

CALTRANS CLIMATE CHANGE

VULNERABILITY ASSESSMENT SUMMARY REPORT

DISTRICT 6

2018





This Summary Report and its associated Technical Report outline climate change effects in District 6. 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. The contents of the District 6 database will also be available to the public in an online interactive mapping tool which currently includes data for District 4; data from District 6 and other districts will be added as it becomes available.¹

*** AASHTO² RESILIENCE DEFINITION: THE ABILITY TO PREPARE AND PLAN FOR, ABSORB, RECOVER FROM, OR MORE SUCCESSFULLY ADAPT TO ADVERSE EVENTS.**

1 - <http://caltrans.maps.arcgis.com/apps/webappviewer/index.html?id=517eef1b5a542e5b0e25f337f87f5bb>

2 - American Association of State Highway and Transportation Officials



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DISTRICT 6 IS HOME TO BOTH LOW VALLEY LANDS AND RURAL MOUNTAINOUS AREAS, AND IS EXPECTED TO BE VULNERABLE TO RISING TEMPERATURE, INCREASED WILDFIRE RISK, AND THE EFFECTS OF HEAVY RAIN EVENTS.

In California and the west, these general climate trends are expected³:

- 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.

3 - "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



BACKGROUND AND APPROACH

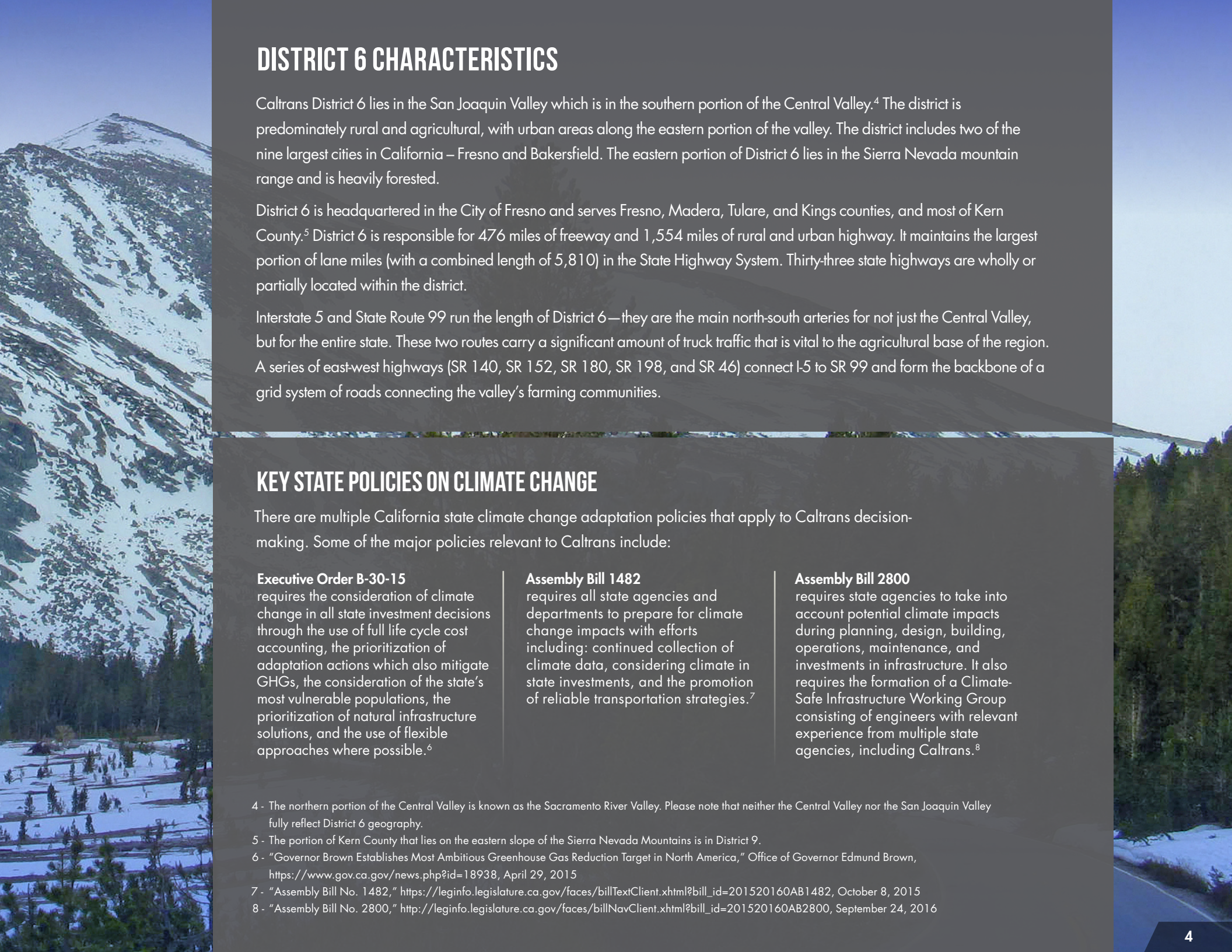
Caltrans is making a concerted effort to identify the potential climate change vulnerabilities of the State Highway System. The information presented in this report is the latest phase of this effort. It identifies portions of the State Highway System that could be vulnerable to different climate stressors 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 6 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 6, 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.**



DISTRICT 6 CHARACTERISTICS

Caltrans District 6 lies in the San Joaquin Valley which is in the southern portion of the Central Valley.⁴ The district is predominately rural and agricultural, with urban areas along the eastern portion of the valley. The district includes two of the nine largest cities in California – Fresno and Bakersfield. The eastern portion of District 6 lies in the Sierra Nevada mountain range and is heavily forested.

District 6 is headquartered in the City of Fresno and serves Fresno, Madera, Tulare, and Kings counties, and most of Kern County.⁵ District 6 is responsible for 476 miles of freeway and 1,554 miles of rural and urban highway. It maintains the largest portion of lane miles (with a combined length of 5,810) in the State Highway System. Thirty-three state highways are wholly or partially located within the district.

Interstate 5 and State Route 99 run the length of District 6—they are the main north-south arteries for not just the Central Valley, but for the entire state. These two routes carry a significant amount of truck traffic that is vital to the agricultural base of the region. A series of east-west highways (SR 140, SR 152, SR 180, SR 198, and SR 46) connect I-5 to SR 99 and form the backbone of a grid system of roads connecting the valley's farming communities.

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.⁶

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.⁷

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.⁸

4 - The northern portion of the Central Valley is known as the Sacramento River Valley. Please note that neither the Central Valley nor the San Joaquin Valley fully reflect District 6 geography.

5 - The portion of Kern County that lies on the eastern slope of the Sierra Nevada Mountains is in District 9.

6 - "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

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

8 - "Assembly Bill No. 2800," http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160AB2800, September 24, 2016

EXTREME WEATHER IMPACTS IN DISTRICT 6

In recent years, the San Joaquin Valley has seen hotter, longer summers and drier winters with minimal to no rain, particularly during the most recent drought. During the drought, groundwater pumping, largely for crop irrigation, caused subsidence in the San Joaquin Valley, and may have permanently decreased aquifer capacities.⁹ Uneven subsidence throughout District 6 could cause roads and irrigation canals to buckle and break, which would require increased maintenance and repair. Heavy rain and snow in the winter of 2016-2017 saturated soils and caused movement under the Highway 120 (Big Oak Flat Road) road bed, resulting in a large fissure in the highway over 100 feet long.¹⁰ That winter also brought historic snowpack to the Sierra Nevada Mountains, which melted at overwhelming rates during the hot summer of 2017.¹¹ Fresno experienced three heat waves during summer 2017, each a triple-digit hot spell lasting over a week.¹² In June 2017 outflows from Pine Flat Lake in Tulare County were increased to make room for more snowmelt, but that caused flooding downstream in Kingsburg. The Department of Water Resources (DWR) reported the San Joaquin precipitation total to be 178 percent that of an average water year, with runoff in the region about 258 percent of average.¹³ Intense storms can cause roadway flooding and transportation infrastructure washout requiring millions of dollars in maintenance and repair costs. Caltrans expects the effects of climate change to increase the frequency of events of this scale. It is important that responses to these events, and similar future events, increase system resiliency and address potential future conditions.

