CALTRANS CLIMATE CHANGE

VULNERABILITY ASSESSMENT SUMMARY REPORT

DISTRICT 10

2019

Caltrans

WSP

RESILIENCE: THE ABILITY TO PREPARE AND PLAN FOR, ABSORB, RECOVER FROM, OR MORE SUCCESSFULLY ADAPT TO ADVERSE EVENTS.[1]

This Summary Report and its associated Technical Report describe climate change effects in District 10. This document provides a high-level review of potential climate impacts to the district's portion of the State Highway System (SHS), while the Technical Report presents detail on the technical processes used to identify these impacts. Similar reports are being prepared for each of Caltrans' 12 districts.

A database containing climate stressor geospatial data indicating changes in climate over time (e.g. temperature rise and increased likelihood of wildfires) was developed as part of this study. The maps included in this report and the Technical Report use data from this database, and it is expected to be a valuable resource for ongoing Caltrans resiliency planning efforts and coordination with stakeholders. Caltrans will use this data to evaluate the vulnerability of the SHS and other Caltrans assets, and inform future decision-making.

In California and the western U.S., these general climate trends are expected[2]:

- More severe droughts, faster melting snowpack, and changes in water availability
- Rising sea levels, more severe storm impacts, and coastal erosion
- Increased temperatures and more frequent, longer heat waves
- Longer and more severe wildfire seasons

1 - American Association of State Highway and Transportation Officials (AASHTO) resilience definition

2 - "Global Warming in the Western United States," Union of Concerned Scientists, last accessed July 12, 2019, http://www.ucsusa.org/global_warming/regional_information/ca-and-western-states.html#.WMwOFm_yvlU

COVER PHOTO: INTERSTATE 5 | PORT OF STOCKTON

PHOTO OF YOSEMITE VALLEY

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OVERVIEW OF METHODOLOGY

The data analysis presented in this report is largely based on global climate data compiled by the Intergovernmental Panel on Climate Change (IPCC) and California research institutions like the Scripps Institution of Oceanography. This data was developed to estimate the Earth's natural response to increasing carbon emissions. Research institutions represent these physical processes through Global Climate Models (GCMs). Thirty-two different GCMs have been downscaled to a regional level and refined so they can be used specifically for California. Of those, ten were identified by California state agencies to be the most applicable to California. This analysis used all ten of these representative GCMs, but only the median model is reported in this Summary Report (and the associated Technical Report) due to space limitations.

The IPCC represents future emissions conditions through a set of representative concentration pathways (RCPs) that reflect four scenarios for greenhouse gas (GHG) emission concentrations under varying global economic forces and government policies. The four scenarios are RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5.

This assessment uses or references:

- RCP 2.6, which assumes that global annual greenhouse gas emissions will peak in the next few years.
- RCP 4.5, which assumes that emissions will peak near mid-century.
- RCP 8.5, which assumes that high emission trends continue to the end of century.

RCP 6.0 represents declining emissions after 2080, but this pathway does not appear in this assessment. Results for RCPs 8.5 and 4.5 were processed for this vulnerability assessment. This Summary Report presents results from the RCP 8.5 analysis - the RCP 4.5 analysis is summarized in the associated Technical Report, and the aforementioned geospatial database.

EVACUATION PLANNING

Among the things that Caltrans must consider when planning for climate change is the role of the SHS when disaster strikes. The SHS is the backbone of most county-level evacuation plans and often provides the only high-capacity evacuation routes from rural communities. In addition, state highways also serve as the main access routes for emergency responders, and may serve as a physical line of defense (a firebreak, an embankment against floodwaters, etc.). As climate-related disasters become more frequent and more severe, this aspect of SHS usage will assume a greater importance that may need to be reflected in design. Future studies should consider these additional factors when identifying adaptation strategies on the SHS.

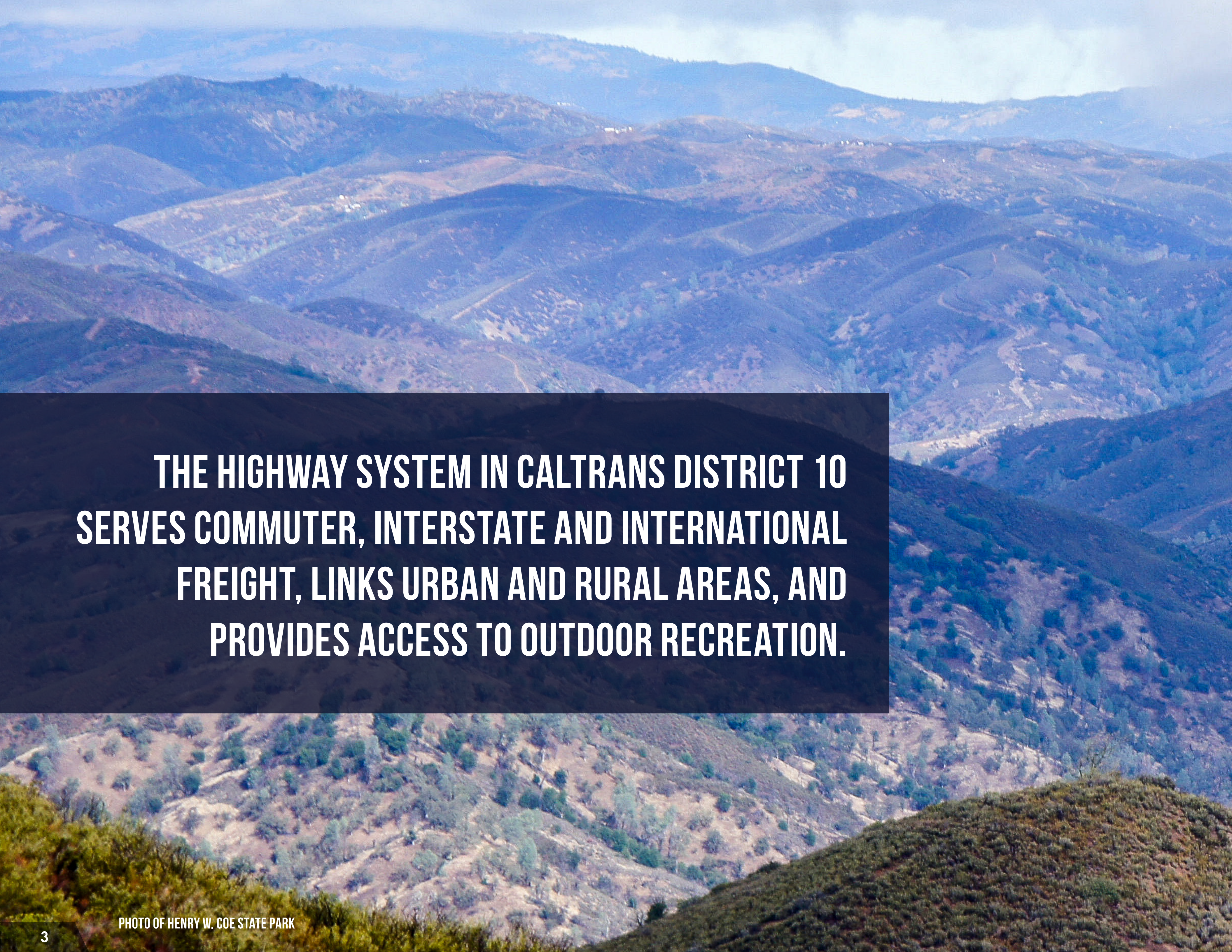
SR 26 | BUTTE FIRE 2015

BACKGROUND AND APPROACH

Caltrans is making a concerted effort to identify the potential climate change vulnerabilities of the SHS. The information presented in this report is the latest phase of this effort. It identifies portions of the SHS that could be vulnerable to different climate stressors and Caltrans processes that may need to change as a result.

This study involved applying available climate data to refine the understanding of potential climate risks, and Caltrans coordinated with various state and federal agencies and academic institutions on how to best use the most recent data. Discussions with professionals from various engineering disciplines helped identify the measures presented in this report.

The information in this Summary Report outlines the potential vulnerabilities to Caltrans' District 10 portion of the SHS and it illustrates the types of climate stressors that may affect how highways are planned, designed, built, operated, and maintained. The intent of the current study is to add clarity regarding climate change (which is a subject with many unknowns) in the region served by District 10 and begin to define a subset of assets on the SHS on which to focus future efforts. This report does not identify projects to be implemented, nor does it present the costs associated with such projects. These items will be addressed in future studies.



THE HIGHWAY SYSTEM IN CALTRANS DISTRICT 10 SERVES COMMUTER, INTERSTATE AND INTERNATIONAL FREIGHT, LINKS URBAN AND RURAL AREAS, AND PROVIDES ACCESS TO OUTDOOR RECREATION.

PHOTO OF HENRY W. COE STATE PARK

DISTRICT 10 CHARACTERISTICS

District 10 encompasses eight counties: Alpine, Amador, Calaveras, Mariposa, Merced, San Joaquin, Stanislaus, and Tuolumne. The district is very diverse with three urban counties in the San Joaquin Valley (San Joaquin, Stanislaus, and Merced), and five rural counties in the Central Sierra Nevada (Amador, Calaveras, Tuolumne, Mariposa, and Alpine). The cities of Stockton, Modesto, and Merced are the three largest cities with a combined population of approximately 1.5 million. Because the district borders the East Bay, many parts of the SHS in the district face increasing levels of congestion due to heavy commuter traffic—the District System Management Plan notes that 25 percent of those who work in District 10 commute from other counties and 15 percent of those living in District 10 commute to other counties. The average commute time is about an hour.[3]

Over 90% of District 10's population resides in the three urban counties, resulting in very distinctive travel demand patterns throughout the district. By 2022, the number of interregional commuters is expected to grow to 120,000, with the largest increase occurring in the urban counties. The five mountain counties are also growing in population, primarily in foothill communities near the Central Sierra mountains—this is due to the district's proximity to Yosemite National Park, which is one of the most popular national parks in the nation.

District 10 maintains 854 bridge structures, 3,547 lane-miles, and 715 acres of landscape areas, 11,000 culverts, 3 rest areas, and 24 maintenance stations. The district also includes 19 airports, the Port of Stockton, and numerous transit rail authorities. The freeway corridors that connect to the Bay Area carry the largest share of traffic. The western interstate and State Route (SR) 99 corridors, for example, experience the largest interregional commuting volume in the district (most of the district's urban areas cluster along Interstate 5 (I-5) and SR 99). To serve this travel market, the district has incorporated managed lanes and ramp-metering projects into the capital investment program. Several of the state routes within the district are included in the Interregional Road System (IRRS), as are facilities to provide interconnections at either expressway or freeway standards. The IRRS plan includes SR 99, SR 152, I-5, and I-580 as "strategic inter-regional corridors," meaning they are high priority routes for the transportation of goods and link rural and urban areas.

KEY STATE POLICIES ON CLIMATE CHANGE

There are multiple California state climate change adaptation policies that apply to Caltrans decision-making. Some of the major policies relevant to Caltrans include:

Executive Order (EO) B-30-15 – requires the consideration of climate change in all state investment decisions through the use of full life cycle cost accounting, the prioritization of adaptation actions which also mitigate GHGs, the consideration of the state's most vulnerable populations, the prioritization of natural infrastructure solutions, and the use of flexible approaches where possible. The Governor's Office of Planning and Research (OPR) have since released guidance for implementing EO B-30-15 titled Planning and Investing for a Resilient California. The document provides high level guidance on how state agencies should consider and plan for future conditions. Caltrans supported the development of this guidance by serving on a Technical Advisory Group convened by OPR.[4]

Assembly Bill 1482 – requires all state agencies and departments to prepare for climate change impacts with efforts including: continued collection of climate data, considering climate in state investments, and the promotion of reliable transportation strategies.[5]

Assembly Bill 2800 – requires state agencies to take into account potential climate impacts during planning, design, building, operations, maintenance, and investments in infrastructure. It also requires the formation of a Climate-Safe Infrastructure Working Group consisting of engineers with relevant experience from multiple state agencies, including Caltrans.[6] The Working Group has since completed Paying it Forward: The Path Toward Climate-Safe Infrastructure in California, which recommends strategies for legislators, engineers, architects, scientists, consultants, and other key stakeholders to develop climate ready, resilient infrastructure for California.[7]

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3 - Caltrans District 10, "District 10 Highway System Management Plan," June 15, 2015

4 - California Governor's Office of Planning and Research, "Planning and Investing for a Resilient California," March 13, 2018, http://opr.ca.gov/planning/icarp/resilient-ca.html

5 - California Legislative Information, "Assembly Bill No. 1482," October 8, 2015, https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201520160AB1482

6 - California Legislative Information, "Assembly Bill No. 2800," September 24, 2016 https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160AB2800

7 - Climate-Safe Infrastructure Working Group, "Paying it Forward: The Path Toward Climate-Safe Infrastructure in California," September, 2018, http://resources.ca.gov/climate/climate-safe-infrastructure-working-group/

EXTREME WEATHER IMPACTS IN DISTRICT 10

Extreme weather events already disrupt District 10 traffic and damage its infrastructure. This section provides examples and discusses the district's response. These types of impacts and their modeled future changes are assessed throughout this report.[8]

TEMPERATURE

On January 17, 2014, Governor Jerry Brown declared a drought state of emergency. The drought began in 2011 and continued for five and a half years—the governor declared an end to the drought in 2017. One of the greatest impacts to Caltrans was the massive tree die-off that resulted—an estimated 102 million trees died in California which contributed to an increased wildfire risk and danger from falling trees across the state. As part of the Governor's proclamation of the drought state of emergency, Caltrans was required to "identify areas of the state that represent high hazard zones for wildfire and falling trees" and "remove dead or dying trees in those high hazard zones." In response, Caltrans District 10 began efforts to remove stands of dead and dying trees along its portion of the SHS.

Following the Detwiler Fire in July of 2017, which impacted SR 49, 140, 132, and 120, District 10 crews removed 780 trees—they removed more after the Donnell Fire in Stanislaus National Forest in August 2018.

PRECIPITATION

California is expected to experience an increase in heavy precipitation events which will result in additional flooding that can impact the state's transportation network.[9] District 10 has already experienced several such events in recent years. In 2018, the Moccasin Storm caused damage and road closures in several District 10 counties. Massive rainfall started on Thursday, March 22, 2018, and within five hours, eight to ten inches of rain fell. The event caused erosion, washouts, and closures on SR 49 in Tuolumne County and SR 132 in Mariposa County because the intensity of the rain caused slides on the steep slopes surrounding the road and overwhelmed the drainage system. Flooding from local rivers will also likely increase in the future; I-5 already experiences such flooding.

District 10 has had to respond to the impacts of storm and flooding events on the SHS in several ways, including relying on the Director's Orders emergency repair efforts to effectively respond to these events and increasing monitoring efforts along areas surrounding the SHS to proactively mitigate risks.

8 - Louise Bedsworth, Dan Cayan, Guido Franco, Leah Fisher, Sonya Ziaja. (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/

9 - Ibid.

10 - Patrick Gonzalez et. al. "Southwest," 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/ 11 - "Sacramento and Stockton Face Biggest Sea Level Rise Threat in California." Climate Central. https://www.climatecentral.org/pdfs/SLR-CA-SS-PressRelease.pdf

WILDFIRE

The size and number of areas affected by wildfire increase with temperatures. The recently released 4th National Assessment of Climate Change reported that climate change had doubled the area burned by wildfire in the west from what would normally be expected between 1984 and 2015. The report also noted that the increase in area burned over the last century is more attributable to climate factors than any other contributing conditions.[10]

District 10 has experienced several wildfire events in recent years. In June, 2015, the Washington Fire, initiated by a lightning strike, grew from 350 acres on June 18, 2015 to over 16,000 acres on June 25, 2015—portions of SR 4, 88, and 89 were closed for nine consecutive days. The Washington Fire burned the vegetation off many hillsides, loosening dirt and rocks and making the hills unstable. In July of 2018, the Ferguson Fire, which grew to 42,017 acres over two weeks, damaged the SHS. The SR 140 corridor was closed on August 3, 2015. Page 23 of this report includes more information about the impacts of the Ferguson Fire.

