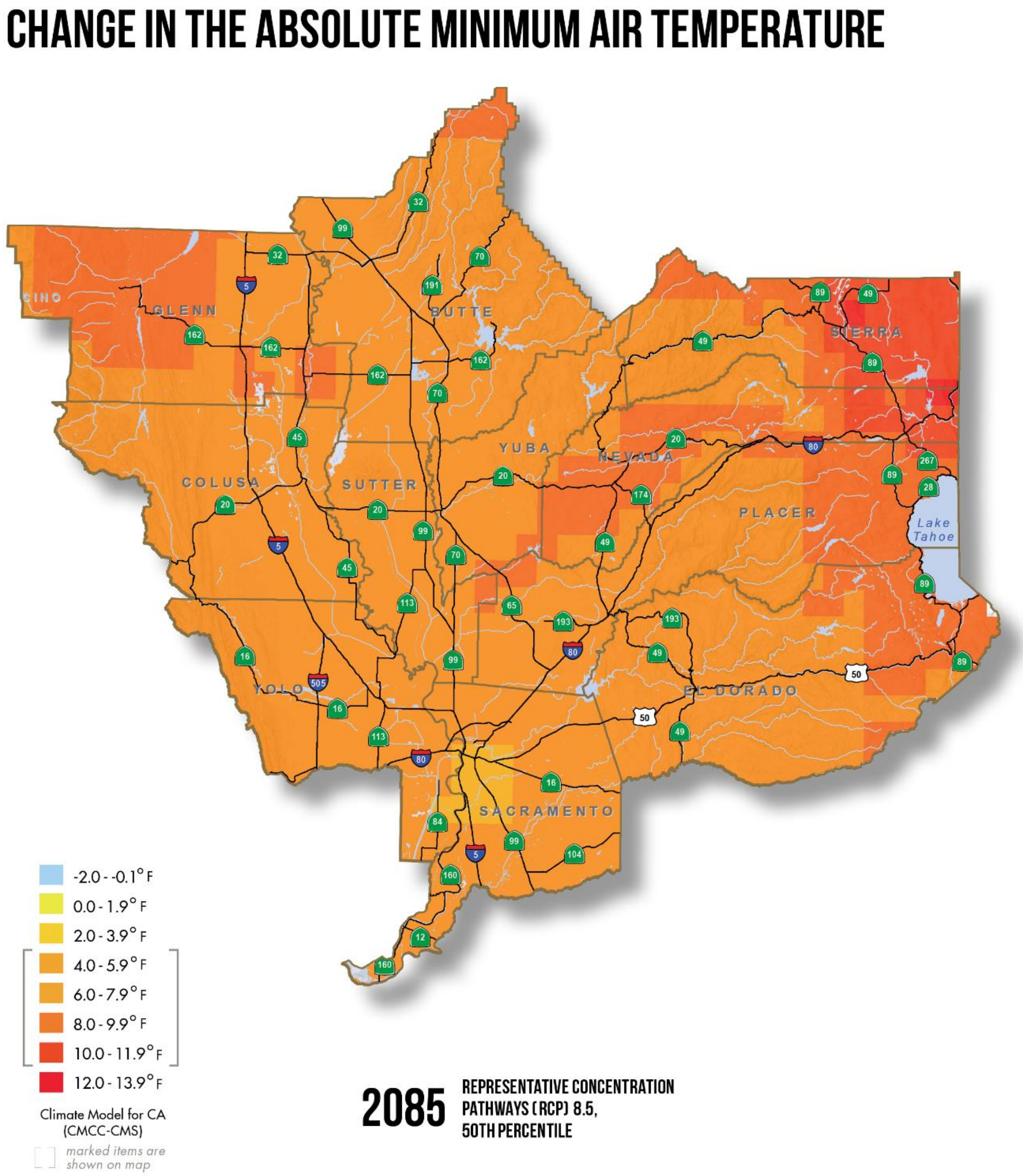
FIGURE 4-2: CHANGE IN THE ABSOLUTE MINIMUM AIR TEMPERATURE 2055



Future Change in the Absolute Minimum Air Temperature within District 3, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 3. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown was generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

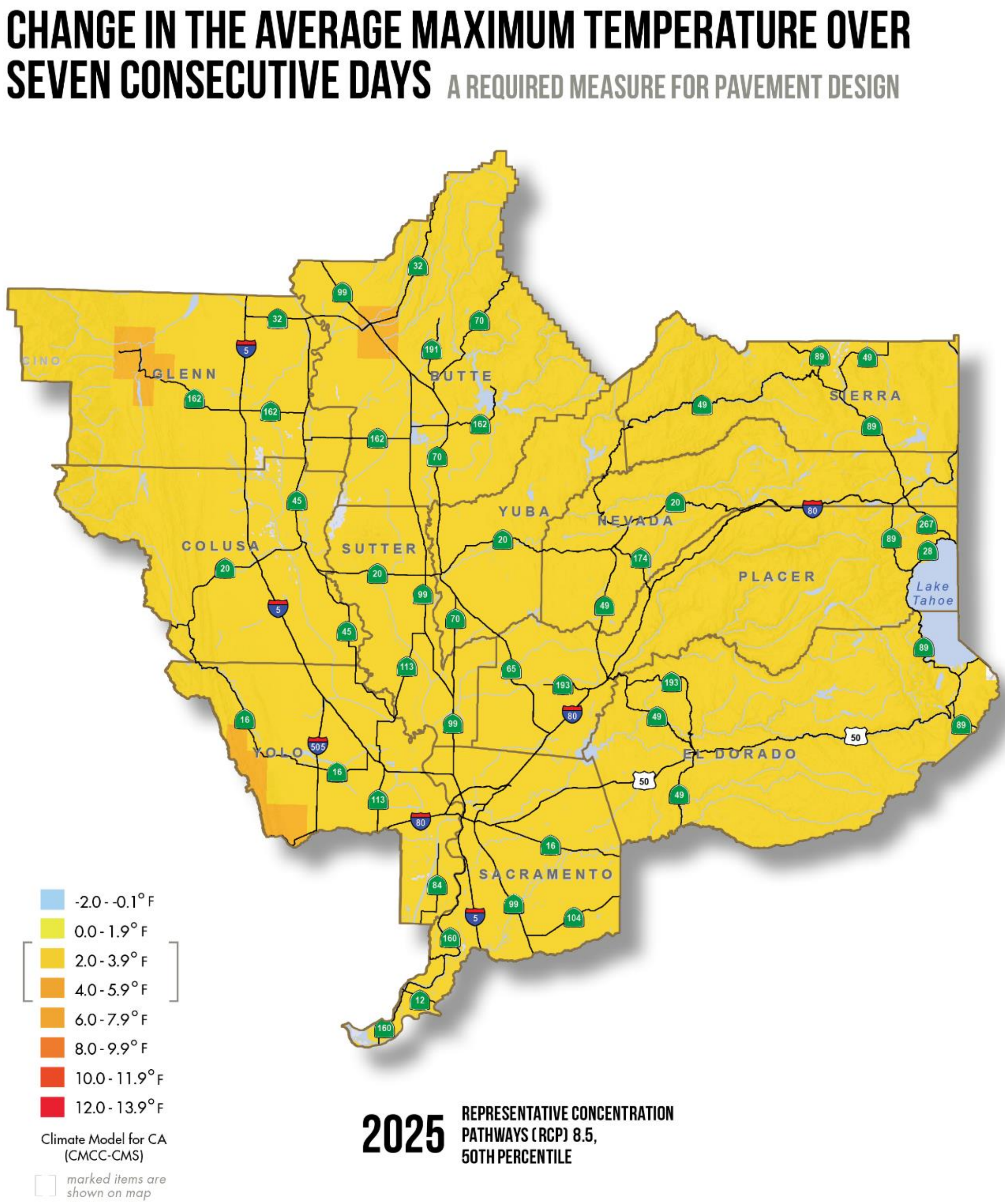
FIGURE 4-3: CHANGE IN THE ABSOLUTE MINIMUM AIR TEMPERATURE 2085



Future Change in the Absolute Minimum Air Temperature within District 3, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 3. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown was generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

FIGURE 4-4: CHANGE IN THE AVERAGE MAXIMUM TEMPERATURE OVER SEVEN CONSECUTIVE DAYS 2025

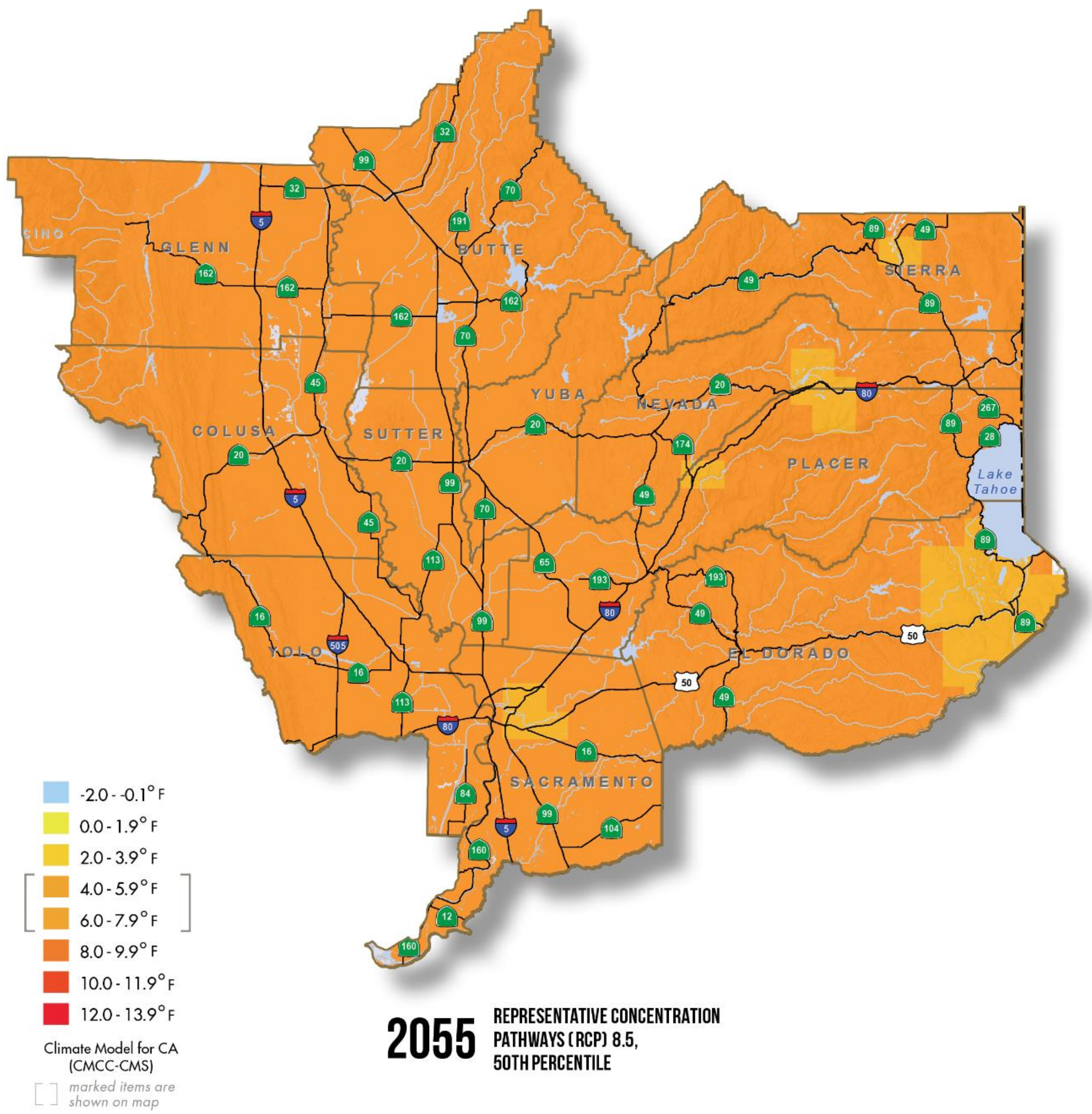


Future Change in the Average Maximum Temperature over Seven Consecutive Days within District 3, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 3. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown was generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

