CALTRANS CLIMATE CHANGE

VULNERABILITY ASSESSMENT SUMMARY REPORT

DISTRICT 2

2018

Caltrans

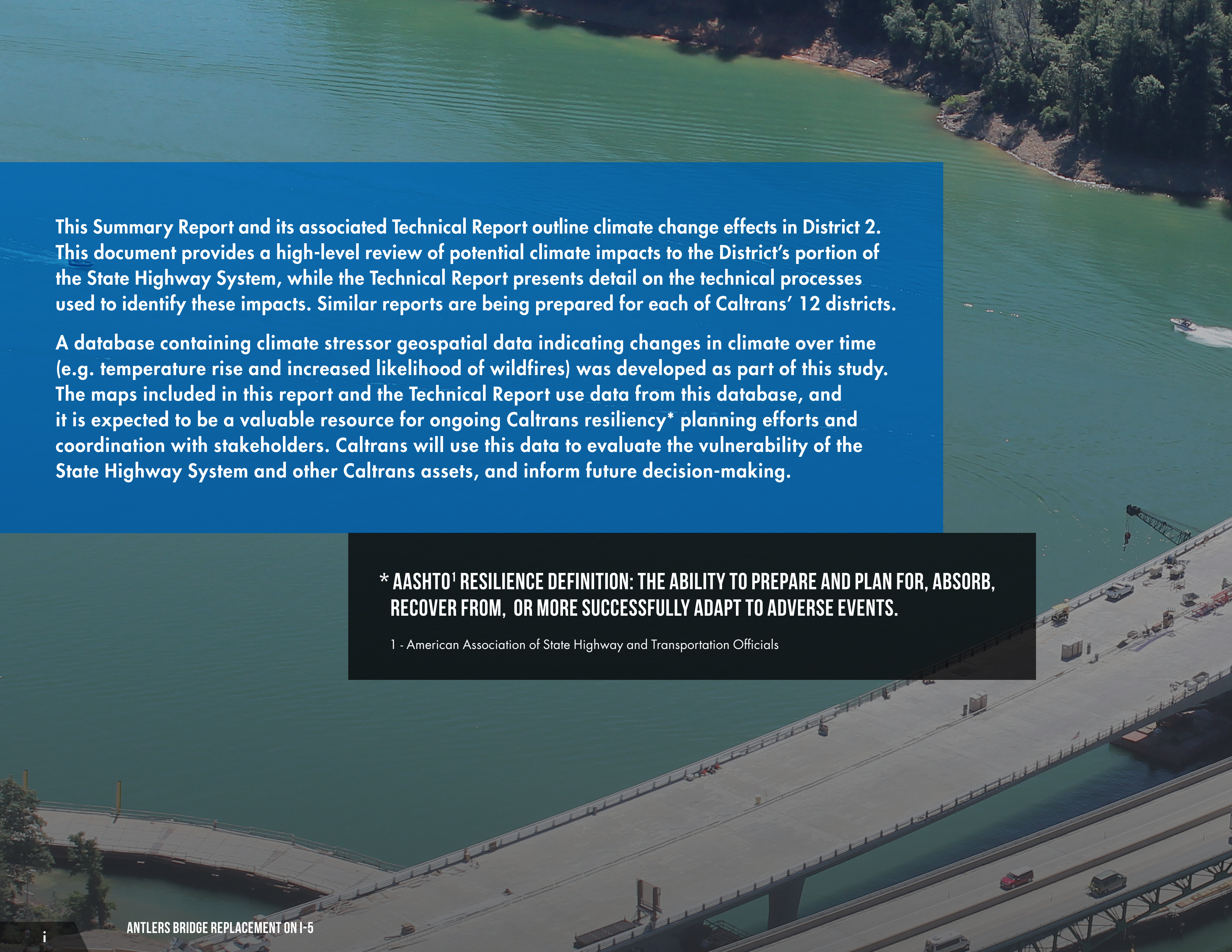
WSP

This Summary Report and its associated Technical Report outline climate change effects in District 2. This document provides a high-level review of potential climate impacts to the District's portion of the State Highway System, 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 State Highway System and other Caltrans assets, and inform future decision-making.

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

1 - American Association of State Highway and Transportation Officials



ANTLERS BRIDGE REPLACEMENT ON I-5

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DISTRICT 2 IS CHARACTERIZED BY A NETWORK OF ROADWAYS THROUGH HEAVILY FORESTED AND STEEP TERRAIN, WITH LIMITED ROUTE OPTIONS.

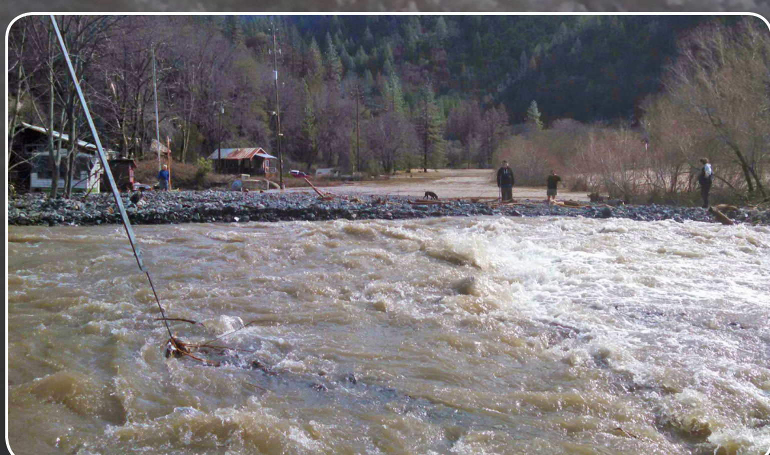
In California and the west, these general climate trends are expected[2]:

- **More severe droughts, less 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**

The data analysis presented in this report is largely based on global climate data compiled by the Intergovernmental Panel on Climate Change (IPCC)—this data was developed to estimate the response of the earth's natural systems to increasing carbon emissions. The IPCC analysis represents future 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/or government policies. The four scenarios are RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 – which assume that carbon emissions would start to decline in the near term, by 2040, by 2080, or will continue unabated to the end of the century, respectively.

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

ROUTE 70 IN PLUMAS COUNTY BEFORE FLOODING



ROUTE 70 IN PLUMAS COUNTY DURING FLOODING

BACKGROUND AND APPROACH

Caltrans is making a concerted effort to identify the potential climate change vulnerabilities of the State Highway System. The information presented in this report is the latest phase of this effort. It identifies portions of the State Highway System 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 the best use of 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 2 portion of the State Highway System, and 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 in the region served by District 2, a subject with many unknowns, and begin to define a subset of assets on the State Highway System on which to focus future efforts. Thus this report does not identify projects to be implemented, nor does it present the cost associated such projects. These items will be addressed in future studies.

THE MOBILITY PROVIDED BY A RESILIENT STATE HIGHWAY SYSTEM ASSURES THE ECONOMIC AND SOCIAL WELL-BEING OF THE DISTRICT’S COMMUNITIES AND RESIDENTS.

ANTLERS BRIDGE, I-5 SHASTA COUNTY

DISTRICT 2 CHARACTERISTICS

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

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

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 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.[3]

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.[4]

Assembly Bill 2800
rrequires 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.[5]

3 - "Governor Brown Establishes Most Ambitious Greenhouse Gas Reduction Target in North America," Office of Governor Edmund Brown, https://www.gov.ca.gov/news.php?id=18938, April 29, 2015
4 - "Assembly Bill No. 1482," https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201520160AB1482, October 8, 2015
5 - "Assembly Bill No. 2800," http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160AB2800, September 24, 2016

EXTREME WEATHER IMPACTS IN DISTRICT 2

Changing climate conditions and associated extreme weather changes present challenges to District 2 in delivering resilient transportation facilities for residents of the District's seven counties. The primary concern is that changing conditions, including extreme weather events, may affect the public and/or the area's transportation infrastructure. In fact, such disruption and damage is already occurring, and may become more severe in the future. In 2017 alone, damage to the District 2 State Highway System was estimated at $85 million. There were 110 damage assessments prepared, and 22 Emergency Directors Order Contracts in five District 2 counties.

Temperature increase is a direct outcome of increasing GHG emissions. Heat waves have directly damaged infrastructure in California, causing pavement buckling and blackouts. District 2 has a Mediterranean climate, characterized by hot, dry summers and cold, wet winters. Temperatures in lower-lying District 2 areas (e.g., the City of Redding) can be very hot. The average summer temperature in Redding is approximately 95 degrees, with a record temperature of 114 degrees recorded in August 2017. Extreme heat events could affect maintenance activities by increasing maintenance costs due to material damage and causing schedule changes to protect maintenance workers from the effects of high temperatures.

Precipitation volatility is expected to increase in the future, with longer dry periods interspersed with unusually wet ones. Increases in heavy precipitation events combined with other changes in land use and land cover can increase the risk of flash flooding. The effects of increased precipitation were especially significant in District 2 during the winter of 2016–2017. Rainstorms and mudslides caused road closures and damage in the District, and intense storms caused roadway flooding and transportation infrastructure washouts, costing Caltrans millions of dollars in maintenance and repair costs.

Higher temperatures and extended periods of drought in California are expected to increase the risk of **wildfires**. Wildfires in the region have caused traffic delays, road blocks, and detours on District 2's portion of the State Highway System. In addition to direct impacts of wildfire, the indirect impacts of smoke can affect visibility and cause public health concerns. Caltrans expects wildfire events to increase in frequency and severity due to climate change.