Grass fires, while not as devastating as forest fires, are also a challenge in District 10. Long, hot, and dry seasons and tinder dry conditions result in numerous grass fires that require district response to manage traffic, replace lost landscaping, and possible closure of facilities for lack of visibility and emergency equipment access to contain grass fires along highways.

WILDFIRE & FLOODING

The combined effects of wildfire and flooding events could increase impacts to the SHS. For example, the Detwiler Fire in July 2017 likely exacerbated the slip-outs and washouts that occurred during the Moccasin Storm in 2018. It also torched over 80,000 acres and destroyed 63 homes before it was contained in early August 2017. The fire impacted SR 49, 140, 132, and 120.

When the Detwiler Fire scorched vegetation on the hillsides along SR 49 in Mariposa County, it removed vegetation that could have absorbed some the heavy rainfall from the Moccasin Storm which would have helped stabilize slopes and sediments. In response, District 10 has adopted preventive measures to reduce the risk of wildfires, including ditch cleaning and ongoing tree removal along the SHS.

SEA LEVEL RISE AND STORM SURGE

So far, there have been no events in District 10 where sea level rise has caused damage to the SHS, but there are 254 miles of roadway between the Stockton and Sacramento areas that sit below the three-foot-high tide line. These roadways will become increasingly vulnerable to sea level rise, storm surge, and flooding events.[11]

According to Climate Central research, roughly 55,000 Stockton residents live in properties at elevations lower than the historical tide and storm records for the San Francisco Bay.[12] Of the at risk communities in Stockton and Sacramento, 60 percent are low income and ethnic minority communities.

11 - Climate Central, "Sacramento and Stockton Face Biggest Sea Level Rise Threat in California," n.d., https://www.climatecentral.org/pdfs/SLR-CA-SS-PressRelease.pdf

12 - Ibid.


SR 49 | SCOURED BRIDGE ABUTMENTS DUE TO DAM FAILURE AT MOCCASIN DAM


SR 4 | WASHINGTON FIRE


AMA 26 | ROCK SLIDE


DONNELL FIRE | HISTORIC MIDDLE FORK STANISLAUS RIVER WOODEN BRIDGE

VULNERABILITY AND THE STATE HIGHWAY SYSTEM

CALTRANS EFFORTS

For the last decade, Caltrans has been addressing climate change concerns—and from these efforts has developed guidance for how to incorporate climate change considerations into project design and other functional Caltrans responsibilities. Activities include:

- The signing of an agreement with the California Coastal Commission and its Integrated Planning Team to ensure effective collaboration between agencies—including planning for sea level rise impacts.[13]
- The release of Guidance on Incorporating Sea Level Rise (2011) to advance effective design and programmatic considerations that incorporate sea level rise projections.
- The issuance of Addressing Climate Change Adaptation in Regional Transportation Plans (2013) which serves as a how-to guide for California Metropolitan Planning Organizations (MPOs) and Regional Transportation Planning Agencies (RTPAs).
- The reporting of adaptation goals and progress to Office of Planning and Research (OPR) through the State Sustainability Roadmaps, Adaptation Chapters.[14]

Caltrans' continuing efforts include developing a more detailed understanding of the risks to the state's transportation system and taking the necessary actions to ensure the resiliency of the transportation system for California residents, businesses, and those engaged in nationwide commerce.

ADDRESSING CONCERNS IN DISTRICT 10

Caltrans District 10's portion of the SHS serves vital functions for communities, commerce, and more. Given the system's importance, understanding the potential impacts of climate change and extreme weather on its performance is a key step in creating a resilient highway system.

The term "vulnerability" is often used to describe how assets, facilities, and even the entire transportation system, might be subject to disruption due to climate change or other stressors. Caltrans' approach focuses on the system's vulnerability to climate-related hazards and extreme weather and recognizes that many Caltrans units have critical roles in supporting a resilient state transportation system.

The approach outlined on the following page presents a process consistent with Caltrans practices. It is focused on assessing likely impacts of climate change-related stresses on the state's transportation system. The approach focuses on three issues:

- **Exposure** – identifying Caltrans assets that could be affected by expected future weather or climate conditions, such as: permanent inundation from sea level rise, temporary storm surge flooding, or a wide range of damages from wildfire.
- **Consequence** – determining what damage might occur to system assets in terms of costs of repair or loss of use.
- **Prioritization** – determining a process for making effective capital programming decisions to address identified risks (including the consideration of system use and timing of expected exposure).

Implementing this approach will require the participation of a wide range of Caltrans professionals from planning, asset management, operations and maintenance, design, emergency response, and economics and will require coordination with environmental and natural resource agencies. It will take an agency-wide effort to successfully implement this approach. This vulnerability assessment is the first stage of implementing this approach; it identifies the portions of the SHS that may be exposed to future climate change and defines projected changes in future conditions.

ENSURING SYSTEM RESILIENCY

After identifying system vulnerabilities, Caltrans will factor "enhanced system resiliency" into choosing projects and project designs. In District 10, this will require implementing projects to help address expected wildfire, precipitation, increased temperatures, sea level rise, and storm surge effects. The following are some general strategies that District 10 could employ to address future climate change effects:

- Anticipate fire in advance by clearing ground vegetation in order to prevent conflagrations originating from the highway.
- Specify fire-resistant materials such as steel guard rails and sign posts rather than wood.
- When designing new facilities in areas identified to be highly exposed to future flooding, incorporate climate change related forecasts into drainage designs.
- Create 'Just-in-time" agreements with clean up contractors, local dump sites, and arborists for dead and dying trees.
- Hazard notifications and Caltrans updates should be provided in multiple languages for system users.

Caltrans is continually looking for effective ways to prepare for the future. Caltrans must be proactive and make capital investments now to secure the long-term viability of the transportation system and advance the general benefits of reducing wildfire, flood, and heat risks for the greater District 10 area.

13 - Integrated Planning Team, "Plan for Improved Agency Partnering: Caltrans and California Coastal Commission," December 21, 2016, http://www.dot.ca.gov/ser/downloads/MOUs/iaccc-improved-agency-partnering-agreement.pdf

14 - Governor's Office of Planning and Research, "Tracking Progress Over Time: State Sustainability Roadmaps," October 12, 2018, http://opr.ca.gov/meetings/tac/2018-10-12/docs/20181012-4_Tracking_Progress_Over_Time.pdf

THE CALTRANS APPROACH TO VULNERABILITY OUTLINED BELOW WAS DEVELOPED TO HELP GUIDE FUTURE PLANNING AND PROGRAMMING PROCESSES. IT DESCRIBES ACTIONS TO ACHIEVE LONG-TERM HIGHWAY SYSTEM RESILIENCY.

THE APPROACH INCLUDES THE FOLLOWING KEY ELEMENTS:

CONDUCT A VULNERABILITY ASSESSMENT OF ALL CALTRANS ASSETS

INCLUDING EXPECTED TIMING OF IMPACTS

IDENTIFY THE SUBSET OF ASSETS EXPOSED TO EXTREME WEATHER EVENTS AND CLIMATE CHANGE

DETERMINE THE CONSEQUENCE OF IMPACTS ON CALTRANS ASSETS

DAMAGE/LOSS DURATION

PRIORITIZE ACTIONS

BASED ON TIMING AND CONSEQUENCE OF IMPACTS

CURRENT STUDY

EXPOSURE

Define the components and locations of the highway system (roads, bridges, culverts, etc.) that may be exposed to changing conditions caused by the effects of climate change such as sea level rise, storm surge, wildfire, landslides, and more. Key indicators for this measure include the potential timing of expected changes – e.g., what year could you expect these conditions to occur.

CONSEQUENCE

Identify the implications of extreme weather or climate change on Caltrans assets. Key variables include estimates of cost of damage and the length of closure to repair or replace the asset and measures of environmental or social impacts. The consequence of failure from climate change include (among others):

- Sea level rise and storm surge inundating roadways and bridges forcing their closure, which could lead to delays and detours.
- Wildfire primary and secondary effects (debris loads/ landslides) on roadways, bridges and culverts.
- Precipitation changes, and other effects such as changing land use, that combined, could increase the level of runoff and flooding.
- Impacts to the safety of the traveling public from flash flooding, loss of guardrails and signage from wildfires, debris on the roadway from flooding, wildfire, and landslide events, and limited visibility from poor air quality.

PRIORITIZATION

Develop a method to support investment decision-making from among multiple options related to future climate risk, with elements including:

- Impacts – what are the projected costs to repair/replace? What is the likely time of outage? What are the likely impacts on travel/goods movement? Who will be directly or indirectly affected?
- Likelihood - what is the probability of impact?
- Timing – how soon can the impacts be expected?

BY USING THIS APPROACH, CALTRANS CAN CAPITALIZE ON ITS INTERNAL CAPABILITIES TO IDENTIFY PROJECTS THAT INCREASE SHS RESILIENCY.

OTHER EFFORTS IN DISTRICT 10 TO ADDRESS CLIMATE CHANGE

Caltrans recognizes that outside of its efforts and statewide efforts, there are also regional projects underway in District 10 to mitigate and address the effects of climate change. Ongoing coordination with local governments and stakeholders will be critical to ensure that methodologies and adaptation strategies are not redundant with other efforts. Regional coordination will be especially important to combat the broad effects of stressors like rising seas and temperatures that will necessitate a collective response. Here are several regional stakeholders and projects that are instrumental to addressing effects of climate change in District 10:

AMADOR-CALAVERAS CONSENSUS GROUP [15]

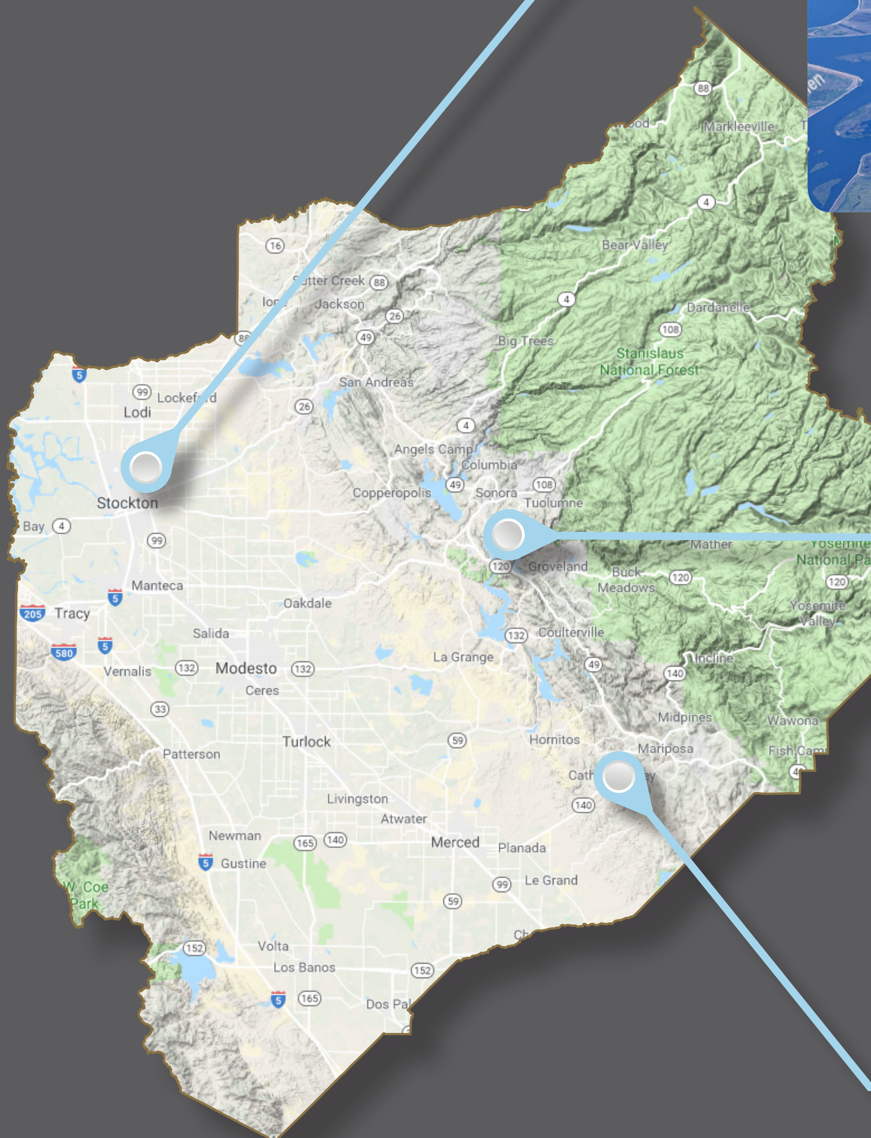
The Amador-Calaveras Consensus Group is a community-based group focusing on protecting communities from wildfires in part by creating fire-safe communities. Members include state and federal agencies, business owners, nonprofit organizations, elected officials, and private citizens. It emphasizes fire prevention and adaptation strategies in the upper Mokelumne River and Calaveras River watersheds east of SR 49.

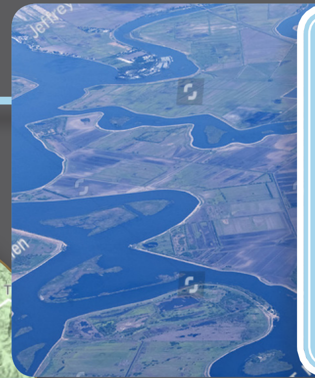
SUSTAINABLE COMMUNITIES COALITION IN STANISLAUS COUNTY [16]

The Coalition has convened groups in San Joaquin and Stanislaus Counties to advocate for land use, housing, and transportation policies that will lead to more sustainable communities. The Coalition is especially interested in environmental justice, as it relates to decisions affecting the built environment, for low income and minority populations. Its efforts have included obtaining funding and technical expertise, and exchanging strategies and best practices for a range of issues—including climate change—and promoting equitable adaptation strategies. The Coalition has worked with county and local governments to develop their Sustainable Communities Strategy, and in two cases, amend the General Plan to be more sensitive to equity issues.

15 - For more on the Amador-Calaveras Consensus Group, visit http://acconsensus.org/about/

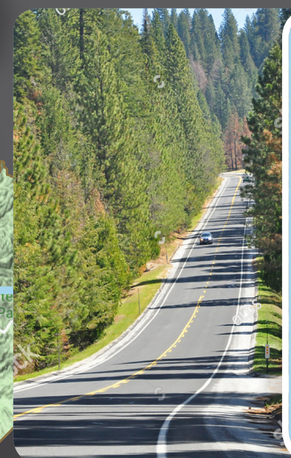
16 - For more on the Sustainable Communities Coalition in Stanislaus County, visit https://ejstockton.org/community/





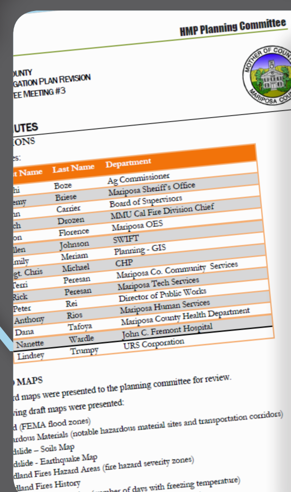
SACRAMENTO-SAN JOAQUIN DELTA CONSERVANCY [17]

The Conservancy is the primary state agency seeking to understand and address potential climate change impacts in the Delta. The Conservancy holds the position that the economic and environmental health of the Delta region is directly linked to its vulnerability to potential climate change impacts. It has placed particular attention on the risks associated with sea level rise. The Conservancy has encouraged programs and funding for projects that promote infrastructure resiliency in anticipation of climate change risks.