⁹ "Current Land Subsidence in the San Joaquin Valley", U.S. Geological Survey, California Water Science Center, <https://ca.water.usgs.gov/projects/central-valley/land-subsidence-san-joaquin-valley.html>.

¹⁰ "Yosemite National Park Working to Repair Big Oak Flat Road", Yosemite National Park News Release, <https://www.nps.gov/yose/learn/news/bofrepairs.htm>, March 2, 2017.

¹¹ Serna, Joseph, "The Kings River flooded from snowmelt that couldn't be measured or predicted", <http://www.latimes.com/local/lanow/la-me-ln-kings-river-flooding-snowpack-20170626-story.html>, June 26, 2017.

¹² Anderson, Barbara and Konstantinovic, Aleksandra, "As Fresno area sets a record for heat, schools take it easy with students", <http://www.fresnobee.com/news/local/article169798137.html>, August 28, 2017.

¹³ "Hydrologic Conditions in California (09/30/2017)", California Data Exchange Center, <http://cdec.water.ca.gov/cgi-progs/reports/EXECSUM>.





FRESNO COUNTY | ROUGH FIRE 2015 | CREATIVE COMMONS LICENSE



ROUTE 41 | TREE MORTALITY IN KERN COUNTY



FROM CALIFORNIA NATIONAL GUARD | GARZA FIRE AT TAR CANYON ROAD, KINGS COUNTY, CALIFORNIA | CREATIVE COMMONS LICENSE

EFFORTS IN DISTRICT 6 TO ADDRESS CLIMATE CHANGE

CLIMATE ACTION PLANS

Many cities and counties in District 6 have adopted Climate Action Plans (CAPs) designed to mitigate GHG emissions and reduce the effects of climate change to their communities. The cities of Madera, Merced, Avenal, and Hanford have all adopted CAPs, as has Tulare County. A recent General Plan Update workshop in Kern County showed public interest in a CAP. The City of Fresno has its own action-oriented plan, called Fresno Green, which consists of 25 different strategies to reduce pollution and transform Fresno into a sustainable city. While these strategies are still primarily focused on GHG mitigation, reports and studies are also addressing the need for climate adaptation. While local institutions are developing plans to reduce emissions and adapt, local institutions are continuing to assess the effects of climate change to the District 6 region.¹⁴

SIERRA CAMP

The Sierra Climate Adaptation and Mitigation Partnership (Sierra CAMP) is a regional collaborative focused on promoting climate adaptation and mitigation strategies across the Sierra Nevada region and building connections with urban areas. Sierra CAMP includes both public and private members such as the US Forest Service, the Sierra Nevada Alliance, Tahoe Mountain Sports, and Ski California, who are focused on engaging other Sierra stakeholders in a discussion about climate change issues in the Sierra and catalyzing climate action in the region. The collaborative is one of five across the state that make up the Alliance for Regional Collaboratives for Climate Adaptation (ARCCA).¹⁴

DISADVANTAGED POPULATIONS AND ENVIRONMENTAL JUSTICE

The San Joaquin Valley area is one of the most disadvantaged and pollution-burdened regions identified by CalEnviroScreen 3.0. Many communities in the San Joaquin Valley still do not have safe drinking water due to nitrate pollution from agricultural runoff. Poorer areas in the San Joaquin Valley suffer from poor air quality and are more likely to be located next to hazardous facilities. Climate change may disproportionately affect these communities, which are already suffering from environmental impacts, and they may lack the resources to respond to additional stressors. In response, the San Joaquin Valley is home to many organizations focused on creating a cleaner and safer California. Some of these organizations include the California Environmental Justice Alliance; the Center on Race, Poverty, and the Environment; United Farm Workers of America; and Voices from the Valley.¹⁵

14 - See the associated District 6 Technical Report for more information and sources.

15 - "Organizations." Voices from the Valley, accessed on October 25th 2017, <http://www.voicesfromthevalley.org/organizations/>

CENTRAL VALLEY HYDROLOGIC MODEL

The Central Valley is a critical agricultural economic engine in California and the US, generating around 8% of US agricultural output on just 1% of US farmland. The valley also provides key habitats for ducks, geese, shorebirds, and other birds that rely on wetlands for migration and survival. Due to the competing demands for water and its limited supply, the region has been the subject of numerous studies to determine how water flows and how uses will change over time. The US Geological Survey (USGS) developed the Central Valley Hydrologic Model (CVHM) to understand how water use, precipitation, and land use changes will affect surface and groundwater flows in the Central Valley. The model's simulations based on a warmer, drier California show that stream flows may decline by up to 40%, which will increase groundwater demand across the region. The effects of increased groundwater draw-down include increased streamflow infiltration, reduced outflow to the Delta, and increased subsidence rates. The USGS and Central Valley stakeholders are continuing to explore future changes to the regional hydrologic system, which may have significant effects on the nearby communities and natural habitats.¹⁴

THE CENTRAL VALLEY FLOOD PROTECTION PLAN

In the past, the Central Valley was largely wetland. Now, only 10% of original wetlands remain and the area is low-lying and flood prone. The Central Valley Flood Protection Plan is updated every five years to improve flood risk management in the Central Valley and develop strategies for reducing risk that provide multiple benefits, including transportation system protection. The most recent update was released in 2017 and includes climate change considerations such as more frequent extreme precipitation, changes in flood magnitudes and frequencies, sea level rise, and increased subsidence.¹⁴

SUBSIDENCE

The San Joaquin Valley is sinking five centimeters per month in some locations, due to multiple factors, but in large part due to groundwater depletion from agriculture draw down combined with hydro compaction. Though groundwater pumping rates have slowed in the region since the 1970s, droughts (such as the 2011 to 2017 drought) typically result in heavy groundwater use. As of today, two main subsidence bowls have been mapped in the San Joaquin Valley, one in the north that sank 37 inches from 2006 to 2010, and one in the south that sank 24 inches in the same time period.

Droughts may become more frequent and the resulting groundwater depletion will continue without a significant effort to replenish aquifers. Impacts to infrastructure (such as state highways) may occur where it crosses these areas, especially where rates of subsidence are uneven across the landscape. Subsidence in the San Joaquin and greater Central Valley areas is of interest to both researchers and infrastructure managers. For example, the California High-Speed Rail Authority is preparing for potential subsidence by using ballast, as opposed to "highway-like" concrete slabs, to support track in subsidence prone areas. This design will be easier to maintain and fix if the land sinks, saving time and costs in the future. Subsidence will be an ongoing issue for the region that will undoubtedly affect infrastructure planning, management, and maintenance for Caltrans and other infrastructure owners.¹⁴

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 6

Caltrans District 6's portion of the State Highway System serves critical functions for the movement of agriculture and other goods. 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 6, adaptive responses will be needed 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.
- Increasing culvert size or installing new, larger culverts where there are anticipated increases in precipitation and flows. Bridges may need to accommodate for larger river flows and increased scour.
- Extending pavement life by installing pavement that retains its strength and quality when exposed to higher temperature conditions.

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



FROM DAVE YNIN | DRIVING THROUGH RIM FIRE ON BIG
OAK FLAT ROAD | CREATIVE COMMONS LICENSE



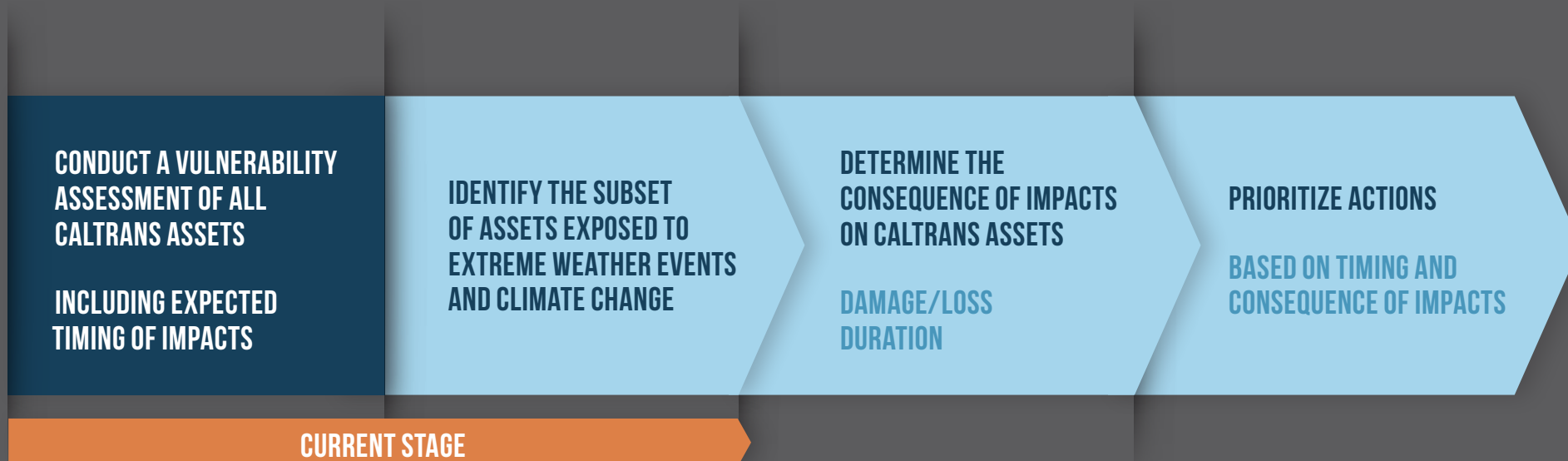
ROUTE 155 | TREE MORTALITY IN KERN COUNTY