It is important that actions taken to respond to these events and similar future events increase system resiliency and address potential future conditions.

CREEK CREATES NEW FLOW PATH

ROUTE 299 | REPAIRING DAMAGE CAUSED BY THE BIG FRENCH CREEK SLIDE


ROUTE 70 | LANDSLIDE


ROUTE 299 | HELENA FIRE


ROUTE 3 | TRINITY COUNTY

EFFORTS IN DISTRICT 2 TO ADDRESS CLIMATE CHANGE

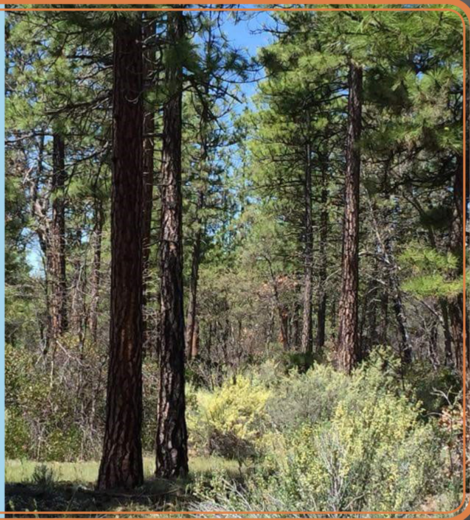
There are regional efforts related to climate change planning and preparedness underway in District 2. Several counties in the District have adopted Climate Action Plans designed to mitigate GHG emissions, reduce the impacts of climate change to their communities, and build resilience to climate change.

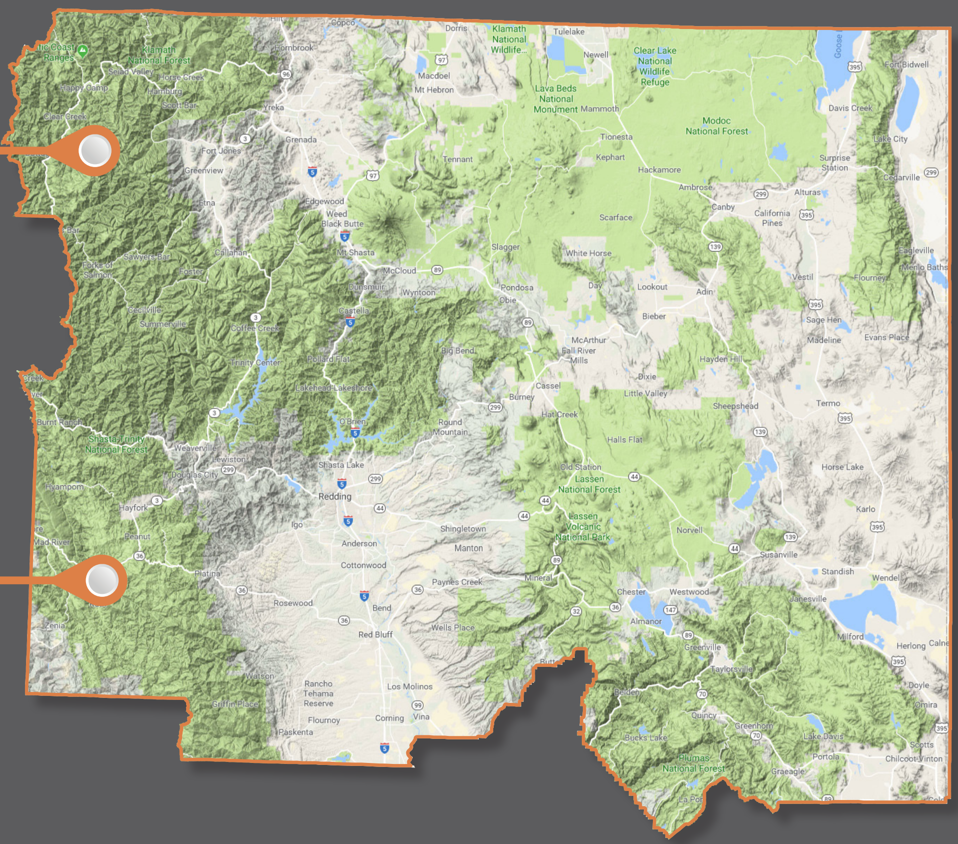
SISKIYOU COUNTY

The Siskiyou County Model Forest Policy Program prepared a Climate Adaptation Plan for the communities of Siskiyou County. The primary purpose of the plan is to build local community resilience against the impacts of climate change by protecting forest and water resources.[6]

TRINITY COUNTY

In 2011, the Model Forest Policy Program, the Cumberland River Compact, and The Watershed Research and Training Center created a Climate Adaptation Plan for Trinity County. Development of the plan was based on the critical need for local community resilience against the impacts of climate change by protecting forest and water resources. This plan also addresses local climate risks by relating possible future climate scenarios to local conditions and culture.[7]





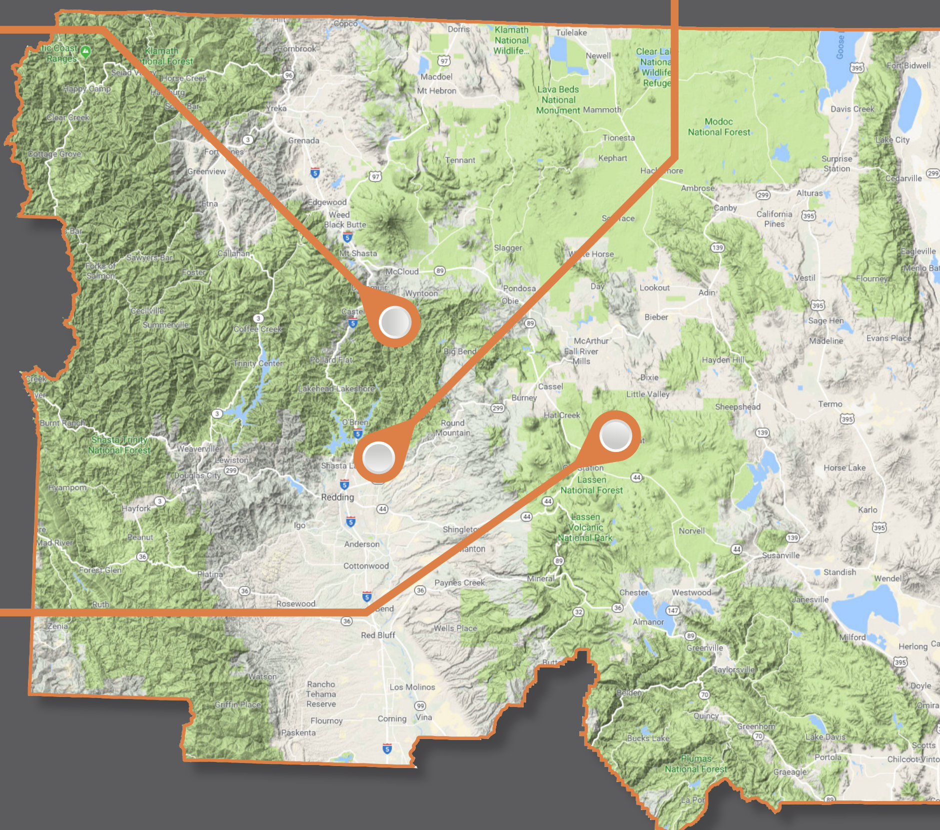
6 - Renew Siskiyou - A Roadmap to Resilience. 2014. http://mtshastaca.gov/wp/wp-content/uploads/2017/04/Siskiyou-Forest-Water-Climate-Adaptation-Plan-Final-2014_Fnl.pdf
7 - Forest and Water Resources Climate Adaptation Plan: Trinity County, CA. 2011. http://www.mfpp.org/wp-content/uploads/2012/03/Trinity-County_CA_Forest-and-Water_Climate-Adaptation-Plan_2011.pdf

SHASTA COUNTY

The Shasta County Air Quality Management District initiated the Regional Climate Action Planning (RCAP) process, with the primary goals of contributing to the state's climate protection efforts and providing California Environmental Quality Act (CEQA) review to streamline benefits for development projects within the region's four jurisdictions: the City of Anderson, the City of Redding, the City of Shasta Lake, and the unincorporated areas of Shasta County. To facilitate these objectives, Shasta County worked with the four jurisdictions to prepare community-specific, independent Climate Action Plans that contain GHG emission inventories and forecasts, emission reduction measures, and implementation and monitoring programs. The Climate Action Plans describe how each jurisdiction will achieve GHG reductions through local actions that contribute to the statewide GHG emissions reduction targets. The RCAP document serves as a collection of the individual Climate Action Plans and demonstrates the region's commitment to the state's GHG reduction efforts. The plan also notes California Climate Change Adaptation Policy Guide and that GHG reductions should occur in tandem with adaptation planning.[8]

ACTIVE TRANSIT IN REDDING

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



LASSEN VOLCANIC NATIONAL PARK

Lassen Volcanic National Park is a part of the National Park Service Climate Friendly Parks program, which provides parks with resources to address climate change impacts and promote sustainable practices. The Climate Friendly Parks program focuses on the following goals: park GHG emissions measurement, climate change education, and assisting parks in developing strategies to reduce emissions and anticipate future climate impacts. Becoming a Climate Friendly Park requires the completion of a GHG inventory, a training to educate park staff and stakeholders on the impacts of climate change, and the completion of an Action Plan to outline the park's sustainability and climate change goals. Lassen Volcanic National Park has completed a Climate Action Plan focused on sustainability planning.[8]

8 - Shasta Regional Climate Action Plan. November 2012. https://www.co.shasta.ca.us/docs/libraries/resource-management-docs/rcap-draft/Cover.pdf?sfvrsn=0
9 - Climate Friendly Parks Program. National Park Service. 2018. https://www.nps.gov/subjects/climatechange/cfpprogram.htm

VULNERABILITY AND THE STATE HIGHWAY SYSTEM

CALTRANS EFFORTS

Caltrans has been addressing concerns associated with climate change over the past five years. For example, Caltrans has been developing guidance on how climate change considerations can be incorporated into project design and other functional Caltrans responsibilities. Activities have included:

- Releasing *Guidance on Incorporating Sea Level Rise* (2011) for effective project programming and design when considering sea level rise.
- Issuing *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).

