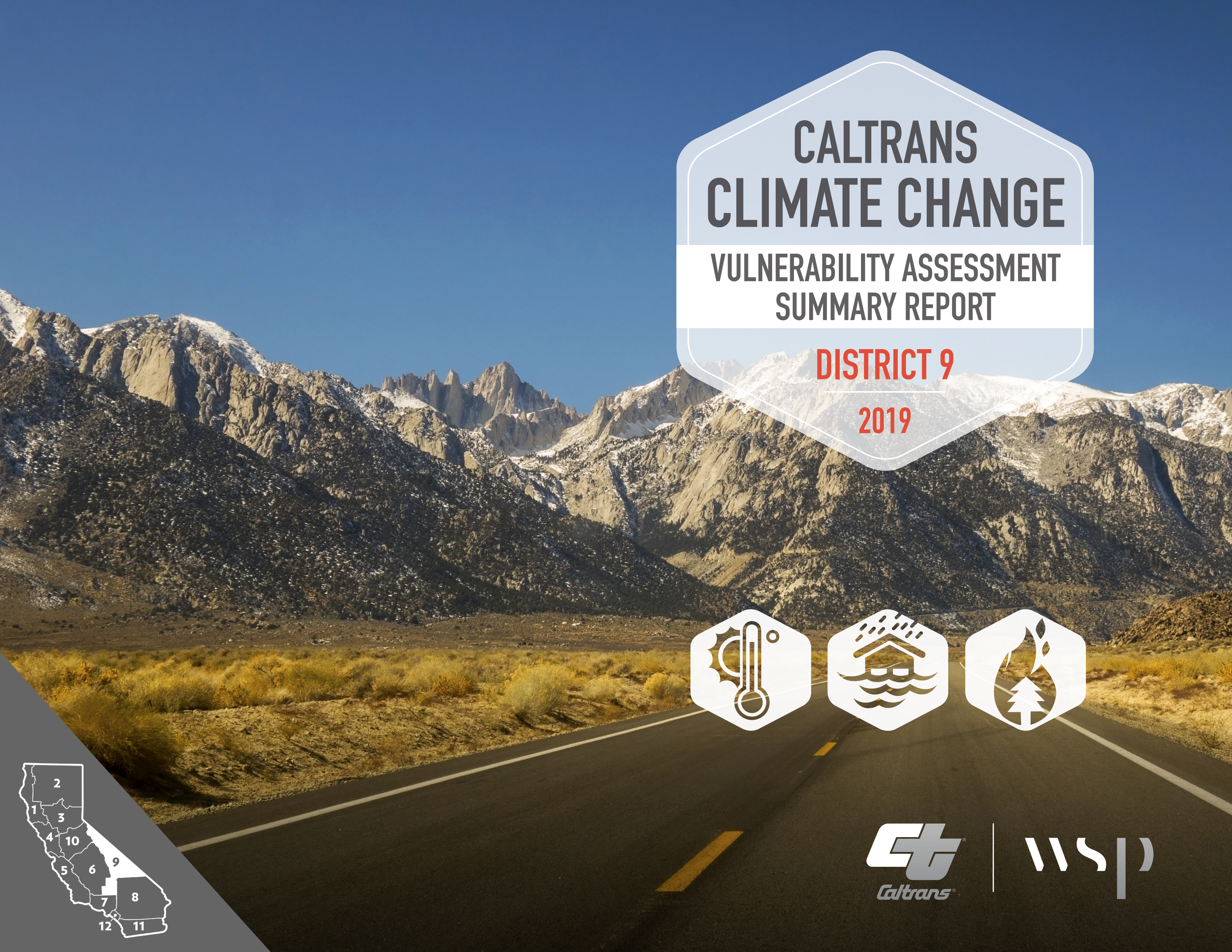

CALTRANS CLIMATE CHANGE

VULNERABILITY ASSESSMENT SUMMARY REPORT

DISTRICT 9

2019

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

This Summary Report and its associated Technical Report outline climate change effects in District 9. This document provides a high-level review of potential climate impacts to the district's portion of the State Highway System (SHS), while the Technical Report presents detail on the technical processes used to identify these impacts. Similar reports are being prepared for each of Caltrans' 12 districts.

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

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

- More severe droughts, faster melting snowpack, and changes in water availability
- Increased temperatures and more frequent, longer heat waves
- Longer and more severe wildfire seasons

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

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

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OVERVIEW OF METHODOLOGY

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

The IPCC represents future emissions conditions through a set of representative concentration pathways (RCPs) that reflect four scenarios for greenhouse gas (GHG) emission concentrations under varying global economic forces and government policies. The four scenarios are RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5. This analysis considered RCP 4.5, which assumes that GHG emissions will peak by mid-century, and RCP 8.5, which assumes a continuation of current emission trends until end of century. This Summary Report presents only results from the RCP 8.5 analysis—the RCP 4.5 analysis is summarized in the associated Technical Report, and the aforementioned geospatial database.

EVACUATION PLANNING

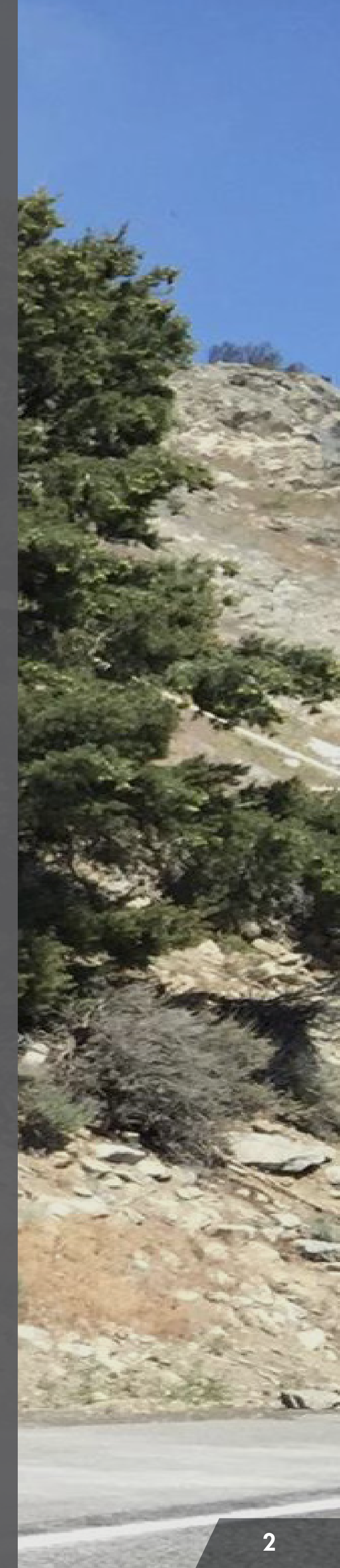
Among the things that Caltrans must consider when planning for climate change is the role of the SHS when disaster strikes. The SHS is the backbone of most county-level evacuation plans and often provides the only high-capacity evacuation routes from rural communities. In addition, state highways also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

BACKGROUND AND APPROACH

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

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

This Summary Report outlines the potential vulnerabilities to the Caltrans' District 9 portion of the SHS. It illustrates the types of climate stressors that may affect how highways are planned, designed, built, operated, and maintained. However, it does not identify projects to be implemented, nor does it present the costs associated with such projects—these will be addressed in future studies. The current study's intent is to add clarity regarding climate change in the District 9 region (which is a subject with many unknowns) and begin to define a subset of assets on the SHS on which to focus future efforts.



THE HIGHWAY SYSTEM IN DISTRICT 9 SUPPORTS LOCAL, RECREATIONAL, AND FREIGHT MOVEMENT, AND COVERS A WIDE RANGE OF GEOGRAPHIES.

DISTRICT 9 CHARACTERISTICS

District 9 borders with Nevada and covers Mono and Inyo counties, as well as the eastern portion of Kern county. The district is primarily rural, and most of its land is under the jurisdiction of governmental agencies and tribal nations. Population estimates range from 50 people in unincorporated rural areas to over 28,000 in incorporated city areas. Due to its proximity to recreational areas, District 9 hosts many tourist-related activities and their associated traffic, which is estimated to be 13 million visitor-days annually.

The district serves 19 US and state numbered highways, and the State Routes (SR) 14 and 58, and US Route (US) 395, are its major transportation corridors. The SR 14 and US 395 corridor is a vital local and regional link, and it has been the focus of many of the district's mobility and access improvement efforts. This corridor also provides a primary route to Southern California and the district's tourist areas. In Kern County, SR 58 is the major east-west corridor, and it links Bakersfield and District 6 with Nevada by connecting to SR 14 and then to US 395.

District 9's climate regions vary widely. It is home to both the highest (Mt. Whitney) and lowest (Death Valley) elevations in the continental United States, and there are mountain ranges on both the eastern and western boundaries. Elevations along the District 9's SHS range from120 feet below to 9,945 above sea level. According to the District 9 System Management Plan, seasonal weather variations subject the district's highways and travelers to subzero temperatures, heavy snowfall, ice, avalanches, high winds, blinding dust, wildfire, excessive summer heat, flash floods, and washouts. Geographical constraints such as cliffs and rivers, and environmental concerns such as sensitive flora and fauna species, are also challenges for planning, designing, building, and maintaining the district's highways.