TUOLUMNE COUNTY GENERAL PLAN [18]

The latest update of the Tuolumne County General Plan included adaptation strategies for a more resilient county. Examples include: 1) identifying critical infrastructure vulnerable to extreme heat events, 2) developing outreach programs for outdoor workers to prevent heat-related illness, 3) exploring options to incorporate cool pavement technology, 4) establishing an excessive-heat emergency response plan, and 5) identifying critical infrastructure vulnerable to wildfire. It is interesting to note that in 2018, the Moccasin Dam was threatening to fail due to too much water entering the reservoir. The excessive and sudden release of water damaged SR 49 and resulted in scoured bridge abutments.



MARIPOSA COUNTY LOCAL HAZARD MITIGATION PLAN [19]

The Mariposa County Local Hazard Plan is a good example of a county plan developed in anticipation of disruptions due to local hazards. The planning committee identified twenty-eight different types of hazards which they then shortened a list of five they considered to be most critical: floods, landslides, wildfires, winter storms, and solid waste and hazardous materials (earthquake and extended power loss were also identified as major concerns but were subsumed in these categories). The plan noted that Mariposa County has experienced major floods and it estimates a 37 percent probability that floods causing more than $10,000 in damage will occur in an average year. The plan also estimates a 70 percent probability of a weather-related landslide.

17 - "Sacramento-San Joaquin Delta Conservancy, "Climate Change." 2015. http://deltaconservancy.ca.gov/climate-change-1/

18 - "Climate Change, Chapter 18." Tuolumne County General Plan. 2015. https://www.tuolumnecounty.ca.gov/DocumentCenter/View/11956/Chapter-18-Climate-Change-Final

19 - "Mariposa County Local Hazard Mitigation Plan." Mariposa County. 2015. http://www.mariposacounty.org/DocumentCenter/View/67481/FINAL-Mariposa-LHMP-Update_February-2015

PHASES FOR ACHIEVING RESILIENCY

California has been a national leader in responding to extreme climatic conditions, particularly with regard to Executive Order B-30-15. Successful adaptation to climate change includes a structured approach that anticipates likely disruptions and institutes effective changes in agency operating procedures. The steps shown below outline the approach to achieve resiliency at Caltrans and show how work performed on this study fits within that framework.

PREDICT CLIMATE CHANGE EFFECTS:
Climate change projections suggest that temperatures will be warmer, precipitation patterns will change, extreme storm events will become more frequent and severe, sea levels will rise, and a combination of these stressors will lead to other disruptions, such as landslides.

UNDERSTAND POSSIBLE TRANSPORTATION IMPACTS:
Higher precipitation levels could cause more flooding and landslides. Sea level rise and/or storm surge could inundate or damage low-lying coastal roads and bridges. Higher temperatures could affect state highway maintenance and risk from wildfires. Understanding these potential impacts provides an impetus to study ways to enhance the resiliency of the SHS.

SCOPE OF THIS STUDY

COORDINATE WITH FEDERAL/STATE RESOURCE AGENCIES ON APPLICABLE CLIMATE DATA:
Many state agencies have been actively engaged in projecting specific future climate conditions to plan for water supply, energy impacts, and environmental impacts. Federal agencies have also been studying climate change for other purposes such as anticipating coastal erosion and wildfires.

INITIATE VULNERABILITY ASSESSMENT:
Alternative climate futures will have varying impacts on the SHS. This step includes an examination of the range of climatic stressors and where, due to terrain or climatic region, portions of the SHS might be vulnerable to future disruptions.

IDENTIFY EXPOSURE OF CALTRANS HIGHWAYS TO POSSIBLE CLIMATE CHANGE DISRUPTIONS:
Identifying locations where Caltrans' assets might be exposed to extreme weather-related disruptions provides an important foundation for decision-making to protect and minimize potential damage. The exposure assessment examines climate stressors such extreme temperatures, heavy precipitation, sea level rise, and more, and relates the likely consequences of these stresses to disruptions to the SHS.

IDENTIFY PRIORITIZATION METHOD FOR CALTRANS INVESTMENTS:
This step identifies the process that Caltrans can use to prioritize projects and actions based on their likely system resiliency benefits through reduced impacts to system users.

This process will focus on resiliency benefits and the timeframe of potential impacts, and could guide the timing of investment actions.

DEVELOP ACTION PLANS FOR EACH CALTRANS FUNCTIONAL AREA

(including planning and modal programs, project delivery, and maintenance and operations):

Each of the functional areas in Caltrans would develop an Action Plan for furthering resiliency-oriented projects and processes in their area of responsibility. These action plans would define specific action steps, their estimated benefits to the State of California, a timeline, and staff responsibility

INCORPORATE RESILIENCY PRACTICES THROUGHOUT CALTRANS:

Each Caltrans functional area will be responsible for incorporating the actions outlined in their Action Plan and regularly reporting progress to agency leadership.

DEVELOP AND IMPLEMENT PILOT STUDIES FOR PLANNING AND PROJECT DEVELOPMENT AND MORE:

Pilot studies could be developed specific to each functional area and provide a "typical" experience for that function. Each pilot study would be assessed from the perspective of lessons learned, how the experience can guide project implementation, and actions similar to those in the pilot studies.

PRIORITIZE A SET OF PROJECTS AND ACTIONS FOR ENGINEERING ASSESSMENTS:

The prioritization method will help Caltrans identify those projects and actions with the most benefit in terms of enhancing system resiliency. Prioritization could focus on projects with primary benefits related to system resiliency, or on projects with benefits that go beyond resiliency.

ADVANCE PROJECTS AND ACTIONS TO APPROPRIATE INVESTMENT PROGRAMS:

Implementing resiliency-oriented actions and projects will require funding and other agency resources. This step advances those actions, and projects prioritized above, into the final decisions relating to funding and agency support—whether it is the capital program or other budget programs.

MONITOR EFFECTS OF PROJECTS AND ACTIONS AND MODIFY GUIDANCE AS APPROPRIATE:

This step is the traditional "feedback" into the decisions that started a particular initiative. In this case, the monitoring of the effects of resiliency-oriented projects and actions adopted by Caltrans is needed to assess if resiliency efforts have been effective over time. This monitoring is a long-term effort, and one that will vary by functional responsibility within Caltrans.

TEMPERATURE

The US National Climate Assessment indicates that the "number of extremely hot days is projected to continue to increase over much of the United States, especially by late century. Summer temperatures are projected to continue rising, and a reduction of soil moisture, which exacerbates heat waves, is projected for much of the western and central US in summer."[20] Given California's size and its many highly varied climate zones, temperatures will likely rise to various extents across the state.

The figure on the following page compares the change in the average maximum temperature over the course of seven consecutive days (an important element for determining the best pavement mix for long-term performance) for three time periods compared to backcasted data from 1975 to 2004. US studies have generally found that rising temperatures could impact the transportation system in several ways, including:

DESIGN

- Water saturation levels and ground conditions can affect foundations and retaining walls.
- Materials exposed to high temperatures for long periods of time can deform (including track buckling or pavement heave). Pavement design must consider high temperatures to mitigate future deterioration.

OPERATIONS AND MAINTENANCE

- Extreme heat events could affect employee health and safety, especially for those that work long hours outdoors.
- Extended periods of high temperatures could increase the need for protected transit facilities along roadways.
- Right-of-way landscaping and vegetation must be able to survive longer periods of high temperatures.
- Higher temperatures could deteriorate bridge joint seals due to expansion, which could accelerate replacement schedules and even affect bridge superstructure.

For Caltrans, besides these types of issues found nationally, there are additional concerns relating to field employee protection in the heat, the need to clear incidents quickly to avoid dangers to travelers waiting in the heat or cold, and the potential traffic impacts to the SHS if track failures caused by heat put additional commuters and freight on the highway. District 10 is especially concerned with projected increases in District 10 Vehicle Miles Traveled and how those additional miles may contribute to greenhouse gas emissions and rising temperatures.

TEMPERATURE CHANGE IN DISTRICT 10

As shown in projections in Figure 1, the average maximum temperature over seven days in District 10 is expected to increase through the end of the century. These projections are averaged for three periods: 1) 2010 to 2039, represented by the year 2025, 2) 2040 to 2069, represented by the year 2055, and 3) 2070 to 2099, represented by the year 2085. In the 2025 period, the temperature increase in District 10 is estimated to be between 0 and 3.9 degrees Fahrenheit, depending on location. In the 2055 period, temperatures are projected to rise by 4 to 5.9 degrees Fahrenheit or by 6 to 7.9 degrees Fahrenheit, depending upon location. In the 2085 period, temperatures are expected to rise by 8 to 11.9 degrees Fahrenheit, depending on location. These increases will impact District 10 activities in various ways, including the design, operations, and maintenance examples described above.

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

SR 18 | DROUGHT EFFECTS

SR 108 | CRACKED HIGHWAY

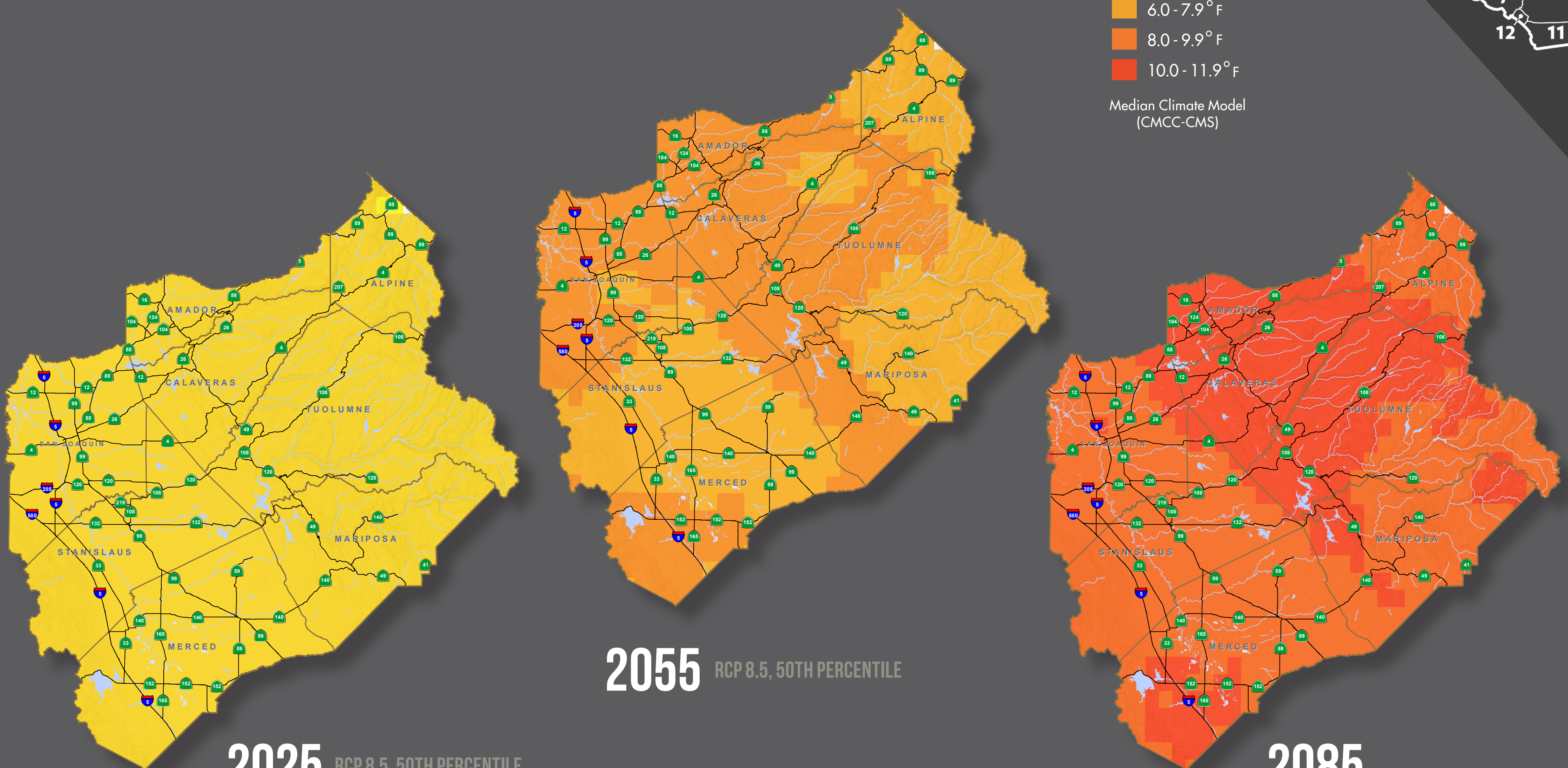
Fig.1

CHANGE IN THE AVERAGE MAXIMUM TEMPERATURE OVER SEVEN CONSECUTIVE DAYS

A REQUIRED MEASURE FOR PAVEMENT DESIGN

0.0 - 1.9° F
2.0 - 3.9° F
4.0 - 5.9° F
6.0 - 7.9° F
8.0 - 9.9° F
10.0 - 11.9° F

Median Climate Model
(CMCC-CMS)



2025 RCP 8.5, 50TH PERCENTILE

2055 RCP 8.5, 50TH PERCENTILE

2085 RCP 8.5, 50TH PERCENTILE

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

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

Results represent the 50th percentile of downscaled climate model outputs under RCP 8.5 for the metric shown, as calculated across the state using the area weighted mean.

PAVEMENT DESIGN AND TEMPERATURE

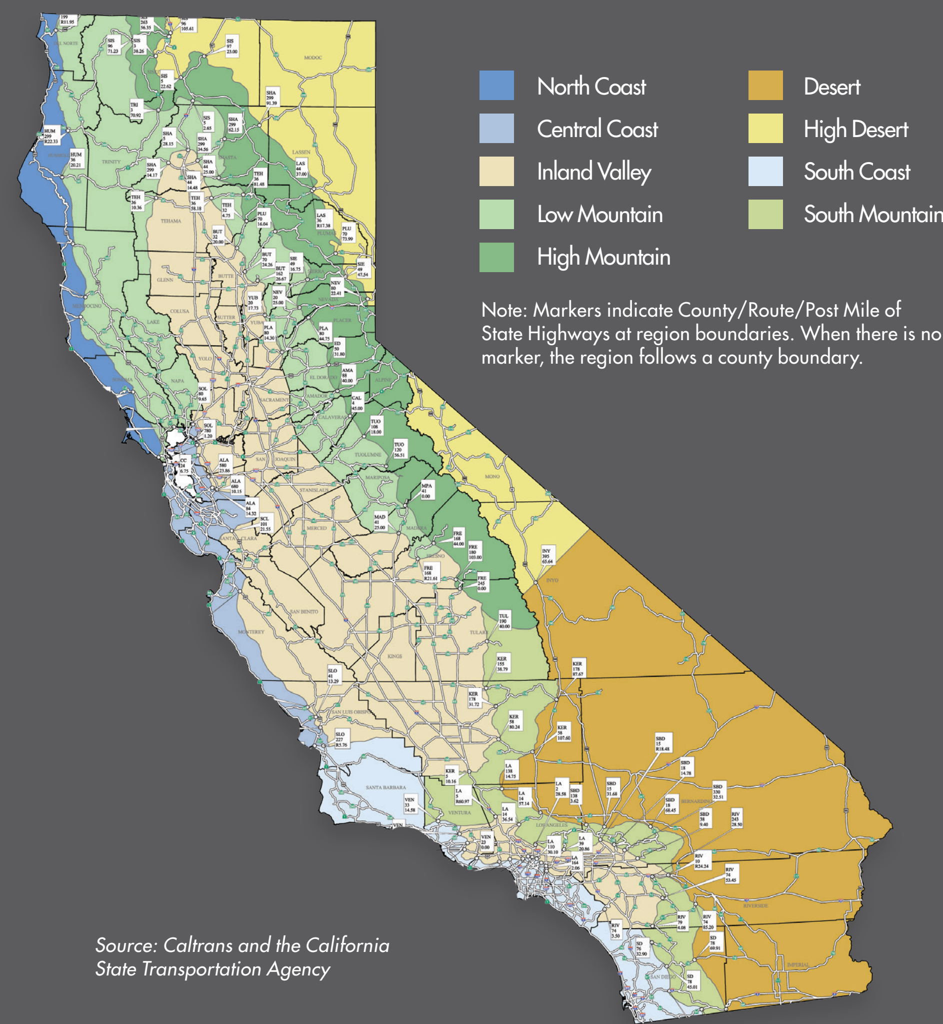
The durability of pavement is affected by how it was designed, and it is an important component of Caltrans' highway asset management strategy. Ensuring that highway pavements maintain their good ride quality and durability under various conditions is a vital responsibility of every state transportation agency. Depending on various factors, highway pavement can be either concrete or asphalt mix—and an element of asphalt pavement design is selecting the pavement binder. This decision is based in part on the project area's temperature conditions.