Caltrans' ongoing 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 for those using the system for nationwide commerce.

ADDRESSING CONCERNS IN DISTRICT 2

Caltrans District 2's portion of the State Highway System serves critical functions for communities, commerce, and more. Given the importance of this system, understanding the potential impacts of climate change and extreme weather on system performance is a key step in creating a resilient highway system.

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

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

- **Exposure** – identifying Caltrans assets susceptible to potential damage or reduced service life from expected future conditions.
- **Consequence** – determining what damage might occur to system assets – in terms of loss of use or costs of repair.
- **Prioritization** – determining how to most effectively make capital programming decisions to address identified risks (including the consideration of system use and/or timing of expected exposure).

Implementing this approach requires the participation of a wide range of Caltrans professionals from planning, asset management, operations/maintenance, design, emergency response, economics, and more. It will take an agency-wide effort to implement successfully.

ENSURING SYSTEM RESILIENCY

Once system vulnerabilities are identified, Caltrans will begin considering enhanced system resiliency when choosing projects and project designs. In District 2, this will require implementing projects that help to address the wildfire, precipitation, and increased temperature effects that are expected to occur. These strategies may include:

- Increasing drainage structures and capacity in areas where wildfires are projected to occur, and installing slope stabilization strategies outside of the roadway right-of-way where landslides are an additional concern. Examples of susceptible roadways in District 2 include Route 299, Route 3, Route 70, and Route 96.
- Adding new (or replacing existing) culverts with large capacity culverts or bridges in areas expected to face increased flow and debris during heavy precipitation events.
- Extending pavement life by installing pavement that retains its strength and quality when exposed to higher temperatures and extreme weather conditions. District 2 has already begun installing long-life asphalt pavement along I-5 to minimize future wear and tear, maintenance, and replacement activities. In two pilot projects, the District replaced 6 miles of pavement near Weed and 14.5 miles near Red Bluff with 40-plus year-life pavement.

These efforts will require Caltrans to be proactive and invest in the long-term viability of the transportation system.

ROUTE 96 | ROCKSLIDE

ROUTE 299 | BIG FRENCH CREK SLIDE

ECLIPSE FIRES SMOKE

THE CALTRANS APPROACH TO VULNERABILITY OUTLINED BELOW WAS DEVELOPED TO HELP GUIDE FUTURE PLANNING AND PROGRAMMING PROCESSES. IT OUTLINES 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 STAGE

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 value of loss, and 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. 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 affect goods movement, and the traveling public.
- 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.

PRIORITIZATION

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

- Timing – how soon can the impacts be expected?
- 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?
- Safety – who will be directly or indirectly affected? How can impacts to vulnerable populations be avoided?

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

PHASES FOR ACHIEVING RESILIENCY

California has been a national leader in responding to extreme climatic conditions, particularly in regards 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 this study fits within that framework.

AASHTO* RESILIENCE DEFINITION:
THE ABILITY TO PREPARE AND PLAN FOR, ABSORB, RECOVER FROM, OR MORE SUCCESSFULLY ADAPT TO ADVERSE EVENTS.

PREDICT CLIMATE CHANGE EFFECTS:
Climate change projections suggest that temperatures will be warmer, that precipitation patterns will change, sea levels will rise, and that a combination of these stressors could lead to other types of disruptions, such as those associated with wildfires.

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 their risk due to wildfires. Understanding these potential impacts provides an impetus to study ways to enhance the resiliency of the State Highway System.

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

SCOPE OF THIS STUDY

INITIATE VULNERABILITY ASSESSMENT:
Alternative climate futures will have varying impacts on the State Highway System. This step includes an examination of the range of climatic stressors and where, due to terrain or climatic region, portions of the State Highway System 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 decisions 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 State Highway System.

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.

* - American Association of State Highway and Transportation Officials. https://www.transportation.org/

DEVELOP ACTION PLANS FOR EACH CALTRANS FUNCTIONAL AREA *(including planning and modal programs, project delivery, and maintenance & 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, the estimated benefits to the State of California related to these steps, a timeline and staff responsibility.

INCORPORATE RESILIENCY PRACTICES THROUGHOUT CALTRANS:

Each Caltrans functional area will be responsible for incorporating those actions that are outlined in their Action Plan, while reporting progress regularly 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 and how the experience can guide project implementation, and actions similar to those in the pilot studies.

PRIORITIZE A SET OF PROJECTS/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 those projects with primary benefits related to system resiliency, or on other projects with benefits that could go beyond resiliency.

ADVANCE PROJECTS/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/ 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 notes 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."[10] Given the size of California and its many highly varied climate zones, it is expected that temperatures will rise across the state but that the degree of rise will vary.

Figure 1 on the following page shows the change in the average maximum temperature over seven consecutive days (which is an important element in determining the right pavement mix for long-term performance) for three time periods compared to a base year of 2004. In general, other studies in the US have found that increasing temperatures could impact the transportation system by affecting:

DESIGN

- Materials exposed to high temperatures over long periods of time can deform (including pavement heave or track buckling). High temperatures must be considered in the design of pavements in particular to mitigate future deterioration.
- Ground conditions and water saturation levels can affect foundations and retaining walls.

OPERATIONS AND MAINTENANCE

- Extended periods of high temperatures could affect safety conditions for employees that work long hours outdoors, such as those working on infrastructure reconstruction and maintenance activities.
- Right-of-way landscaping and vegetation must be able to survive longer periods of high temperatures.
- Extended periods of high temperatures could increase the need for protected transit facilities along roadways.
- Maintenance priorities could change with higher temperatures, heavier precipitation, and wildfires.

EFFECTS OF TEMPERATURE CHANGE IN DISTRICT 2

Ensuring long-term pavement quality on Caltrans roadways requires consideration of high and low temperatures in the study area. As shown in Figure 1, temperatures are expected to warm considerably in District 2 by the year 2085, requiring a review of pavement design parameters. District-wide, maximum seven-day high temperatures are expected to increase by an estimated 0° - 3.9° (F) by 2025, 4°-9.9° (F) by 2055, and 9° -13.9° (F) by 2085. Maximum seven-day high temperatures increase mostly uniformly across the District, with greater temperature rise projected in Siskiyou County.

DISTRICT 2 PAVEMENTS AND MAINTENANCE RESPONSE

The lifespan of pavements may be affected as temperatures rise and extreme heat events and freeze/thaw activity cause cracking, distortion, rutting, buckling, or asphalt movement.[11] If no adaptations are made, changes in climate may necessitate increased pavement maintenance to ensure an acceptable level of service life and safety. District 2 currently has 11 pavement projects underway and some are major maintenance and repair projects. Out of the 4,000 lane-miles (or 1,719 center-line miles) in District 2, 45% are in "Fair" condition and 12% are in "Poor" condition. More pavement from District 2 roadways could potentially end up in fair or poor condition as temperatures rise and stress on pavements increase.

Choosing the proper pavement maintenance and repair methods depends upon the type and amount of repair needed. Surface treatments can seal a roadway surface to keep water out of cracks and mitigate the negative effects of the sun.[12] Resurfacing may be necessary to cover old asphalt, address existing surface cracks, and help strengthen the roadway.[13] Pavement base repair is often more intensive and requires deeper excavation—it is typically done to address roadways that are older or in poor condition as it requires that the rock base and asphalt street surface be replaced. Typical costs for repair of pavement can range from $10,000 to $500,000+ per mile.[14]

10 - U.S. National Climate Assessment, http://nca2014.globalchange.gov/report/our-changing-climate/extreme-weather.
11 - https://www.ce.udel.edu/UTC/20110926_FinalReport_Pavement_ClimateChange.pdf
12 - https://www.portlandoregon.gov/transportation/article/453872
13 - https://www.sandiegocounty.gov/content/sdc/dpw/roads/surface.html
14 - https://www.portlandoregon.gov/transportation/article/453872

HIGH TEMPERATURES CAUSE PAVEMENT TO WEAR FASTER AND ALSO INCREASES MAINTENANCE COSTS

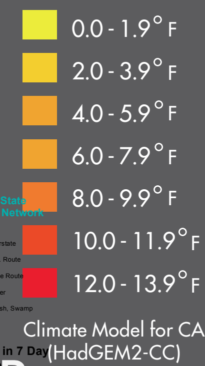
DROUGHT TOLERANT LANDSCAPING HAS BEEN PLANTED TO SURVIVE LONGER PERIODS OF HIGH TEMPERATURES WITH LOW WATER USE