KEY STATE POLICIES ON CLIMATE CHANGE

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

Executive Order (EO) B-30-15 – requires the consideration of climate change in all state investment decisions through the use of full life cycle cost accounting, the prioritization of adaptation actions which also mitigate GHGs, the consideration of the state's most vulnerable populations, the prioritization of natural infrastructure solutions, and the use of flexible approaches where possible. The Governor's Office of Planning and Research (OPR) have since released guidance for implementing EO B-30-15 titled *Planning and Investing for a Resilient California*. The document provides high level guidance on how state agencies should consider and plan for future conditions. Caltrans supported the development of this guidance by serving on a Technical Advisory Group convened by OPR. [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 – 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.[4] The Working Group has since completed Paying it Forward: *The Path Toward Climate-Safe Infrastructure in California*, which recommends strategies for legislators, engineers, architects, scientists, consultants, and other key stakeholders to develop climate ready, resilient infrastructure for California.[6]

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

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

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

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

EXTREME WEATHER IMPACTS IN DISTRICT 9

Extreme weather events already disrupt and damage District 9 infrastructure. The following examples include a variety of issues and events that Caltrans District 9 has faced in the past, and which may become more prevalent in the future, as climate changes and extreme weather become more frequent.

- **Temperature** – With its high mountainous regions at one extreme and its low desert areas at the other, District 9 experiences a broad range of temperatures. In July 2018, Death Valley experienced the highest average monthly temperature in recorded history with an average day and night temperature of 108 degrees. From July 24 to 27 during that month, the high was 127 degrees—just two degrees shy of Death Valley's all-time high of 134 degrees (2013). Both average and extreme temperatures are expected to rise in mountainous areas, and a higher tree mortality rate due to drought and heat will likely result. Over the longer term, changes in temperature also contribute to unusual snowmelt patterns.

- **Precipitation** – District 9 regularly experiences road closures due to flooding and occasional mudslides. Sudden and extreme rain events can exceed highway culvert capacities and inundate roadways—SR 168E was closed due to heavy flooding in August 2018, as was US 395 in January 2017. In 2015, SR 58 was closed when District 9's largest mudslide in five years covered the road and trapped over 200 vehicles—mud depth varied from 2 to 12 feet along the 3,000-foot road section. The frequency of flooding and mudslides is expected to increase in California, and events like these will likely become more common in District 9.

- **Wildfire** – Wildfire risk is expected to increase as temperatures rise and precipitation patterns become more unpredictable. Recent research has found that the droughts of the last 15 years were more intense than early- to mid-20th-century droughts, had greater temperature and precipitation extremes, and likely contributed to more severe fires and widespread tree mortality. There were many severe wildfires following the 2011 to 2017 drought throughout California.[7] In 2010, approximately 36% (6,720 residents) of Inyo County's total population of over 18,000 lived in fire hazard zones of moderate to very high severity. From 1980 to 1989, 31 wildfires of at least 490 acres in size consumed a total of 97,602 acres in the Southeast Sierra Region, much of which is in District 9.[8]

- **High Wind** – High wind is one of District 9's most pervasive challenges, and due to its geography of high peaks and low valleys, 60 to 75-mile per hour wind gusts are not uncommon. The district must frequently close its roads to avoid threats to vehicles and overturned big rigs. On November 16th 2016, high winds overturned three big rigs—one near Pearsonville on US 395 and two near the US 395 and SR 14 junction. Two more were overturned near Pearsonville on US 395 the next month. When these events occur, the district and local California Highway Patrol must close the most vulnerable stretches of highway (typically US 395 and SR 14). Given these challenges, District 9 is interested in how winds will change due to climate change. Future wind speeds are incorporated into downscaled GCMs applied in California. Wind speeds appear to show small decreases over time in the ten GCMs that most closely simulate California's climate.[9]

CHRIS FIRE | 2017

7 - Joseph Crockett, A.L. Westerling, "Greater Temperature and Precipitation Extremes Intensify Western US Droughts, Wildfire Severity, and Sierra Nevada Tree Mortality," Master's Thesis in Environmental Systems, University of California, Merced, 2017, https://cloudfront.escholarship.org/dist/prd/content/qt3t39d8jq/qt3t39d8jq.pdf?t=osfbdf&v=lg

8 - California Department of Public Health, "Climate Change and Health Profile Report, Inyo County," 2017, https://www.cdph.ca.gov/Programs/OHE/CDPH%20Document%20Library/CHPRs/CHPR027Inyo_County2-23-17.pdf

9 - David Pierce, Julie Kalansky, and Dan Cayan, (Scripps Institution of Oceanography), "Climate, Drought, and Sea Level Rise Scenarios for the Fourth California Climate Assessment," California's Fourth Climate Change Assessment, California Energy Commission, 2018. Publication Number: CNRA-CEC-2018-006, http://www.climateassessment.ca.gov/techreports/docs/20180827-Projections_CCCA4-CEC-2018-006.pdf

SR 168 | ROCK FALL


REDS | 2018


WHITNEY PORTAL ROAD ROCKFALL

VULNERABILITY AND THE STATE HIGHWAY SYSTEM

CALTRANS EFFORTS

By compiling information from a decade of addressing climate change concerns, Caltrans has developed guidance for how to incorporate climate change considerations into project design and other functional Caltrans responsibilities. Activities include:

- The formation of a Climate Change Branch, under the Caltrans Division of Transportation Planning.
- Reporting adaptation goals and progress to OPR through the State Sustainability Roadmaps, Adaptation Chapters.[10]
- The issuance of *Addressing Climate Change Adaptation in Regional Transportation Plans* (2013) which serves as a how-to guide for California Metropolitan Planning Organizations (MPOs) and Regional Transportation Planning Agencies (RTPAs).

Caltrans' continuing efforts include more thoroughly understanding the risks to the state's transportation system and ensuring the resiliency of the transportation system for California residents, businesses, and those using the system for nationwide commerce.

ADDRESSING CONCERNS IN DISTRICT 9

Caltrans District 9's section of the SHS serves critical functions for communities, commerce, and goods movement. Given its importance, understanding the potential impacts of climate change and extreme weather on its performance is key to creating a resilient highway system.

"Vulnerability" often describes the degree to which assets, facilities, and even the entire transportation system, might be subject to disruption from climate change or other stressors. Caltrans' approach focuses on the system's vulnerability to extreme weather and climate-related hazards. It recognizes that many Caltrans units have important roles in supporting the system's resiliency.

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

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

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

ENSURING SYSTEM RESILIENCY

Once system vulnerabilities are identified, Caltrans will consider the best options to enhance system resiliency when choosing projects and project designs. In District 9, this will require implementing projects that help address the expected wildfire, precipitation, and increased temperature effects. Following are some general strategies that District 9 may use:

- Projected changes in heavy rain events are more extreme than other Caltrans districts, with up to a 35% increase in 100-year storm depth projected for part of Mono County in 2055. To mitigate this risk, District 9 may need to factor higher storm magnitudes into bridge and drainage infrastructure design in at-risk areas.
- Wildfire threats will be most prominent in Mono and Kern counties as opposed to the less-vegetated desert regions in Inyo County. District 9 can mitigate wildfire risk by preparing Caltrans facilities with fire-resistant materials, covering building openings with metal mesh, and using Class A fire-rated roofing.
- Temperature changes in already dry and arid environments could affect the health of District 9 maintenance employees. Work schedules may need to be adjusted to help employees avoid high heat and direct sunlight.

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

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

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

THE APPROACH INCLUDES THE FOLLOWING KEY ELEMENTS:

CONDUCT A VULNERABILITY ASSESSMENT OF ALL CALTRANS ASSETS

INCLUDING EXPECTED TIMING OF IMPACTS

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

DETERMINE THE CONSEQUENCE OF IMPACTS ON CALTRANS ASSETS

DAMAGE/LOSS
DURATION

PRIORITIZE ACTIONS

BASED ON TIMING AND CONSEQUENCE OF IMPACTS

CURRENT 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 flooding, storm surge, wildfire, landslides, and more. Key indicators for this measure include the potential timing of expected changes – e.g., what year could you expect these conditions to occur.