Climate change preparation is different for pavement design than for other assets. Many of Caltrans' assets, including bridges, roadways, and culverts, will likely be in use for a long time so decisions made for them today need to consider their longer lifespan. Asphalt pavement is replaced more often—approximately every 20-40 years depending on its purpose.

Caltrans has divided the state into nine pavement climate regions (shown in Figure 2) to help determine the best pavement types for each area. Pavement design considers two primary criteria: average maximum temperature over seven consecutive days, and the change in absolute minimum air temperature. The temperature projections for this assessment have been formatted to fit these metrics. A primary consideration for Caltrans and its pavement design engineers will be whether the boundaries of these climate regions might shift because of climate change, or whether pavement design parameters might need to change due to California's climatic changes.

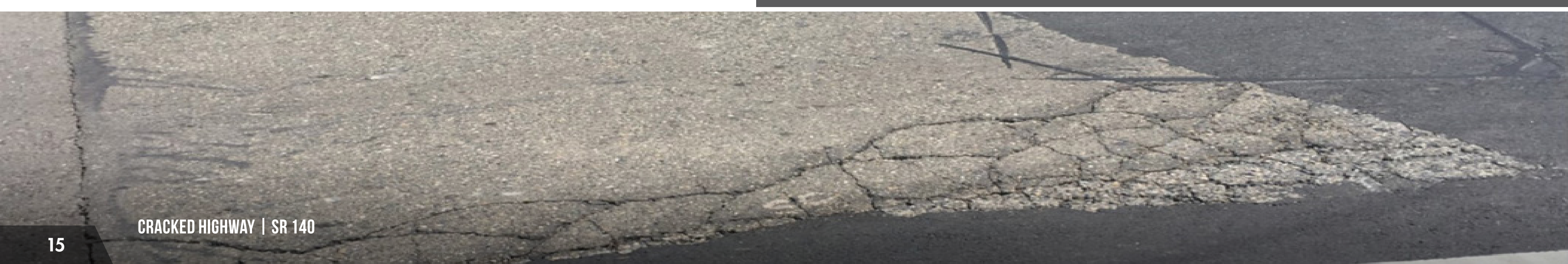
Fig. 2

CALTRANS PAVEMENT REGIONS



Note: Markers indicate County/Route/Post Mile of State Highways at region boundaries. When there is no marker, the region follows a county boundary.

Source: Caltrans and the California State Transportation Agency



TIMEFRAMES AND ASSET DECISION-MAKING

Decision-making for transportation assets requires consideration of many factors, including how long an asset will be in place. This is often referred to as the design life, or useful life, of an asset. Some assets managed by Caltrans, like asphalt pavement, is replaced around every 20-40 years while others, like bridges, are built which the expectation of a useful life of 50 years or longer. A road alignment may be in place for a century or longer.

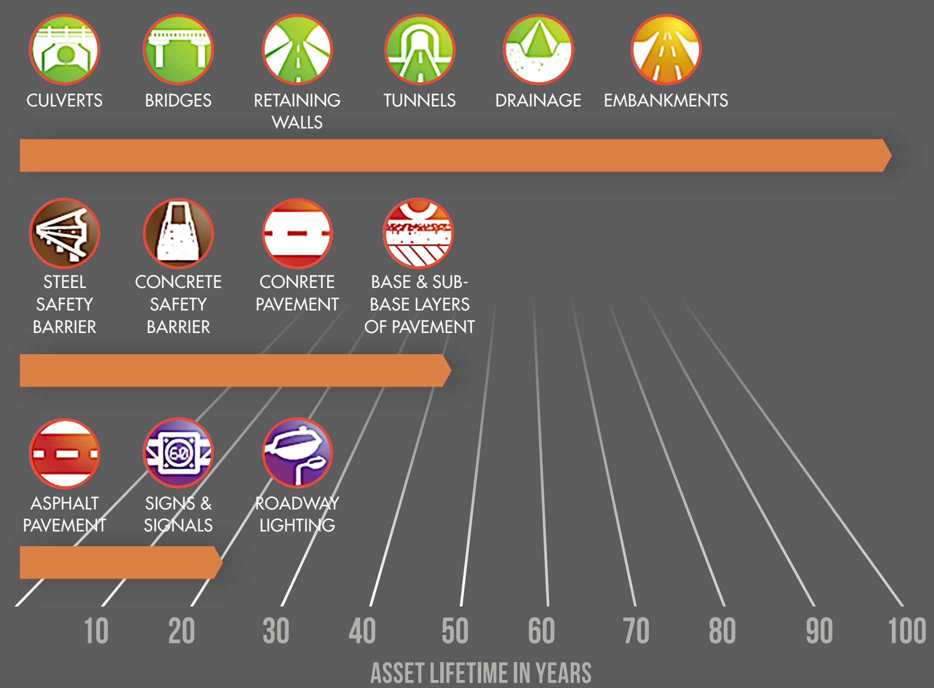
The two graphics included on this page highlight how design life considerations are a critical part of planning for transportation investment. The figure below shows how future temperature scenarios vary widely depending on emission levels and global response. One thing to note is that the conditions are somewhat consistent through around 2050, after which they begin to diverge more significantly. This means that decisions made on investments nearing the end of century need to include a much wider range of temperature uncertainty for future conditions.

Fig. 4 **TRANSPORTATION INFRASTRUCTURE ASSETS**

SOME ASSETS MANAGED BY CALTRANS, LIKE ASPHALT PAVEMENT, ARE REPLACED AROUND EVERY 20-40 YEARS WHILE OTHERS, LIKE BRIDGES, ARE BUILT WITH THE EXPECTATION OF A USEFUL LIFE OF 50 YEARS OR LONGER.

ASSETS WITH LIFETIMES IN THE MEDIUM RANGE, LIKE SAFETY BARRIERS, REQUIRE CONSIDERATION OF MID-RANGE FUTURE CONDITIONS.

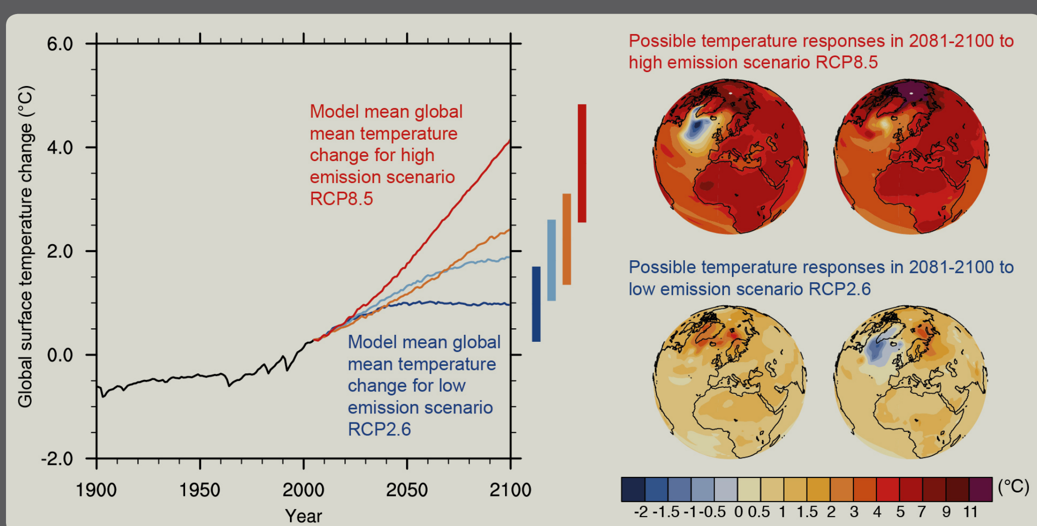
ASSETS WITH SHORTER LIFETIMES, LIKE ASPHALT PAVEMENT, REQUIRE CONSIDERATION OF NEARER TERM FUTURE CONDITIONS.



The graphic above was prepared to show how assets maintained by Caltrans will require different considerations for planning and design. All decisions should be forward-looking instead of based on historic trends, because all future scenarios show changing conditions. These future conditions must be considered when designing new transportation assets to ensure that they achieve their full design life.

Source: UK Highways Agency

Fig. 3 **IPCC - CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS FAQ 12.1**



Source: IPCC

PRECIPITATION

The increase in atmospheric moisture and energy caused by increasing temperatures is expected to change the nature of precipitation events in California. More intense storms, combined with other changes in land cover and land use, can raise the risk of damage or loss from flooding. Precipitation affects transportation assets in California in many ways, including landslides, flooding, washouts, erosion, and structural damage. The primary threat to transportation assets comes not from a higher overall volume of rainfall over an extended period, but rather from larger and more frequent storm events—and their potential for damaging the SHS.

The Scripps Institution of Oceanography at the University of California, San Diego has projected future rainfall data to the year 2100 using two different GHG emission scenarios and a variety of models. The "100-year storm event" (a storm with a likelihood of occurring once every 100 years—or a one percent chance of occurring in any given year) is one good way to examine this data. A storm of this magnitude could cause major damage, so it is a good design standard for infrastructure projects. Understanding how the 100-year storm may change in the future can help Caltrans to build more resilient infrastructure, designed to accommodate heavier storm events. See the figure on the following page for the percentage increase in the 100-year storm depth across District 10.

PRECIPITATION CHANGE IN DISTRICT 10

As shown in Figure 5, the depth of a 100-year precipitation event in District 10 is expected to increase relative to today's conditions. Projections vary by location, with some of the most significant changes anticipated in the Sierra Nevada, and parts of Alpine, Tuolumne, and Mariposa Counties. In the 2025 period (mean of the years 2010 to 2039), 100-year precipitation depths are expected to increase by 0 to 4.9% in the western counties and 5 to 9.9 % in the eastern counties. In the 2055 period (mean of the years 2040 to 2069), precipitation increases range from to 0 to 14.9%, with most occurring in the eastern counties. In the 2085 period (mean of the years 2070 to 2099), the range continues to be between 0 to 14.9%, depending on location. While the 2085 period projections generally entail higher precipitation amounts than historical observations, the model featured here indicates the potential for a slight decrease in precipitation depths over the Sierra between the 2055 and 2085 time periods. Modeling future precipitation is still an uncertain practice, and these projections vary depending on the climate model and statistical processing techniques used. Generally, storms like the 100-year event are expected to become more severe, while droughts between periods of rain become longer and more extreme. Decadal to multi-decadal megadroughts are expected to become more likely in the west as temperatures rise, despite the increased frequency of heavy downpours.[21]

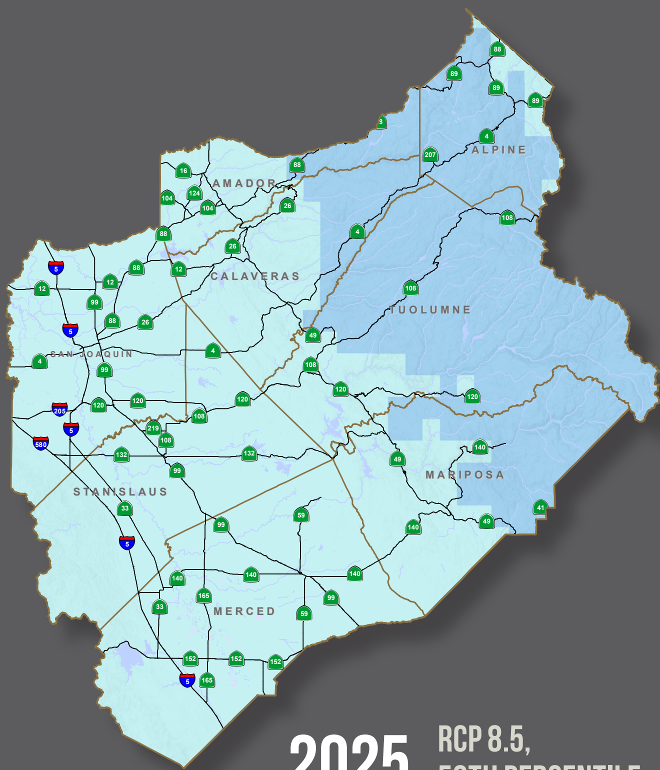
21 - Patrick Gonzalez, et al., "In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]," U.S. Global Change Research Program, doi: 10.7930/NCA4.2018.CH25, (2018): 1101–1184, accessed from https://nca2018.globalchange.gov/chapter/25/

SR 4 | SINK HOLE | MARKLEEVILLE

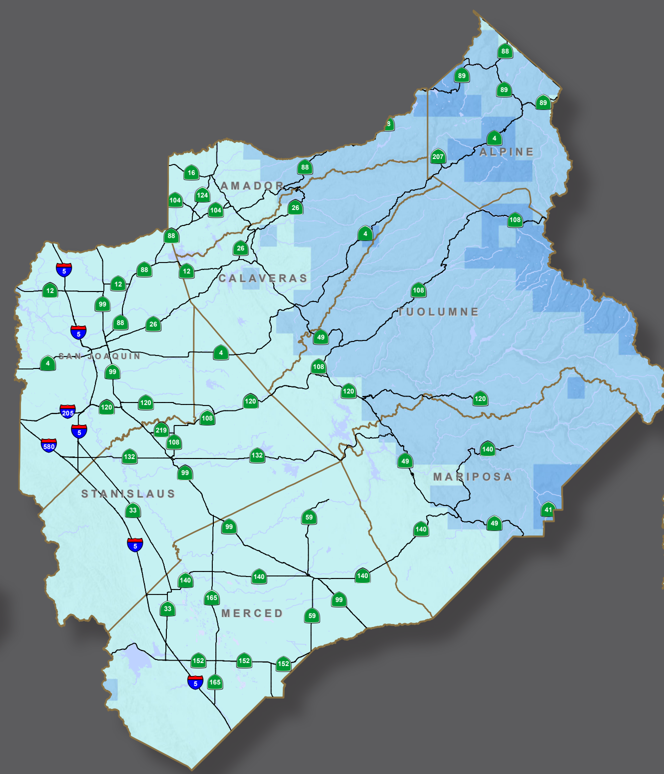
SR 4 | SINK HOLE | MARKLEEVILLE

Fig. 5

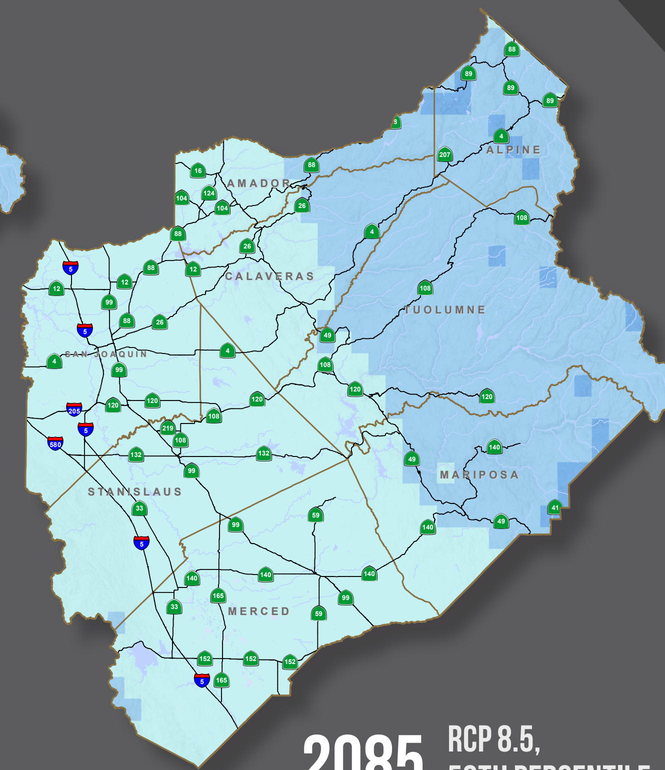
PERCENT CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH



2025 RCP 8.5, 50TH PERCENTILE



2055 RCP 8.5, 50TH PERCENTILE



2085 RCP 8.5, 50TH PERCENTILE

0.0 - 4.9%
5.0 - 9.9%
10.0 - 14.9%

Median Climate Model (HadGEM2-CC)

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

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

Results represent the 50th percentile of downscaled climate model outputs under RCP 8.5 for the metric shown, as calculated across the state using the area weighted mean. 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.