FIGURE 4-5: CHANGE IN THE AVERAGE MAXIMUM TEMPERATURE OVER SEVEN CONSECUTIVE DAYS 2055

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

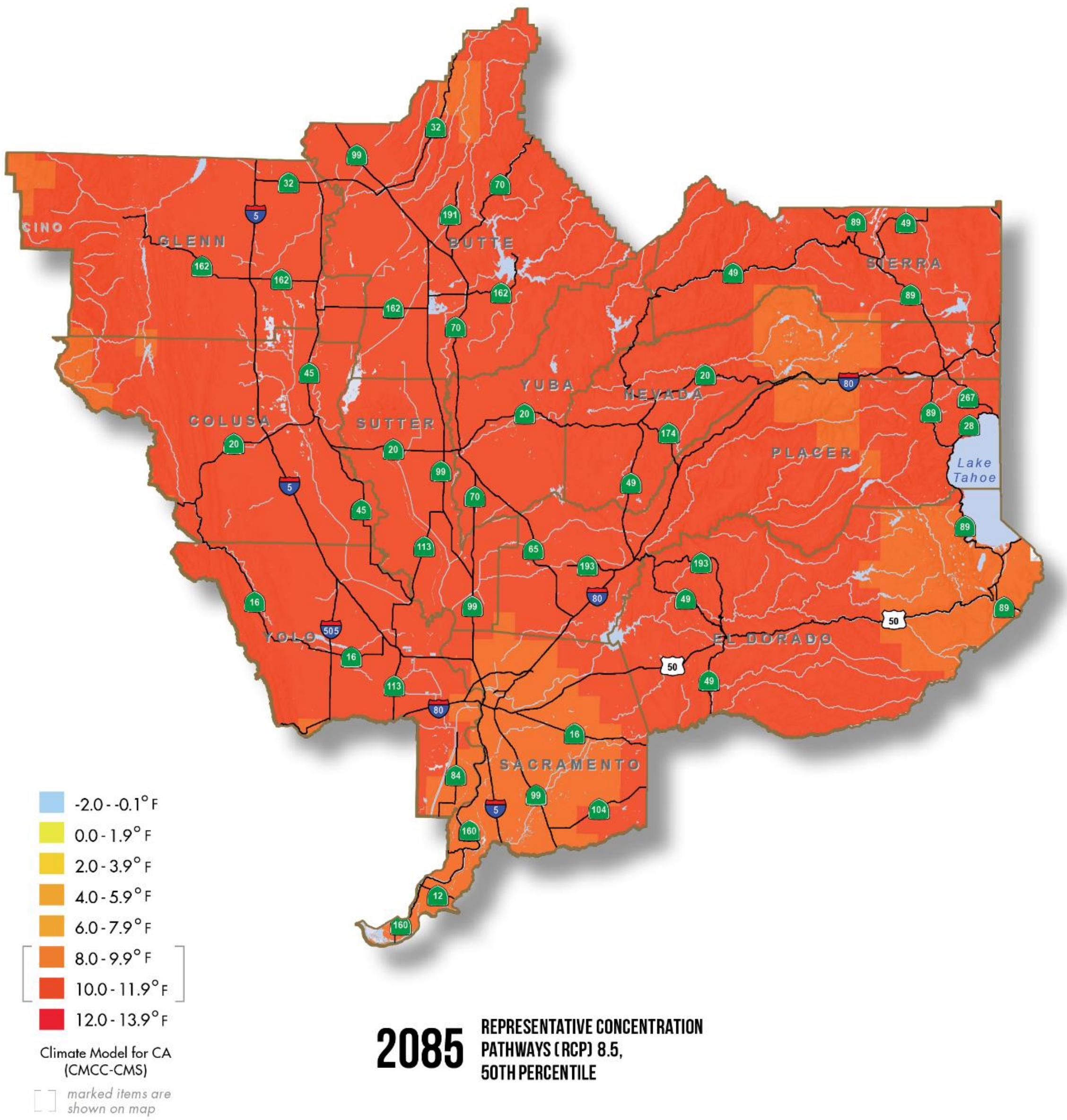


Future Change in the Average Maximum Temperature over Seven Consecutive Days within District 3, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 3. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown was generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

FIGURE 4-6: 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 3, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 3. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown was generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

5. PRECIPITATION

The Southwest region of the United States is expected to have less precipitation overall in the future,[38] but with the potential for heavier individual events, and with more precipitation falling as rainfall. This section of this report focuses on how heavy precipitation events may change and become more frequent/severe over time.

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

Transportation assets in California are affected by precipitation in a variety of ways—from inundation/flooding, to landslides, washouts, or structural damage from heavy rain events. Current transportation design uses return period storm events as a variable to include in asset design criteria (e.g. for bridges or culverts). A return period storm event is the historical intensity of storms based on how often such level of storms have occurred in the past. A 100-year flood 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*.[39]

Assessing the true risks of a 100-year flood requires complex and expensive flood modeling. This level of analysis is done by the Federal Emergency Management Agency (FEMA) to understand which US properties lie within floodplains. This type of assessment has rarely been completed using future precipitation projections and would be a major effort to complete across the entire state, or even just within SHS ROW. Given the challenges associated with this level of flooding analysis, the project study team needed to find an alternative way to understand future flood risks to Caltrans assets.[40] Therefore, the 100-year storm was analyzed to determine how 100-year storm rainfall is expected to change, using best available precipitation projections available for the state.

The Scripps Institution for Oceanography, other academic institutions, and state agencies are working to better understand future precipitation projections. The most up-to-date precipitation research for the state was compiled as a part of *California's Fourth Climate Change Assessment*. Scripps and the researchers behind *California's Fourth Climate Change Assessment* developed daily rainfall data for a set

[38] Jerry Melillo, Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program, 841 pp. doi:10.7930/J0Z31WJ2. Accessed July 31, 2018, https://www.nrc.gov/docs/ML1412/ML14129A233.pdf

[39] Caltrans, "Highway Design Manual," July 2, 2018, http://www.dot.ca.gov/hq/oppd/hdm/hdmtoc.htm

[40] The Caltrans Climate Change Vulnerability Assessment Project did not have the resources to do projections of future flows by return periods throughout the state and assess the exposure of the state highway system. The project that follows this, the Caltrans Climate Action Report project, does have a component that involves projecting future flows at bridges and culverts to get a sense of the relative exposure of different assets. Look for results of that analysis in the months ahead.

of climate models, and RCPs 4.5 and 8.5, for every day to the year 2100. Climate change specialists from the study team worked with researchers from Scripps to estimate extreme precipitation changes over time. Specifically, the team requested precipitation datasets across the set of 10 international GCMs that were identified as having the best applicability for California, for both RCPs 4.5 and 8.5.[41]

These raw datasets were then processed to provide the percent change in the 100-year storm precipitation depth over a 24-hour period. The historical data used to calculate the percentage changes are synthetic historical backcasted data from the climate models over the period 1950 to 2005.[42] Standard practice in climate science is to derive the percentage changes using backcasted historical modeled data and future projected modeled data. This mitigates against model bias affecting the derivation of the percent change.

This newly processed data was analyzed for three time periods to determine how precipitation might change through the end of century. The years shown in the following figures represent the mid-points of the same 30-year statistical analysis periods used for the temperature metrics and explained in the 3.4.1 Time Periods Section. To reiterate, these time periods are: 1) 2010 to 2039, where the mid-point year is 2025, 2) 2040 to 2069, where the mid-point year is 2055, and 3) 2070 to 2099, where the mid-point year is 2085.

The results of this assessment are shown in the District 3 maps below. The three maps depict the percentage change in the 100-year storm rainfall event predicted for the three analysis periods, and for the RCP 8.5 emissions scenario (the RCP 4.5 results are not shown). The median precipitation model (HadGEM2-CC) was used in this mapping.[43] Note that the change in 100-year storm depth is positive throughout District 3, indicating heavier rainfall during storm events.

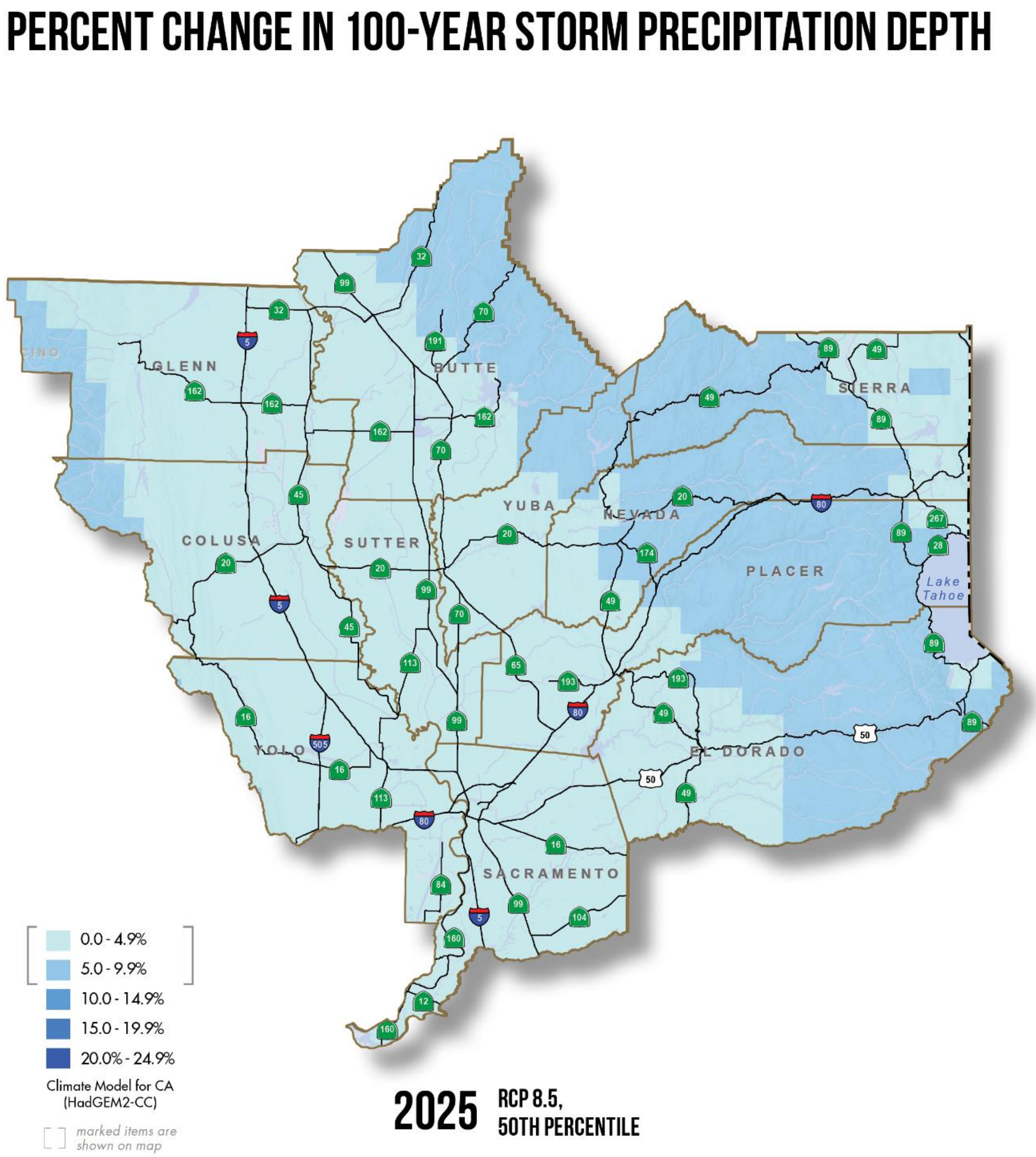
Heavy storm events could have serious implications for the SHS. Understanding those implications will help Caltrans engineers and designers implement designs that are more adaptive to changing conditions. That said, site-specific, hydrological analysis of flood flows is necessary to determine how future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

[41] These were the only RCPs available.

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

[43] There were two models that lay at the center point of the distribution. Only one of these models was chosen (HadCEM2-CC) because the best practice in climate science is not to merge the results of multiple climate models.

FIGURE 5-1: PERCENT CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH 2025

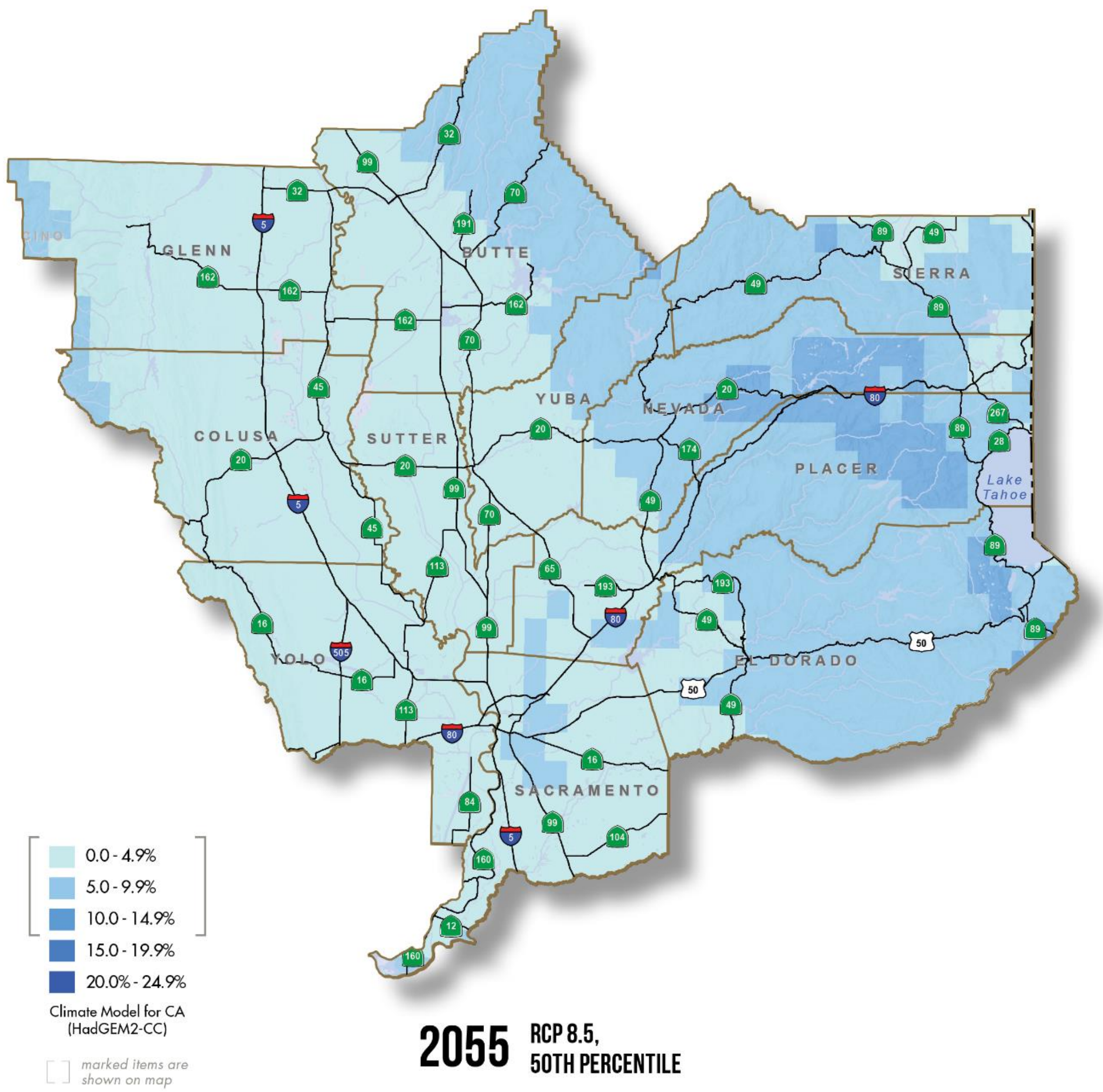


Future Percent Change in 100-year Storm Precipitation Depth within District 3, Based on the RCP 8.5 Emissions Scenario