CONSEQUENCE

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

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

PRIORITIZATION

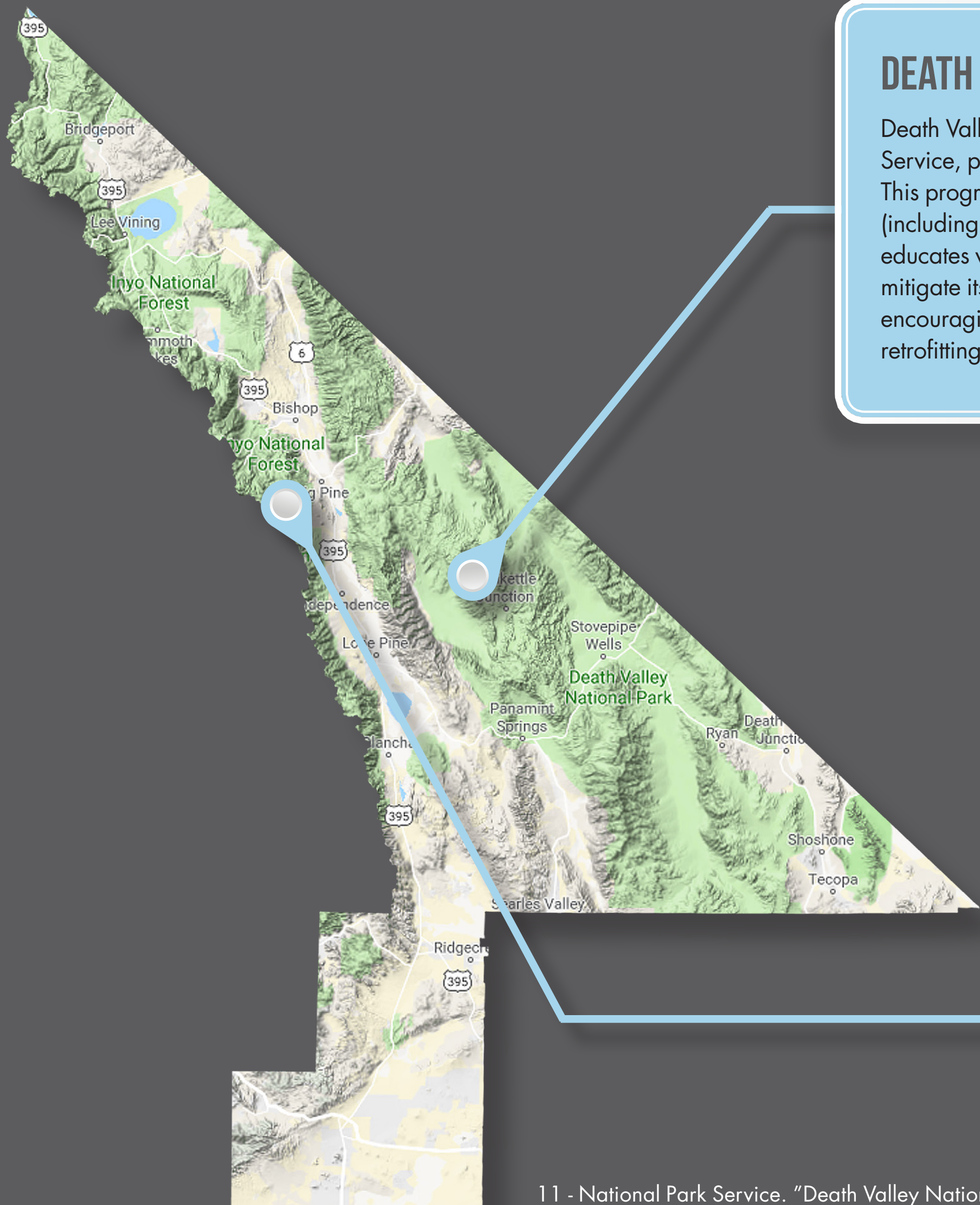
Develop a method to support investment decision-making from multiple options related to future climate risk, with elements including:

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

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

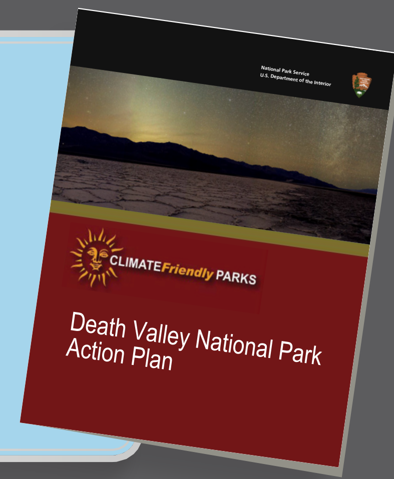
EFFORTS IN DISTRICT 9 TO ADDRESS CLIMATE CHANGE

In addition to Caltrans' completed and ongoing efforts, there are regional efforts related to climate change planning and preparedness underway in District 9. Examples include:



DEATH VALLEY NATIONAL PARK ACTION PLAN[11]

Death Valley National Park, managed by the National Park Service, participates in the Climate Friendly Parks Program. This program promotes sustainable behavior in park operations (including energy, transportation, and waste management), and educates visitors about climate change and ways they can help mitigate its impacts. Some current and planned strategies include encouraging carpooling and the reduction of vehicle idling, and retrofitting park facilities to improve energy efficiency.



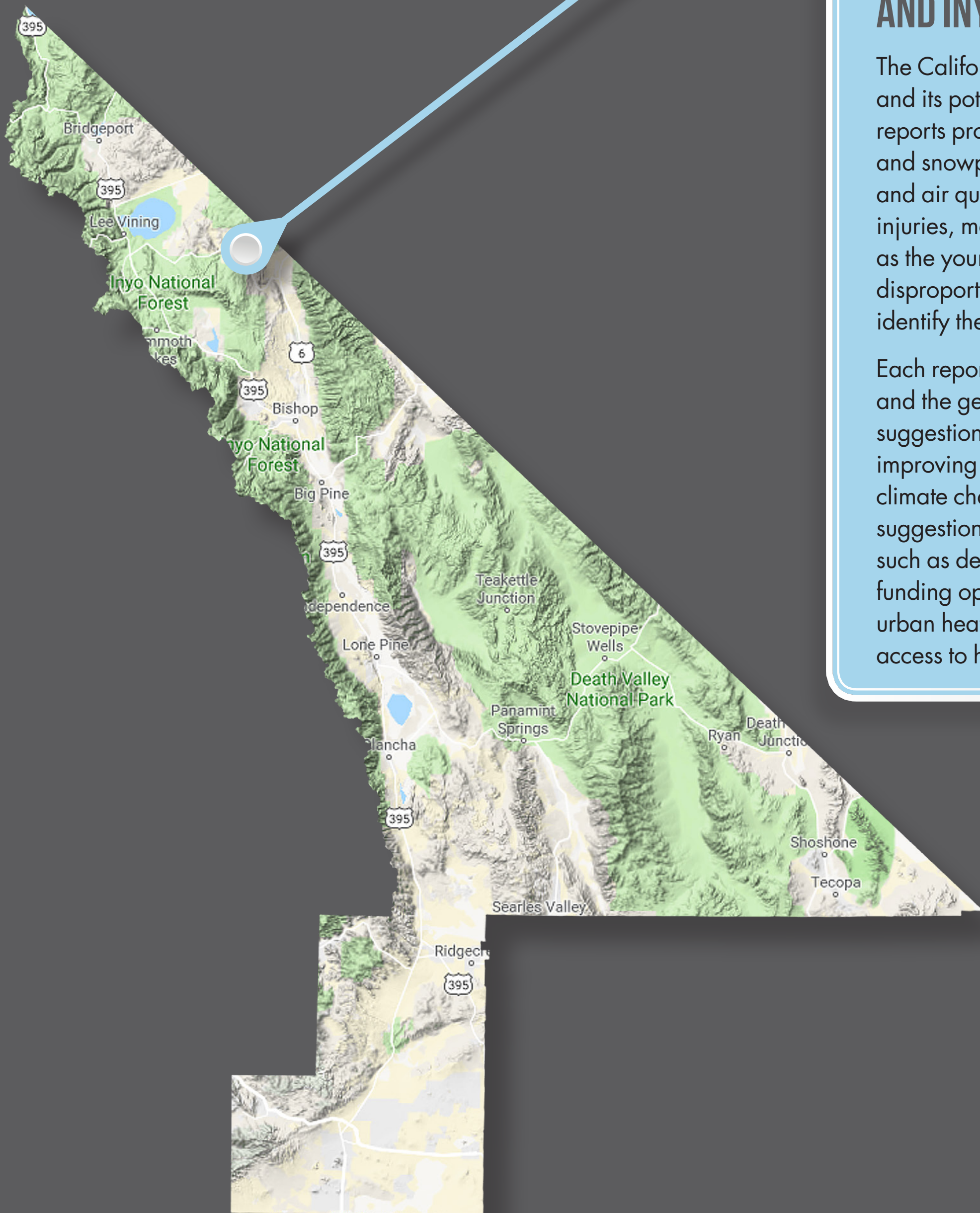
INYO NATIONAL FOREST ASSESSMENT

A UC Davis and US Department of Agriculture Forest Service study examined historical and future climate conditions in the Inyo National Forest,[12] and found that:

- By 2100, the volume of river flow during the highest flow days could more than double in many Sierra Nevada rivers, and the effects of snowmelt will cause greater peak-flow increases in high-elevation river basins.
- Increases in the number of extreme hydrologic events across the western US will be especially pronounced in the California coastal mountain range and the Sierra Nevada. Such events could cause unprecedented debris flow and landslides.
- Large proportions of the Sierra Nevada landscape may see an increase in fire intensity by the end of the century. Future precipitation patterns will determine the actual increase.