ROUTE 155 | TREE MORTALITY IN KERN COUNTY

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:



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 – i.e., 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 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.

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.

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 as extreme temperatures, heavy precipitation, sea level rise, and more, and relates the likely consequences of these stresses to disruptions to the State Highway System.

SCOPE OF THIS STUDY

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.

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 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.

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.

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.

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.

DEVELOP ACTION PLANS FOR EACH CALTRANS FUNCTIONAL AREA

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

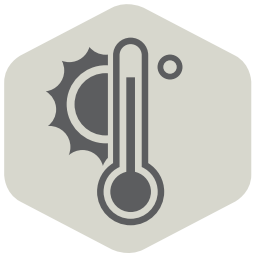
Each of the functional areas in Caltrans would develop an Action Plan for furthering resiliency-oriented projects and processes in their area of responsibility. These action plans would define specific action steps, the estimated benefits to the State of California related to these steps, a timeline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

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.

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.



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.”¹⁶ Given the size of California and its many highly varied climate zones, it is expected that temperatures will rise across the state and the degree of rise will vary.

The figure 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.

TEMPERATURE CHANGE IN DISTRICT 6

Temperatures across District 6 are expected to increase considerably by the year 2100, which will necessitate a review of roadway pavement design parameters. The eastern, mountainous regions of District 6 will likely show the greatest temperature increase. In Fresno, Madera, and Tulare Counties, the average weekly high temperature is expected to increase by 2°- 4° (F) by 2025. By 2085, these same areas may show up to a 12.8° (F) average weekly temperature rise.

¹⁶ - U.S. National Climate Assessment, <http://nca2014.globalchange.gov/report/our-changing-climate/extreme-weather>.

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



ROADSIDE LANDSCAPING WILL NEED TO SURVIVE LONGER PERIODS OF HIGH TEMPERATURES

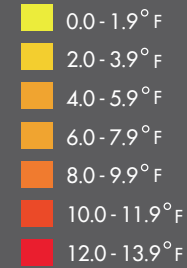


ROUTE 168 | TREE MORTALITY IN FRESNO COUNTY

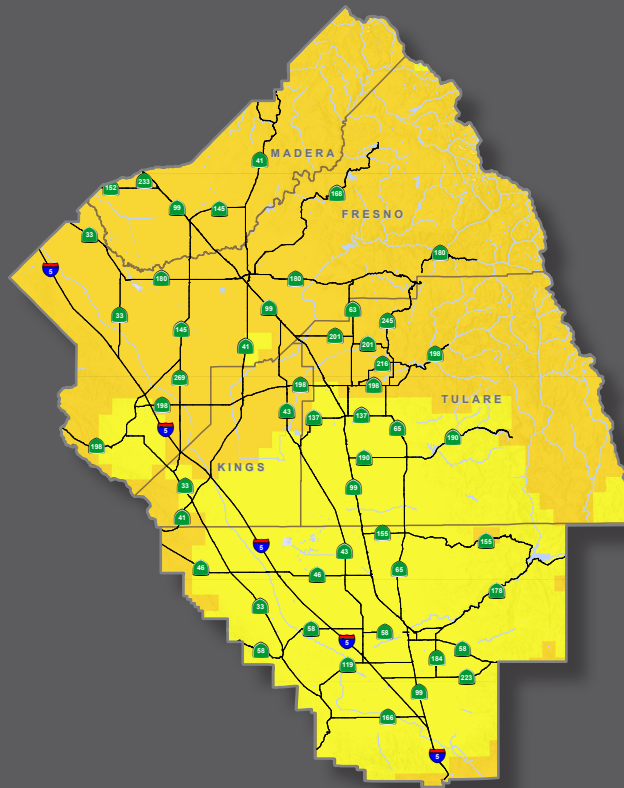
Fig.1

CHANGE IN THE AVERAGE MAXIMUM TEMPERATURE OVER SEVEN CONSECUTIVE DAYS

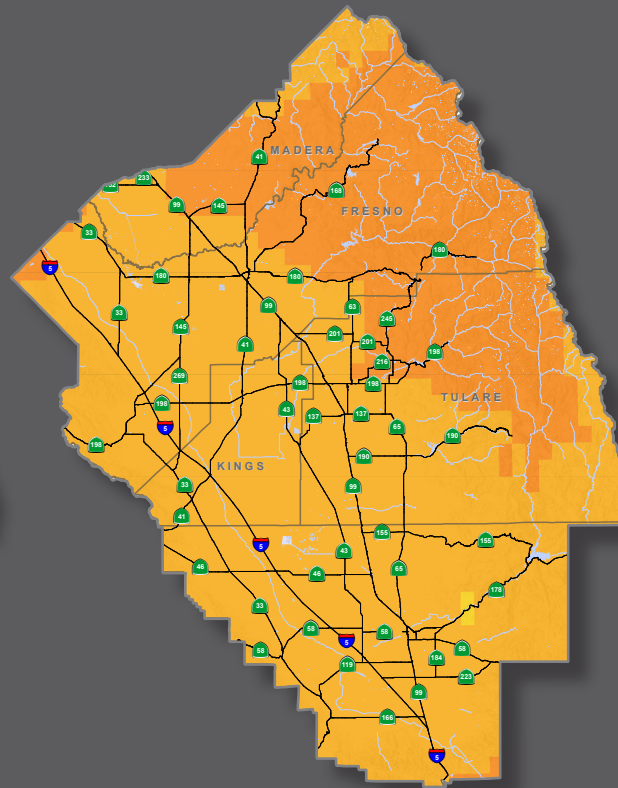
A REQUIRED MEASURE FOR PAVEMENT DESIGN



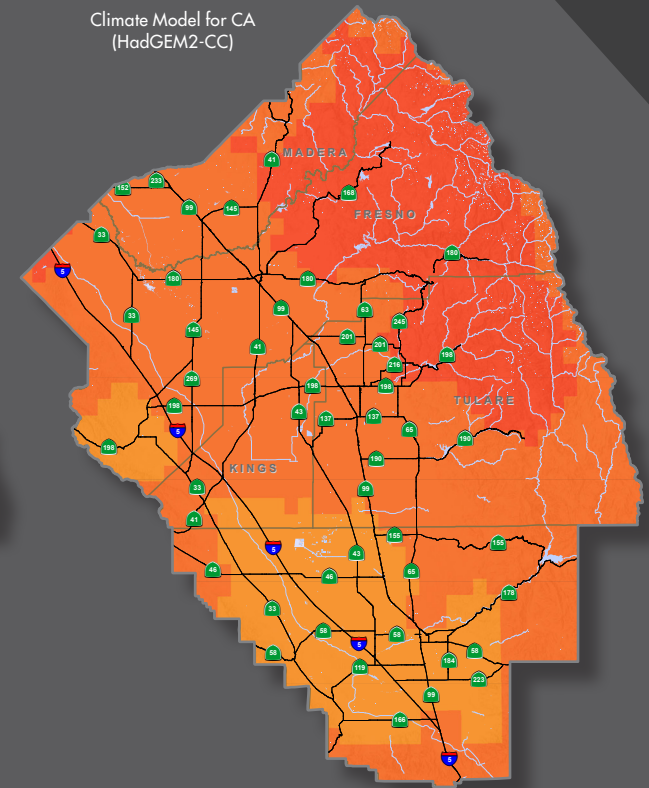
Climate Model for CA
(HadGEM2-CC)