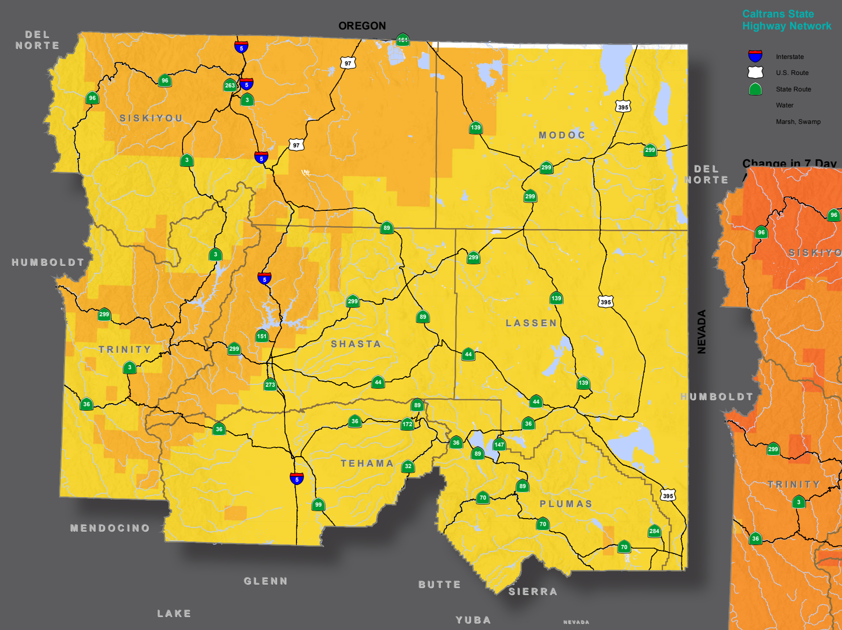
CORNING STATE ROADSIDE REST AREA

Fig.1

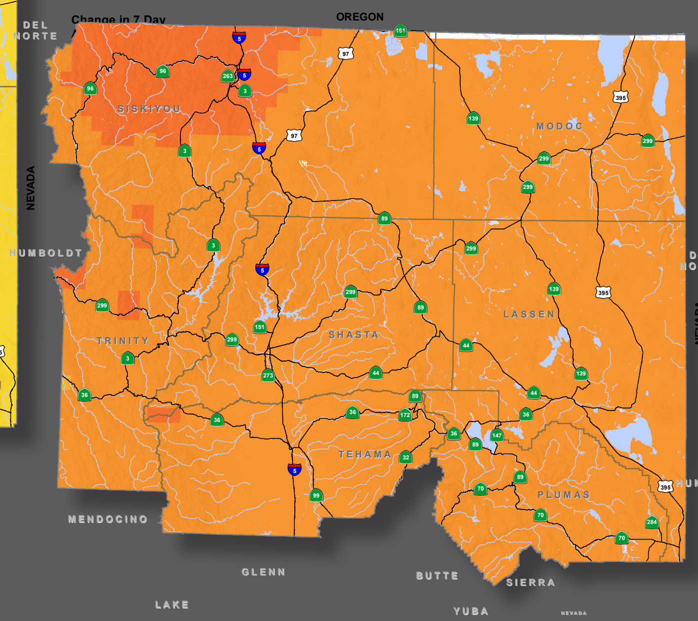
CHANGE IN THE AVERAGE MAXIMUM TEMPERATURE OVER SEVEN CONSECUTIVE DAYS

A REQUIRED MEASURE FOR PAVEMENT DESIGN

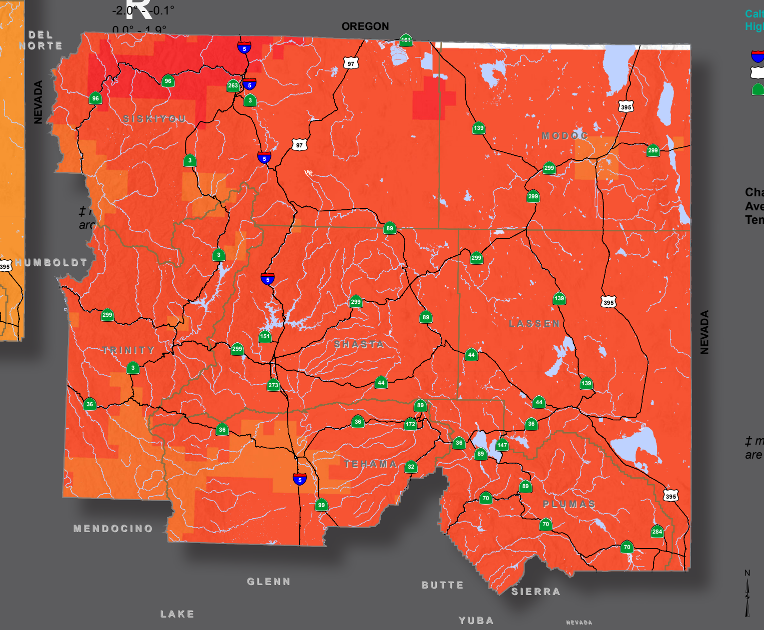




2025 REPRESENTATIVE CONCENTRATION PATHWAYS (RCP) 8.5, 50TH PERCENTILE



2055 REPRESENTATIVE CONCENTRATION PATHWAYS (RCP) 8.5, 50TH PERCENTILE



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

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

Caltrans Transportation Asset Vulnerability Study, District 2. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown was generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

PAVEMENT DESIGN

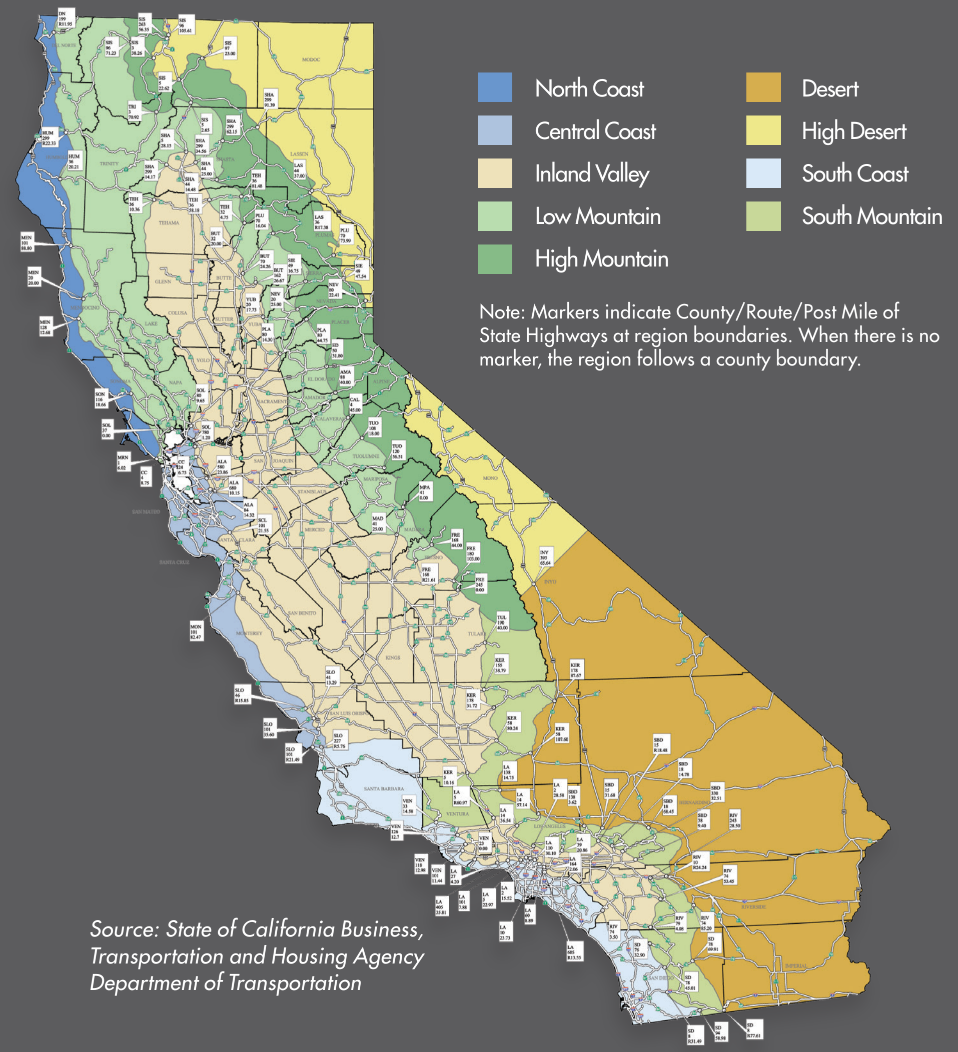
Pavement condition is related to how pavement is designed and is an important component of Caltrans' highway asset management strategy. Ensuring that highway pavements remain durable and maintain good ride quality when exposed to various conditions is an important responsibility of every state transportation agency. Highway pavement can be either concrete or asphalt mix, with the choice dependent on various conditions. One element of asphalt pavement design is the selection of the pavement binder, a decision based in part on temperature conditions in the project area.

The timing of climate change is different for pavement design when compared to other assets. Many of Caltrans' assets, including roadways, bridges, and culverts, will likely be in place for a long time. Decisions made today for these assets need to incorporate a longer-term view, so the asset is effective through its design life. This is not the case for asphalt pavement, which is replaced approximately every 20 years, or sooner, depending on how quickly the quality degrades.