Caltrans Transpotation Asset Vulnerability Study, District 3. 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 5-2: PERCENT CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH 2055

PERCENT CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH

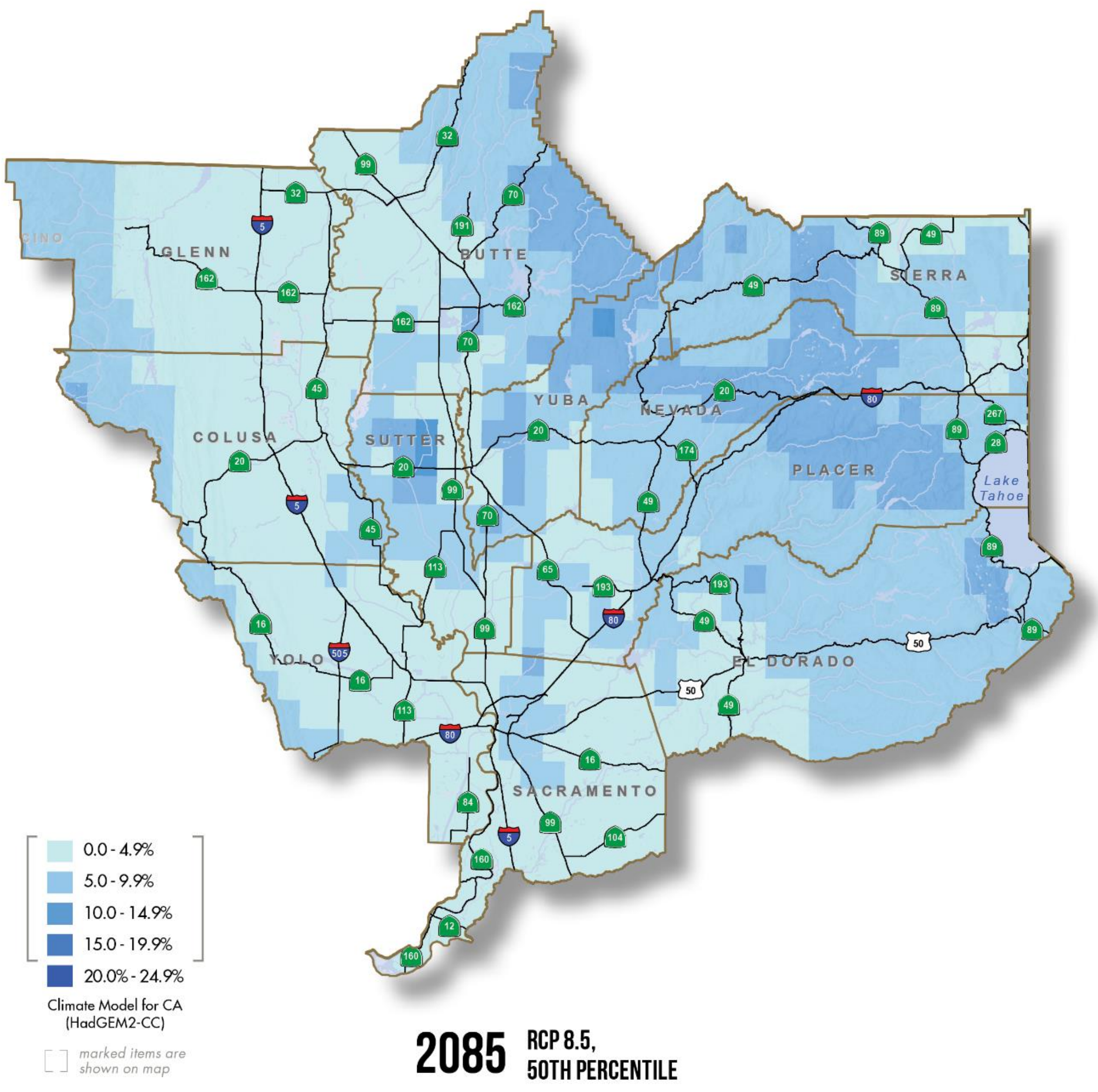


Future Percent Change in 100-year Storm Precipitation Depth within District 3, Based on the RCP 8.5 Emissions Scenario

Caltrans Transpotation Asset Vulnerability Study, District 3. 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 5-3: PERCENT CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH 2085

PERCENT CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH



Future Percent Change in 100-year Storm Precipitation Depth within District 3, Based on the RCP 8.5 Emissions Scenario

Caltrans Transpotation Asset Vulnerability Study, District 3. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown were generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

6. WILDFIRE

Increasing temperatures, changing precipitation patterns, and resulting changes to land cover are expected to affect wildfire frequency and intensity. Human infrastructure, including the presence of electrical utility infrastructure or other sources of fire potential (mechanical devices, open fire, accidental or intentional), may also influence the occurrence of wildfires. The direct impacts of wildfire may include, but not be limited to, combustion of wooden pilings for guardrails and elsewhere, sign posts, roadside utility poles (especially where the wood is creosote-treated), construction falsework, delamination of road surfaces, fractured rock and concrete structures, roadside vegetation including landscaping, as well as direct safety impacts to travelers and vehicles due to heat, reduced visibility, and respiratory system impediment. Indirectly, wildfires can contribute to landslide and flooding exposure, by burning off soil-stabilizing land cover and reducing the capacity of the soils to absorb rainfall; and wildfire smoke can affect visibility and the health of the public and Caltrans staff. They also contribute to bottlenecks and operational failures, particularly during evacuations and in accessing more remote or underserved communities.

The recent wildfire seasons have been significant and devastating. District 3 has been affected by major wildfires in recent years, which caused impacts to the SHS requiring emergency repairs. These events include: The Rocky Fire, which burned in 2015 and led to slope destabilization on SR-16 in Colusa County, the 2016 Emerald Fire, which caused damages and erosion on SR-89 in El Dorado County, and the Farad Fire, which burned along I-80 in Nevada and Sierra Counties, causing $2,000,000 in damages in 2017. The costs to Caltrans for repairing wildfire-related damage could extend over months for individual events and could require years of investment to maintain the viability of the SHS for its users. The conditions that contributed to these impacts, notably a wet rainy season followed by very dry conditions and heavy winds, are likely to occur again in the future as climate conditions change and storm events become more dynamic. Wildfires also tend to be a secondary impact associated with drought conditions.

The information gathered and assessed to develop wildfire vulnerability data for District 3 included research on the effect of climate change on wildfire recurrence. This is of interest to several agencies, including the US Forest Service (USFS), the US Environmental Protection Agency (EPA) and the California Department of Forestry and Fire Protection (CalFire), who have developed their own models to understand the trends of future wildfires throughout the US and in California.

6.1. Ongoing Wildfire Modeling Efforts

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

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

- **University of California Merced model,** developed by Leroy Westerling, University of California Merced

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

The second wildfire model used was developed by Leroy Westerling at the University of California, Merced. This statistical model was developed to analyze the conditions that led to past large fires (defined as over 1,000 acres) in California and uses these patterns to predict future wildfires. Inputs to the model included climate, vegetation, population density, development footprint, and fire history. This model then incorporated future climate data and projected land use changes to project wildfire recurrence in California to the year 2100.[44]

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

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

- MC2 - EPA
- MC2 - ASCL
- UC Merced

6.2. Global Climate Models Applied

Projections of future wildfire conditions used a series of GCM outputs. In this analysis, the project study team used the four recommended GCMs from Cal-Adapt for wildfire outputs (CAN ESM2, CNRM-CM5, HAD-GEM2-ES, MIROC5). In addition, all of the modeling efforts used RCPs 4.5 and 8.5, representing realistic lower and higher ranges for future GHG emissions. Table 6-1Table 6-1 graphically represents the wildfire models and GCMs used in the assessment.

[44] Anthony Leroy Westerling (University of California, Merced), "Wildfire Simulations for California's Fourth Climate Change Assessment: Projecting Changes in Extreme Wildfire Events with a Warming Climate," California's Fourth Climate Change Assessment, California Energy Commission, Publication Number: CCCA4-CEC-2018-014, August 2018, http://www.climateassessment.ca.gov/techreports/docs/20180827-Projections_CCCA4-CEC-2018-014.pdf

TABLE 6-1: WILDFIRE MODELS AND ASSOCIATED GCMS USED IN WILDFIRE ASSESSMENT

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

6.3. Analysis Methods

The wildfire projections for all model data were developed for the three future 30-year time periods used in this study (median years of 2025, 2055, and 2085). These median years represent 30-year averages, (e.g., 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 are expressed in individual grid cells on a map, like the LOCA data used in the temperature and precipitation analyses. The final wildfire projections for this effort provides a summary of the percentage of each of these grid cells that burns for each time period. The raster grid cell size applied is 1/16 of a degree square for the MC2 - EPA and UC Merced/Westerling models, which matches the grid cell size for the LOCA climate data applied in developing these models. The MC2-University of Idaho effort generated data at 1/24 of a degree square to match the grid cells generated by the MACA downscaling method.

The model data were 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 grid 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 $1/16^{th}$ degree grid to enable comparisons and to summarize across multiple models. The resulting area contained within these grid cells ranged in area between roughly 8,000 and 10,000 acres for grid cells sizes that were 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 grid cells. This difference could be caused by any number of factors, including the assumption of changing vegetation that is included in the MC2 models, but not in the UC Merced/Westerling model.

6.4. Categorization and Summary

The final method selected to determine future wildfire risks throughout California takes advantage of the presence of three modeled datasets to generate a broader understanding of future wildfire exposure. The project team found that this would provide more robust results than applying only one of the available wildfire models. A cumulative total of percentage grid cell burned was developed for each grid 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 grid cell burned. The classification was defined as:

- Very Low 0-5%,
- Low 5-15%,
- Medium 15-50%,
- High 50-100%,
- Very High 100%+.[45]

Thus, if a grid cell were to show a complete burn or higher (8,000 to 10,000 acres+) over a 30-year period, that grid cell was identified as a very high wildfire exposure grid 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 grid cell in every model. This was done to provide a consistent number of data points for each wildfire model.

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

Finally, the project study team assigned a score for each grid 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 grid cell (a simple majority) were consistent in estimating the percentage of grid cell burned for each 30-year period. The figures on the following pages show the results of this analysis using the classification scheme explained above. The wildfire model composite summaries are based on wildfire projections from three models: MC2-EPA, MC2-ACSC, and UC Merced. These figures show projections for RCP 8.5 only and red highlights show portions of the Caltrans SHS that are likely to be exposed to wildfire. Areas that do not show Medium to Very High wildfire risk (the areas shown in white) would be classified as Low or Very Low.

The tables below summarize the total centerline miles of the District 3 SHS exposed to wildfire risk by emissions scenario and District 3 county. The total mileage of the District 3 SHS exposed to wildfire under the RCP 8.5 scenario does not change over time (from beginning to end of century). 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 as can be observed in the maps on the following pages. These changes are not reflected in the mileage summary in Table 6-2, which totals mileage of the SHS exposed to all wildfire concern areas from Medium to Very High. The centerline mileage does not change at all under RCP 4.5 (the same areas are exposed to Medium to Very High wildfire risk).

[45] >100% means fires are burning portions of each grid cell more than once in the time period.