WILDFIRE

Higher temperatures and changing precipitation patterns are expected to affect both the intensity and scale of wildfires. Higher temperatures lower the moisture in soils and vegetation—which increases wildfire risk. Wildfires can contribute to landslide and flooding exposure by removing protective land cover and reducing the underlying soils' capacity to absorb rainfall. California is already prone to serious wildfires, and future climate forecasts suggest that this vulnerability will increase. To address these concerns, Governor Jerry Brown announced a new fund (in May 2018) to reduce wildfire risk and support forest management. Governor Newsom subsequently issued Executive Order N-05-19 to create a task force to develop a community resilience and education campaign and provide the Governor with immediate, mid-, and long-term suggestions to prevent destructive and deadly wildfires.

The areas shaded in red in Figure 6 indicate an increased likelihood of wildfires based on projected percentages of area burned over time. The data for these projections was generated by the MC2 – EPA (from the United States Forest Service), MC2 – Applied Climate Science Lab (University of Idaho), and the Cal-Adapt 2.0 (UC Merced) wildfire models. Each model was paired with three downscaled global climate models to produce nine future scenarios. Starting with three different wildfire models was a conservative methodology because final data shows the highest wildfire risk categorization of all model results. The results for RCP 8.5, the high-emissions scenario, are provided in Figure 6. See the associated Technical Report for results processed for RCP 4.5.

DONNELL FIRE | FIRE DAMAGE TO HISTORIC MIDDLE FORK STANISLAUS RIVER WOODEN BRIDGE

WILDFIRE EFFECTS IN DISTRICT 10

Figure 6 highlights where lengths of the SHS pass through moderate to very high concern areas for the RCP 8.5 emissions scenario. The District 10 Technical Report includes a summary of exposure for RCP 4.5 (the low emissions scenario). Table 1 provides the total centerline mileage of the SHS exposed to moderate to very high wildfire concern in the year 2085, under RCP 8.5. Only the year 2085 is shown, as the total mileage is consistent across the coming century. The level of wildfire concern does change over time, as can be seen in Figure 6. Portions of the Sierra Nevada range that show moderate projections of concern in the 2025 period change to high concern by 2055, and very high concern by 2085. Western portions of Alpine, Tuolumne, and Mariposa counties do not show moderate risk until 2055. Overall, the projected wildfire risk for the district is high, given that a large portion of the district consists of forested foothills and mountain ranges. Urban areas and land primarily used for agriculture do not have the same level of risk as forested areas, though there is always some wildfire risk wherever there is fuel. Lower-risk areas are shown in Figure 6 in parts of San Joaquin, Stanislaus, and Merced.

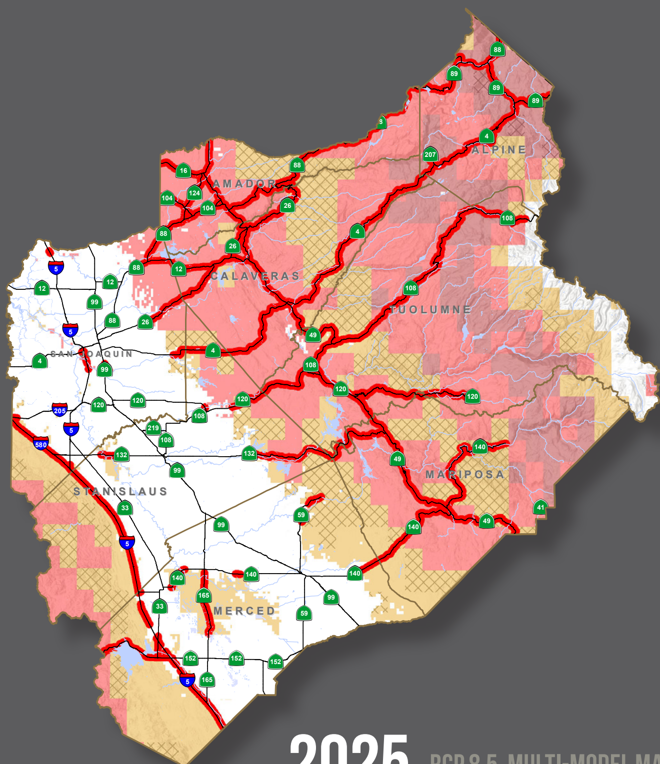
Table 1: Total Centerline Mileage Exposed to Medium to Very High Wildfire Concern by End of Century, Under RCP 8.5

County	Year 2085
Alpine	82.7
Amador	123.1
Calaveras	147.2
Mariposa	116.9
Merced	63.7
San Joaquin	39.2
Stanislaus	56.9
Tuolumne	156.2
Total Miles Exposed	**785.8**

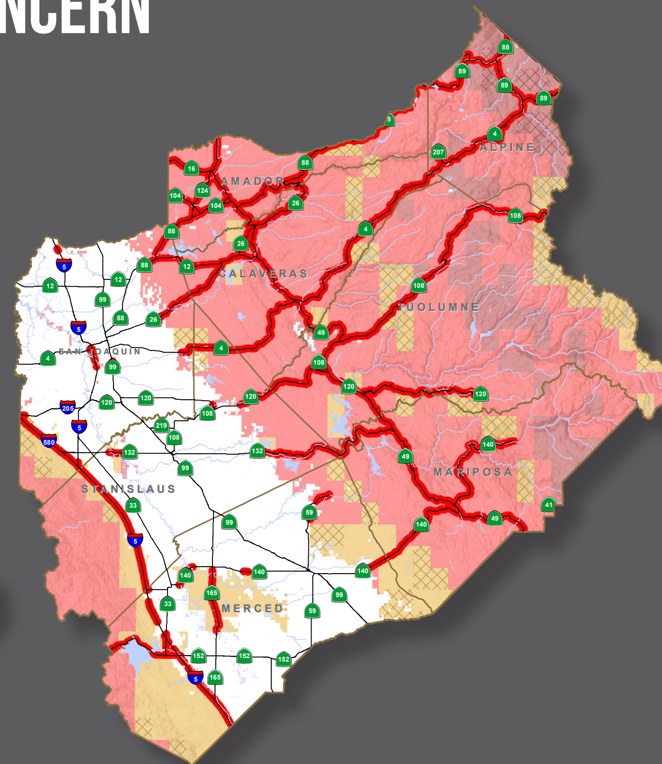
Note: Part of Mariposa County lies in District 6. These mileage totals are not included here.

Fig. 6

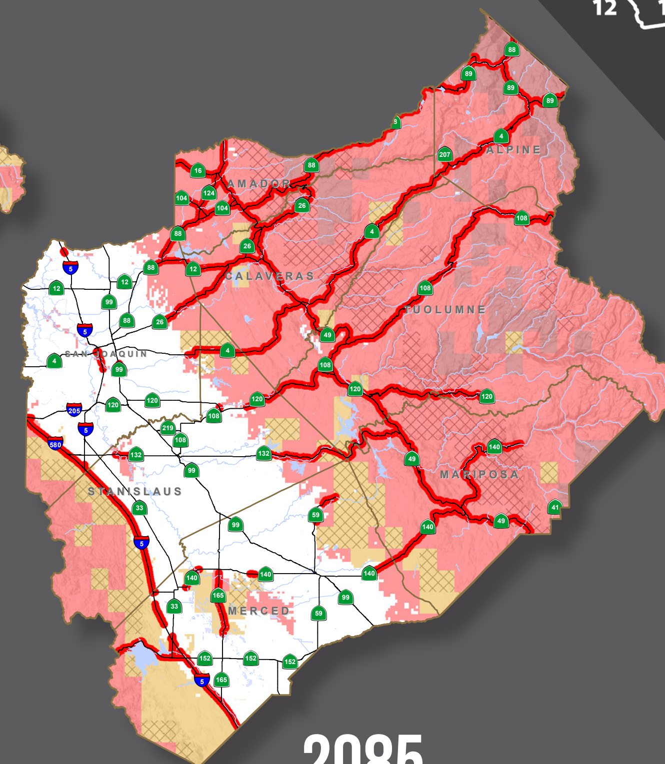
LEVEL OF WILDFIRE CONCERN



2025 RCP 8.5, MULTI-MODEL MAXIMUM



2055 RCP 8.5, MULTI-MODEL MAXIMUM



2085

RCP 8.5, MULTI-MODEL MAXIMUM

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

The fire model composite summaries shown are based on wildfire projections from three models: (1) MC2 - EPA Climate Impacts Risk Assessment, developed by John Kim, USFS; (2) MC2 - Applied Climate Science Lab at the University of Idaho, developed by Dominque Bachelet, University of Idaho; and (3) University of California Merced model, developed by Leroy Westerling, University of California Merced. For each of these wildfire models, climate inputs were used from three GCMs: (1) CAN ESM2; (2) HAD-GEM2-ES; and (3) MIROC5. The maps show the multi-model maxima for each grid cell across the nine combinations of the three fire models and the three GCMs. Moderate wildfire concern indicates an expected 15 to 50% of an area burning, high concern being 50 to 100%, and very high being over 100%. A greater than 100% burn can occur when the same area is projected to burn multiple times over a given period.

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

For more information on burn classifications, see the associated Technical Report.

Levels of Concern

- VERY HIGH
- HIGH
- MODERATE
- HIGH MODEL AGREEMENT*
- EXPOSED ROADWAY

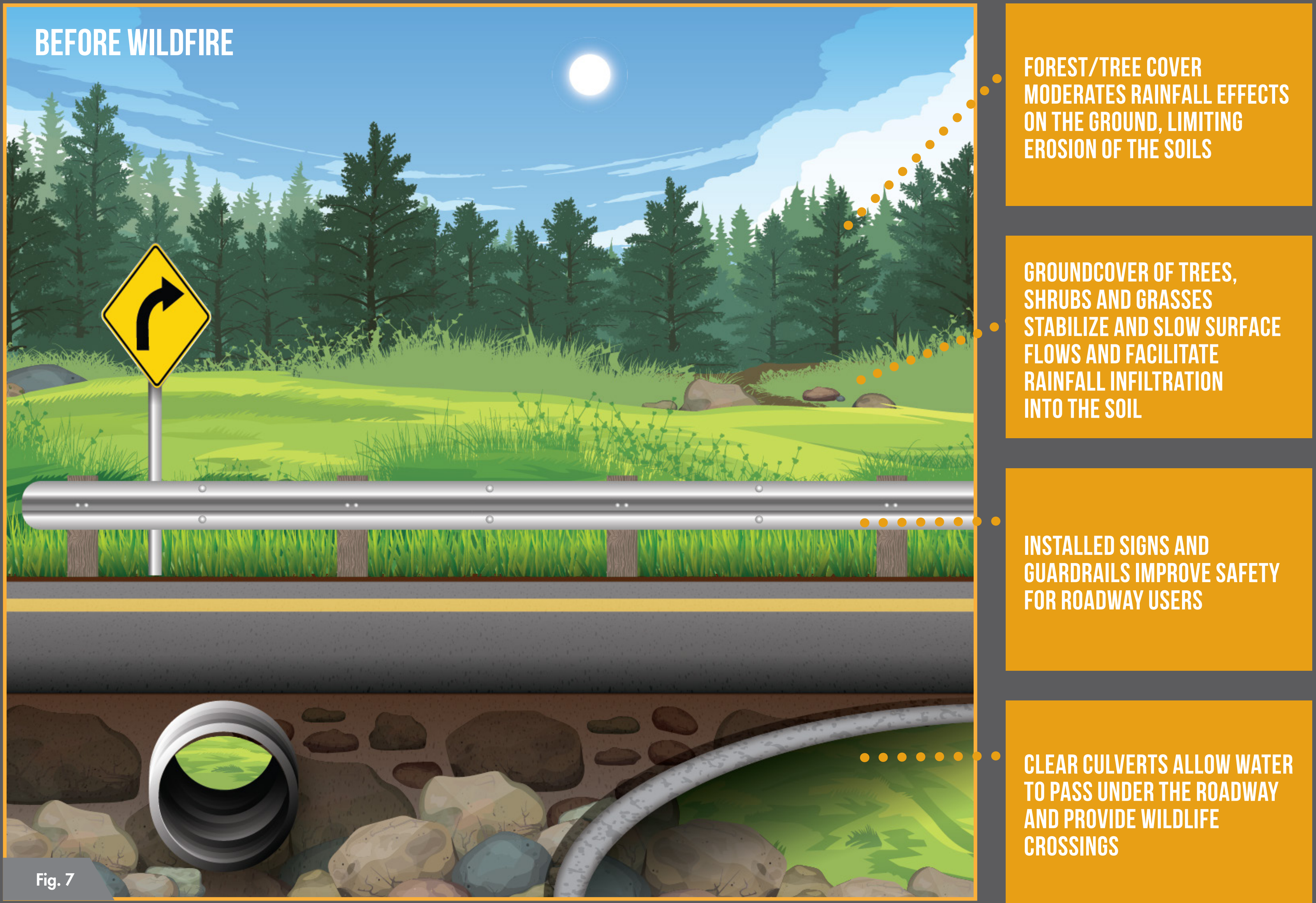


Fig. 7

Healthy, vegetated areas provide various ecosystem benefits including precipitation infiltration and soil stabilization. These natural systems help prevent potential damage to roadways, bridges, and culverts by mitigating excessive flood water and preventing erosion.

LOSS OF FOREST COVER RESULTS IN MORE EROSION OF SOILS

BURNED SOILS ARE UNABLE TO FACILITATE THE INFILTRATION OF RAINFALL, INCREASING RUNOFF

LOSS OF STABILIZING GROUNDCOVER RESULTS IN LOOSER SOILS AND INCREASED LANDSLIDE POTENTIAL

BURNED GROUND COVER LEADS TO MORE DEBRIS THAT CAN CLOG CULVERTS/BRIDGES DURING RAINFALL EVENTS

DESTROYED SIGNS AND GUARDRAILS REDUCE DRIVER SAFETY

DAMAGED OR CLOGGED CULVERTS INCREASE RISK OF ROAD OVERWASHING, DAMAGE, AND ELIMINATES OPTIONS FOR WILDLIFE CROSSING

Fig. 8

After wildfires have occurred, new risks are posed to transportation assets in the area. Immediately after a fire, the loss of signs and guardrails presents a danger to travelers and requires an immediate response. Other impacts noted in the graphic above can exist as a potential risk to Caltrans assets for years after a wildfire event occurs.

THE FERGUSON FIRE

The Ferguson Fire struck District 10 in California's famed Stanislaus National Forest and Yosemite Valley. It burned from July 13 to August 19, 2018, and before it was contained, it scorched 96,901 acres of land, destroyed 10 structures, and caused two fatalities and 19 injuries. Overall, it resulted in an estimated $171 million in damage. Even after containment, hot spots continued to smolder well into September.

Several communities were placed under mandatory evacuation, and except for one, all entrances to Yosemite National Park were closed. In addition to the tragic fatalities and physical damage, low-level smoke hampered visibility which grounded aircraft and inhibited driving. Several roads were closed, including Highways 140 and 41 (Highway 41 turns into Wawona Road north of Fish Camp). Figure 9 shows the Ferguson Fire perimeter as of July 2018 and the portions of routes 140 and 41 that were affected. Highway 41 was also heavily impacted by falling trees and branches, and rock slides. Some of the closed roads were the only access into and out of remote sites such as campgrounds, hindering their evacuation.