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 6, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 6. 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

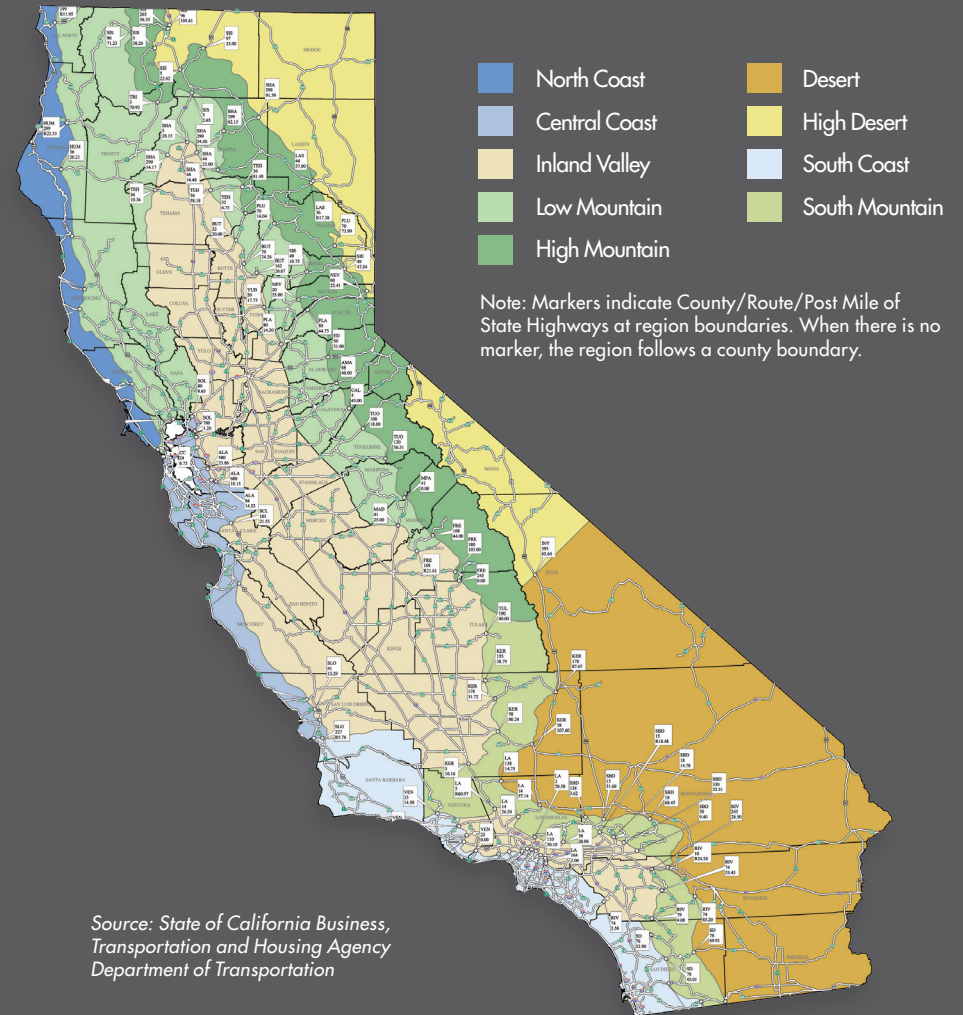
Pavement condition is related to how pavement is designed and is an important component of Caltrans' highway asset management strategy. Ensuring that highway pavements remain durable and maintain good ride quality when exposed to various conditions is an important responsibility of every state transportation 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



POTHOLES FORMING FROM FREEZE & THAW IMPACTS ON PAVEMENT, ILLUSTRATING PAVEMENT QUALITY CONCERNS

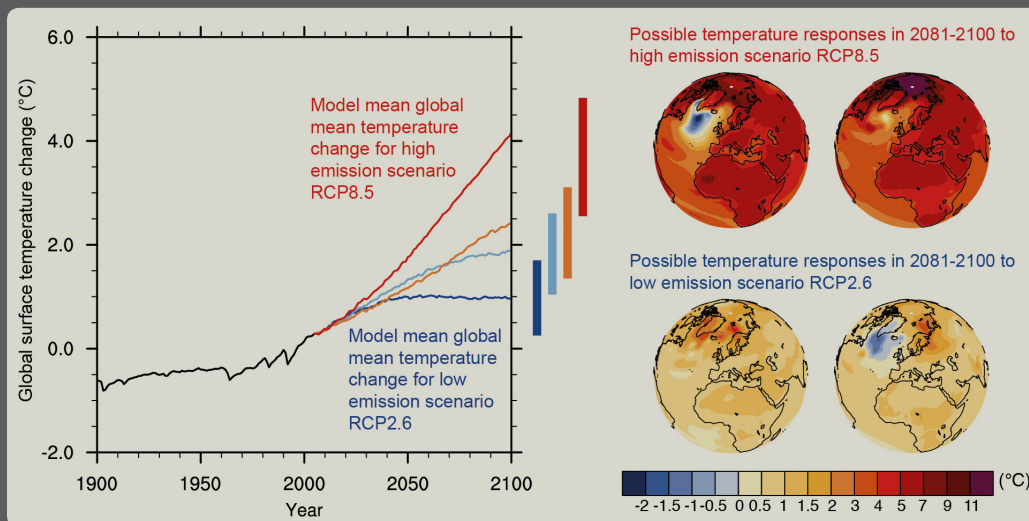
TIMEFRAMES AND ASSET DECISION-MAKING

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 with 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. 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. 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.

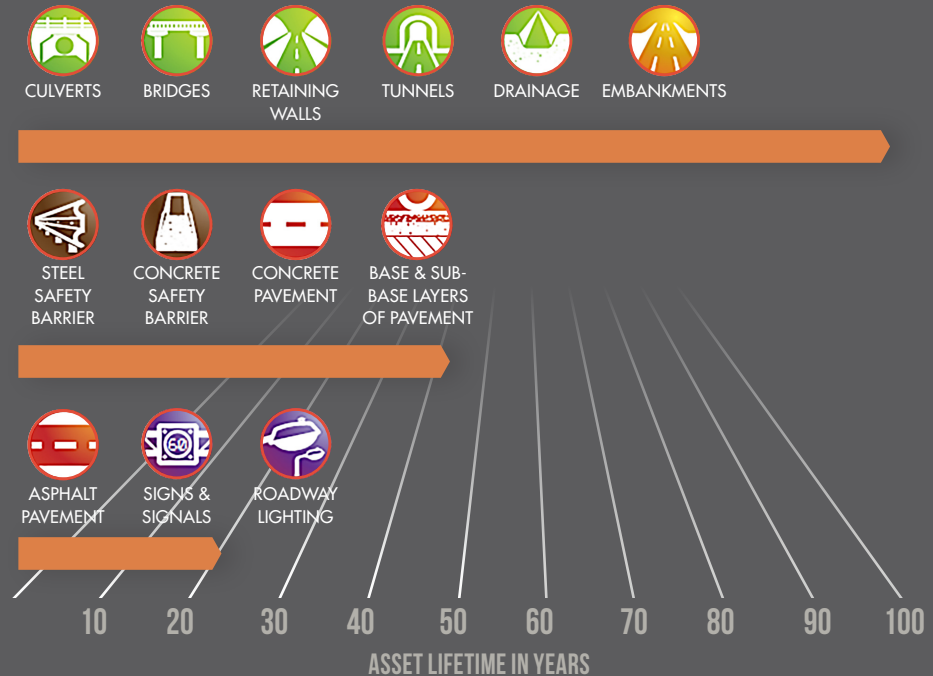
Fig. 4

TRANSPORTATION INFRASTRUCTURE ASSETS

SOME CALTRANS ASSETS, LIKE BRIDGES, HAVE VERY LONG LIFETIMES. THESE ASSETS MAY BE AFFECTED BY A BROAD VARIETY OF FUTURE CONDITIONS, REQUIRING A **LONGER TERM** VIEW IN ASSET DESIGN.

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.