11 - National Park Service. "Death Valley National Park Climate Action Plan." https://www.nps.gov/subjects/climatechange/upload/DEVA-CFP-Action-Plan-508compliant.pdf

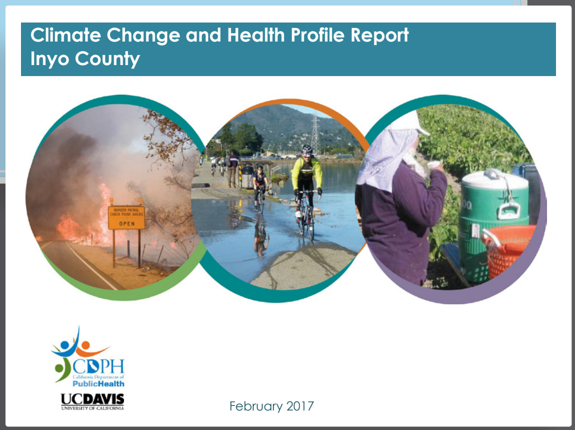
12 - Chris Mallek, Hugh Safford, Sarah Sawyer, "A Summary of Current Trends and Probable Future Trends in Climate and Climate-Driven Processes in the Inyo National Forest and Adjacent Lands," Inyo NF Climate Change Trend Assessment, January 2013, https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprd3820115.pdf



CLIMATE CHANGE AND HEALTH PROFILE REPORTS FOR MONO AND INYO COUNTIES

The California Department of Public Health has produced reports on climate change and its potential future health impacts on Mono and Inyo County residents.[13] Both reports provide climate projections for temperature, heat waves, fire, precipitation, and snowpack, and detail on how these changes could affect public health. Poor water and air quality, extreme weather, and environmental degradation can lead to disease, injuries, malnutrition, and mental health challenges—and vulnerable populations such as the young, elderly, disabled, low income, or those with health conditions may be disproportionately affected. Both county reports provided local population profiles to identify the size of the population groups that are at the greatest risk.

Each report suggested ways that the counties can act to protect vulnerable populations and the general public against the projected climate-related health impacts. Some suggestions can be enacted in the near-term, such as public outreach campaigns, improving heat warning systems, and furthering research on the nexus between climate change and health. Other suggestions are long-term goals, such as developing resiliency funding opportunities, reducing urban heat islands, and promoting access to health care.


Climate Change and Health Profile Report
Inyo County

CDPH
PublicHealth
UCDAVIS

February 2017

13 - California Department of Public Health. 2017. "Climate Change and Health Profile Report, Inyo County." https://www.cdph.ca.gov/Programs/OHE/CDPH%20Document%20Library/CHPRs/CHPR027Inyo_County2-23-17.pdf

PHASES FOR ACHIEVING RESILIENCY

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

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

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

SCOPE OF THIS STUDY

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

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

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

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

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

DEVELOP ACTION PLANS FOR EACH CALTRANS FUNCTIONAL AREA

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

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

INCORPORATE RESILIENCY PRACTICES THROUGHOUT CALTRANS:

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

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

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

PRIORITIZE A SET OF PROJECTS AND ACTIONS FOR ENGINEERING ASSESSMENTS:

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

ADVANCE PROJECTS AND ACTIONS TO APPROPRIATE INVESTMENT PROGRAMS:

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

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

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

TEMPERATURE

The US National Climate Assessment states 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."[14] Due to California's size and its many highly varied climate zones, temperatures will likely rise in varying degrees across the state.

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

DESIGN

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

OPERATIONS AND MAINTENANCE

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

EFFECTS OF TEMPERATURE CHANGE IN DISTRICT 9

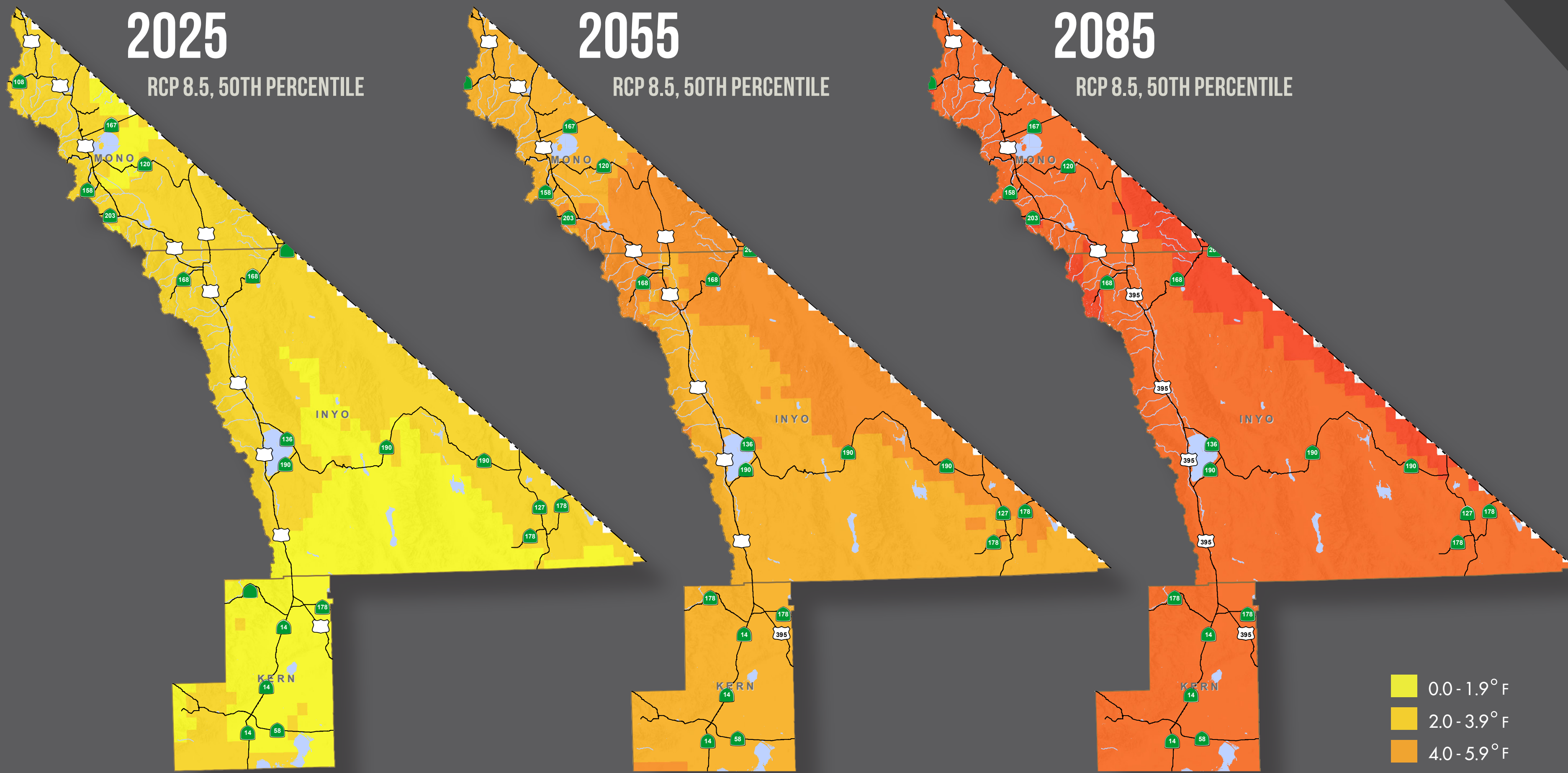
Under the high emission concentration scenario (RCP 8.5), both the maximum and minimum temperature values in District 9 are predicted to increase over time with the maximum temperature changes generally being greater than the changes in minimum temperatures. Some areas may experience a change in the maximum temperature up to between 8 and 12°F by the end of the century. These temperature increases could affect the road materials used by District 9, maintenance schedules, landscaping, and have indirect effects such as increasing wildfire risk.

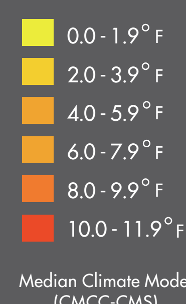
14 - "Extreme Weather," U.S. National Climate Assessment, accessed April 29, 2019, http://nca2014.globalchange.gov/report/our-changing-climate/extreme-weather

Fig.1

CHANGE IN THE AVERAGE MAXIMUM TEMPERATURE OVER SEVEN CONSECUTIVE DAYS

A REQUIRED MEASURE FOR PAVEMENT DESIGN





Future Change in the Average Maximum Temperature over Seven Consecutive Days within District 9, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 9. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown was generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