USA Today reported on the 2018 wildfires in the west and noted, "battling wildfires year-round is now the norm."[22] This situation creates significant challenges for firefighters, emergency management organizations, and public agencies. Caltrans' concerns include the safety of its staff and their families, keeping evacuation routes open as long as possible, and funding the efforts necessary to bring SHS roads back into operation.

22 - Lindsay Schnell, "Battling Wildfires Year-Round is Now the Norm. How Did We Get Here?" USA Today, August 8, 2018, https://www.usatoday.com/story/news/2018/08/08/california-fires-battling-wildfires-year-round-new-normal/930394002/

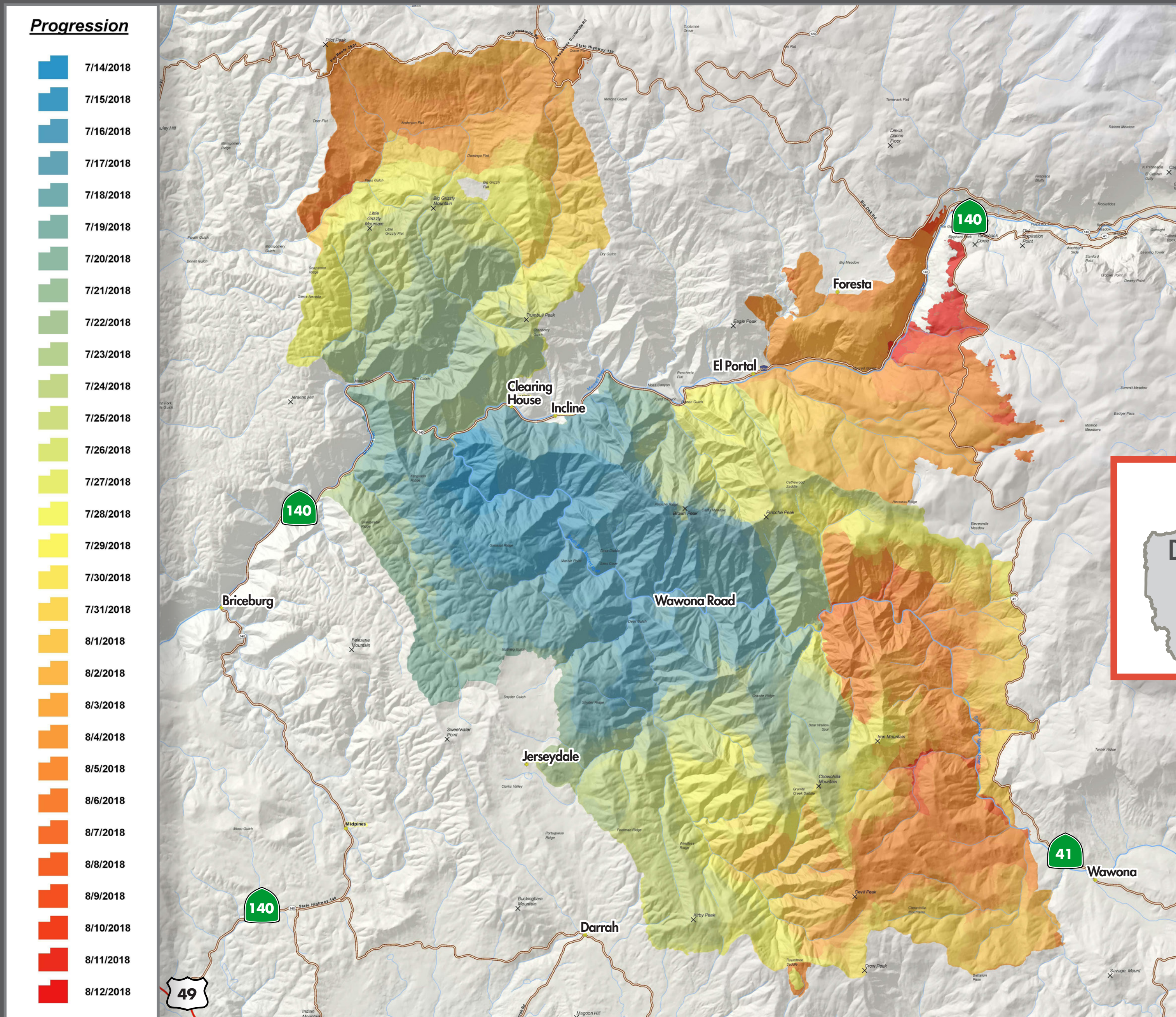
FERGUSON FIRE | AN A-STAR HELICOPTER UTILIZED AS AN AERIAL PSD IGNITION PLATFORM
SIERRA NF, CA., 2018 | FOREST SERVICE PHOTO BY KARI GREER

FERGUSON FIRE BURNS OFF HIGHWAY 41 | FOREST SERVICE PHOTO

SMOKE FILLED VALLEY DUE TO FERGUSON FIRE | FOREST SERVICE PHOTO

Fig. 9

FERGUSON FIRE PROGRESSION



Note: Maps represent approximate information. Map accessed from the Sierra National Forest, US Forest Service and modified for the purposes of this report.

SEA LEVEL RISE IN THE DELTA

Before it became the focus for residential and commercial development, the Sacramento-San Joaquin River Delta (the Delta) was a dynamic area, continually shifting due to the influence of the rivers and tides. It was a great, reedy freshwater marsh with riparian forest lining its stream channels and it was populated by fish, deer, elk, and waterfowl.[23] Since then, the Delta has changed. Starting with the Gold Rush and continuing today, human agriculture and habitation have altered the area forever. Stretches of land were cleared for crops, and levees to protect those crops were constructed from peat and muck in the late 1800s. Water from the Delta was systematically diverted for irrigation and household use, and today more than half of the water that once flowed through the Delta is diverted for human purposes.[24] Flooding was and still is relatively common in the Delta, and about 100 levee failures have occurred since 1890. Today, the Delta is made up of about 55 islands, predominantly used for agriculture, which are protected by over 1,000 miles of levees.[25] The land disturbance from the creation of levees and the drawdown of groundwater has led to land subsidence throughout the Delta. Historically, the Delta islands were slightly above or near sea level—now large areas are up to 15 feet below it.[26]

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. Flood-prone areas of the Delta are largely reliant on the levee system for flood protection, but recent estimates find that protection is adequate for only about half of the Delta.[27]

The levee system is also important to the SHS, which traverses the Delta and connects Sacramento, Stockton, and other neighboring cities. The SHS sits atop levees in parts of the Delta and is elevated on viaducts in others, but there is a significant network that extends through low-lying farmland and suburban neighborhoods. These areas could be increasingly vulnerable to flooding and its associated damage, especially considering the potential for subsidence and sea level rise. Portions of SR 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, travelers, and goods or freight movement. Given the high level of importance of the SHS in and around the Delta, Caltrans has included the potential for sea level rise in this vulnerability assessment. This assessment will help Caltrans identify which routes may be vulnerable to inundation, scour, erosion, or other effects due to higher water levels.

This analysis used sea level models developed by Climate Central, which identify potential flooding conditions if levees and flood control barriers[28] do remain resilient, 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 extent," which assumes that levees and other barriers are 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. Flooding risks posed to the SHS are highlighted in Figure 10 and are summarized below.

SEA LEVEL RISE INUNDATION IN DISTRICT 10

Figure 10 summarizes the portions of the SHS in District 10 that could be permanently inundated or otherwise impacted by sea level rise. This data assumes that levee protection is adequate to protect against higher water levels except for in the areas indicated by hatch marks. This figure includes bridges on the SHS that may be overtopped or exposed to conditions, such as increased scour and erosion and a higher water table, that could affect their long-term viability. These areas may require additional analysis to determine the level of risk. See Figure13 for more on potential impacts to bridges from future sea level rise and storm surge.

If all levees and flood control structures provide adequate flood protection, segments of I-5 and SR 12 could still experience isolated flooding with sea level rises of 1.74, 3.28, and 5.74 feet. The Ocean Protection Council's (OPC) "likely range" projections show a 66% chance of isolated flooding happening by 2060 with 1.74 feet of sea level rise. Using more conservative estimates, 1.74 feet of sea level rise could happen sooner—sometime between 2040 and 2050. At 5.74 feet of sea level elevation, large segments of I-5 through San Joaquin County could be affected.

ABOUT 14 CENTERLINE MILES OF THE HIGHWAY SYSTEM IN SAN JOAQUIN COUNTY MAY BE VULNERABLE TO FLOODING FROM 5.74 FEET OF SEA LEVEL RISE. THIS NUMBER RISES TO AROUND 40 MILES WHEN CONSIDERING LEVEE PROTECTED AREAS.

Note: Mileage summarized for District 10 includes parts of the highway system in District 3 that are on the border of the two districts.

23 - US Geological Survey, "Sacramento-San Joaquin Delta," N.d. https://pubs.usgs.gov/circ/circ1182/pdf/11Delta.pdf

24 - Delta Stewardship Council, "Delta Plan Executive Summary," 2013. https://deltacouncil.ca.gov/delta-plan/.

25 - Ibid.

26 - Exposure to oxygen accelerates the decay of organic matter and peat soil, leading to soil loss and subsidence.

27 - Delta Stewardship Council, "Delta Plan Executive Summary," 2013. http://deltacouncil.ca.gov/sites/default/files/documents/files/Delta_Plan_Executive_Summary_2013.pdf.

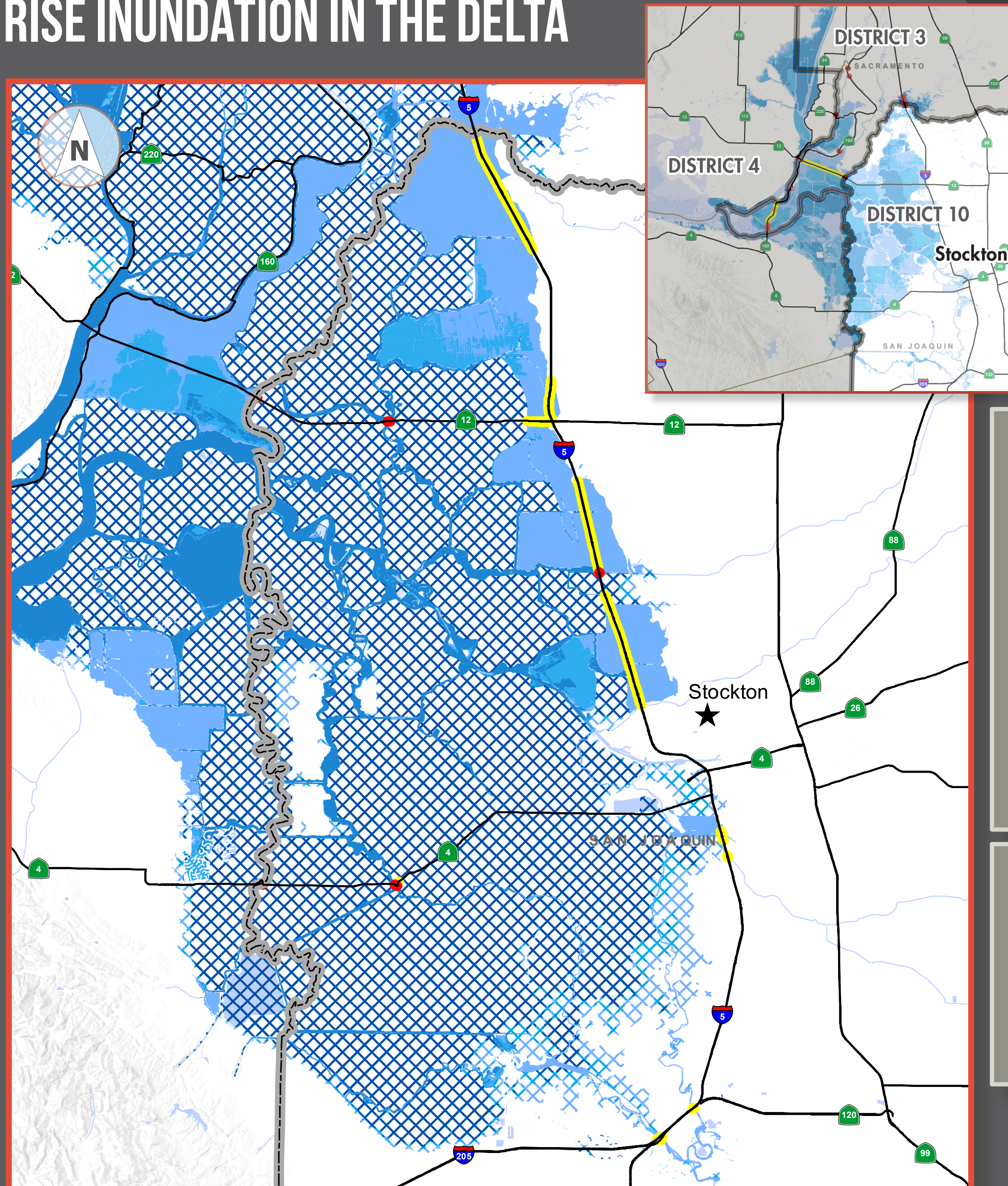
28 - Barriers are not exclusively levees, but "walls, dams, ridges, or other features that protect or isolate some areas, e.g., block hydrologic connectivity." See http://sealevel.climatecentral.org/ for more information.

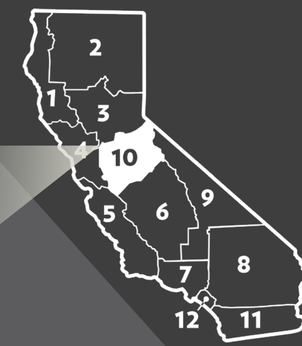
Fig. 10

SEA LEVEL RISE INUNDATION IN THE DELTA

Sea Level Rise Inundation of the Caltrans SHS in District 10

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





AT-RISK AREAS ASSUMING LEVEES PROVIDE ADEQUATE PROTECTION

State Highway System Impacts by Sea Level Rise Inundation Extent

- 1.64 Ft (0.50 M)
- 3.28 Ft (1.00 M)
- 5.74 Ft (1.75 M)

Sea Level Rise Inundation Extent

- 1.64 Ft (0.50 M)
- 3.28 Ft (1.00 M)
- 5.74 Ft (1.75 M)

AT-RISK AREAS ASSUMING LEVEES FAIL

Sea Level Rise in Levee Protected Areas

- 1.64 Ft (0.50 M)
- 3.28 Ft (1.00 M)
- 5.74 Ft (1.75 M)

STORM SURGE IN THE DELTA

As seas rise and move inland over low-lying areas, there is a greater potential for storm surge due to meteorological events to become more devastating. Storm surge is defined as "an abnormal rise of water generated by a storm, over and above the predicted astronomical tide."[29] 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.[30] Figure 11, developed by NOAA, shows how wind-driven events create a surge at the coastline and inland.

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 have raised sea levels by as much as 3 feet during severe winter storms.[31] 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 coastal waters. This type of combined water flow could significantly impact the Delta, where the San Joaquin and Sacramento Rivers meet and then flow through the Central Valley's one natural outlet, the Carquinez Strait. Storm surge moving inland, combined with water flows moving seaward, could lead to even higher water levels in the Delta and San Francisco Bay.

An analysis of the potential effects of sea level rise, combined with storm surge in the Delta, was completed using data from the 3Di model developed by John Radke (et al.) of University of California, Berkeley.[32] 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.[33] Three future water levels associated with sea level rise were used as the baseline water elevation and combined with the identified storm event to determine future surge levels. The levels used were 1.64, 3.28, and 4.62 feet (or 0.50, 1.00, and 1.41 meters, respectively), and, except for the highest, they align with the sea level rise data used in the previous section. The different methodologies and inputs used in each model result in different outcomes for what parts of the SHS may be exposed, and when. The resulting flood impacts are identified in the sections below.