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 overall 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. The figure 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 6 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 6

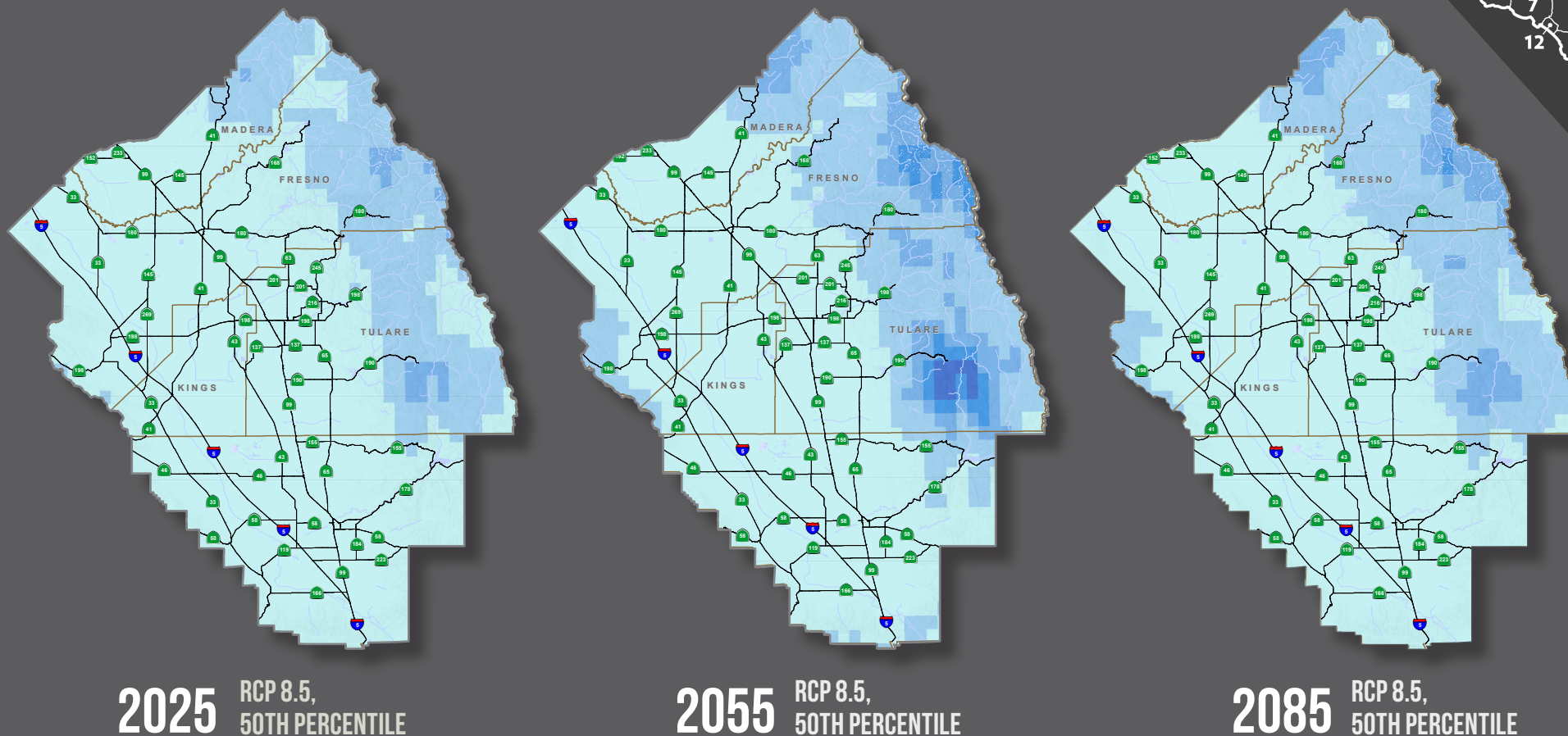
The maps of 100-year storm depth change for District 6 show the midpoint of predicted precipitation increase. The data shows that the more-mountainous regions of District 6 will likely have the greatest change in 100-year precipitation depths. The most significant increase is in Tulare County, where depths are projected to increase by around 15% by mid-century. Increases in precipitation could result in flash flooding, which may submerge, displace, scour, or erode elements of Caltrans infrastructure. To better understand the potential effects and potential adaptation measures, detailed precipitation and flooding analyses of Caltrans infrastructure will be necessary.



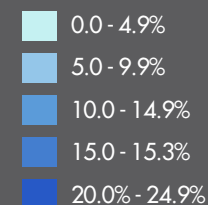
SAN JOAQUIN VALLEY, FRIANT DAM AREA | FLOODING OF FARMLANDS ALONG THE SAN JOAQUIN RIVER
CREATIVE COMMONS LICENSE

Fig. 5

PERCENT CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH



Future Percent Change in 100-year Storm Precipitation Depth within District 6, Based on the RCP 8.5 Emissions Scenario



Caltrans Transportation Asset Vulnerability Study, District 6. 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.

Climate Model for CA
(HadGEM2-CC)



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.

WILDFIRE EFFECTS IN DISTRICT 6

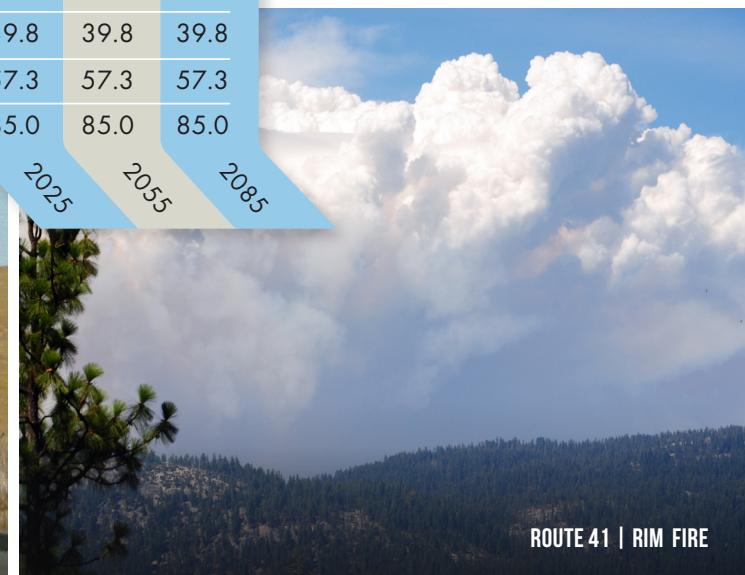
District 6 wildfire risk is projected to be consistent from now until the end of century. The portions of State Routes 41, 168, 108, 180, 198, 190, 155, and 178 which run through forests in the Sierra Nevada Mountains are projected to be the most vulnerable to wildfire risk. These highways are critical for access to foothill communities of the district where there is less redundancy in state routes, unlike in the Central Valley where highways running in parallel are more common. In the event of a major wildfire, these routes would be crucial as evacuation routes and as entry ways for emergency responders. The western portion of the district also shows a projected increase in wildfire concern, though it is moderate as compared to the high and very high increase projected for the Sierra Nevada. The more urban and agricultural regions of the district are less vulnerable to wildfires in the future.

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

County	Miles		
Fresno	172.2	172.2	172.2
Kern	285.2	277.3	285.2
Kings	39.8	39.8	39.8
Madera	57.3	57.3	57.3
Tulare	85.0	85.0	85.0
	2025	2055	2085