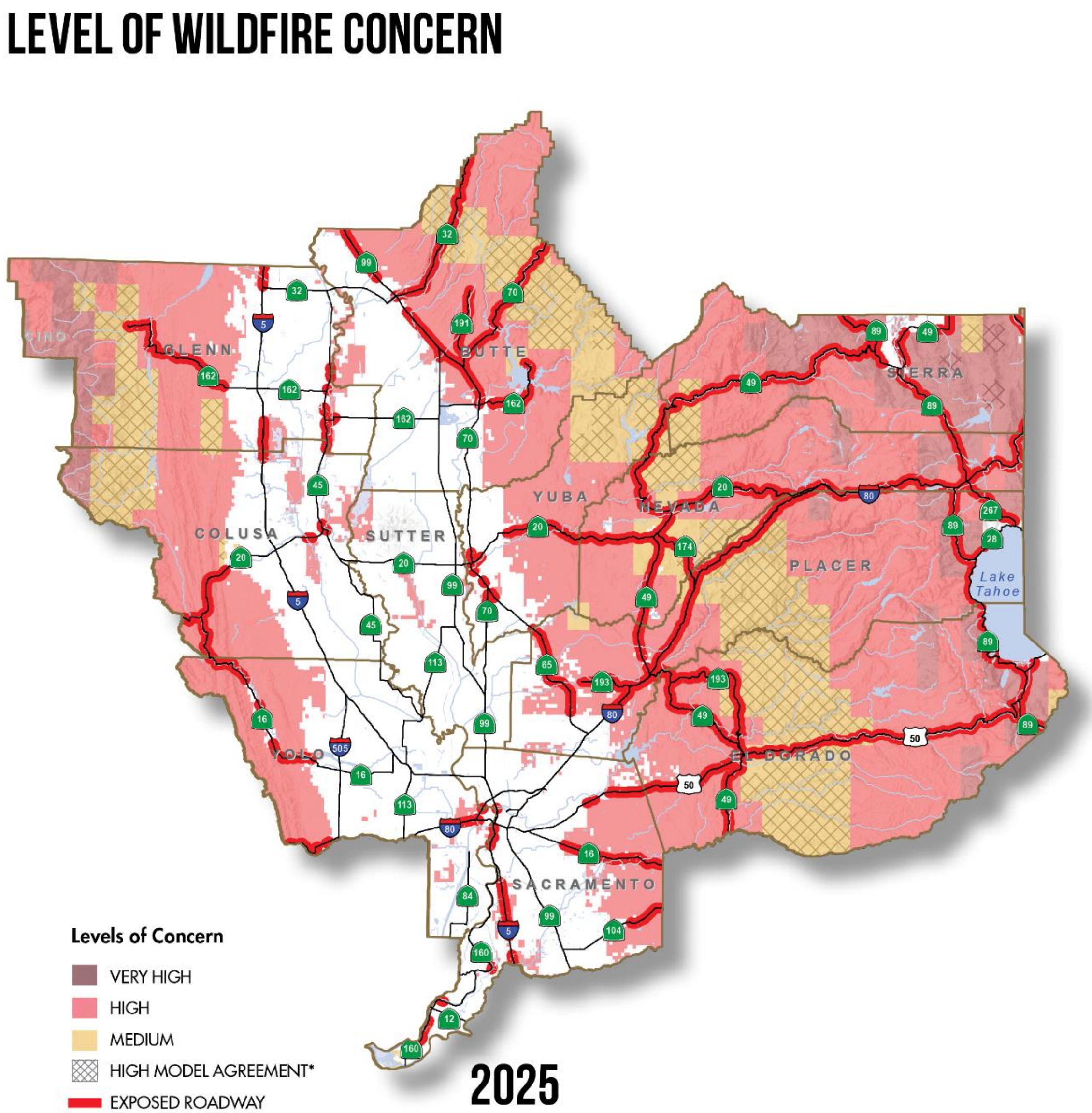
TABLE 6-2: CENTERLINE MILES EXPOSED TO MEDIUM TO VERY HIGH WILDFIRE CONCERN FOR THE RCP 8.5 SCENARIO

District 3 County	2025			2055			2085		
	Med	High	Very High	Med	High	Very High	Med	High	Very High
Butte	25	77	0	1	101	0	0	68	33
Colusa	0	25	0	0	25	0	0	25	0
El Dorado	29	95	35	16	109	35	4	82	74
Glenn	2	33	0	0	35	0	0	35	0
Nevada	33	68	26	4	94	29	3	54	70
Placer	22	73	25	4	92	24	6	92	23
Sacramento	0	41	0	0	41	0	0	39	2
Sierra	6	26	53	13	28	44	4	49	31
Yolo	0	22	0	0	22	0	0	22	0
Yuba	9	18	0	0	27	0	0	18	9
District 3 Totals by Level of Concern and Year	**126**	**477**	**140**	**37**	**573**	**132**	**16**	**484**	**243**
District 3 Total by Year	**743**			**743**			**743**		

TABLE 6-3: CENTERLINE MILES EXPOSED TO MEDIUM TO VERY HIGH WILDFIRE CONCERN FOR THE RCP 4.5 SCENARIO

District 3 County	2025			2055			2085		
	Med	High	Very High	Med	High	Very High	Med	High	Very High
Butte	21	80	0	3	99	0	1	101	0
Colusa	0	25	0	0	25	0	0	25	0
El Dorado	15	109	35	17	108	35	12	116	32
Glenn	0	35	0	0	35	0	4	31	0
Nevada	25	73	29	16	80	30	0	98	29
Placer	16	79	25	7	89	24	0	96	24
Sacramento	0	41	0	0	41	0	0	41	0
Sierra	1	34	49	0	40	44	0	45	39
Yolo	0	22	0	0	22	0	0	22	0
Yuba	6	21	0	0	27	0	0	27	0
District 3 Totals by Level of Concern and Year	**84**	**520**	**138**	**43**	**566**	**134**	**16**	**603**	**124**
District 3 Total by Year	**742**			**743**			**743**		

FIGURE 6-1: INCREASE IN WILDFIRE EXPOSURE 2025

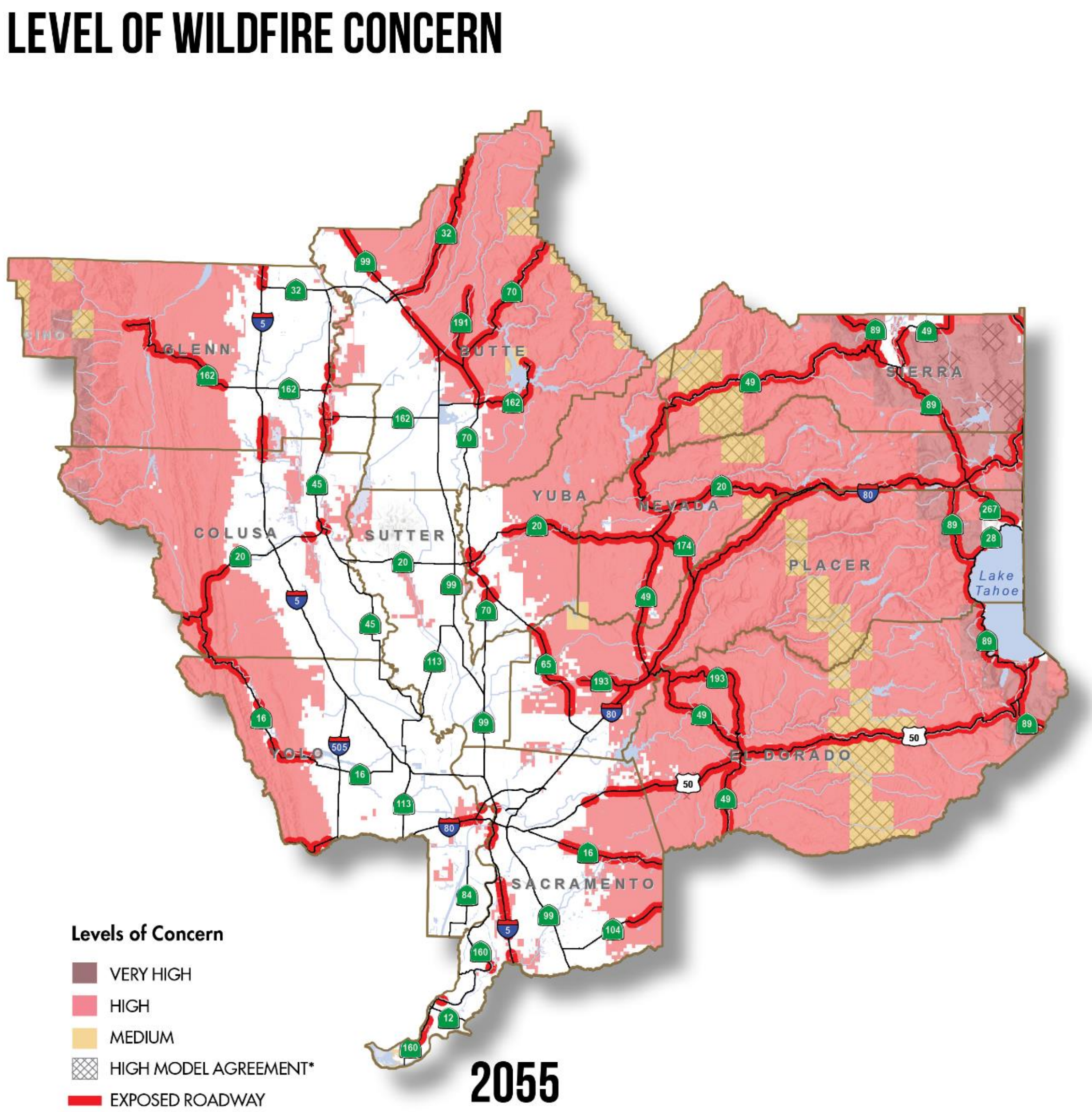


Future Level of Wildfire Concern for the Caltrans State Highway System within District 3, Based on the RCP 8.5 Emissions Scenario

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 6-2: INCREASE IN WILDFIRE EXPOSURE 2055

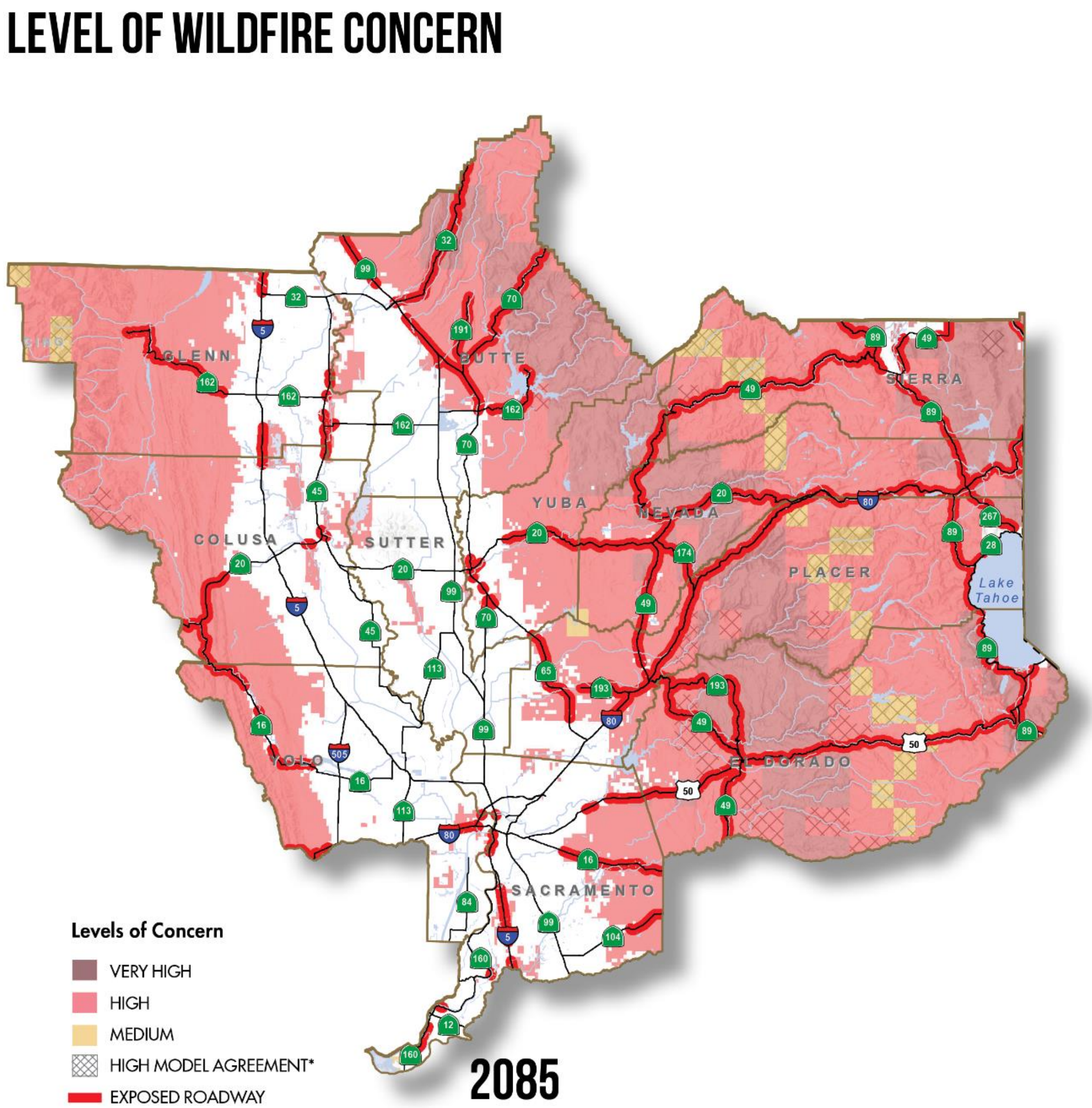


Future Level of Wildfire Concern for the Caltrans State Highway System within District 3, Based on the RCP 8.5 Emissions Scenario

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 6-3: INCREASE IN WILDFIRE EXPOSURE 2085



Future Level of Wildfire Concern for the Caltrans State Highway System within District 3, 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 was subject to 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 great reedy freshwater marsh with riparian forest lining its stream channels and was populated by fish, deer, elk, and waterfowl.[46] 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 were constructed from peat and muck to protect those crops in the late 1800's. 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.[47]

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.[48] The short-term benefits of the engineered solutions may be outweighed by the long-term challenges they have caused. Soil erosion and settling and oxidation[49] 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.[50]

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, and 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.[51] These flood-prone areas of the Delta are largely reliant on the levee system for flood protection, but recent estimates have suggested that protection is adequate for only about half of the Delta.[52]

The lack of available inventory data on the levee system fosters uncertainty about the adequacy of these levees to provide protection, and this is exacerbated by the complexities of levee ownership and responsibility. The State is responsible for maintaining and regulating only a third of the Delta levees, while the remaining are split among 70 local reclamation districts.[53] The US Army Corps of Engineers, in partnership with the Department of Water Resources, conducts periodic inspections of district levees as part of the Corps' Levee Safety Program.[54] But of the 6,500 miles of levees in the Central Valley, only

[46] US Geological Survey, "Sacramento-San Joaquin Delta," N.d. https://pubs.usgs.gov/circ/circ1182/pdf/11Delta.pdf
[47] Delta Stewardship Council, "Delta Plan Executive Summary," 2013, http://deltacouncil.ca.gov/delta-plan-0
[48] Ibid.
[49] Exposure to oxygen accelerates the decay of organic matter and peat soil, leading to soil loss and subsidence.
[50] Delta Stewardship Council, "Delta Plan Executive Summary," 2013, http://deltacouncil.ca.gov/delta-plan-0
[51] US Geological Survey, "Sacramento-San Joaquin Delta," N.d. https://pubs.usgs.gov/circ/circ1182/pdf/11Delta.pdf
[52] Delta Stewardship Council, "Delta Plan Executive Summary," 2013, http://deltacouncil.ca.gov/delta-plan-0
[53] Ibid.
[54] US Army Corps of Engineers, "Levee Safety Program," N.d. https://www.spk.usace.army.mil/Missions/Civil-Works/Levee-Safety-Program/

1,760 are in the Corps' program.[55] And out of 27 recent levee inspections in the Delta, 24 received a rating of "unacceptable." [56] If levee failure occurred due to flooding from storm events, sea level rise, or some combination of both, 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.[57] The study found that in Sacramento, 22,808 people live in areas at risk from under three feet of sea level rise and 14,628 of those people were identified as being in high-vulnerability populations (low income and ethnic minorities). A large portion of those affected in recent disasters in California have been disadvantaged or vulnerable populations, including the elderly, who may be restricted in their ability to evacuate during an emergency.