Caltrans has divided the state into nine pavement climate regions (as shown in Figure 2) which helps determine the types of pavement recommended for each area. Pavement design uses as two of its primary criteria "average maximum seven-day moving average temperature" and the "change in absolute minimum air temperature." The temperature projections for this assessment have been formatted to fit these metrics. An important consideration for Caltrans and its pavement design engineers will be whether the boundaries of these climate regions could shift due to climate change, or whether pavement design parameters might need to change due to climatic changes across the state.

Fig. 2

CALTRANS PAVEMENT REGIONS



Source: State of California Business, Transportation and Housing Agency Department of Transportation

POTHOLES FORMING FROM FREEZE & THAW IMPACTS ON PAVEMENT

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 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—a reality highlighted by the fact that alignment of the first national highway (as it was defined then), built to connect settlers to the Ohio Valley and the west, is still in existence today.

The two graphics included on this page highlight how design life considerations are a critical part of planning for transportation investment. Figure 3 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

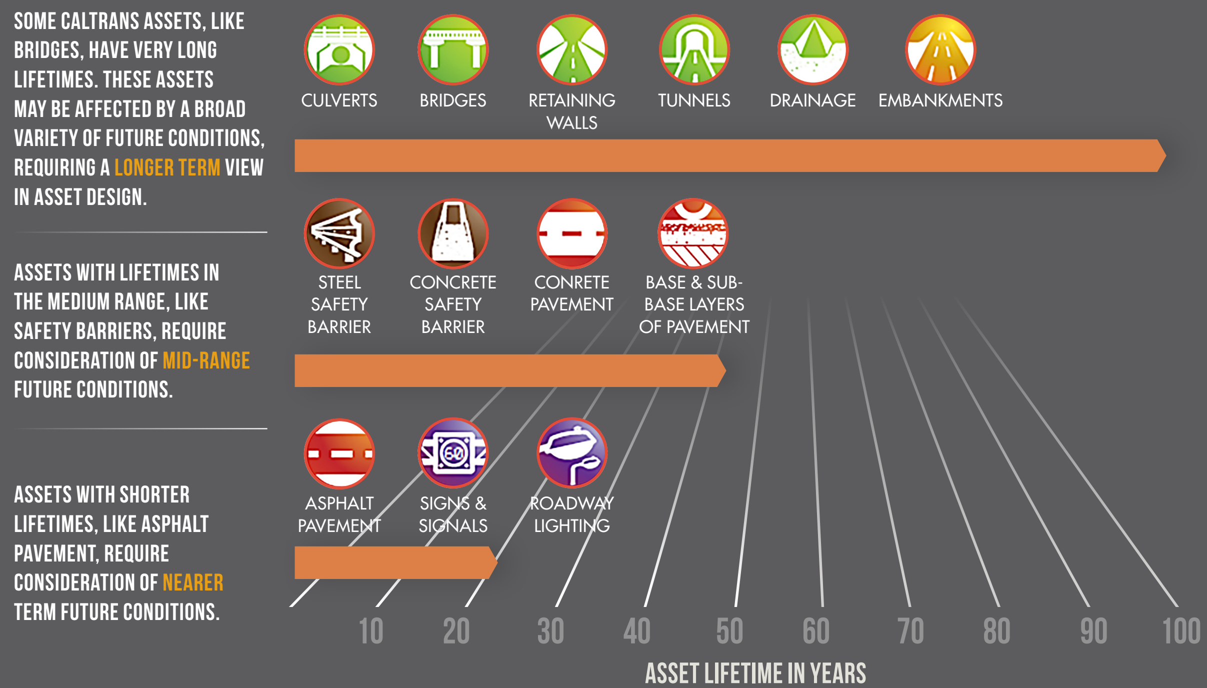
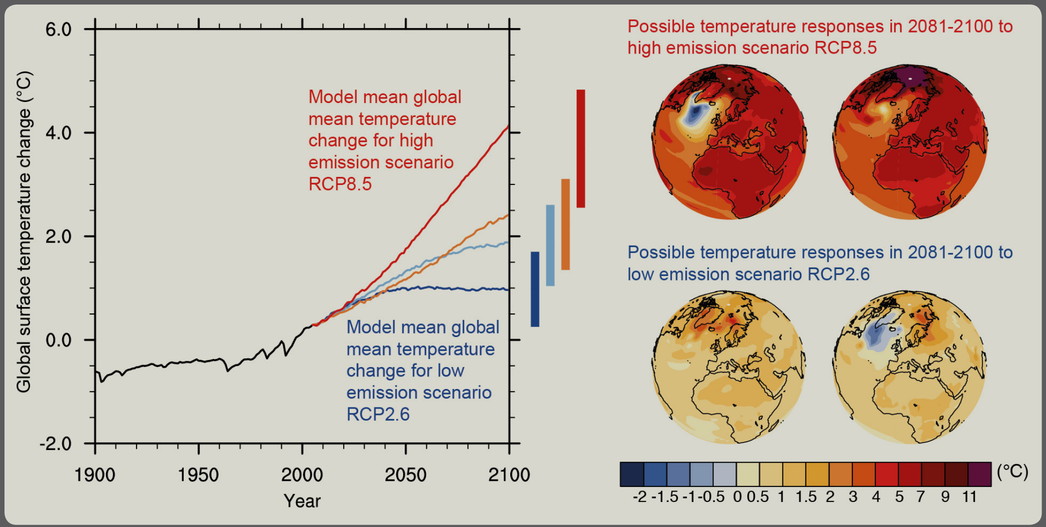


Fig. 3 IPCC - CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS FAQ 12.1



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.

PRECIPITATION

Increasing temperatures are expected to cause changing precipitation events, due to an increase in energy and moisture in the atmosphere. Heavier storm events, combined with other changes in land use and land cover, can increase the risk of damage or loss from flooding. Transportation assets in California are affected by precipitation in a variety of ways, including inundation, flooding, landslides, washouts, and structural damage from heavy rainfall. The primary concern regarding transportation assets is not the average volume of rainfall over an extended period, but rather more frequent and larger storm events and their potential for damaging the State Highway System.

The Scripps Institution of Oceanography at the University of California, San Diego has generated projected future rainfall data to the year 2100 using two different GHG emission scenarios and a variety of models. One useful way to examine this data is to assess changes to the 100-year storm event over time. The 100-year storm event has a likelihood of occurring once every 100 years—in other words, it has a 1% chance of happening in any given year. A storm of this magnitude could cause a great deal of damage and is therefore a design standard for infrastructure projects. However, the 100-year storm level is typically based on historic precipitation data. Figure 5 on the right shows future projections of the 100-year storm depth. These values were developed from projected rainfall data produced by the Scripps Institution.

Indications of increased precipitation in District 2 means that Caltrans must assume higher rainfall and associated flooding, and plan improvements to the State Highway System accordingly. This situation can be exacerbated by increased development, which reduces the natural absorption capacity of the land in drainage areas. Complex conditions like these require a longer-term view be considered for design and flood response for facilities in these areas to ensure that they remain operational to the end of their design lives. Improving long-term resiliency will require that Caltrans conduct a comprehensive assessment of future conditions, and incorporate new values for precipitation in design.

PRECIPITATION CHANGE IN DISTRICT 2

As seen in the Figure 5, District 2 will likely experience anywhere from a 0-20% increase in precipitation depth from a 100-year storm, depending upon location. The data also shows that by end of century, Siskiyou, Trinity, and Plumas will have the greatest change in 100-year storm depth out of the seven District 2 counties This information is useful for planning level studies, but the District will conduct hydrologic analyses to finalize design of bridges, culverts, and other assets dependent upon runoff and river flows. These analyses should still consider future precipitation projections to ensure that assets are sized correctly given future conditions.

DISTRICT 2 CULVERTS DON'T JUST SERVE TO TRANSPORT WATER, THEY ALSO ACT AS WILDLIFE CROSSINGS.