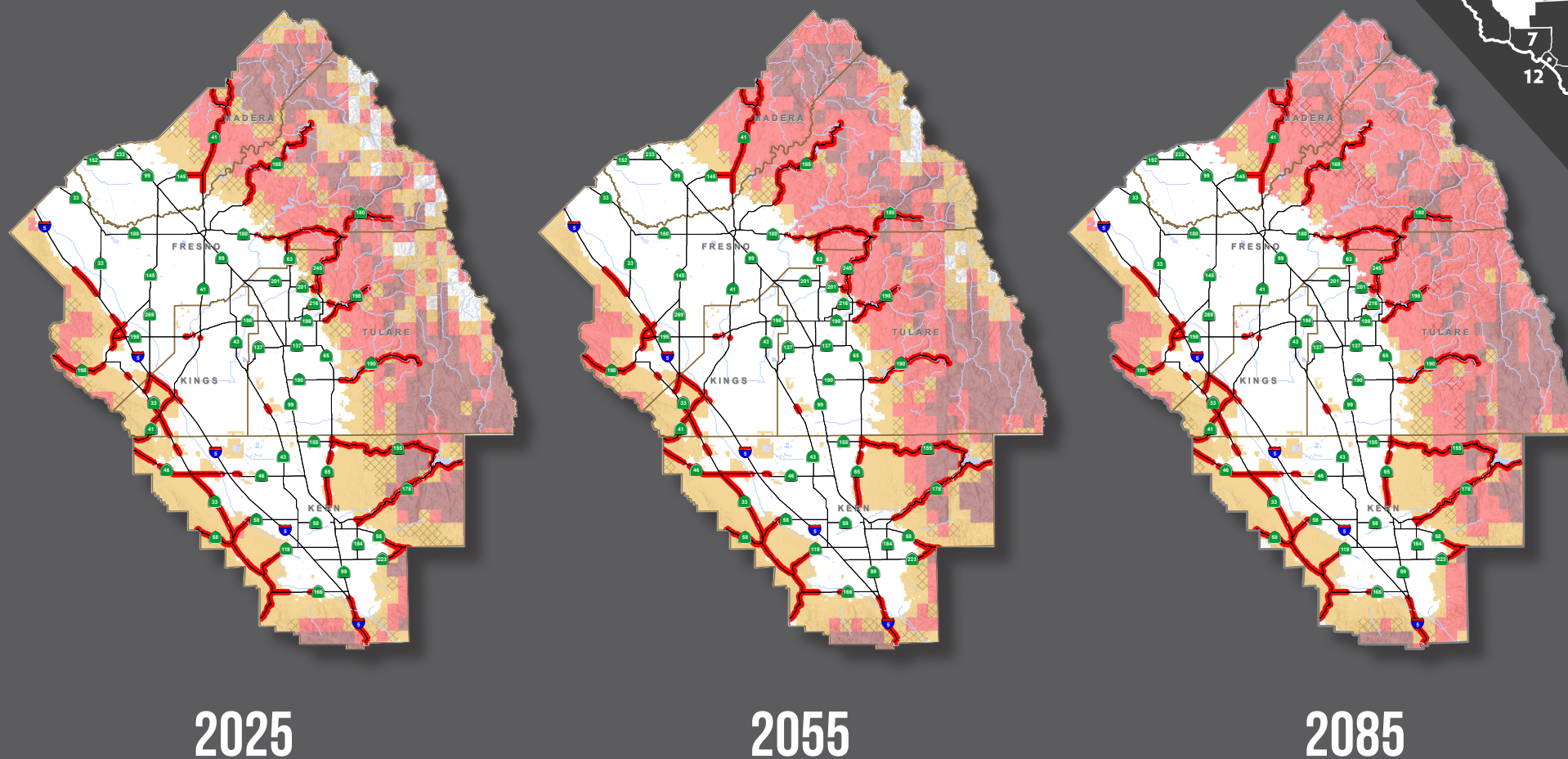
I-5 NEAR FRESNO | WILD FIRE



ROUTE 41 | RIM FIRE

Fig. 6

LEVEL OF WILDFIRE CONCERN



Future Level of Wildfire Concern for the Caltrans State Highway System within District 6, 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 Dominique 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.

Levels of Concern

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

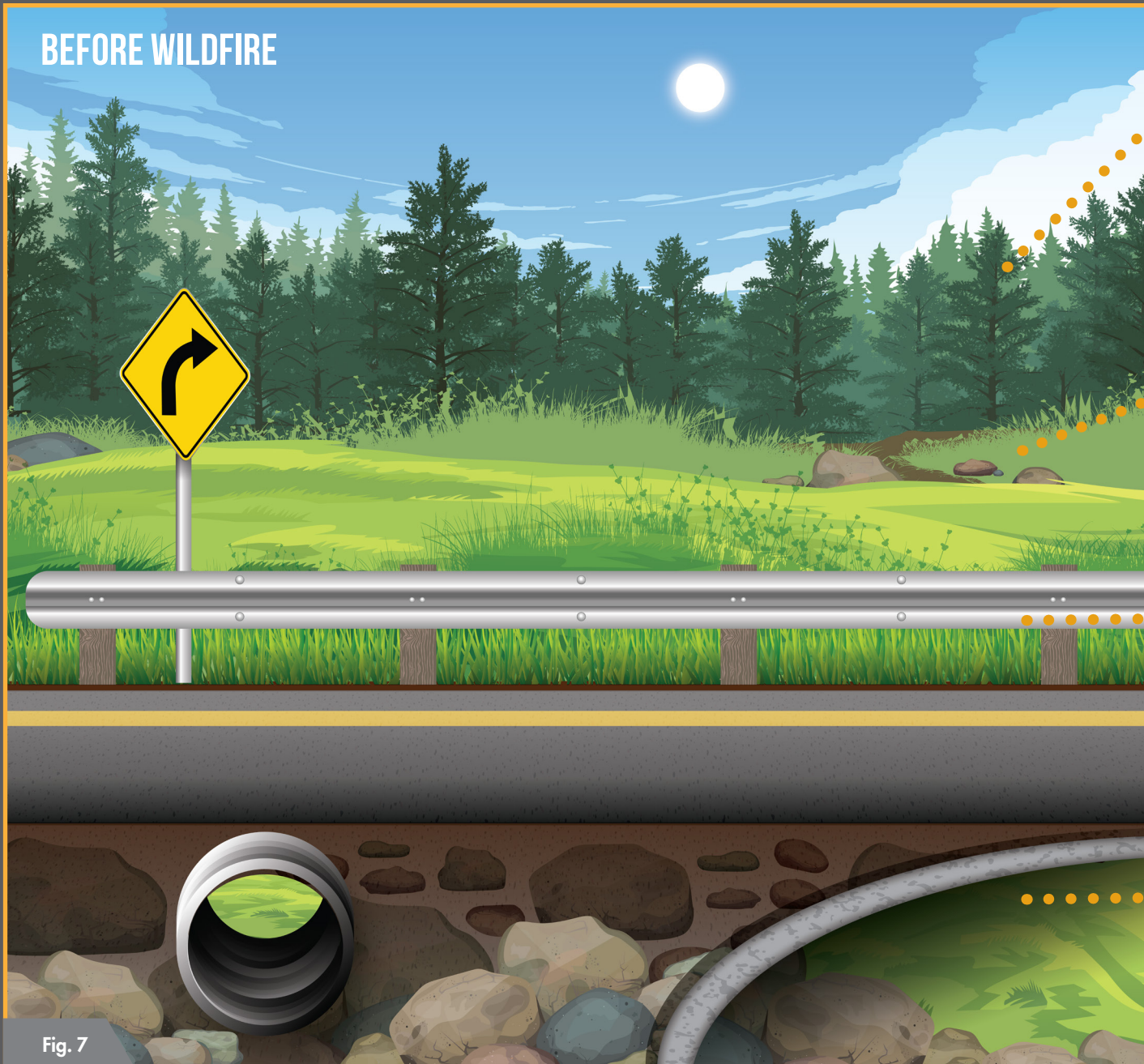


Fig. 7

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

**GROUND COVER 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 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
GROUND COVER RESULTS IN
LOOSER SOILS AND INCREASED
LANDSLIDE POTENTIAL**

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

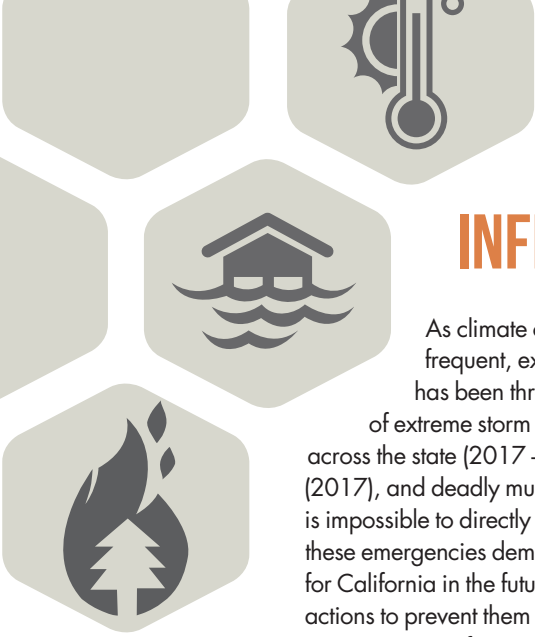
**DESTROYED SIGNS AND
GUARDRAILS REDUCE
DRIVER SAFETY**

**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

As climate changes, California could be affected by more frequent, extreme weather events. In recent years, California has been through a severe drought (2011 – 2017), a series of extreme storm events that caused flash flooding and landslides across the state (2017 – 2018), the worst wildfire season on record (2017), and deadly mudslides in Southern California (2018). While it is impossible to directly link any one of these events to climate change, these emergencies demonstrate what could become more commonplace for California in the future. It is important to learn from these events, take actions to prevent them wherever possible, and increase the resiliency of transportation infrastructure for near- and long-term threats. This section provides an example of a weather-related event at the district level and the district response.