STORM SURGE FLOODING IN DISTRICT 10

The call-out below summarizes the number of centerline miles of the District 10 SHS that could be flooded by a 100-year storm event, given 4.62 feet of sea level rise, as identified by the 3Di model. Assuming 1.74 feet of sea level rise and a 100-year storm, the model projects that isolated sections on I-5 and SR 4, 12, and 120 may temporarily flood and suffer storm surge damage. With 3.28 feet of sea level rise, Interstate 5 could flood along longer segments—this could also happen to SR 12. Under the highest sea level rise scenario modeled (4.62 feet), a much longer section of I-5 and SR 12 might flood or be otherwise impacted. Figure 11 shows the progression of flood extent with storm surge as sea levels rise.

It should be noted that significant uncertainties inherent in flood modeling suggest some caution when considering these projections. Future research on the implications of long-term flooding in District 10 is necessary.

10.5 MILES OF SAN JOAQUIN COUNTY HIGHWAYS ARE MODELED TO BE VULNERABLE TO 4.62 FEET OF SEA LEVEL RISE AND A 100-YEAR STORM EVENT.

Note: Mileage summarized for District 10 includes parts of the highway system in District 3 that are on the border of the two districts.

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29 - "Introduction to Storm Surge," National Oceanic and Atmospheric Administration, last accessed May 21, 2019, https://www.nhc.noaa.gov/surge/surge_intro.pdf

30 - Ibid.

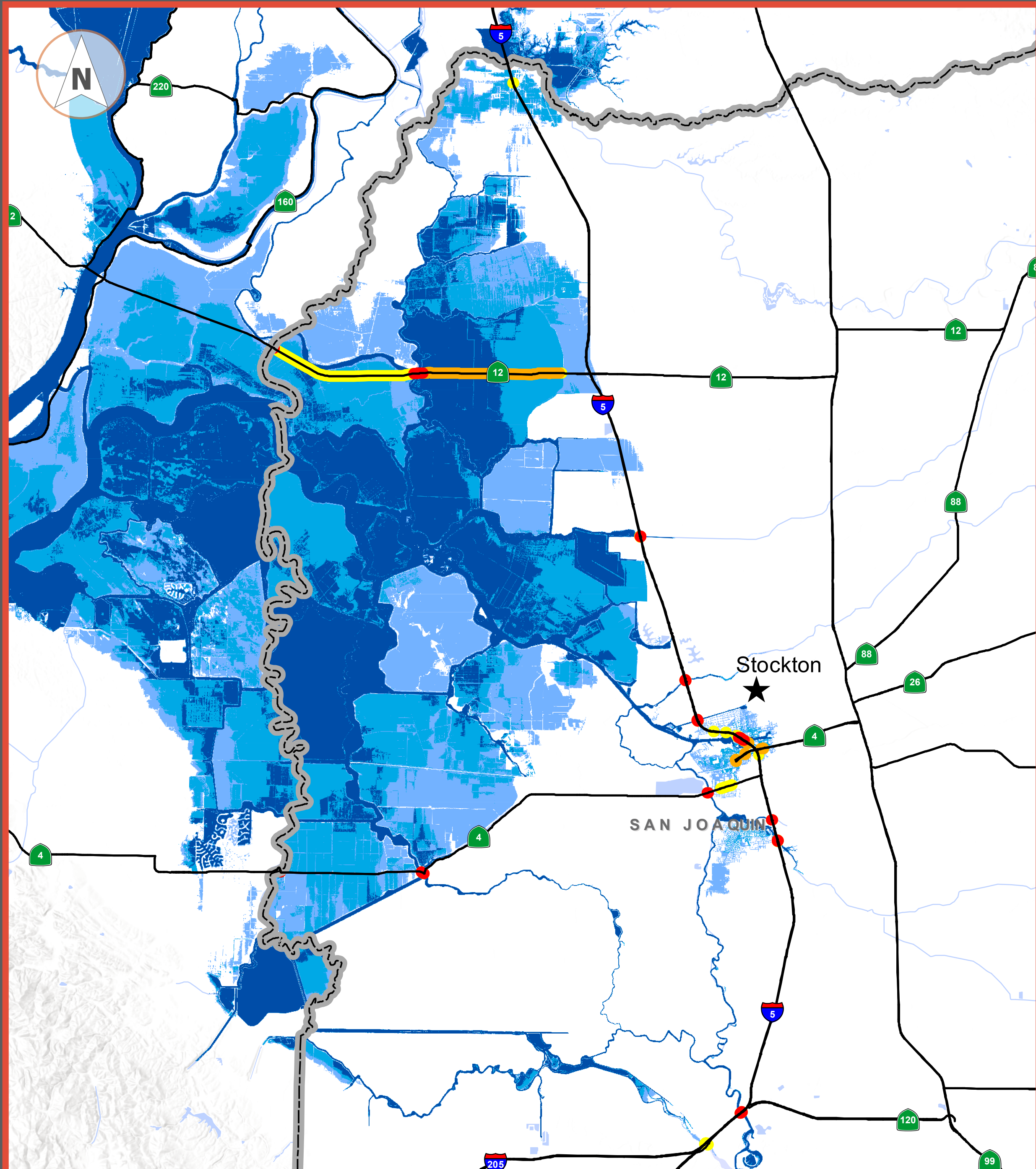
31 - Ibid.

32 - "Sea Level Rise CalFloD-3D," Cal-Adapt, https://cal-adapt.org/

33 - 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, https://www.energy.ca.gov/2017publications/CEC-500-2017-008/CEC-500-2017-008.pdf

Fig. 11

FLOODING FROM STORM SURGE IN THE DELTA



Impacts to District 10 SHS by Sea Level Rise Inundation Extent

- 1.64 Ft (0.50 M)
- 3.28 Ft (1.00 M)
- 4.63 Ft (1.41 M)

Sea Level Rise Inundation Extent

- 1.64 Ft (0.50 M)
- 3.28 Ft (1.00 M)
- 4.63 Ft (1.41 M)

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

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

PROJECTIONS OF SEA LEVEL RISE FOR SAN FRANCISCO AND THE DELTA

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 12 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).[34] 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:

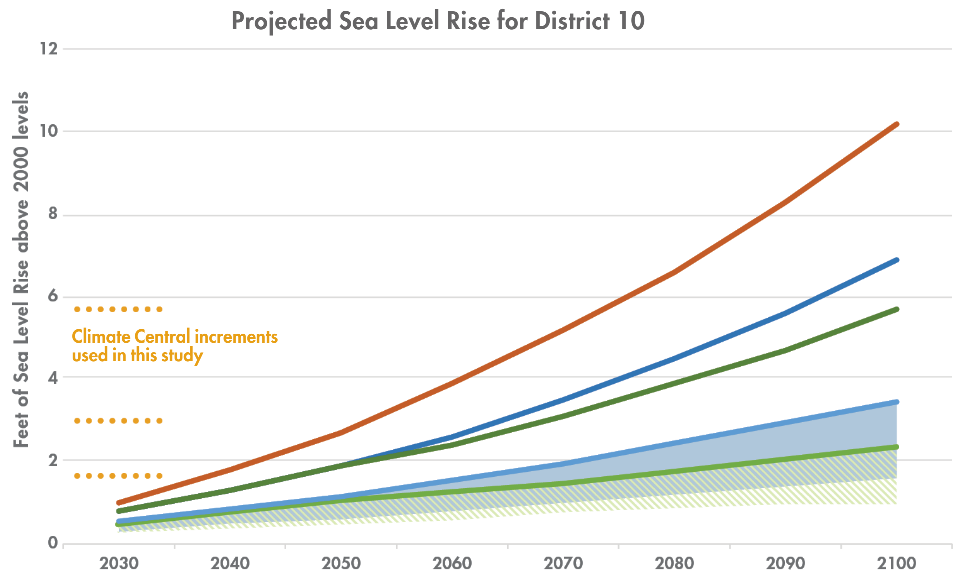
- A median (50%) probability scenario
- A likely (66%) probability scenario
- A 1-in-20 (5%) probability scenario
- A low (0.5%) probability scenario
- An extreme (H++) scenario to be considered when planning for critical or highly vulnerable assets with a long lifespan

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 8.6 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 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.

Fig.12



Note: RCP 2.6 values for 2030-2050 are linearly interpolated from the 2000 baseline, with interpolated values constrained to maximum of their equivalent RCP 8.5 values.

OPC Estimates for Sea Level Rise

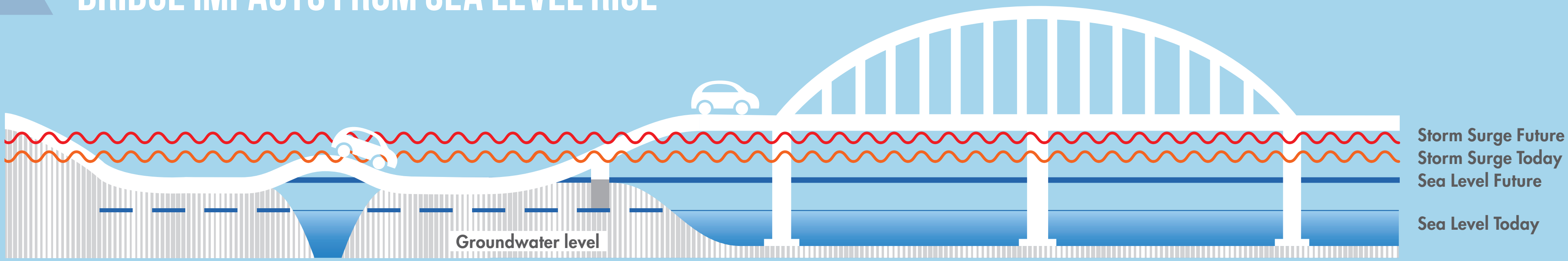
- Extreme Estimate of Sea Level Rise (H++ Scenario)
- **Low Probability** Estimate (0.5% Probability Scenario) for **High Emissions** Scenario
- **Low Probability** Estimate (0.5% Probability Scenario) for **Low Emissions** Scenario
- **High End of the Likely Range** (17% Probability Scenario) for **High Emissions** Scenario
- **Likely Range** (66% Probability Range) for **High Emissions** Scenario
- **High End of the Likely Range** (17% Probability Scenario) for **Low Emissions** Scenario
- **Likely Range** (66% Probability Range) for **Low Emissions** Scenario

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 12. 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 be working over the coming months to develop a policy for how best to incorporate these estimates and OPC guidance into its processes and procedures.

34 - California Ocean Protection Council, State of California Sea-Level Rise Guidance: 2018 Update, March 14, 2018, http://www.opc.ca.gov/webmaster/ftp/pdf/agenda_items/20180314/Item3_Exhibit-A_OPC_SLR_Guidance-rd3.pdf

Fig. 13

BRIDGE IMPACTS FROM SEA LEVEL RISE



Climate change can impact infrastructure in multiple ways. Bridges in the Delta, for example, can be directly impacted by rising sea levels and storm surge effects. Today's bridges were designed and built for current tidal and surge conditions, so increasing water levels may increase the risk for these facilities in the future.

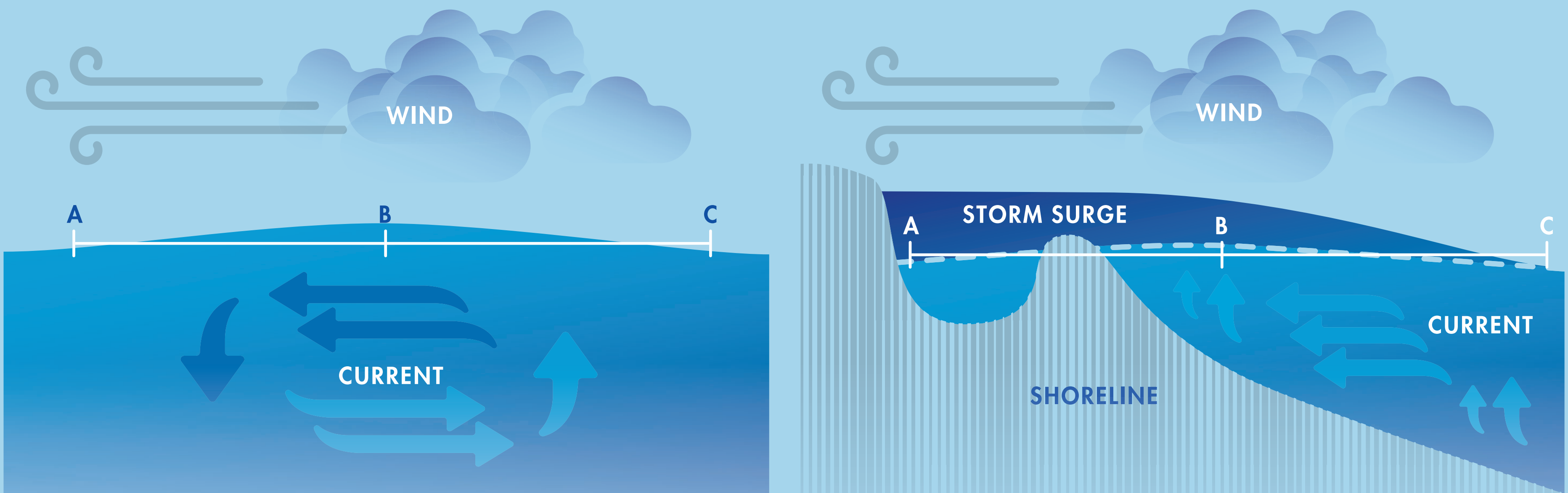
Some of bridge vulnerabilities include:

1. Rising groundwater table inundating supports that were not built for saturated soil conditions, leading to erosion of soils and loss of stability.
2. Higher sea levels exerting greater forces on the bridge during normal tidal processes, increasing scour effects on bridge structure elements.
3. Higher water levels causing higher, more forceful, storm surges which could cause scour on bridge substructure elements.
4. Bridge approaches (where the roadway transitions to the bridge deck) delete sustaining damage from storms.
5. Surge and wave effects loosening or damaging portions of the bridge and requiring repair, or replacement of bridge parts.
6. Bridge use becoming limited due to the loss or damage of a roadway or minor bridges near the approach.

Most bridges are built with added safety factors during design so these concerns may not present an issue for every Delta bridge, but they should be factored into decision-making to ensure that all Caltrans bridges can withstand conditions that will change over time.

Fig. 14

VERTICAL CIRCULATION DURING A STORM EVENT



Source: National Oceanic and Atmospheric Administration

ADAPTIVE DESIGN, RESPONSE, AND RISK MANAGEMENT

Risk-based design strategies are one way of developing an effective adaptation response to climate stressors and dealing with the uncertainties of future climate conditions. A risk-based decision approach considers the broader implications of damage and loss in determining the design approach. The Federal Highway Administration (FHWA) has developed a framework for making design decisions that incorporates climate change: the Adaptation Decision-Making Assessment Process (ADAP)[35] process.

At its core, the ADAP process is a risk-based, scenario-driven design process. It incorporates broader economic and social costs, as well as projected future climate conditions, into design decision-making. It can be considered a type of sensitivity test for Caltrans assets and it incorporates an understanding of the implications of failure on Caltrans system users, and the agency's repair costs. The ADAP flowchart shows the basic elements of climate change assessment in District 3 for existing and future roadways. The following section highlights a district effort that demonstrates adaptive design, emergency response, and/or risk management. These efforts are examples of how Caltrans districts can prepare for, and respond to, future climate change and extreme weather events.