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

PAVEMENT DESIGN

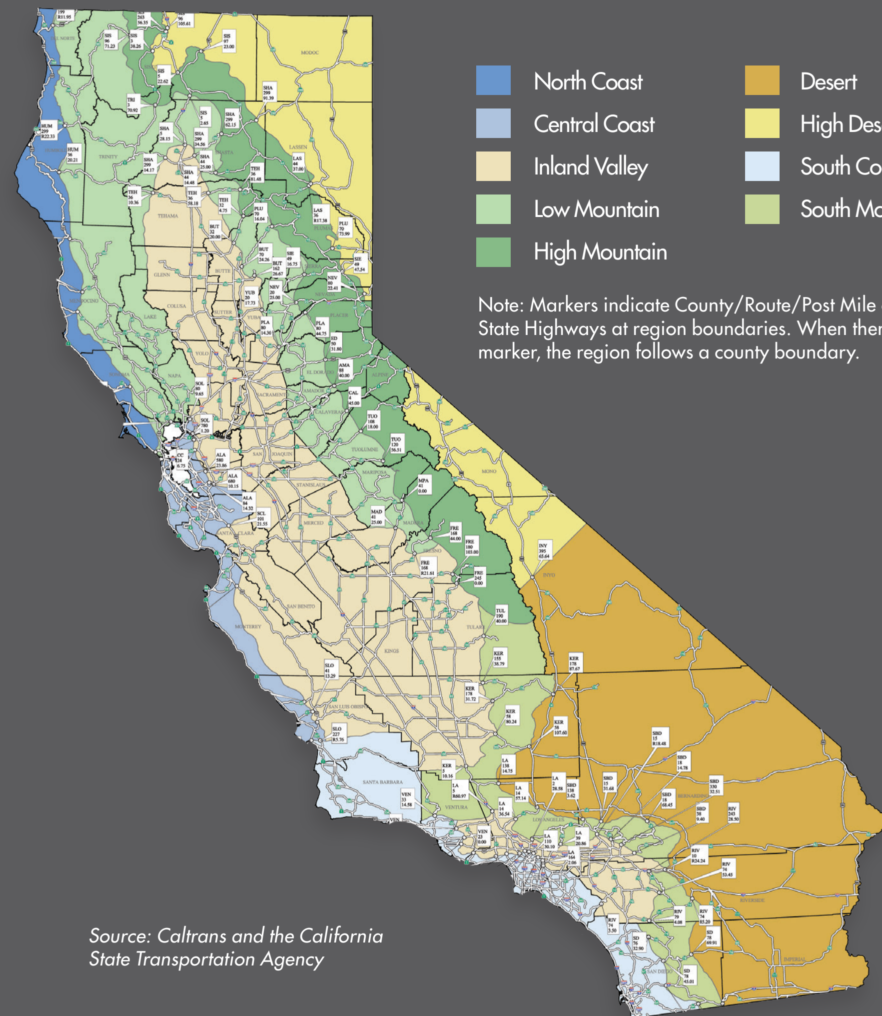
Pavement design affect its durability, and it is an important component of Caltrans' highway asset management strategy. Ensuring that highway pavements maintain durability and good ride quality under varying conditions is an important responsibility of every state transportation agency. Highway pavement can be either concrete or asphalt mix (depending on various factors), and good asphalt pavement design requires selecting the best pavement binder. This decision is based in part on the project area's temperature conditions.

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

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

Fig. 2

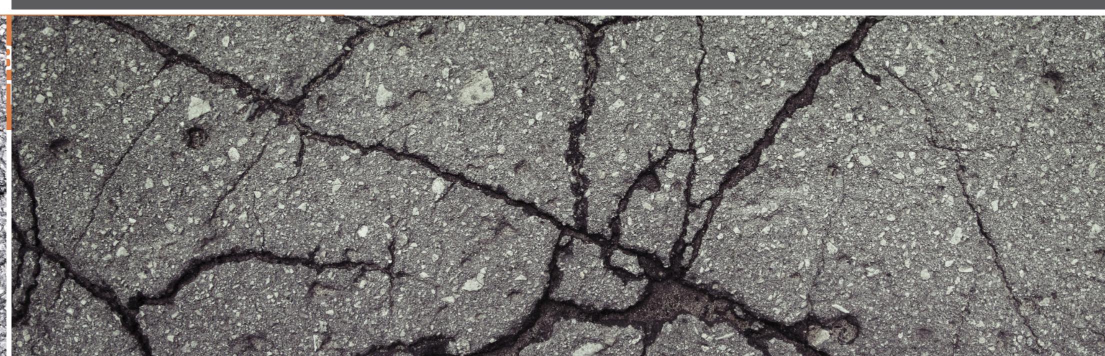
CALTRANS PAVEMENT REGIONS



North Coast
Central Coast
Inland Valley
Low Mountain
High Mountain
Desert
High Desert
South Coast
South Mountain

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

Source: Caltrans and the California State Transportation Agency



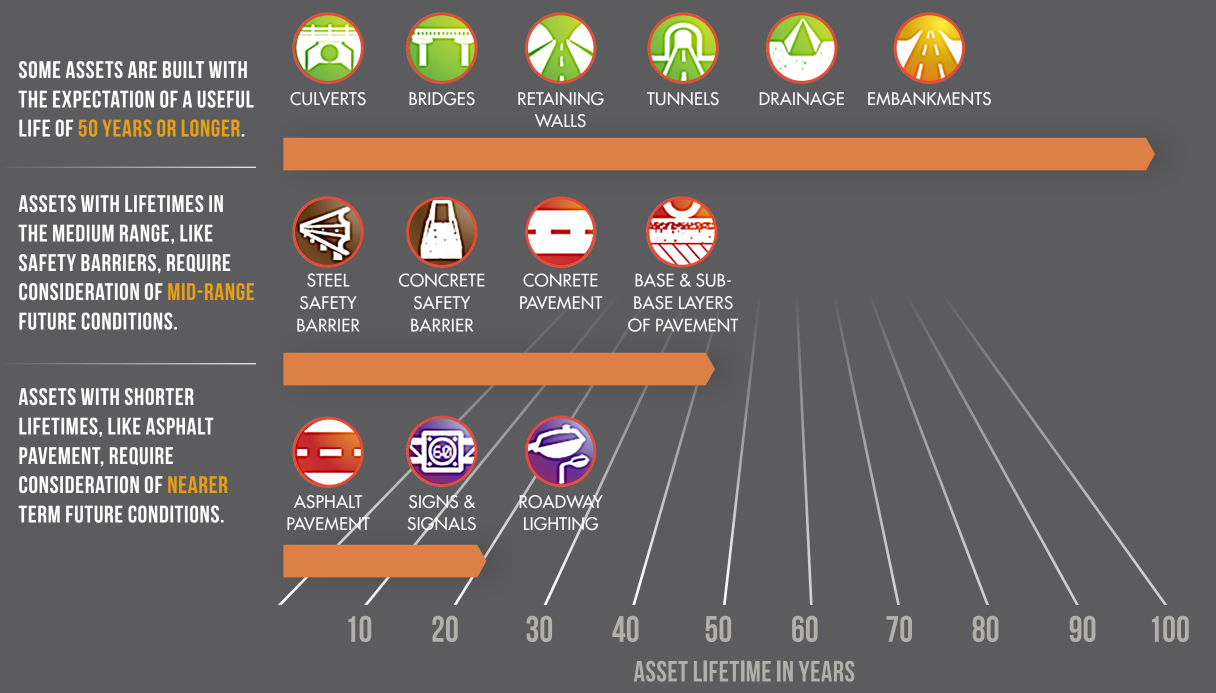
TIMEFRAMES AND ASSET DECISION-MAKING

There are many factors to consider when making transportation asset decisions, including how long the asset will be in place (known as the asset's design life, or useful life). Some assets managed by Caltrans, like asphalt pavement, are replaced around every 20-40 years while others, like bridges, are built expecting a design life of 50 years or longer. A road alignment may be in place for a century or more—just as the first national highway (as it was defined then), built to connect settlers to the Ohio Valley and the west, is still in use today.

The two graphics on this page highlight how design-life considerations are a critical part of transportation investment planning. Figure 3 shows how future temperature scenarios vary widely depending on emission levels and global response. Notice that the conditions are fairly consistent through around 2050, after which they begin to diverge more significantly. This means that decisions made on investments near the end of the century must include a much wider range of future temperature uncertainty.

Fig. 4

TRANSPORTATION INFRASTRUCTURE ASSETS

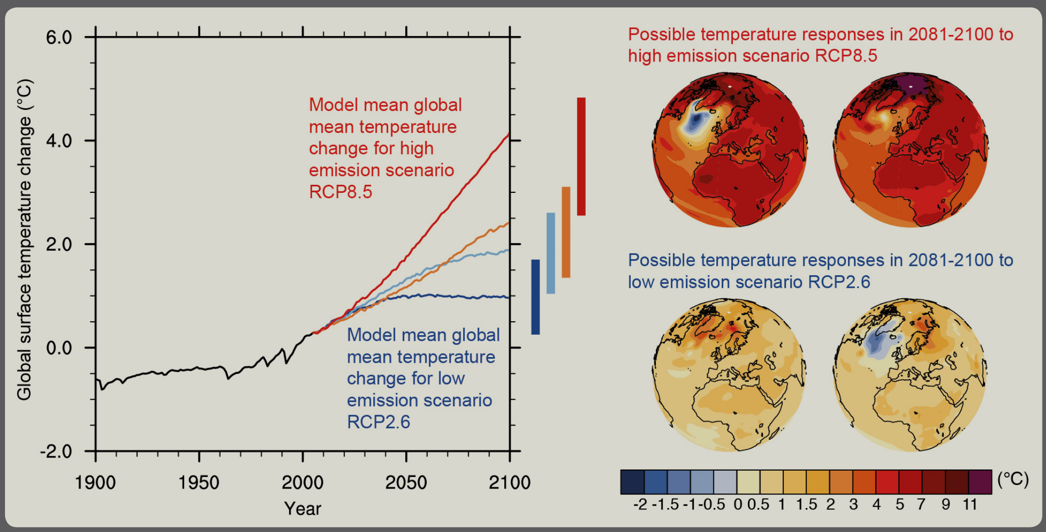


The graphic above shows how assets maintained by Caltrans will require different considerations for planning and design. All decisions should be forward-looking instead of based on historic trends, because all future scenarios show changing conditions. These future conditions must be considered when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

Source: UK Highways Agency

Fig. 3

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



Source: IPCC

PRECIPITATION

The nature of precipitation events in California is expected to change due to the increase in atmospheric moisture and energy caused by increasing temperatures. More intense storms, combined with changes in land cover and land use, can raise the risk of damage or loss from flooding. Precipitation affects California's transportation assets in many ways, including landslides, flooding, washouts, erosion, and structural damage. Larger and more frequent storm events—and their potential for damaging the SHS—are a greater threat to transportation assets than a high volume of rainfall over an extended period.