HIGHWAY 41 WASHOUT

To highlight how climate change may impact Caltrans facilities, an event in District 6 was chosen to illustrate impacts from heavy rain events and erosion. Highway 41 is one of three roadways that enter Yosemite Valley, the others being Big Oak Flat Road and Highway 140. At one point following heavy precipitation events in 2017, both Highway 41 and Big Oak Flat were closed at the same time due to storm damage. Highway 41 was closed at Fish Camp near Summerdale Campground

due to a February 9 washout that eroded the southbound shoulder of the highway. Caltrans workers responding to the washout noticed that the northbound lane was sinking and eventually a five-foot hole in the roadway opened. Water had eroded the roadbed under part of Highway 41, so it needed to be excavated and rebuilt. Repairs cost over a million dollars.

Highway 41 passes through rural and forested areas in Madera County on the way to Yosemite Valley, so it is exposed to potential wildfires. Based on the high emissions scenario used in this assessment, large portions of Highway 41 are expected to lie in medium to high wildfire concern areas by 2025. Wildfires along Highway 41 could have a variety of impacts, including loss of forest cover leading to faster water runoff and less infiltration during storm events. Increased flows and looser soils from vegetation loss could lead to increased landslide risk. The washout and erosion of Highway 41 was caused by a reactivated underground spring following heavy rain events. Highway 41 was restored following the event, but future extreme precipitation events could lead to similar impacts in this area. These impacts could be even more severe in periods following a wildfire. The 100-year storm depths are expected to increase in the northern segment of Highway 41 by about 5 to 10%, by 2025.



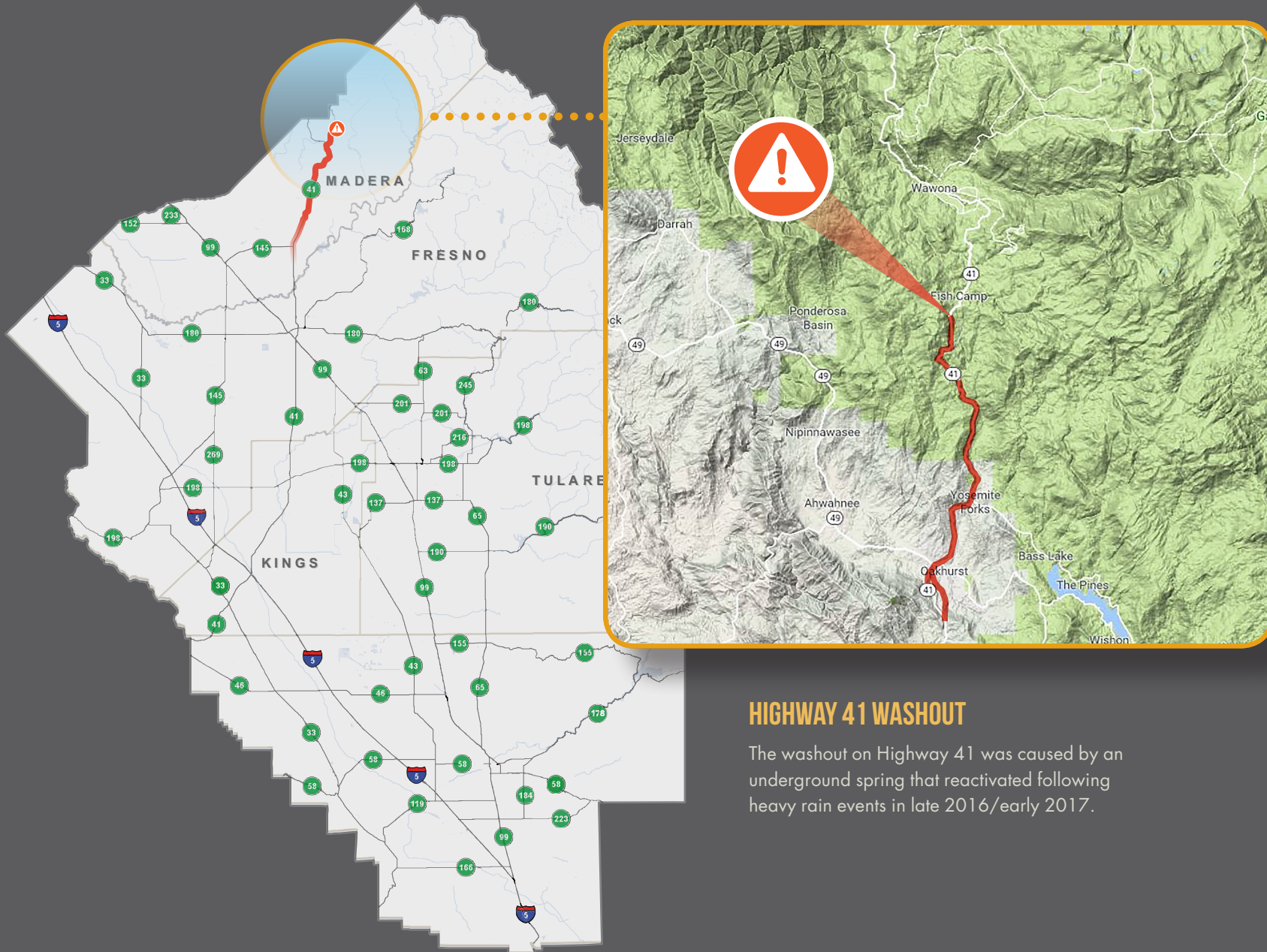
ROUTE 41



FULLY CLOSED IN BOTH DIRECTIONS DUE TO THE COLLAPSING ROADWAY

Fig. 9

HIGHWAY 41 IS HEAVILY TRAFFICKED BY TOURISTS ON THEIR WAY TO YOSEMITE VALLEY.



HIGHWAY 41 WASHOUT

The washout on Highway 41 was caused by an underground spring that reactivated following heavy rain events in late 2016/early 2017.

ADAPTIVE DESIGN, RESPONSE, AND RISK MANAGEMENT

Many areas of District 6 experienced flood damage or extended periods of road closure due to recent heavy rainfall. Maintenance and design responses to similar events in the future should consider the findings in this report: that future extreme precipitation events will likely contain more rainfall and thus increase flood damage potential. Addressing damage by rebuilding to previous designs may not be the most appropriate strategy.

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 what could be included in the assessment of flooding for existing roads in District 6. The same procedures could be used in planning and design of future projects so that climate change is appropriately considered.