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. However, there is a significant portion of the 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 assessed the potential impacts of Delta sea level rise in this vulnerability assessment. This assessment identified which routes may be vulnerable to inundation, scour, erosion, or other effects due to higher water levels. This analysis also incorporates the risks associated with the failure of levees and other flood control barriers.

The District 3 Delta sea level rise analysis used a model developed by Climate Central, which identified potential flooding conditions if levees and flood control barriers[58] provide adequate protection, and conditions if they do not. The following sections show 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). 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 levees and other barriers were to fail. Note that the original sea level rise inundation data (non-levee protected) received from Climate Central was clipped to be consistent with the storm surge inundation data described in the next section.

7.1. Sea Level Rise Inundation in District 3

If all levees and flood control structures provide adequate flood protection, SR-12 would be the primary District 3 route vulnerable to inundation by sea level rise. SR-12 would not be vulnerable until higher sea level rise scenarios – only minor portions appear vulnerable until the 5.74 feet (1.75 meter) sea level rise scenario. Short segments of SR-160, SR-220, I-5, and I-80 may also be at risk, but these areas appear to

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

[56] "National Levee Database," US Army Corps of Engineers, last accessed June 12, 2019, https://levees.sec.usace.army.mil/

[57] Climate Central, "Sacramento and Stockton Face Biggest Sea Level Rise Threat in California," N.d. http://www.climatecentral.org/pdfs/SLR-CA-SS-PressRelease.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.

mainly cross channels in the Delta and may be false positives. Further analysis of these areas is necessary to understand sea level rise risk.

If certain levees and flood barriers failed or provided inadequate protection, sea level rise could flood larger portions of SR-160, SR-220, and I-5, and additionally affect SR-84. These areas are at risk from just 1.64 feet (0.5 meters) of sea level rise given levee failure—the Ocean Protection Council's (OPC's) "likely range" projections show a 66% chance of this happening by 2060. Assuming more extreme estimates (H++ scenario), 1.64 feet of sea level rise could happen sooner—sometime between 2040 and 2050 (see Figure 7-4). It is important to note that this scenario assumes that ALL levees and flood barriers fail, which is highly unlikely. However, it is also important to identify the worse-case scenarios so actions can be taken to determine and mitigate the potential risks and adequately protect the SHS.

Table 7-1 summarizes the centerline mileage of the SHS in District 3 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. Table 7-2 summarizes centerline mileage of the SHS that could be inundated by sea level rise in levee protected areas. Both mileage summaries include bridges, which require additional analysis to determine if they are at risk of flood damage. Sacramento and Yolo counties are the only ones affected and other District 3 counties are omitted from the tables.

TABLE 7-1: CENTERLINE MILES INUNDATED BY SEA LEVEL RISE IN THE DELTA

District 3 Counties	Sea Level Rise Height		
	1.64 ft (0.50 m)	3.28 ft (1.00 m)	5.74 ft (1.75 m)
Sacramento	1	1	10
Yolo	0	0	1
District Total	**1**	**1**	**11**

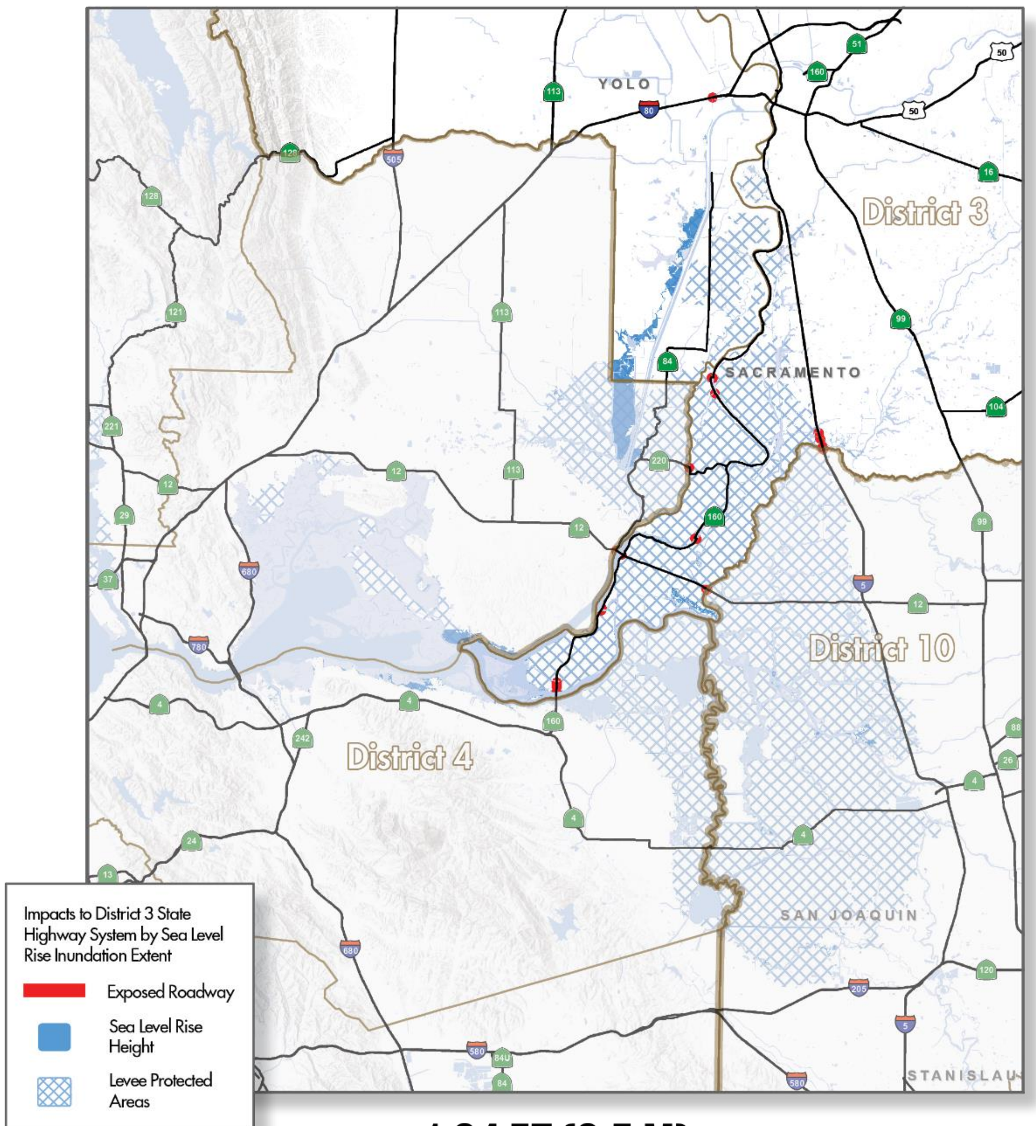
TABLE 7-2: CENTERLINE MILES INUNDATED BY SEA LEVEL RISE IN LEVEE PROTECTED AREAS

District 3 Counties	Sea Level Rise Height		
	1.64 ft (0.50 m)	3.28 ft (1.00 m)	5.74 ft (1.75 m)
Sacramento	32	38	46
Yolo	6	8	11
District Total	**38**	**46**	**57**

NOTE: MILEAGE SUMMARIZED FOR DISTRICT 3 INCLUDES PARTS OF THE HIGHWAY SYSTEM IN DISTRICT 4 AND 10 THAT ARE ON THE BORDER OF THE TWO DISTRICTS.

FIGURE 7-1: SEA LEVEL RISE INUNDATION 1.64 FEET (0.50 METERS)

SEA LEVEL RISE INUNDATION IN THE DELTA



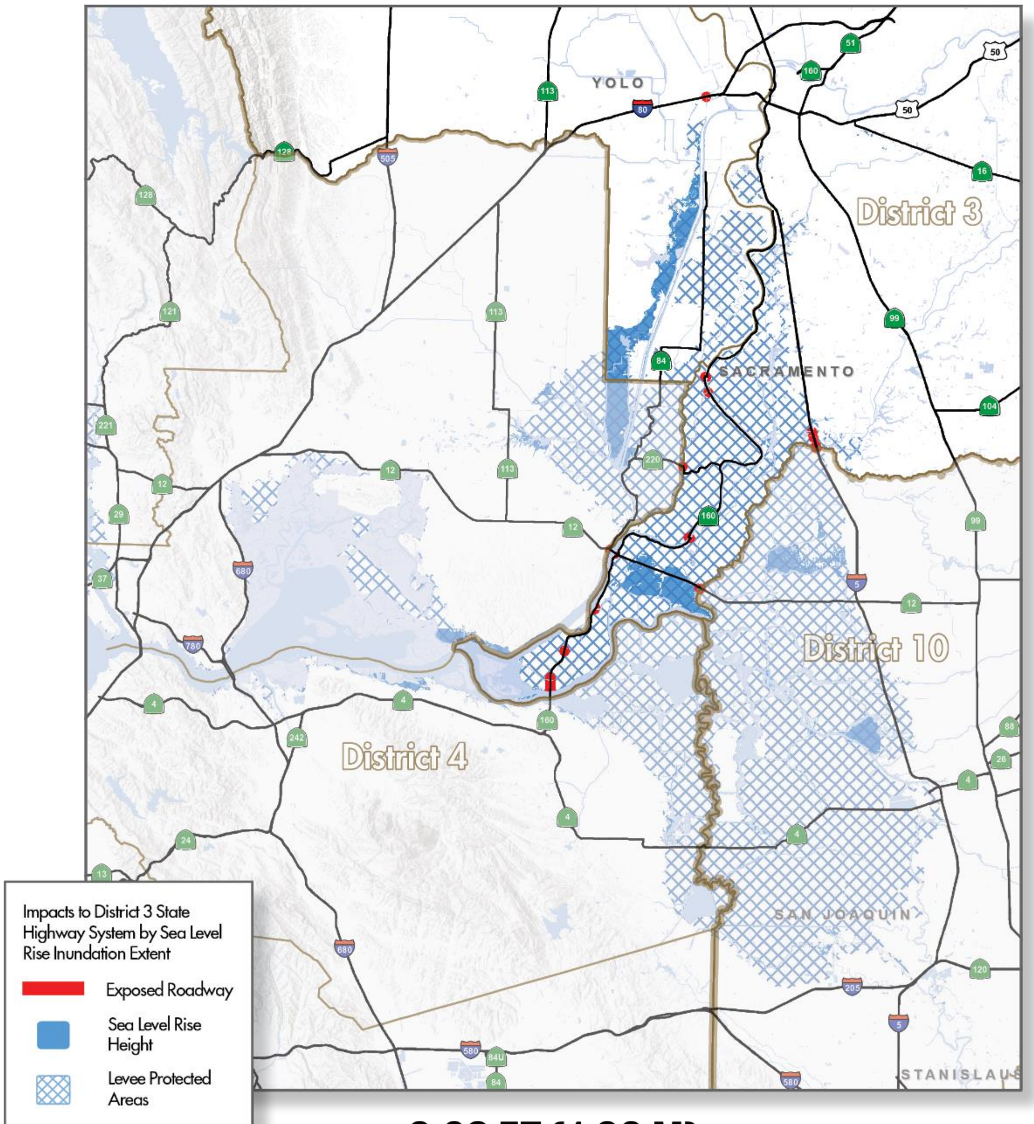
1.64 FT (0.5 M)

Sea Level Rise Inundation of the Caltrans State Highway System in District 3

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 if levees stop the flow of water, except for where the water is high enough to overtop them. 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 7-2: SEA LEVEL RISE INUNDATION 3.28 FEET (1.00 METER)