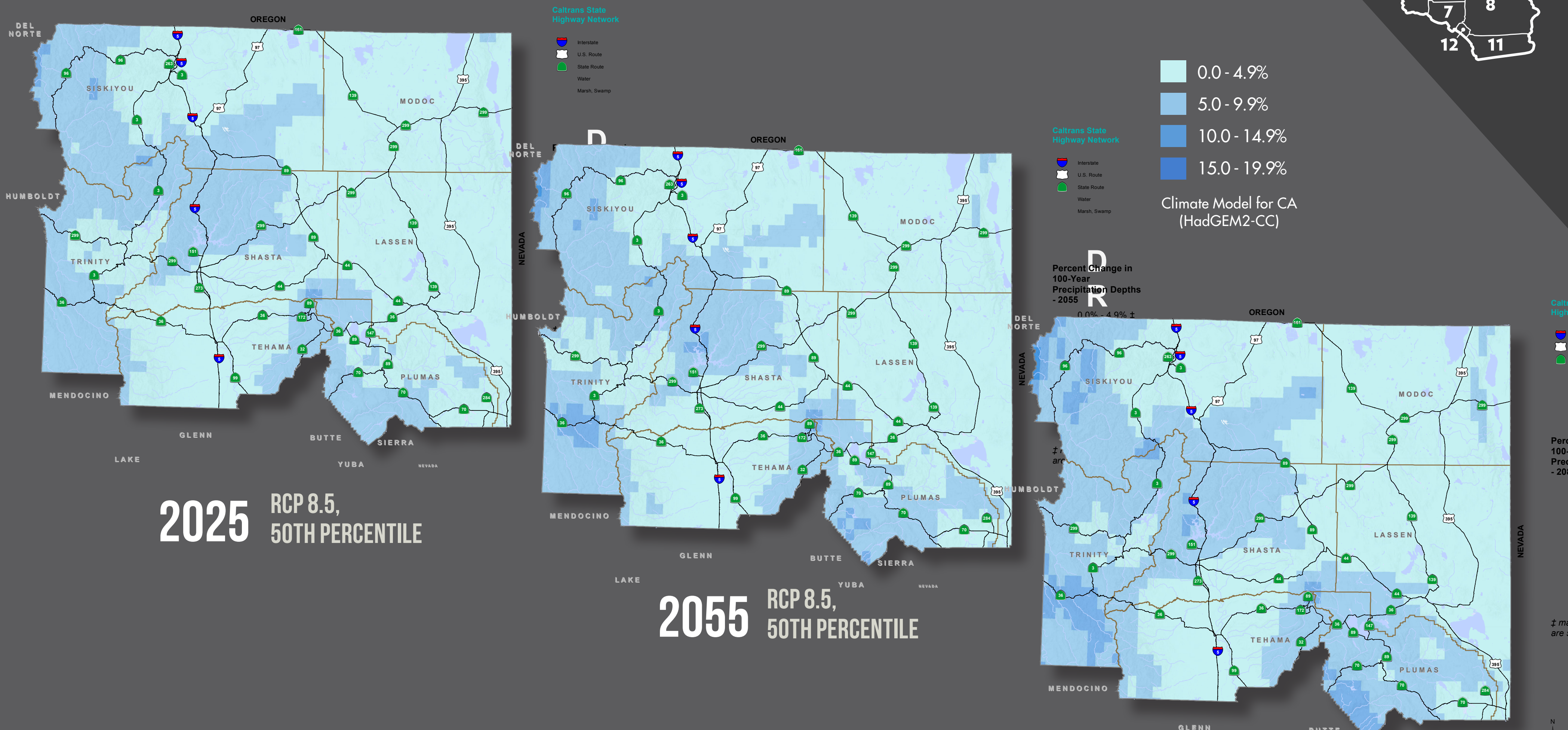
WILDLIFE CROSSING

ROADS CONSTRUCTED IN RIVER VALLEYS FACE INCREASED EXPOSURE

FLOODING ON PLU 70 IN FEATHER RIVER CANYON

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

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

Caltrans Transportation Asset Vulnerability Study, District 2. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown was generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

WILDFIRE

Higher temperatures and changing precipitation patterns are expected to influence the likelihood and severity of wildfires. Decreased precipitation creates drier conditions, thus increasing wildfire risk. Increasing precipitation contributes to growth in land cover, thereby increasing the amount of fuel available for wildfires. Wildfires can also contribute to landslide and flooding exposure by burning off protective land cover and reducing the capacity of the soils to absorb rainfall. California is already prone to serious wildfires, and the results of future climate forecasts suggests that wildfires will get worse. The need to address these concerns led Governor Jerry Brown to announce, in May 2018, a new fund to help forest management and reduce wildfire risk.

The areas shaded in red in Figure 6 indicate increased likelihood of wildfires in the future. These projections of wildfire likelihood are from data 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 of these models was paired with three downscaled Global Climate Models to produce nine future scenarios. Starting with three different wildfire models was a conservative methodology, as final data shows the highest wildfire risk categorization of all model results.

15 - USDA Fire Service https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd564471.pdf

16 - Caltrans Emergency Director's Orders, accessed 07/03/2018

WILDFIRE EFFECTS IN DISTRICT 2

Wildfires are a significant concern in District 2. The Helena fire of 2017 burned from August 30 until it was extinguished on November 15th, after destroying 21,962 acres of land, 61 minor structures, and 72 single family residences.[15] Caltrans spent $2.6 million for rehabilitation of burned or destroyed facilities along Highway 299.[16]

Also on Hwy 299, the CARR fire in 2018 started on July 23 and was 93% contained on August 22 burning 229,651 acres, destroying 1,079 and damaging 190 residences; destroyed 22 and damaged 26 commercial structures, and destroyed 503 and damaged 63 outbuildings. Caltrans spent $24 million on emergency work. Subsequently the Delta Fire in 2018 made significant damage and closure of I-5 to travelers, consuming 60,227 acres in Shasta, Siskiyou and Trinity Counties and destroyed 17 structures.

Given the forested geography of the District, every State Route that passes through District 2 is vulnerable to wildfire risk. District 2 highways also have limited redundancy, so an impact to one route can have a huge effect to the traveling public. For example, if someone was trying to drive from Redding to the coast, and Route 299 was blocked, the resulting detour would add approximately an hour to their drive.

Table 1: Miles of Roadways in Moderate to Very High Wildfire Exposure Areas for the RCP 8.5 Scenario

County	Miles		
	2025	2055	2085
Lassen	246.0	257.6	261.9
Modoc	130.2	130.2	130.2
Plumas	157.9	160.9	167.0
Shasta	294.2	294.2	294.2
Siskiyou	332.1	332.1	332.1
Tehama	175.4	175.4	175.4
Trinity	200.0	200.0	200.0