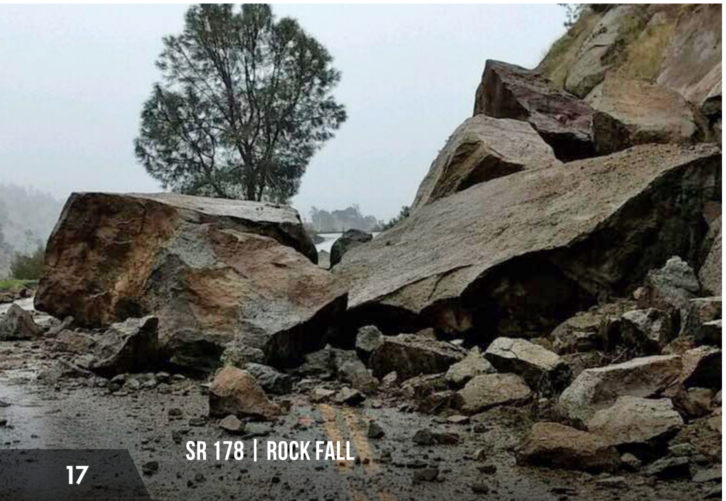
The Scripps Institution of Oceanography at the University of California, San Diego has projected future rainfall data to the year 2100 using two different GHG concentration pathways and several different models. The "100-year storm event" (a storm with a one percent chance of occurring in any given year, or a likelihood of occurring once every 100 years) is one good way to analyze this data. Storms of this magnitude can cause major damage, so they are a good design standard for infrastructure projects. Understanding the potential effects of the 100-year storm, and how they may change in the future, can help Caltrans build infrastructure that is more resilient to heavier storm events. See the figure on the following page for the percentage increase in the 100-year storm depth across District 9.

PRECIPITATION CHANGE IN DISTRICT 9

The 100-year storm precipitation depth is projected to increase by anywhere from 0-34.9% in District 9, depending on the timeframe and location. The mountainous areas show higher likely precipitation increases, which could increase flash flood frequency. The district can use several mitigation strategies to reduce flooding and landslide risk, including changing drainage design requirements, adding vegetation to reduce runoff, and building barriers to protect roadways from land or rock slides.

Potential increased precipitation in District 9 means that Caltrans should assume higher rainfall and flooding levels in project design for high-risk areas, and plan SHS improvements accordingly. The likely impacts can be exacerbated by increased commercial and residential development, which reduces the natural absorption capacity of the land in drainage areas.

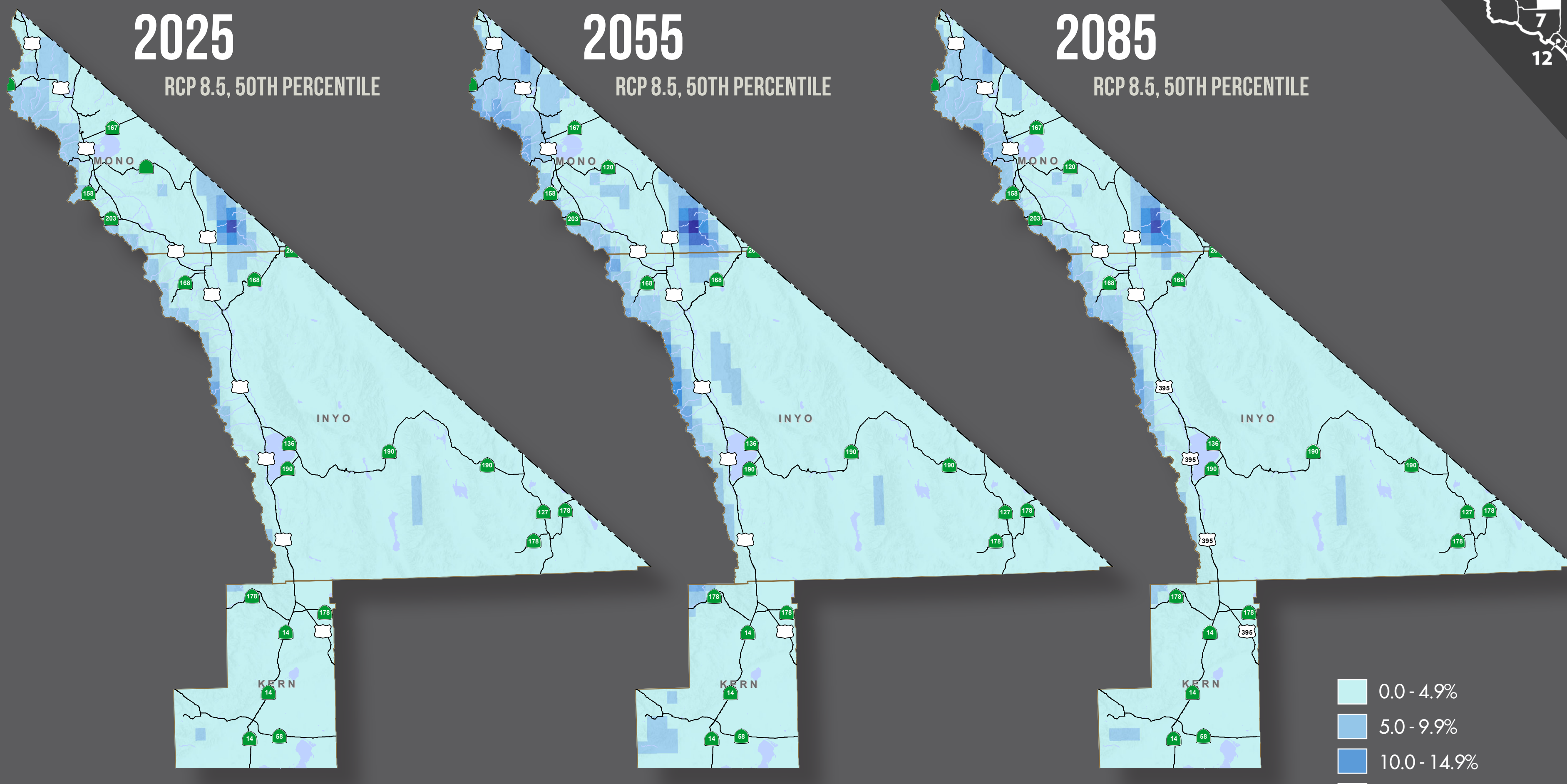
Complex topographic and environmental conditions at project sites will require a longer-term view of flood response in facility design to ensure that facilities remain operational to the end of their design lives. Improving long-term highway system resiliency will require that Caltrans conduct a comprehensive assessment of future conditions and incorporate new precipitation data in design when warranted.


SR 178 | ROCK FALL


WALKER US 395 | MUD SLIDE

Fig. 5

PERCENT CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH



0.0 - 4.9%
5.0 - 9.9%
10.0 - 14.9%
15.0 - 19.9%
20.0% - 24.9%
25.0% - 29.9%
30.0% - 34.9%

Median Climate Model (HadGEM2-CC)

Future Percent Change in 100-year Storm Precipitation Depth within District 9, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 9. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown was generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

Results represent the 50th percentile of downscaled climate model outputs under RCP 8.5 for the metric shown, as calculated across the state using the area weighted mean. There are several methodological challenges with using downscaled global climate model projections to derive estimations of future extreme precipitation events, addressable through vetted and available methods. Results should be compared across multiple models to conduct a robust assessment of how changing precipitation conditions may impact the highway system, and to make informed decisions.

WILDFIRE

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

The areas shaded in red in Figure 6 highlight increased wildfire likelihood based on projected percentages of area burned over time. 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 generated the data for these projections. Each model was paired with three downscaled GCMs to produce nine future scenarios. Starting with three different wildfire models was a conservative approach because final data shows the highest wildfire risk categorization of all model results. The results for RCP 8.5, the high GHG concentration scenario, are provided in Figure 6 and Table 1. See the associated Technical Report for results processed for RCP 4.5.