SEA LEVEL RISE INUNDATION IN THE DELTA



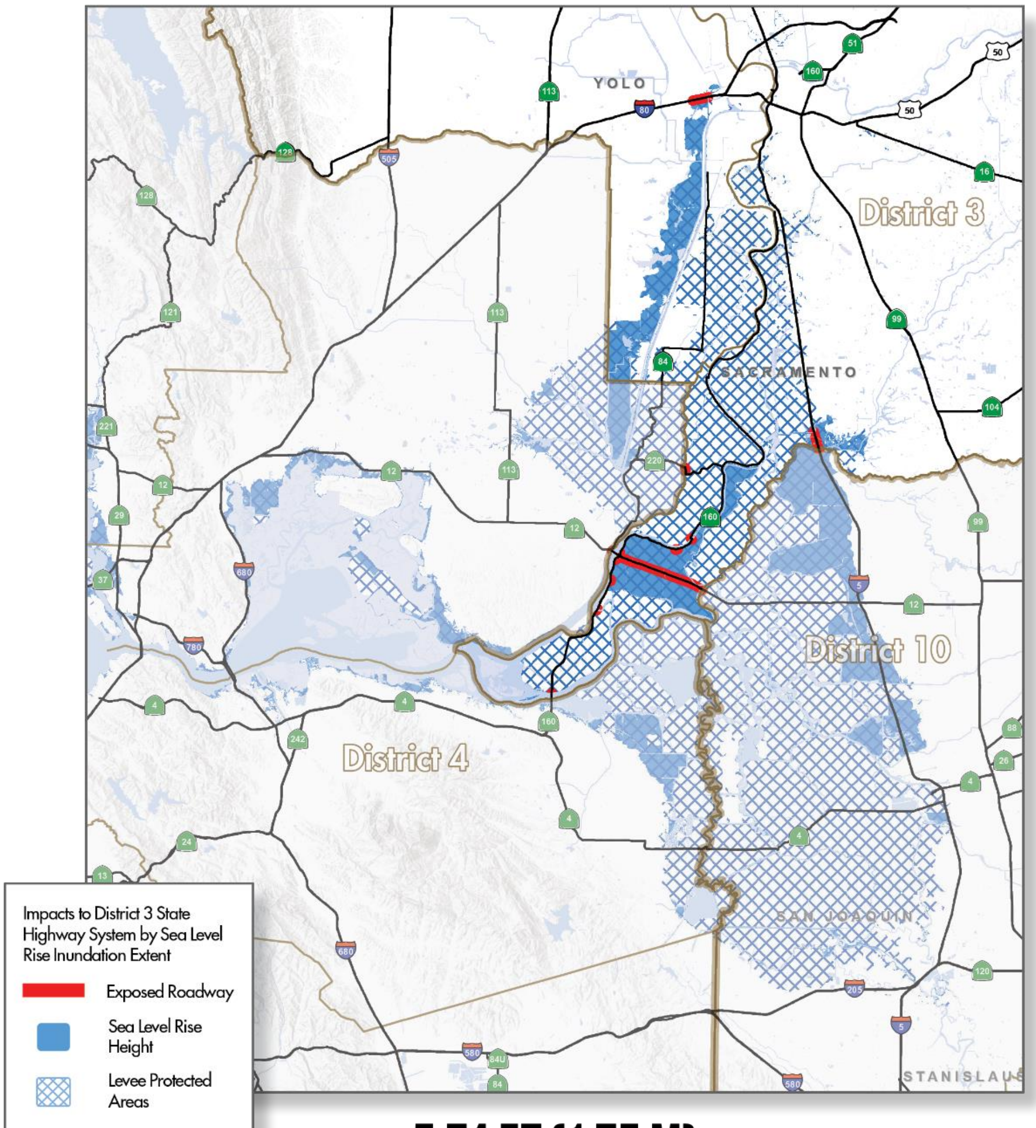
3.28 FT (1.00 M)

Sea Level Rise Inundation of the Caltrans State Highway System in District 3

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 if levees stop the flow of water, except for where the water is high enough to overtop them. 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 7-3: SEA LEVEL RISE INUNDATION 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 3

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 if levees stop the flow of water, except for where the water is high enough to overtop them. 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. Sea Level Rise Projections 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 7-4 below shows 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—though the assumptions for global emissions associated with the RCP 8.5 scenario are considered "business-as-usual." The OPC guidance provides estimates derived for the RCP 8.5 scenario until 2050, and for both scenarios through 2150. 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:

- 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.

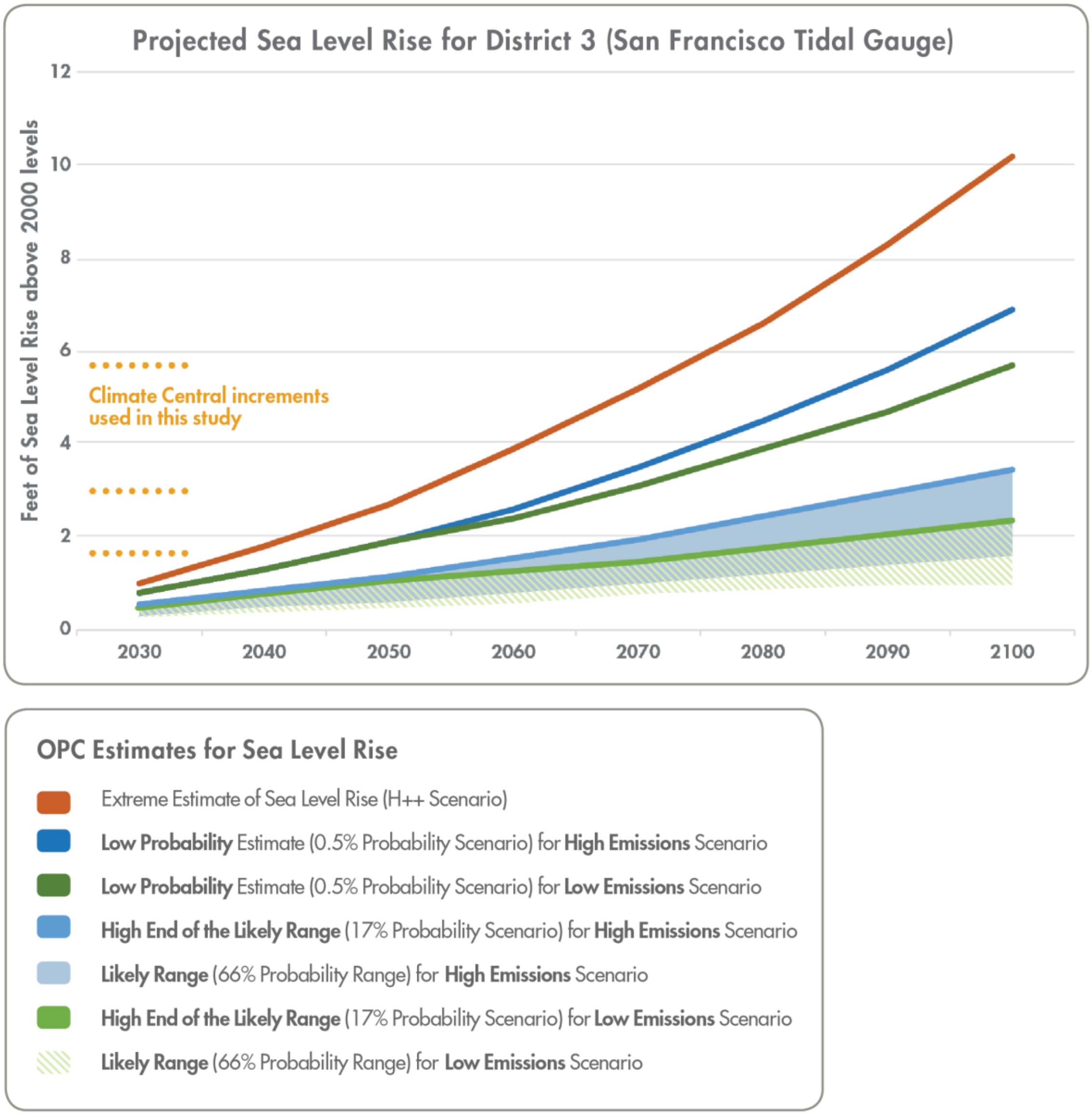
The OPC guidance was developed to help State and local governments understand the potential future risks associated with sea level rise and incorporate this understanding into work efforts, investment

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

decisions, and policy mechanisms. The OPC recognizes that the science surrounding sea level rise projections is still improving and anticipates updating their guidance at least every five years 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 7-4. 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 will need to develop a policy for how best to incorporate these estimates and OPC guidance into its processes and procedures.

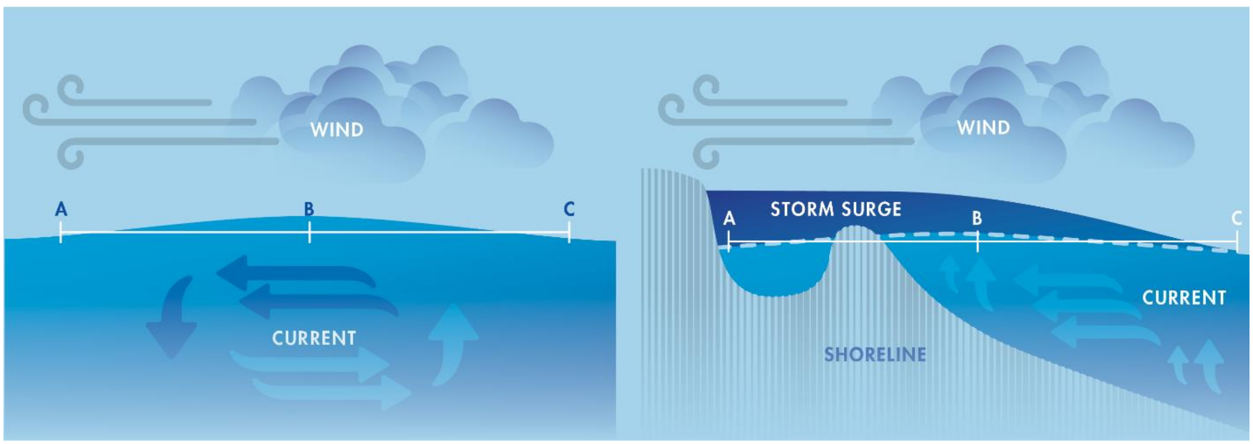
FIGURE 7-4: PROJECTED SEA LEVEL RISE FOR SAN FRANCISCO BAY



8. STORM SURGE IN THE DELTA

As seas rise and move inland over low-lying areas, there is a greater potential for storm surge 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 which 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 8-1 below, developed by the National Oceanic and Atmospheric Administration (NOAA) and edited for this report, shows how wind-driven events create surge at the coastline and inland.

FIGURE 8-1: VERTICAL CIRCULATION DURING A STORM EVENT



SOURCE: NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

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 coastline, but they can still raise sea levels during severe winter storms. Heavy rain during these events can also contribute to coastline flooding. Higher river levels can channel additional water into affected areas where it flows into the ocean. 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 the 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 levels associated with sea level rise were used as the baseline water elevation and

[60] National Oceanic and Atmospheric Administration, "Introduction to Storm Surge," N.d. https://www.nhc.noaa.gov/surge/surge_intro.pdf
[61] Ibid.
[62] "Sea Level Rise CalFloD-3D," Cal-Adapt, last accessed June 12, 2019, http://cal-adapt.org/data/slr-calflod-3d/
[63] John Radke et al. (University of California, Berkeley), "Assessment of Bay Area Natural Gas Pipeline Vulnerability to Climate Change," California Energy Commission, Publication number: CEC-500-2017-008, 2016.

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.

8.1. Storm Surge Flooding in District 3

The model results indicate that for water levels associated with 1.64 feet of sea level rise, combined with a 100-year storm, small segments of SR-160, I-5, and SR-80 may temporarily flood and suffer storm surge damage. These affected areas expand as sea level rises, and under the highest rise scenario modeled (4.62 feet) larger portions of SR-12 may flood or be otherwise impacted. Table 8-1 below summarizes highway centerline miles of District 3 SHS that could be flooded by a 100-year storm event, given 1.64, 3.28, or 4.62 feet of sea level rise, as identified by the 3Di model. For individual project designs, information from the Cal-Adapt website would be used to identify the most appropriate input data.