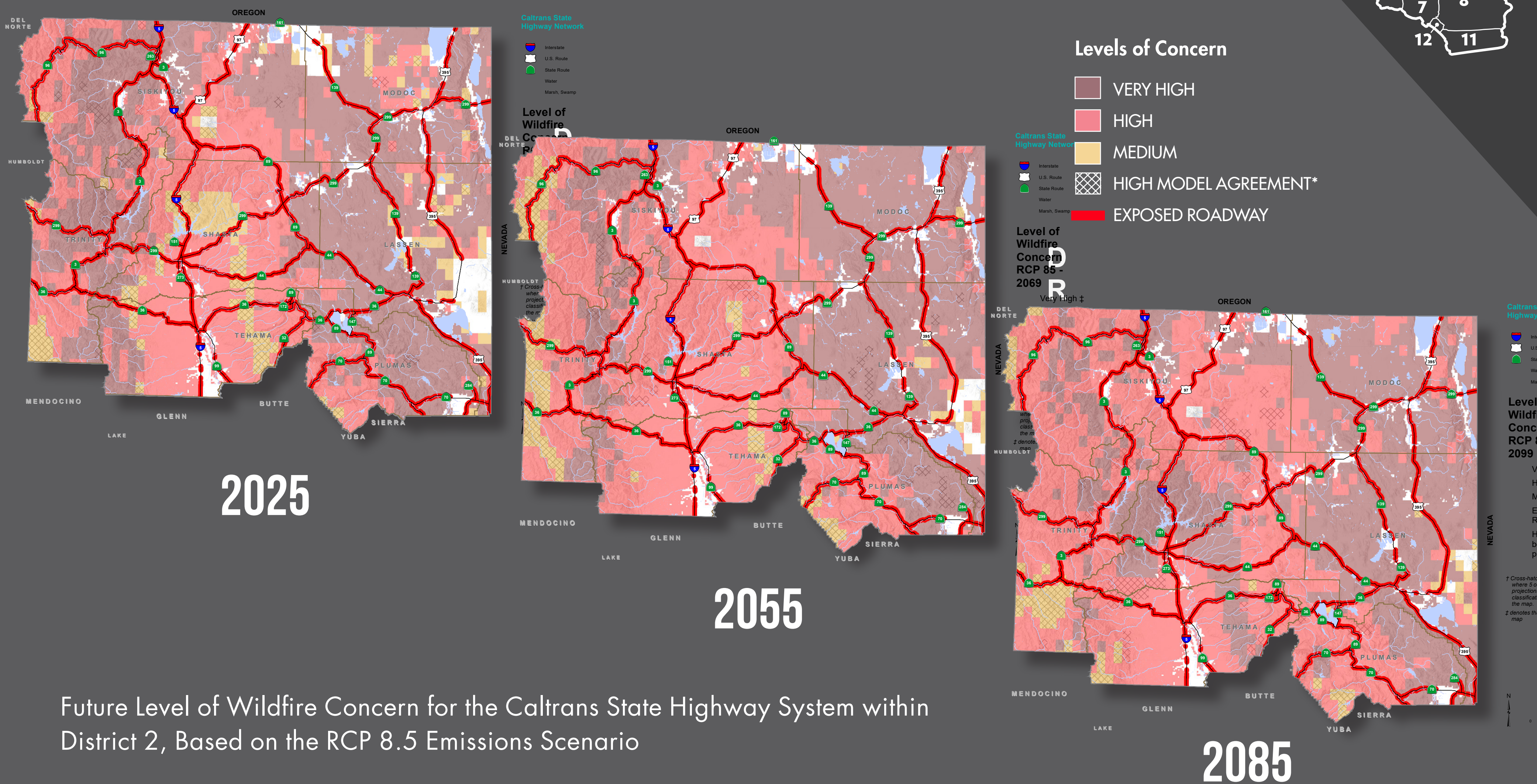
HELENA WILDFIRE

CARR WILDFIRE

DELTA WILDFIRE

Fig. 6

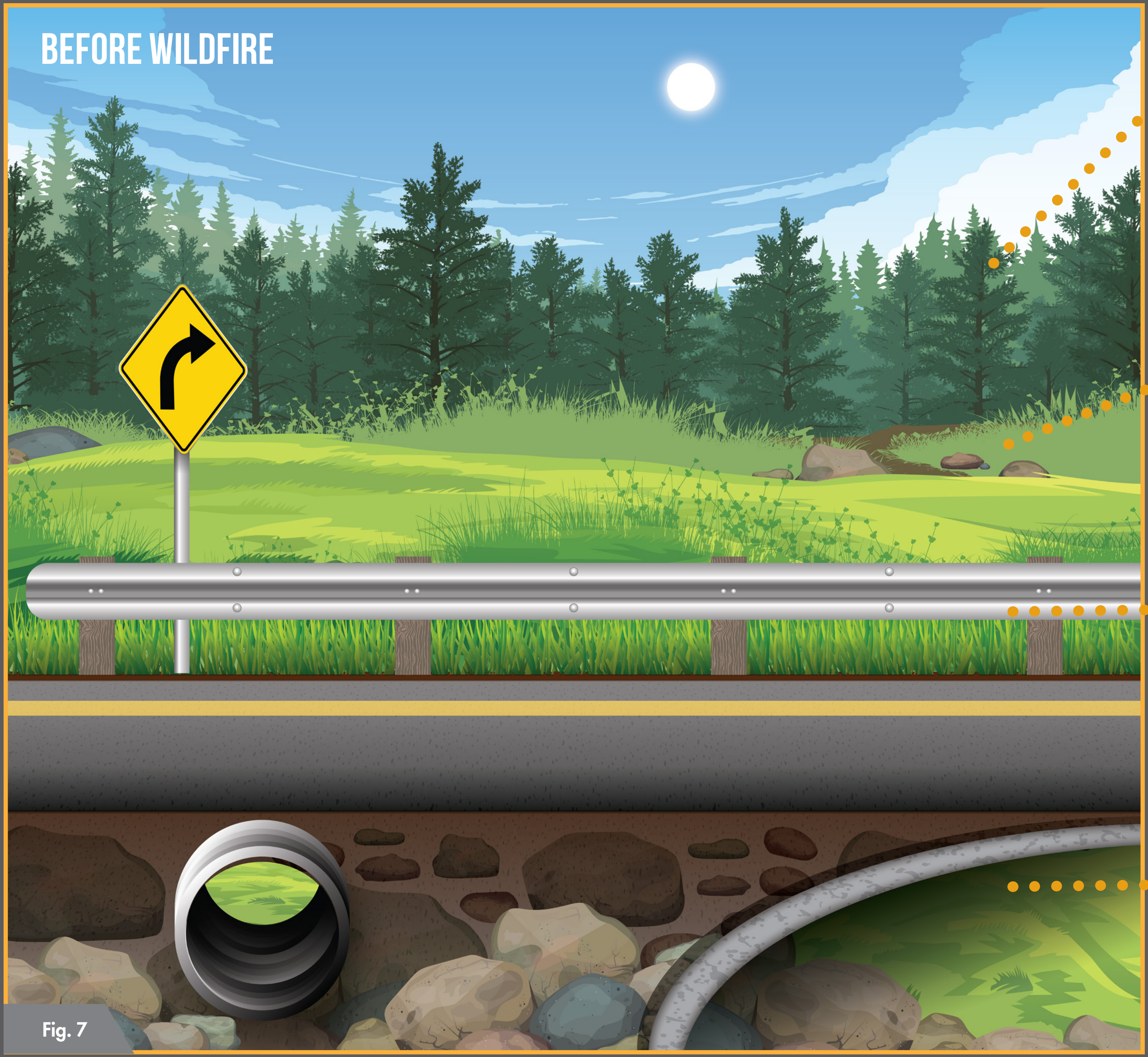
LEVEL OF WILDFIRE CONCERN



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

The fire model composite summaries shown are based on wildfire projections from three models: (1) MC2 - EPA Climate Impacts Risk Assessment, developed by John Kim, USFS; (2) MC2 - Applied Climate Science Lab at the University of Idaho, developed by Dominque Bachelet, University of Idaho; and (3) University of California Merced model, developed by Leroy Westerling, University of California Merced. For each of these wildfire models, climate inputs were used from three GCMs: (1) CAN ESM2; (2) HAD-GEM2-ES; and (3) MIROC5. The maps show the multi-model maxima for each grid cell across the nine combinations of the three fire models and the three GCMs.

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



FOREST/TREE COVER MODERATES RAINFALL EFFECTS ON THE GROUND, LIMITING EROSION OF THE SOILS

GROUNDCOVER OF TREES, SHRUBS AND GRASSES STABILIZE AND SLOW SURFACE FLOWS AND FACILITATE RAINFALL INFILTRATION INTO THE SOIL

INSTALLED SIGNS AND GUARDRAILS IMPROVE SAFETY FOR ROADWAY USERS

CLEAR CULVERTS ALLOW WATER TO PASS UNDER THE ROADWAY AND ALSO PROVIDE PASSAGE UNDER THE ROAD FOR AREA WILDLIFE AS WELL AS WILDLIFE CROSSING

Healthy vegetated areas provide various ecosystem services contributing to 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 require 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.

INFRASTRUCTURE IMPACT EXAMPLE

BIG FRENCH CREEK SLIDE

To highlight how climate change may impact infrastructure in District 2, an example Caltrans highway location was selected to illustrate how projected climate changes can impact a roadway. The location is State Route 299 PM 23.3 at the Big French Creek Slide in Trinity County. Inclement weather patterns forced continued road closures between 2016 - 2017. The weather and the dynamic nature of the slide brought multiple challenges, creating a need for Caltrans to act quickly. Key dates and events included:

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

BIG FRENCH CREEK SLIDE

Fig. 9

BIG FRENCH CREEK SLIDE

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 has developed a framework for making design decisions that incorporates climate change: the Adaptation Decision-Making Assessment Process (ADAP)[17] 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 2 for existing and future roadways. The following section highlights a district effort that demonstrates adaptive design, emergency responses, and risk management. These efforts are examples of how Caltrans districts can prepare for, and respond to, future climate change and extreme weather events.

HELENA WILDFIRE RESPONSE

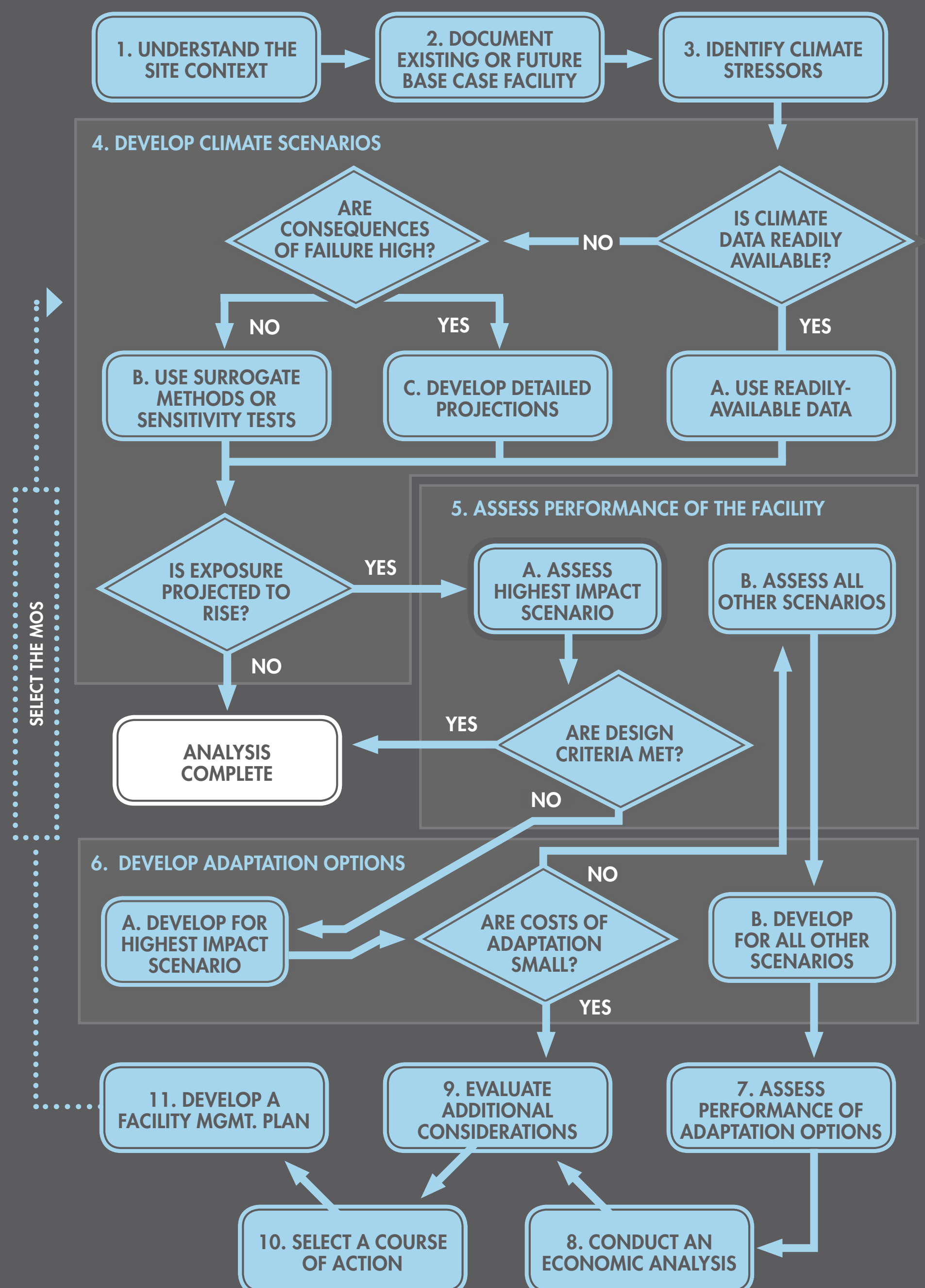
The Helena wildfire in August – September 2017 burned vegetation along the slope adjacent to State Route 299 in Trinity County, resulting in potential slope instability near PM 45.0. Caltrans utilized hydroseeding via helicopter to reseed the impacted slope. As previously described, wildfire is an immediate concern for driver safety, system operations, and infrastructure. Indirectly, wildfires contribute to slope instability by burning off soil-stabilizing land cover/vegetation and reducing the capacity of the soils to absorb rainfall. As a result, after a wildfire, a slope is extremely vulnerable to failure during and after precipitation events. In this situation, Caltrans proactively planned for and implemented hydroseeding to begin immediate slope stabilization in anticipation of future precipitation events, implementing risk-based design measures.