DISTRICT 10 EMERGENCY REPAIR COORDINATION – SR 49 REPAIRS

This vulnerability assessment is the first step in a multipart effort to identify SHS exposure to climate change impacts, identify potential consequences, and prioritize needs and actions. The final step will be prioritizing some assets for detailed, ADAP-style assessments and risk-based design responses. This effort is underway today, and District 10 continues to respond to extreme weather while taking steps to increase the resiliency of their portion of the SHS. The following is one example of collaborative emergency repair used to respond to damage on the District 10 SHS and prevent further impacts:

In March 2018, an extreme storm resulted in heavy rains and flash floods. The flooding caused several washouts and slip-outs on District 10-managed highways. Because of the slip-outs that occurred on SR 49 in Tuolumne County, hundreds of feet of roadway fill slope along the highway eroded. In some locations, cut slopes failed and deposited soil and rock debris on the roadway. Given these hazards, SR 49 was closed to traffic. As part of the recovery effort, the District 10 Maintenance Engineering Branch coordinated efforts with the Caltrans Headquarters Geotechnical Team, the Construction Office, the Environmental Office, and a contractor to effectively and promptly make the necessary repairs. This coordinated group also repaired other damage caused by the storm event, including culverts on SR 49 in Mariposa County. The emergency repair work in on SR 49 in Tuolumne County was completed in May of 2018, and the emergency repair work on SR 49 in Mariposa County was completed in early August 2018. The work included rebuilding and repairing the failed slope areas and roadway sections, replacing existing damaged culverts and inlets, installing flume down drains at various locations, and overlaying the roadway with asphalt.

This is one of many examples of emergency repair work conducted by the District 10 Maintenance Engineering Branch and other coordinated offices under Director's Orders. Director's Orders require coordinated action to ensure that emergency contracts and repair work comply with environmental laws and regulations, permit requirements, and all other standard Caltrans project requirements. The collaborative and team-oriented approach to emergency repairs in District 10 provides effective and rapid response to emergencies.

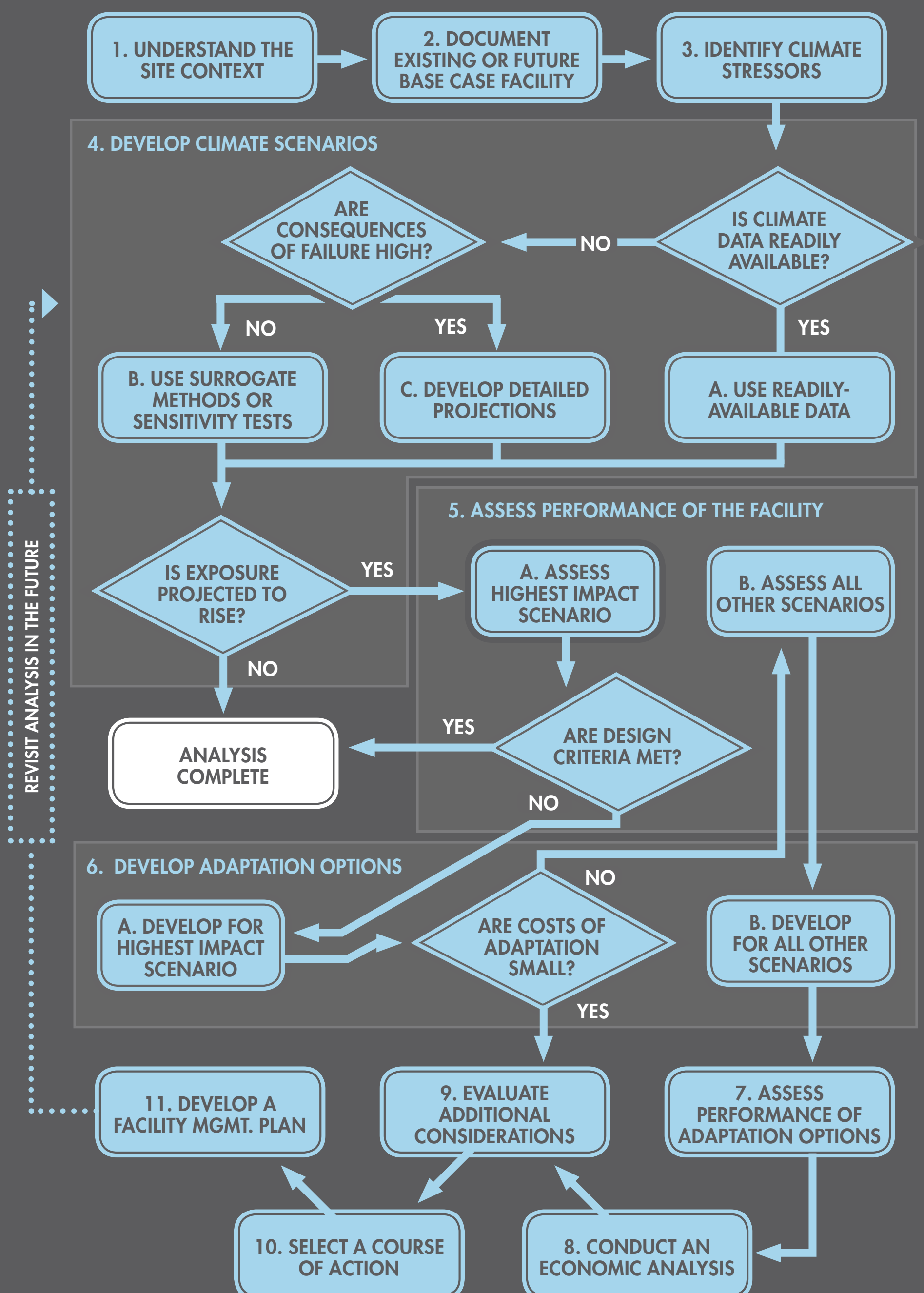
35 - "Adaptation Decision-Making Assessment Process," FHWA, last modified January 12, 2018, https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/teacr/adap/index.cfm

STATE ROUTE 49 | ERODED SLOPE AND SHOULDERS | MARCH, 2018

STATE ROUTE 140 | FLOODED HIGHWAY

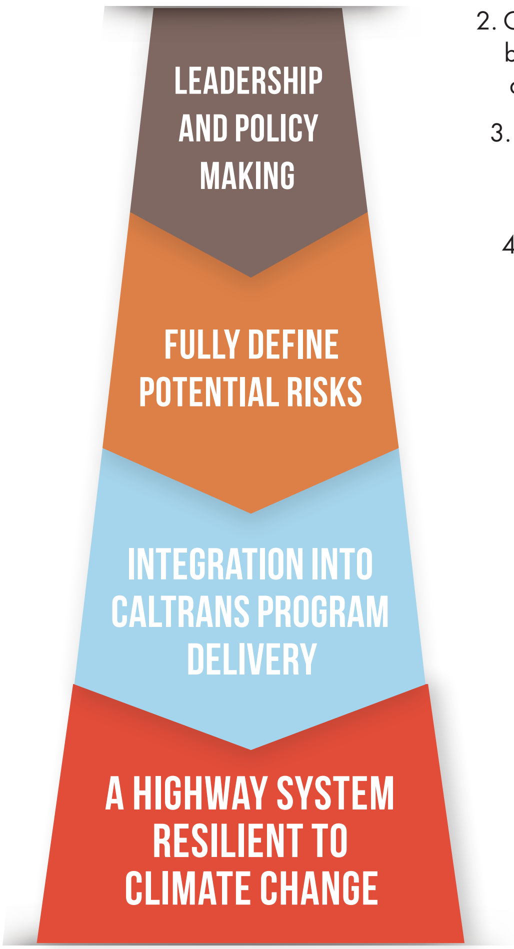
Fig. 15

FHWA'S ADAP DESIGN PROCESS



COMPLETED REPAIRS ON SR 49

WHAT DOES THIS MEAN TO CALTRANS?



GENERAL CONCLUSIONS

District 10's recent extreme weather events offer an opportunity to address many of the potential climate change impacts described in this report. Caltrans can draw these conclusions:

1. Updated design approaches should be developed based on best available climate data from state resource agencies. (page 11 – phases for achieving resiliency)
2. Consequence costs should factor into redesign to assess broader economic measures and the potential cost savings from adaptation (page 7 – vulnerability approach)
3. Efforts to build or repair District 10 facilities should consider future conditions as opposed to focusing solely on historical conditions (page 4 – state policies)
4. FHWA's ADAP process should be applied when planning or designing assets and facilities. This will help account for uncertainties in climate data and provide a benefit-cost assessment methodology that considers long-term costs to guide decisions (page 31 – Adaptive Design, Response, and Risk Management

Many climate stressors pose a risk for the SHS, as outlined in this report. Effective management of these risks will require a response that prioritizes the system's most vulnerable and critical assets first. Addressing these climate concerns will also require:

FULLY DEFINING RISKS

This report does not include a full accounting of risks from changing climate conditions. Using the ADAP process is necessary to identify specific risks from the full range of potential impacts at an asset-by-asset level. To fully assess and address risks, assets outside of normal Caltrans control (but which could affect state highway operations if they failed, such as dams and levees), should also be evaluated.

INTEGRATION INTO CALTRANS PROGRAM DELIVERY

Caltrans programs, including policies, design, planning, operations, and maintenance, should be redesigned to address long-term climate risks. They should also incorporate uncertainties inherent in climate data by adopting a climate scenario-based decision-making process that includes the full range of climate predictions. Caltrans is currently evaluating internal processes to understand how best to incorporate climate change into decision-making.

LEADERSHIP

Leadership at both the state government and transportation agency levels will be required. Transportation systems are often undervalued because the full economic implications of their damage, loss, or failure are not adequately considered. Avoiding potential impacts of extreme weather events and climate change on the SHS should be priorities for policy and capital programming.

COMMUNICATION AND COLLABORATION

Adapting to climate change challenges will require a collaborative and proactive approach. Caltrans recognizes that stakeholder input and coordination are required to develop analyses and adaptation strategies that support and expand the state's current body of work. Working with local communities and other state agencies on adaptation strategies can lead to better decisions, a collective response, and work that is done outside of "silos".

NEXT STEPS

This vulnerability assessment is the first effort of many in understanding, and responding to, the impacts of climate change on the SHS. This first step is a high-level assessment – an initial look at how climate change should be considered, and much more work will be needed to comprehensively and systematically consider climate change risks at the asset-level. As a next step, Caltrans is conducting further assessments for each of its districts, which will identify a subset of assets that may be of higher risk from changing conditions and should be evaluated at the site-level. These assets will be summarized for each district in a Climate Action Report. Another effort will produce a statewide Adaptation Strategy Report, which summarizes next steps Caltrans can take as an agency to incorporate climate change into its practices.

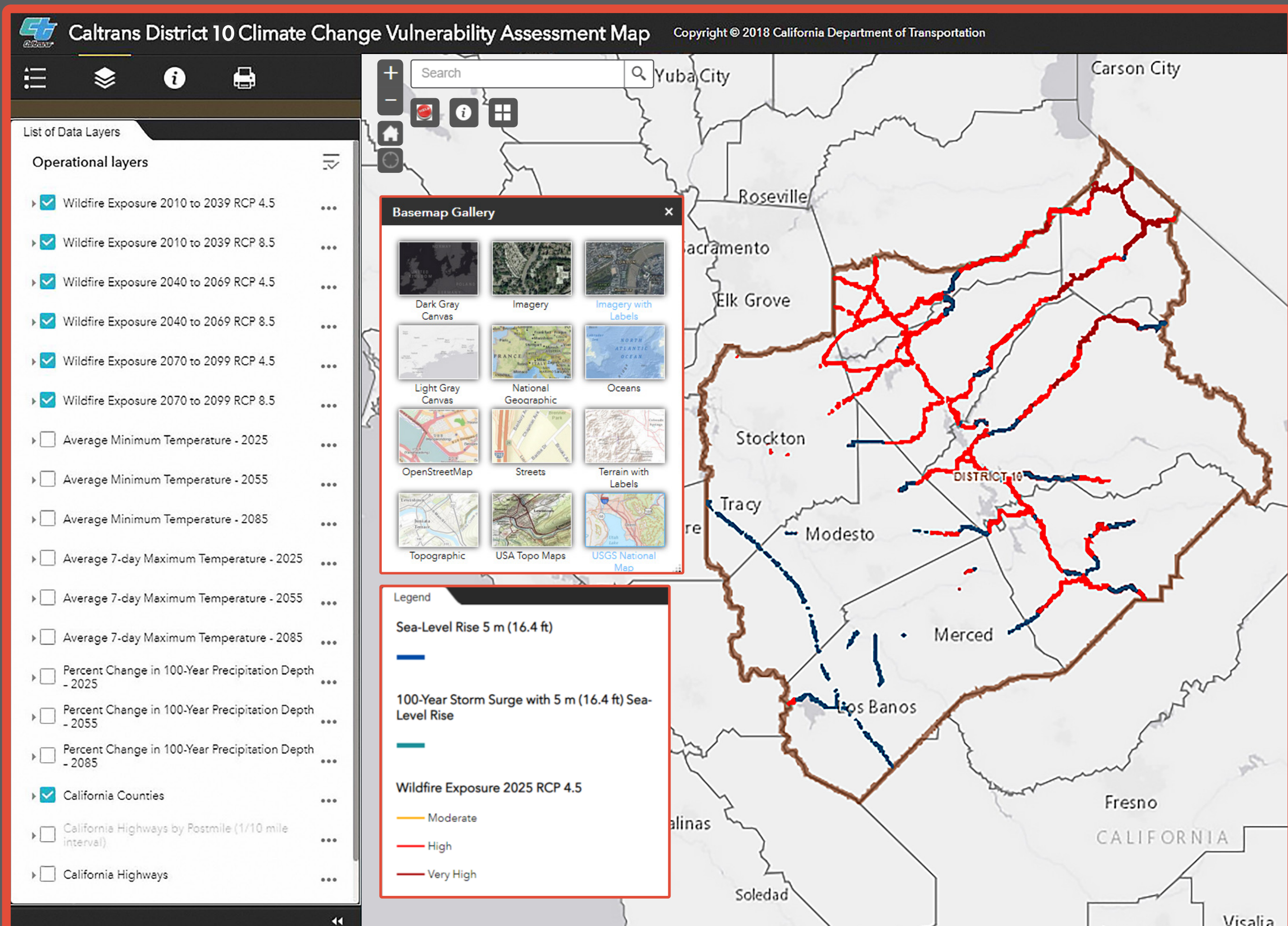
ON-LINE MAPPING TOOL FOR DECISION-MAKING

Caltrans has created an online mapping program to provide information for users across the state, using data assembled for this project. The Caltrans Climate Change Vulnerability Assessment Map can be accessed here.[36]

This tool enables Caltrans staff, policy-makers, residents and others to identify areas along the SHS where vulnerabilities may exist, or how temperature and precipitation may change over time.

The map viewer will be dynamic, incorporating new data as it is developed from various projects undertaken by Caltrans and will be maintained to serve as a resource for all users. The tool will be updated with data for each district as vulnerability assessments are developed.

36 - Caltrans makes no representation about the suitability, reliability, availability, timeliness, or accuracy of its GIS data for any purpose. The GIS data and information are provided "as is" without warranty of any kind. See the map tool for more information.



Complex geospatial analyses were required to develop an understanding of Caltrans assets exposed to sea level rise, storm surge, cliff retreat, temperature, and wildfire. The general approach for each stressor's geospatial analysis went as follows:

- **Obtain/conduct stressor mapping:** The first step in each GIS analysis was to obtain or create maps showing the presence and value of a given climate stressor at various future time periods.
- **Determine critical thresholds:** To highlight areas affected by climate change, the geospatial analyses for certain stressors defined the critical thresholds for which the value of a hazard would be a concern to Caltrans.
- **Overlay the stressor layers with Caltrans SHS to determine exposure:** Once high hazard areas had been mapped, the next step was to overlay the Caltrans SHS centerlines with the data to identify the segments of roadway exposed.
- **Summarize the miles of roadway affected:** The final step in the geospatial analyses involved running the segments of roadway exposed to a stressor through Caltrans' linear referencing system, which provides an output GIS file indicating the centerline miles of roadway affected by a given hazard.

Upon completion of the geospatial analyses, GIS data for each step was saved to a database that was supplied to Caltrans. This GIS data will be valuable for future Caltrans efforts and is provided on the Caltrans online map viewer shown here.

Ferguson Slide | SR 140