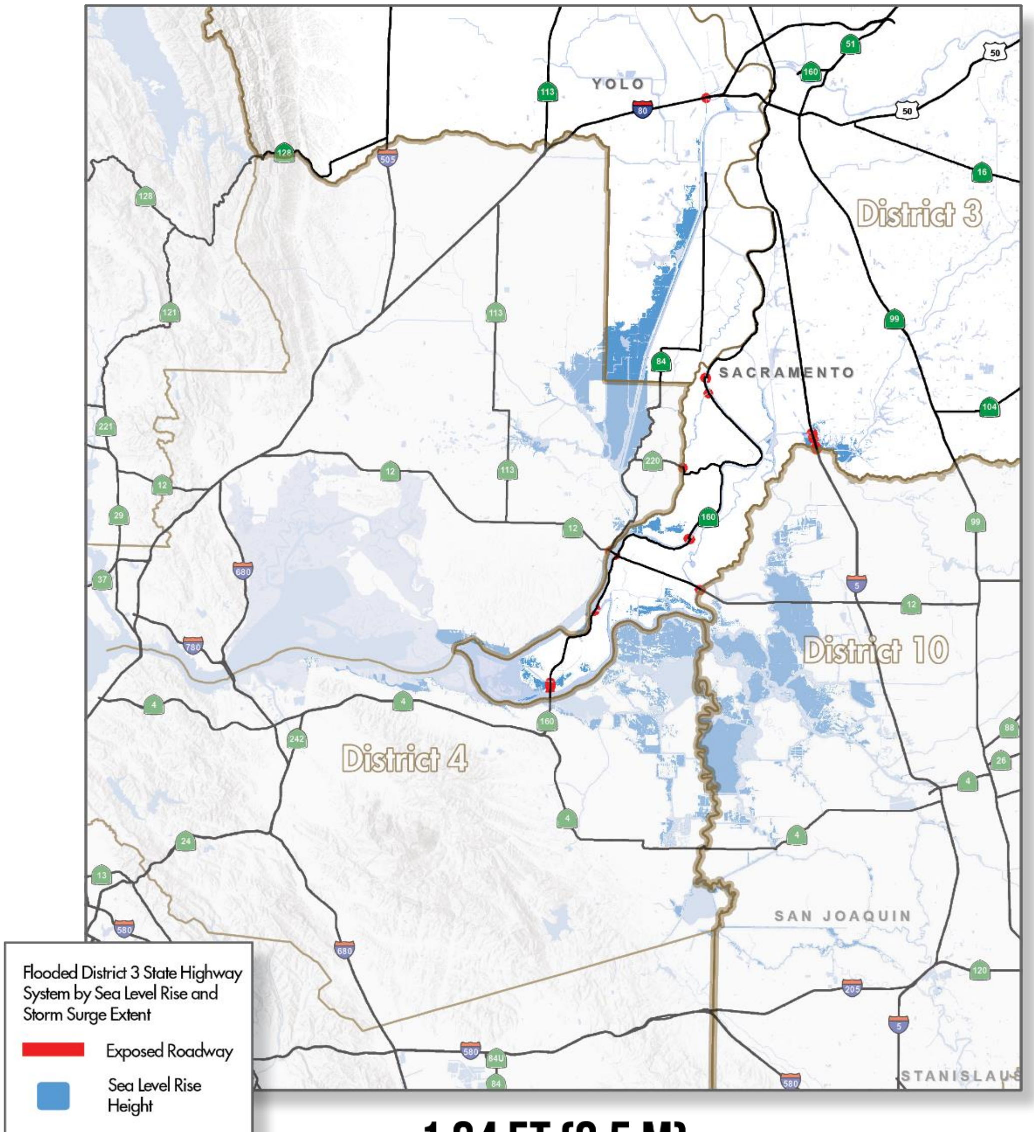
TABLE 8-1: CENTERLINE MILES FLOODED BY SEA LEVEL RISE AND SURGE (100-YEAR STORM)

	Sea Level Rise Height		
District 3 Counties	**1.64 ft (0.50 m)**	**3.28 ft (1.00 m)**	**4.62 ft (1.41 m)**
Sacramento	2	2	**11**
Yolo	0	0	**0**
District 3 Total	**2**	**2**	**11**

NOTE: DISTRICT 3 MILEAGE INCLUDES PARTS OF THE HIGHWAY SYSTEM THAT BORDER AND CROSS INTO DISTRICTS 4 AND 10.

FIGURE 8-2: SEA LEVEL RISE AND STORM SURGE FLOODING (WITH 1.64 FEET (0.50 METERS) OF SEA LEVEL RISE)

FLOODING FROM STORM SURGE IN THE DELTA

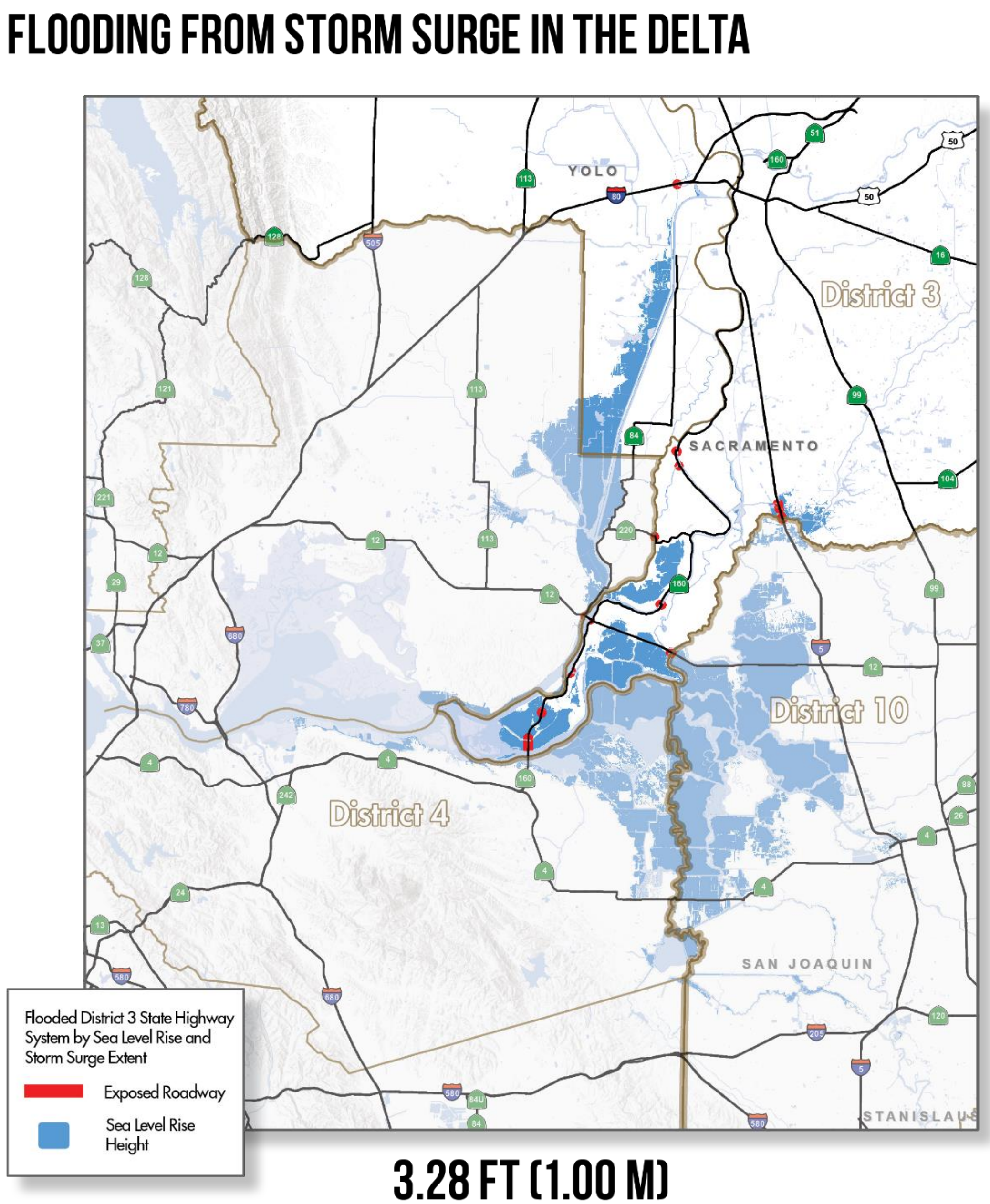


1.64 FT (0.5 M)

Flooding of the Caltrans State Highway System in District 3 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 8-3: SEA LEVEL RISE AND STORM SURGE FLOODING (WITH 3.28 FEET (1.00 METER) OF SEA LEVEL RISE)

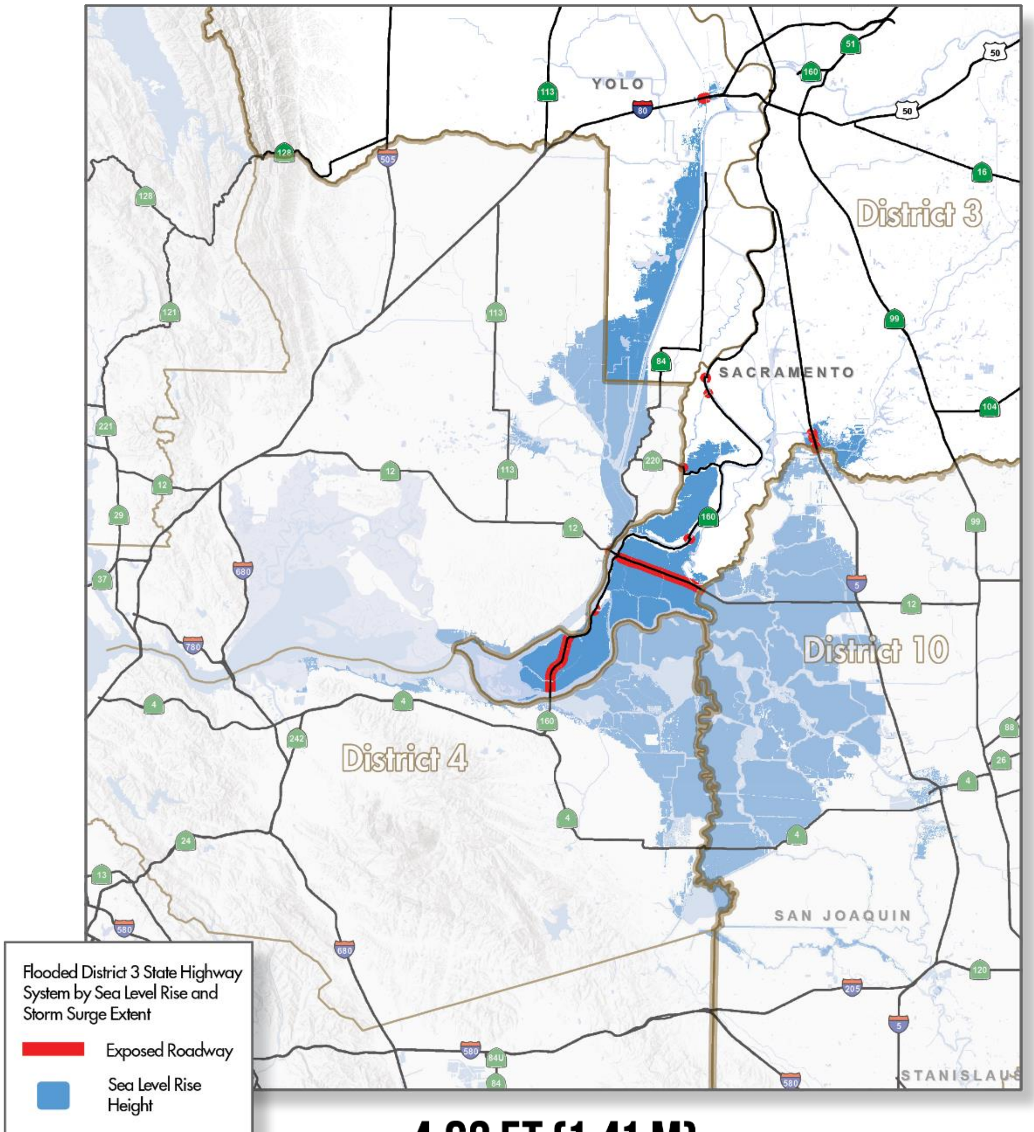


Flooding of the Caltrans State Highway System in District 3 given the 100-Year Storm Event and Sea Level Rise

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 8-4: SEA LEVEL RISE AND STORM SURGE FLOODING (WITH 4.62 FEET (1.41 METERS) OF SEA LEVEL RISE)

FLOODING FROM STORM SURGE IN THE DELTA



4.62 FT (1.41 M)

Flooding of the Caltrans State Highway System in District 3 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. INCORPORATING CLIMATE CHANGE INTO DECISION-MAKING

9.1. Risk-Based Design

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

One outcome of the FHWA studies was a step-by-step method for completing facility (or asset) design, such that climate change was considered and inherent uncertainties in the timing and scale of climate change were included. This method, termed the Adaptation Decision-Making Assessment Process (ADAP),[64] provides facility designers with a recommended approach to designing a facility when considering possible climate change effects. The key steps in ADAP are shown in Figure 9-1: FHWA's Adaptation Decision-Making Process.

The first five steps of the ADAP process cover the characteristics of the project and the context. The District 3 Vulnerability Assessment has worked through these first steps at a high level and the data used in the assessment has been provided to Caltrans for future use in asset level analyses. These five steps should be addressed for every exposed facility during asset level analyses.

Step 5 focuses on conducting a more detailed assessment of the performance of the facility. When analyzing one facility, it is important to assess the highest impact scenario. This does not necessarily correspond to the highest temperature range, or largest storm event. In this case, the analysis should determine which scenarios will have the greatest effect on a facility. For example, a 20-year storm may cause greater impacts than a 100-year storm, depending on wind and wave directions. If the design criteria of the facility are met even under the greatest impact scenario, the analysis is complete. Otherwise, the process moves onto developing adaptation options.