WILDFIRE EFFECTS IN DISTRICT 9

The more-densely forested areas in the district's northern portion have the highest wildfire risk, with the greatest risk being in Mono County's Inyo National Forest and areas surrounding Mt. Patterson. District 9 can mitigate wildfire risk in these areas by using fire-resistant materials in construction, maintaining defensible space for district assets, and using fire-safe landscaping along roadways. The district can also limit wildfire concern by actively removing dead or diseased trees, thinning vegetation, and working in tandem with partner agencies such as CalFire and the US Forest Service.

Table 1: Centerline Miles of Highways in Medium to Very High Wildfire Exposure Areas for the RCP 8.5 Scenario

County	Year		
	2025	2055	2085
Inyo	**9**	**26**	**34**
Kern	**63**	**60**	**63**
Mono	**224**	**246**	**253**

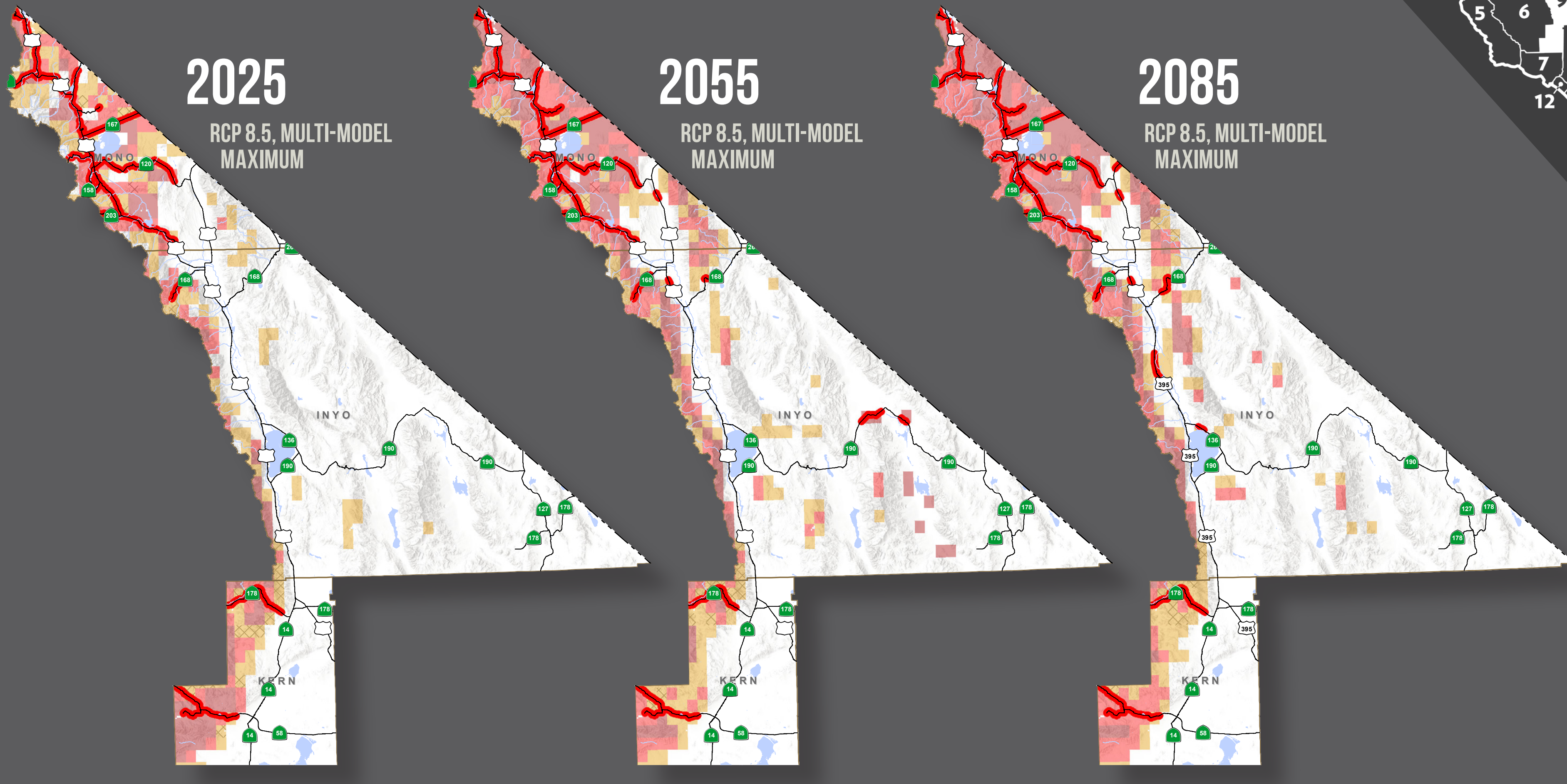
Note: Kern mileage only represents a portion of the county.

SLINKARD FIRE

PLEASANT VALLEY FIRE

Fig. 6

LEVEL OF WILDFIRE CONCERN



Future Level of Wildfire Concern for the Caltrans SHS within District 9, Based on the RCP 8.5 Emissions Scenario

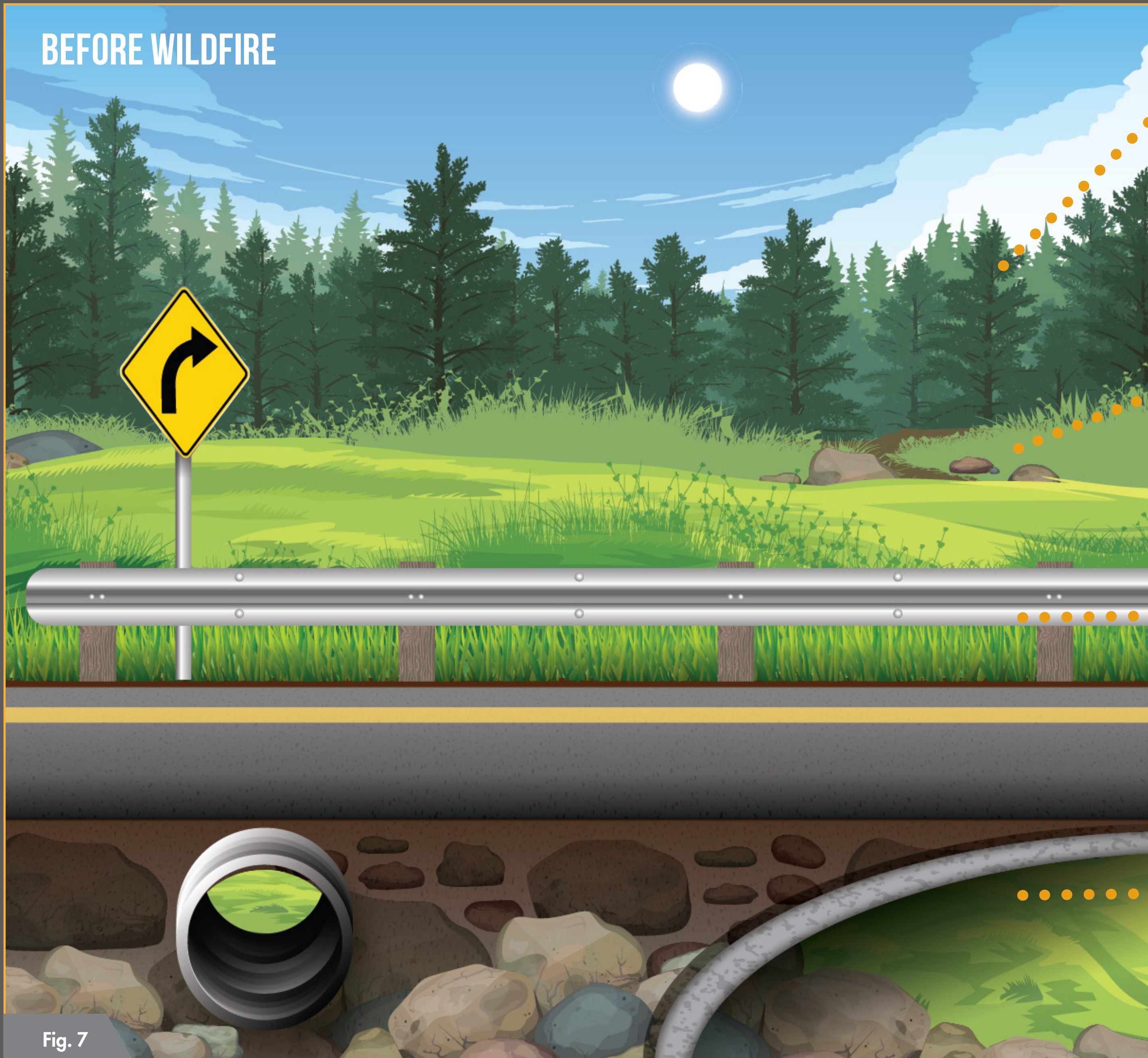
The fire model composite summaries shown are based on wildfire projections from three models: (1) MC2 - EPA Climate Impacts Risk Assessment, developed by John Kim, USFS; (2) MC2 - Applied Climate Science Lab at the University of Idaho, developed by Dominque Bachelet, University of Idaho; and (3) University 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.