DROUGHT-STRICKEN TREE REMOVAL

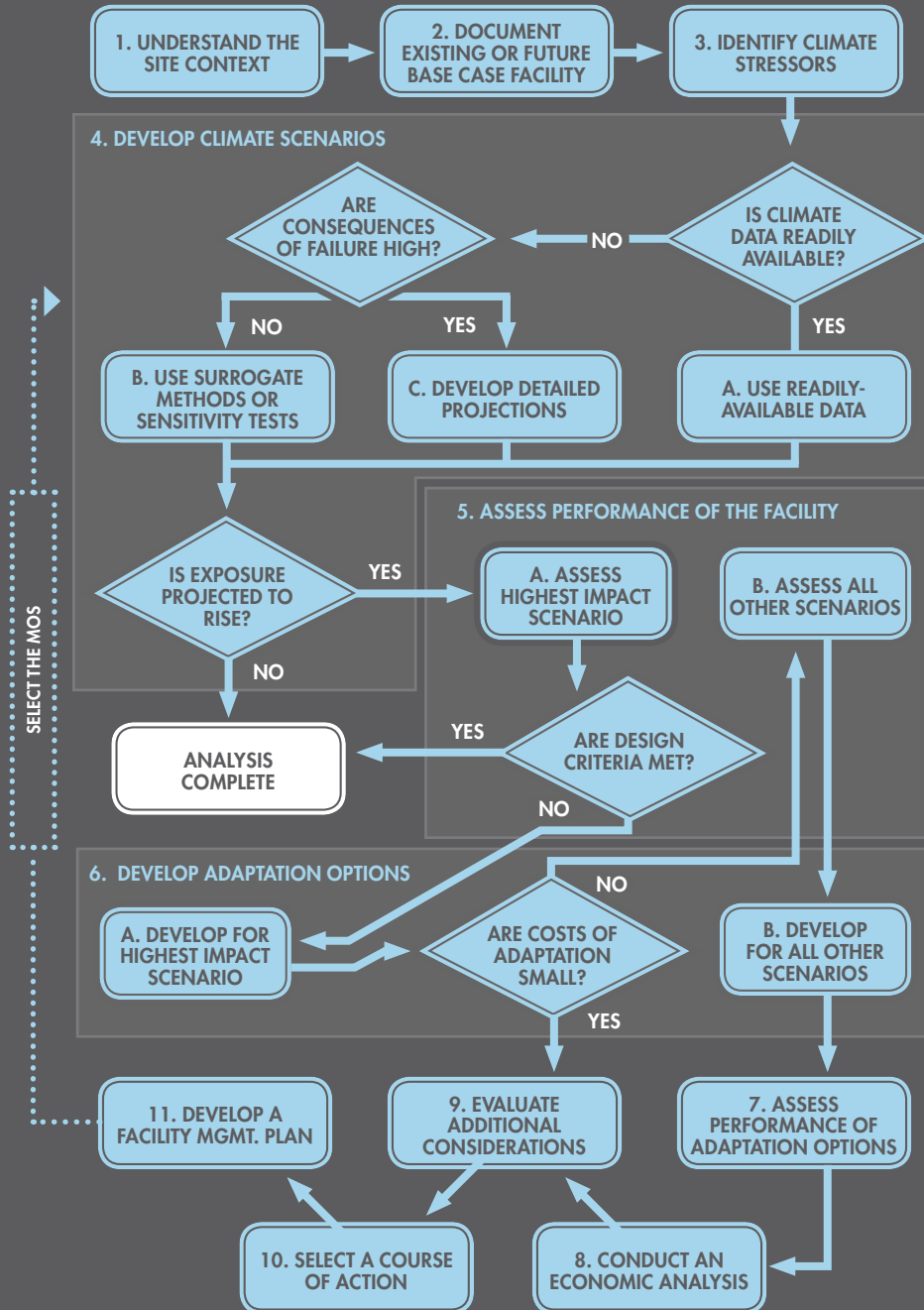
From mid-2016 into 2017, Caltrans District 6 staff began a series of efforts to remove stands of dead trees from District 6 state highway rights-of-way. Millions of trees across the state had died due to multiple years of drought, which extended from 2011 to 2017. The drought weakened the trees, leaving them less resistant to the bark beetle which infected many of the trees and caused additional damage. On October 30th of 2015, Governor Jerry Brown issued a State of Emergency in response to the massive tree die-off. This proclamation also ordered state agencies to remove the stands of dead trees to protect public health and safety. In response to this proclamation, and in recognition of the wildfire risk posed by dead trees, District 6 began issuing emergency bids for tree removal in its counties. In total, the district removed 40,191 trees between 2016 and 2017. These efforts provide an excellent example of preventative measures that can pre-emptively mitigate risk.

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



Fig. 10

FHWA'S ADAP DESIGN PROCESS





WHAT DOES THIS MEAN TO CALTRANS?

GENERAL CONCLUSIONS

The spring 2017 storm events that occurred within and near Caltrans District 6 caused extensive damage to the State Highway System and closed roadways for extended periods. These events provide an opportunity to address many of the points contained throughout this report. Some conclusions that can be reached from the perspective of this report:

1. The repair of District 6 facilities should include the consideration of climate change (page 4 – state policies)
2. Consequence costs should be a determinant in redesign – 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 be 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.

LEADERSHIP
AND POLICY
MAKING

FULLY DEFINE
POTENTIAL RISKS

INTEGRATION INTO
CALTRANS PROGRAM
DELIVERY

A STATE HIGHWAY
SYSTEM RESILIENT
TO CLIMATE CHANGE

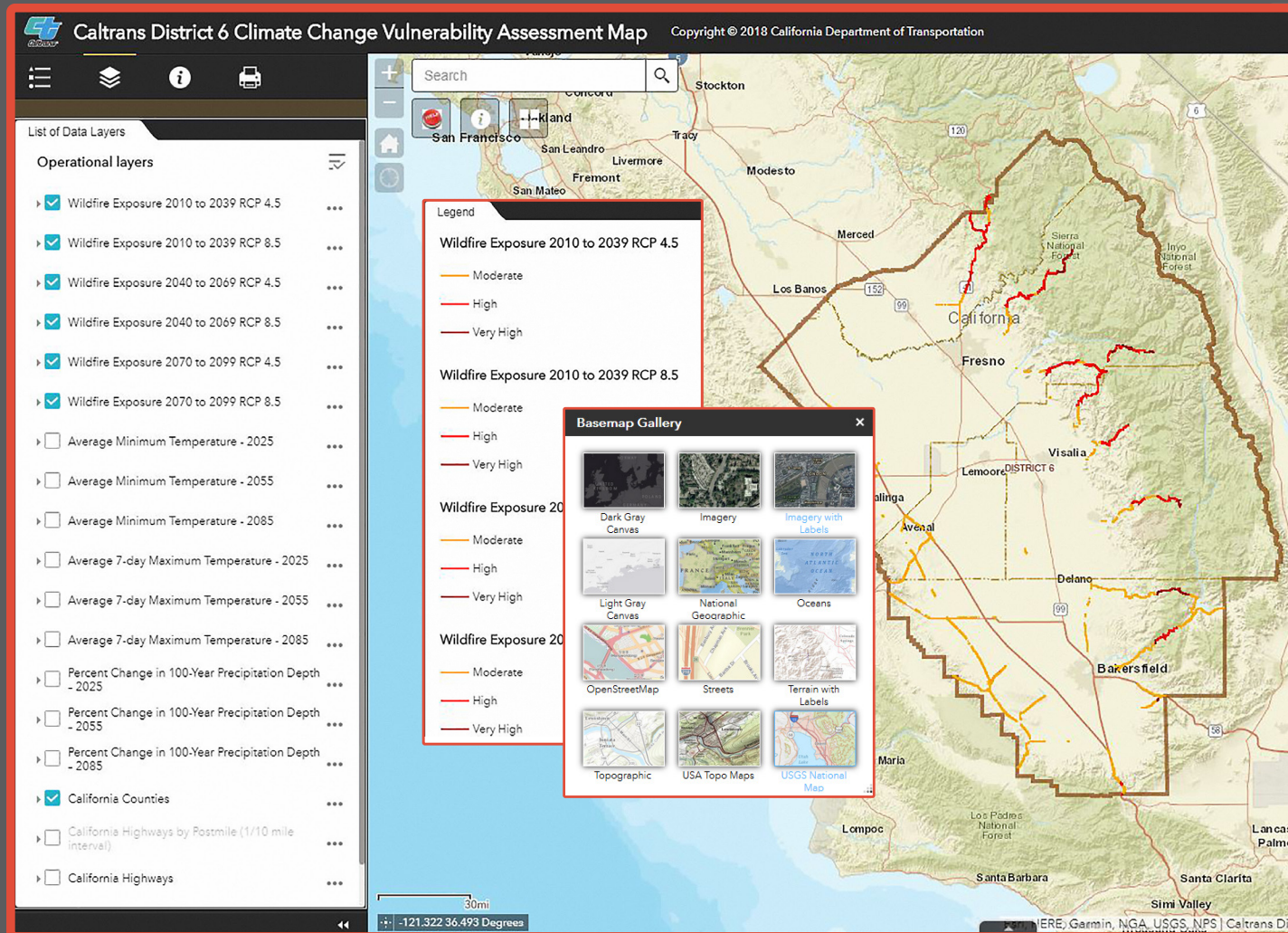
ON-LINE MAPPING TOOL FOR DECISION-MAKING

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.



SR41 Fresno County