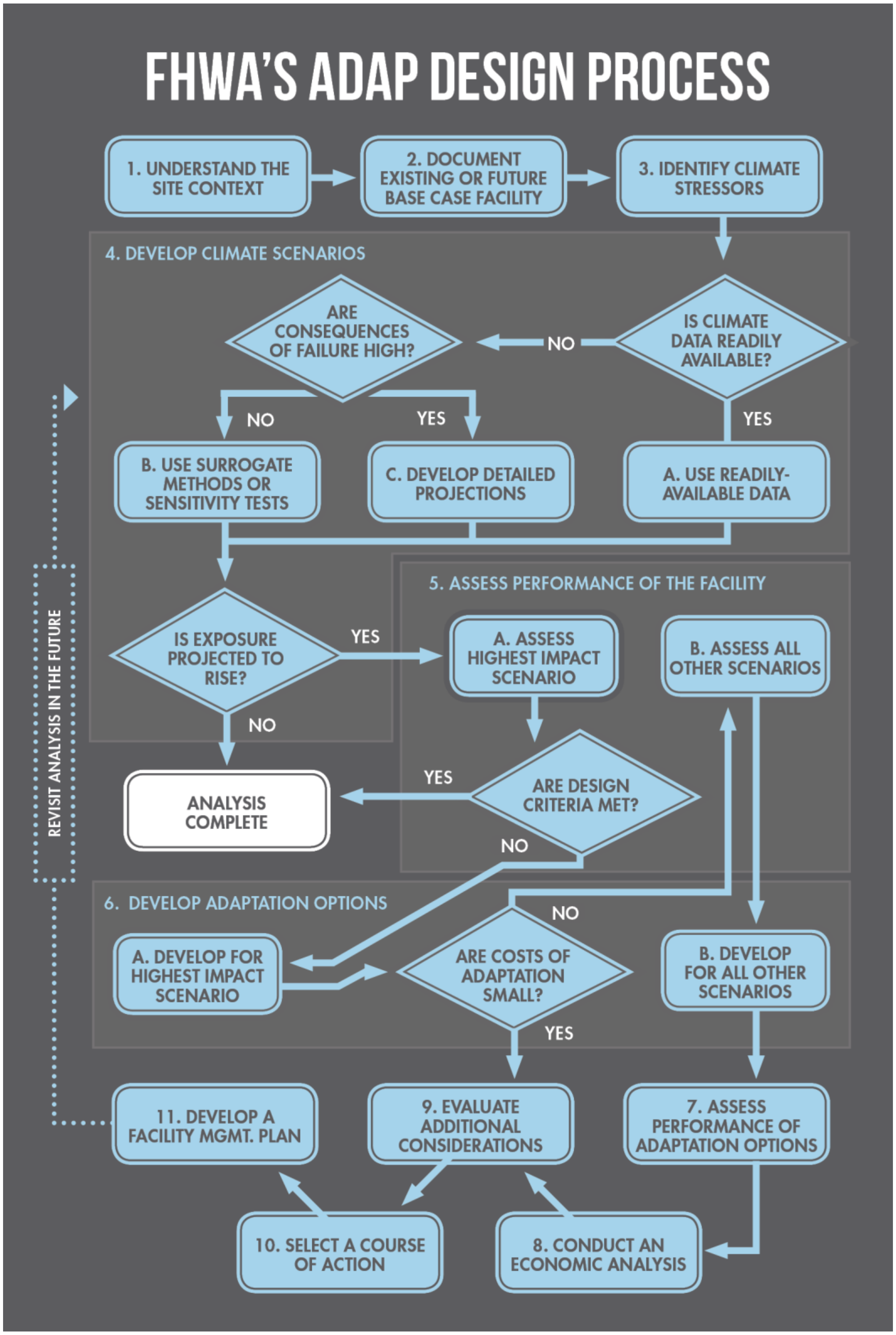
Options should be developed that will adapt the facility to the highest impact scenario. If these options are affordable, they can move to the final steps of the process. If they are not, other scenarios can be considered to identify more affordable options. These alternative design options will need to move through additional steps to critique their performance and economic value. Then, they also move to the final steps of the process. These last three steps are critical to implementing adaptive designs. Step 9 involves considering other factors that may influence adaptation design and implementation. For example, California Executive Order B-30-15 requires consideration of:

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

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

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

FIGURE 9-1: 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

9.1.1. District 3 Design Response – SR-16 and SR-20 Stabilization

This 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. The 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. While this effort is underway today, District 3 continues to respond to extreme weather impacts and take steps to increase the resiliency of their portion of the SHS, wherever possible. The following is one example of a design response to damage on the District 3 SHS to prevent further impacts.

In 2015, the Rocky Fire in Colusa and Yolo counties burned nearly 70,000 acres and forced the closure of local highways, including SR-16 and SR-20. There was observed damage to both routes, including scorched slopes, burned vegetation, and minor roadway impacts. Given concern about potential impacts from rainfall, District 3 initiated a Director's Order to respond before the winter season. This response involved armoring the eroded areas by recontouring and placing Rock Slope Protection, which included a fabric underlayment, drainage, a layer of rock, a soil mixture between rocks, and vegetation, to stabilize the soils of the scorched slope. Vegetation was applied through hydroseeding and typically includes shallow rooting plants like grasses. Deeper rooted plants like willows and subtrees can also be used for soil stabilization, if used without fabric underlayment.[65] Figure 9-2 shows some of the scorched slopes along SR-16 and SR-20, and Figure 9-4 shows some flooding and landslide impacts following the Rocky Fire on SR-16.

FIGURE 9-2: BURN AREA FROM ROCKY FIRE #1

[65] "Soil Filled Rock Slope Protection (Nonstandard)," Caltrans, last accessed June 12, 2019, http://www.dot.ca.gov/design/lap/landscape-design/erosion-control/steepslopes/soilfilledrsp.html

FIGURE 9-3: BURN AREA FROM ROCKY FIRE #2

FIGURE 9-4: SMALL LANDSLIDE AND FLOOD EVENT ON SR-16

9.2. Prioritization of Adaptive Response Projects

The project prioritization approach outlined below is based on a review of the methods in other transportation agencies, and lessons learned from other adaptation efforts. These methods—mostly developed and used by departments of transportation in other states—address long-term climate risks and are intended to inform project priorities across the range of diverse project needs. The method outlined below recognizes the following issues when considering climate change adaptation for transportation projects:

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

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

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

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

The prioritization method requires the following information:

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

What are the levels for stressors (sea level rise, storm surge,[66] wildfire, etc.) that would cause damage and or loss?

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

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

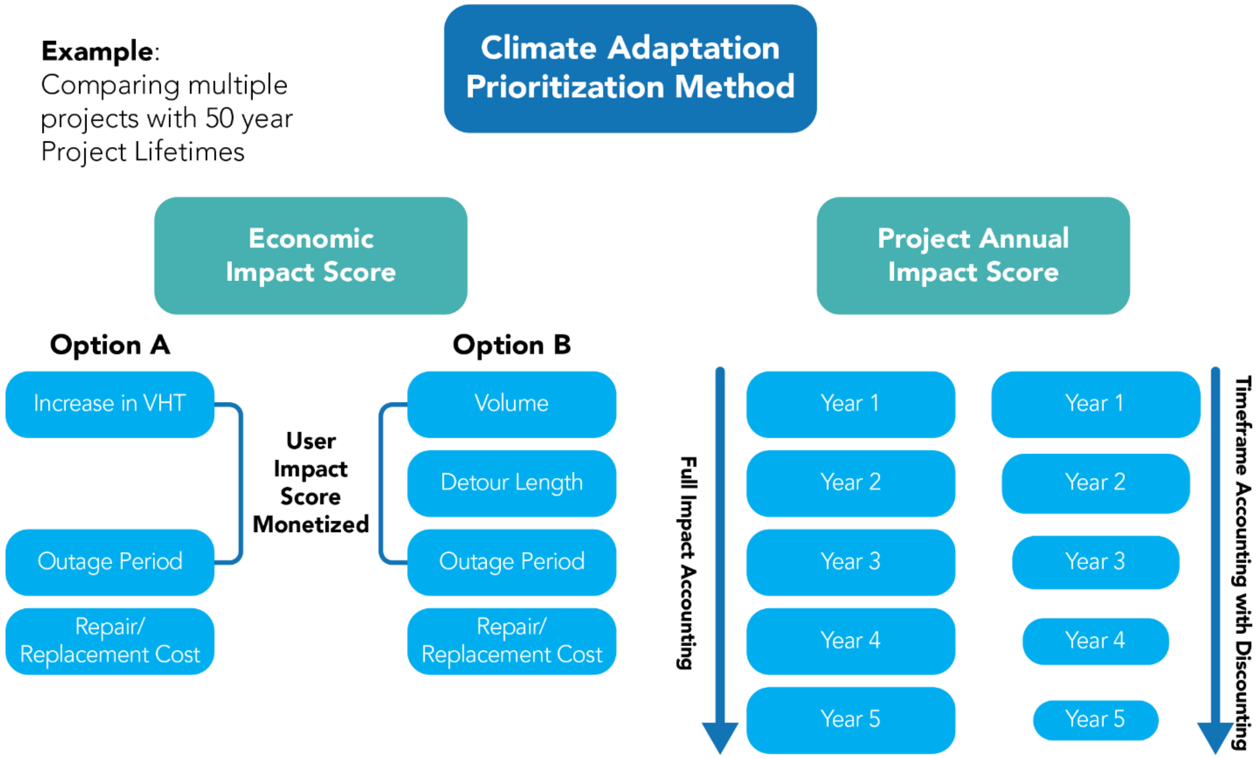
A project annual impact score is used to reflect two conditions, summarized by year:

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

These two pieces of information are important to better understand the full cost of impacts over time. Figure 9-5 shows the general approach for the prioritization method.

[66] *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.

FIGURE 9-5: APPROACH FOR PRIORITIZATION METHOD



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

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

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

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

Probabilities of an event occurring over each year would be used to summarize costs per year as well as a summarized cumulative total cost for the project over the lifetime. The resulting values would set the prioritization metric in terms of net present value for Caltrans to apply in selecting projects. The identification of an annual cost metric, which includes discounting, enables the important decision-making process on which project should advance given limited project resources. Table 9-1 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 9-1: EXAMPLE PROJECT PRIORITIZATION

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

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

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

9.3. Infrastructure Voluntary Evaluation Sustainability Tool

In addition to ADAP, FHWA developed another tool called the Infrastructure Voluntary Evaluation Sustainability Tool (INVEST), which is used to enhance the sustainability and resiliency of highway projects across the US. The tool is used to identify how successful a project is at incorporating sustainability and resiliency principles into planning, design, and operations and maintenance, and identify room for improvement. Criteria specifically related to climate change include the "Infrastructure Resiliency" credit, which is achieved when the state DOT assesses future impacts from hazards (including climate change) and "Infrastructure Resiliency Planning and Design" credit, which is achieved when a project responds to current and future risks. INVEST can be useful for Caltrans to consider when developing SHS projects in District 3 and across the state, especially as Caltrans begins to incorporate climate change considerations into SHS projects. Caltrans can also showcase successful projects with other DOTs through use of the INVEST tool.[67]

[67] "INVEST," US Department of Transportation Federal Highway Administration, last accessed on June 12, 2019, https://www.sustainablehighways.org/

10. CONCLUSIONS AND NEXT STEPS

This report represents an initial effort to identify areas of exposure to potential climate change for facilities owned and operated by Caltrans District 3. The study utilized various data sources to identify how climatic conditions may change from today and where these areas of high exposure to future climate risks appear in District 3. The study distilled the larger context of climate change down to a more localized understanding of what such change might mean to District 3 functions and operations, District 3 employees, and the users of the transportation system. It is intended, in part, as a transportation practitioner's guide on how to include climate change into transportation decision making.

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

This report provides District 3 with the information on areas of climate change exposure it can utilize to proceed to more detailed, project-level assessments. In other words, the report has identified where climate change risks are possible in District 3 and where project development efforts for projects in these areas should consider changing future environmental conditions. There are several steps that can be taken to transition from a traditional project development process based on historical environmental conditions to one that incorporates a greater consideration for facility and system resiliency. This process can incorporate the benefits associated with climate change adaptation strategies and use climate data as a primary decision factor. District 3 staff, with its recent history of assessing long-term risks associated with climate change, has the capacity to adopt such an approach and ensure that travelers in the region are provided with a resilient system over the coming years.

The following section provides some context as to what the next steps for Caltrans and District 3 may be, to build upon this work and create a more resilient SHS.

10.1. Next Steps

The work completed for this effort answers a few questions and raises many more. The scope of this work was focused on determining what is expected in the future and how that may affect the Caltrans SHS. This analysis has shown that climate data from many sources indicates an expanded set of future risks – from increased extreme precipitation, to higher temperatures, and an increase in wildfires – all concerns that will need to be considered by District 3.

There are a few steps that will be required to improve decision making and help Caltrans achieve a more resilient SHS in District 3. These include:

10.1.1. Policy Changes

- Agency leadership will need to provide guidance for incorporating findings from this assessment into decision making. This area is a new focus and requires a different perspective that will not be possible without strong agency leadership.
    - Addressing climate change should be integrated throughout all functional areas and business processes; including Planning, Environmental, Design, Construction, Maintenance and Operations.
- Risk-based decision-making. The changing elements of climate change require the consideration of the implications of those changes and how they may affect the system. Caltrans will need to change its methods to incorporate measures of loss, damage and broader social or economic costs as a part of its policies. (See 9.1 Risk-Based Design).

10.1.2. 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 3 (and the State of California).
    - Improved asset data – including accurate location of assets (bridges, culverts) and information on the waterway opening at those locations.
- Improved topo data covering all watersheds that drain to District 03 should be developed. Access to a database with current and proposed land use data would also be beneficial.
- The assessment of wildfire potential along the SHS is an ongoing effort. Follow up will be required to determine the results of new research and whether updated models indicate any additional areas of risk.
- The precipitation and temperature data presented in this report is based off a data set that is newly released. Methods to summarize this data across many climate models is ongoing and the conclusions of that work may yield information that may more precisely define expected future changes for these stressors.
- There are efforts underway to refine the understanding of other stressors, including landslide potential. Further refinements of those efforts will require additional investment and coordination to complete. Research efforts are constantly being refined and Caltrans will need to be an active partner in participating in, and monitoring, the results of these efforts to determine how to best incorporate the results of these efforts into agency practices.

10.1.3. Implementation

- The data presented in this report indicates directions and ranges of change. These data points will need to become a part of Caltrans practice for planning and design for all future activities.
- The use of this data will require the development of educational materials and the training of Caltrans staff to ensure effective implementation.

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

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12. GLOSSARY

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.

Backcasted data: Data produced when a GCM is ran in "reverse," or provides outputs for historical periods.

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 otherwise disrupt the component.

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

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

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

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

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.

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

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