17 - https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/teacr/adap/index.cfm

HELENA FIRE

Fig. 10

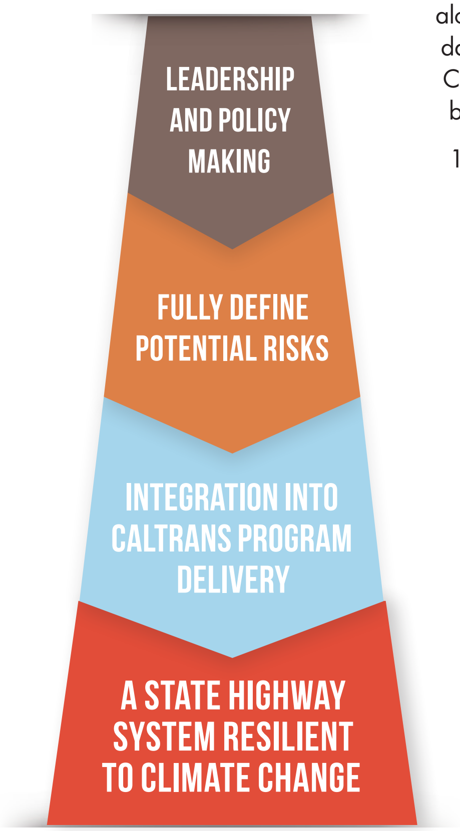
FHWA'S ADAP DESIGN PROCESS



HYDRO SEEDING

DROUGHT-RESISTANT LANDSCAPING

WHAT DOES THIS MEAN TO CALTRANS?



GENERAL CONCLUSIONS

Changing climate conditions and associated extreme weather changes present a series of challenges to District 2 in delivering resilient transportation facilities to District residents. The primary concern is that changing conditions, such as extreme weather events, may affect the public or the transportation infrastructure in the area. These events are already disrupting and damaging District 2 infrastructure, with the potential for impacts to become more severe in the future. In 2017 alone, damage was estimated at $85 million in District 2, with 110 damage assessments prepared, and 22 Emergency Directors Order Contracts in five of the District 2 counties. Some conclusions that can be reached from the perspective of this report:

1. The repair of District 2 facilities should include the consideration of climate change (page 4 – state policies)
2. Consequence costs should be a determinant in re-design – assessing broader economic measures than facility damage costs (page 10 – vulnerability approach)
3. The development of updated design approaches, which includes data from state resource agencies (including the Scripps Institution) should be a part of the response to these events (page 11– phases for achieving resiliency)
4. The assessment of precipitation effects should include the higher estimated rainfall totals derived from the climate data (page 17 – Precipitation section)
5. FHWA's ADAP process should be applied in any potential redesign of a facility to incorporate uncertainties in climate data and utilize a benefit-cost assessment methodology that considers long-term costs to guide decisions (page 25 – An Adaptive Design Process)

Not all of the Caltrans State Highway System is at risk from climate change. However, there are some assets that could significantly affected, resulting in severe consequences, as outlined in this report. Effective management of these risks will require a sustained effort on the part of Caltrans officials because the methods for doing so are very different from those found in typical state Departments of Transportation (DOTs). Most importantly, these methods focus on examining the potential of future risks, determined through current vulnerability assessments rather than depending on historical data, to define the future.

Taking steps to address these climate concerns will require the following:

LEADERSHIP

Leadership will be required at both the state government and transportation agency level. Transportation systems are often undervalued by not considering the broader economic implications of damage, loss, or failure. Avoiding the possible impacts of extreme weather events and climate change on the State Highway System should be made a policy and capital programming priority.

FULLY DEFINE RISKS

This report does not provide a full accounting of risks from changing climate conditions. Additional work will be required to identify risk at an asset-by-asset level from the full range of potential impacts. To fully assess and address risks, assets outside of normal DOT control, but which could affect state highway operation if they failed (e.g., dams and levees), should be evaluated.

INTEGRATION INTO CALTRANS PROGRAM DELIVERY

Caltrans programs including policies, planning, design, operations, and maintenance, should be redesigned to include the consideration of long-term climate risks. Uncertainties inherent in climate data should be accounted for by adopting a climate scenario-based decision-making process, which involves considering the full range of climate predictions.

A STATE HIGHWAY SYSTEM RESILIENT TO CLIMATE CHANGE

The end result of considering climate change in a systematic and comprehensive way, with the efforts defined by this report being the first steps, will be a State Highway System more resilient to major storm events in the short term, and to climate change in the long-term.

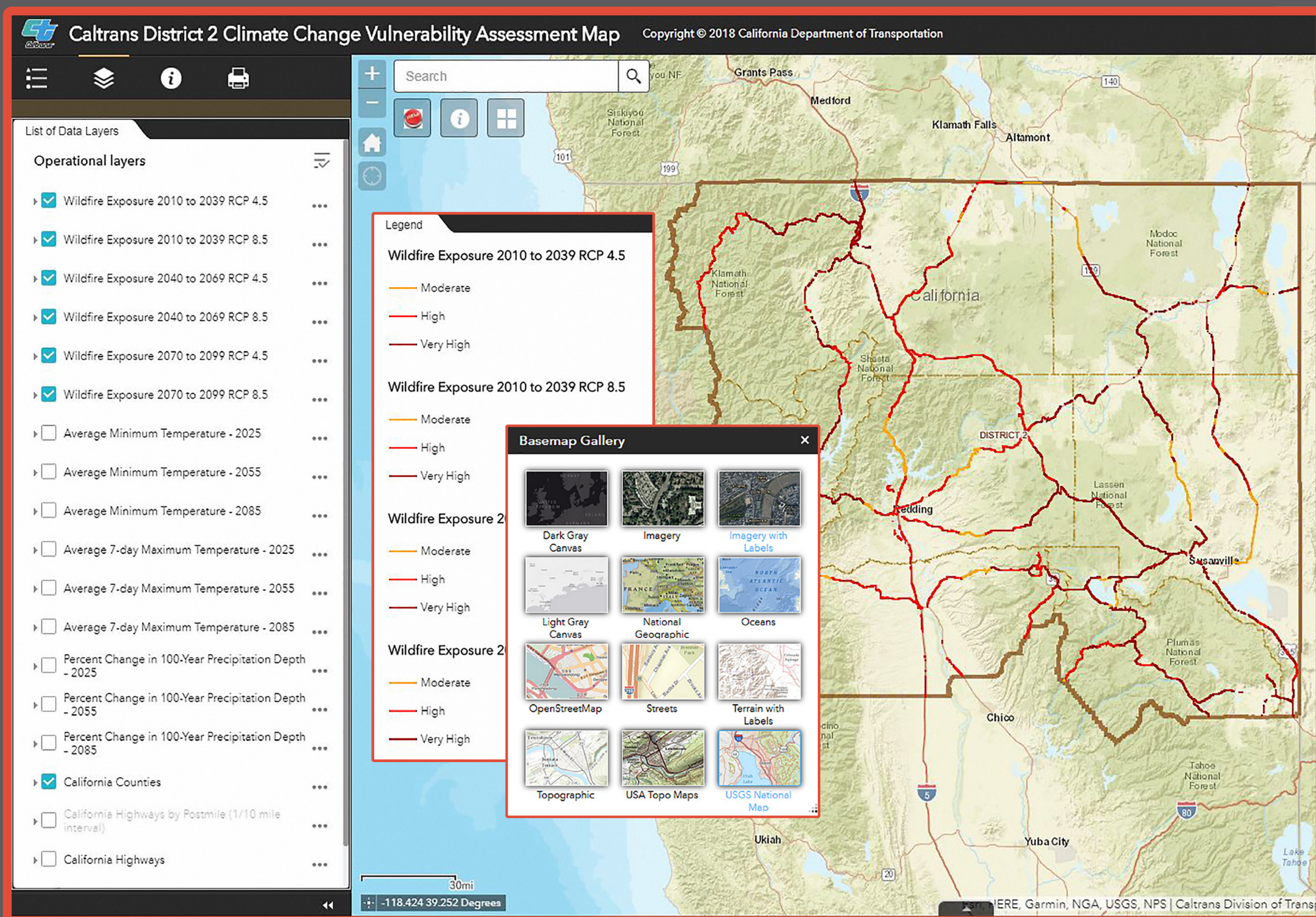
ON-LINE MAPPING TOOL FOR DECISION-MAKING

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 via the vulnerability assessment web page at:

http://www.dot.ca.gov/transplanning/ocp/vulnerability-assessment.html

This tool enables Caltrans staff, policy-makers, residents and others to identify areas along the State Highway System 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.



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 State Highway System to determine exposure:** Once high hazard areas had been mapped, the next step was to overlay the Caltrans State Highway System 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.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