Areas in white do not necessarily mean there is no wildfire risk, only that the risk classification is below medium. More information on models used and the classifications for levels of concern can be found in the associated Technical Report.

Levels of Concern

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



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 PROVIDE WILDLIFE CROSSINGS

Fig. 7

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

LOSS OF FOREST COVER RESULTS IN MORE EROSION OF SOILS

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

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

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

DESTROYED SIGNS AND GUARDRAILS REDUCE DRIVER SAFETY

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

Fig. 8

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

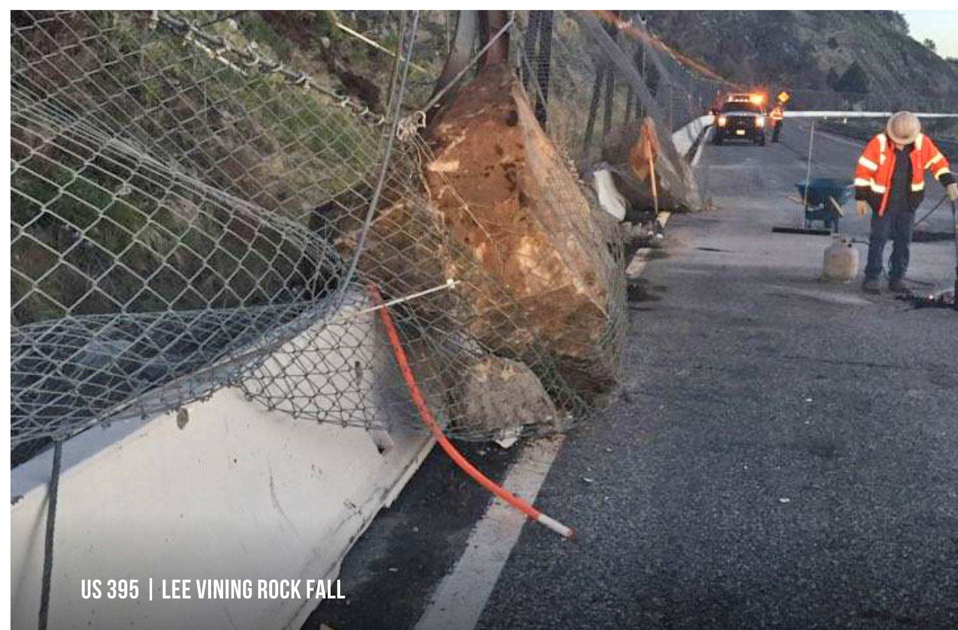
INFRASTRUCTURE IMPACT EXAMPLE

As the climate changes, California could be affected by more frequent, extreme weather events. In recent years, California has experienced a severe drought (2011 – 2017), a series of extreme storm events that caused flash flooding and landslides across the state (2017 – 2018), the most destructive and deadly wildfire season on record (2018), and deadly mudslides in Southern California (2018). These emergencies demonstrate what could become more commonplace throughout California as droughts, storms, and wildfires become more frequent and severe. It is important to learn from these events, take all possible actions to prevent them, and increase the near- and long-term resiliency of transportation infrastructure. Below is an example of a district-level weather-related event and the district's response.

LEE VINING – US 395 ROCK FALL PROTECTION

US 395 is a major transportation corridor connecting the Eastern Sierra, Southern California, and Western Nevada. The corridor is a major north-south route that enables the efficient movement of goods, services, and travelers. It is a vital component of the Eastern Sierra region's economy. US 395 has a history of rock falls on both the shoulders and highway travel lanes north of Lee Vining. The Marina Fire left severe burn scars that furthered the rock fall vulnerability of this area. District 9 maintenance personnel had to remove fallen rocks throughout the year, but most frequently during the rainy season and periods of high snowmelt. Boulders of up to 3,000 pounds have fallen in this area, and there are anecdotal staff reports of vehicles colliding with fallen rocks despite frequent rock removal efforts.

In 2013, District 9 began the Lee Vining Rock Fall Project, which included rock scaling on six slopes to remove unstable boulders, debris, and dead or dying trees. See Figure 6 for these locations on US 395. Portions of the slopes were groomed and shaped for erosion mitigation, seeding, and the installation of steel netting. While this project was underway, the Marina Fire started northwest of Lee Vining and burned approximately 650 acres adjacent to the project area. To mitigate the subsequent erosion and erosion risks, District 9 implemented the Marina Fire Emergency Restoration Project to install k-rail (also known as Jersey Barriers), repair and replace guardrail, and construct several rockfall barriers. To prevent excessive debris flow, District 9 constructed channels and detention basins and installed pipe risers and debris guards at all culverts within project boundaries. These actions have reduced both debris flow in the area and the number of boulders affecting the highway.



US 395 | LEE VINING ROCK FALL

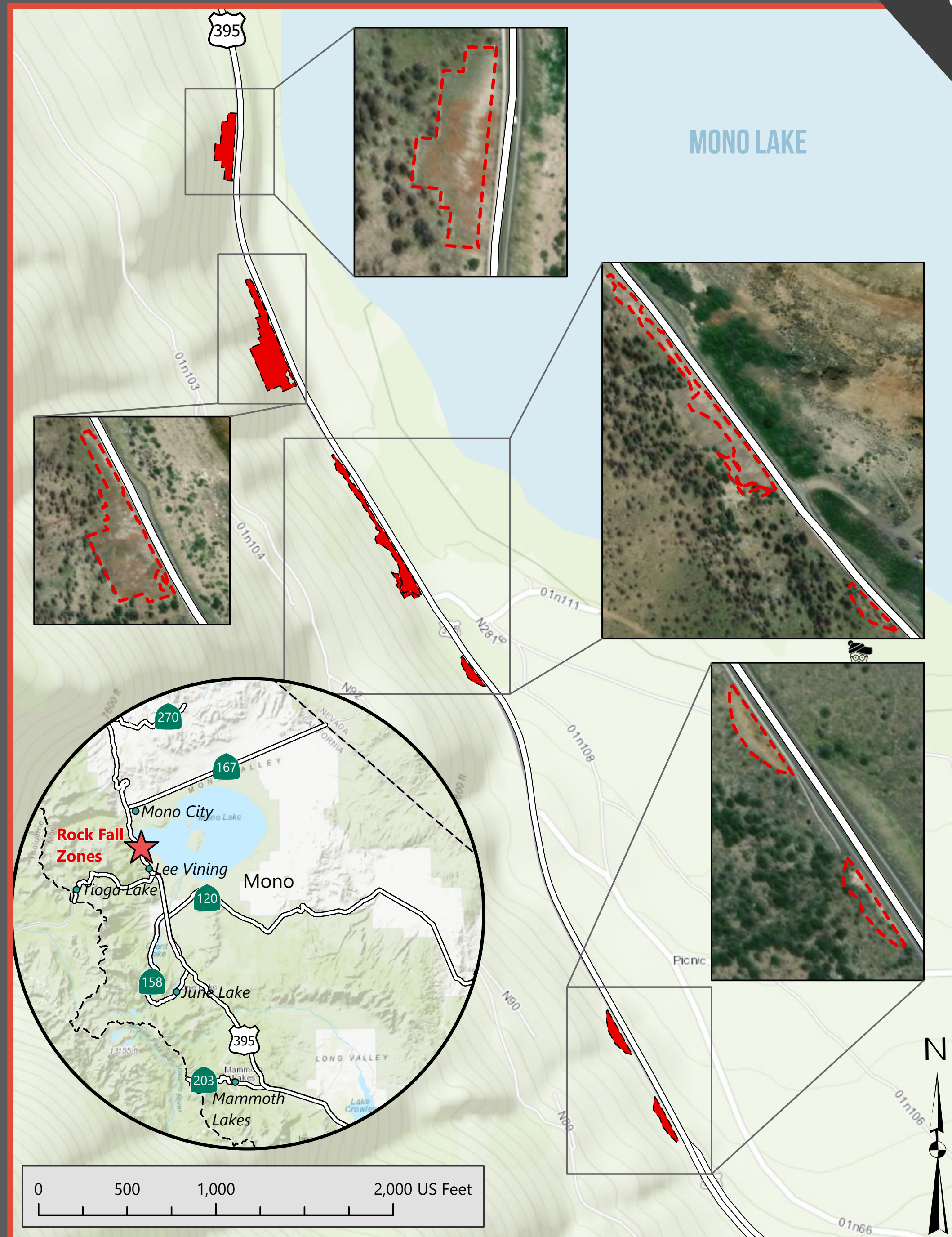
Fig. 9

LEE VINING ROCKFALL PROJECT - MITIGATION SITES


US 395 | BURNED-OFF HILLSIDE NEAR MONO LAKE


US 395 | LANDSLIDE FENCING

US 395 | VMS FOR FALLING ROCK



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)[15] 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 9 for existing and future roadways. The following section highlights a district effort that demonstrates adaptive design, emergency response, and risk management. These efforts are examples of how Caltrans districts can prepare for, and respond to, future climate change and extreme weather events.

SR 190 FLASH FLOOD PROTECTION

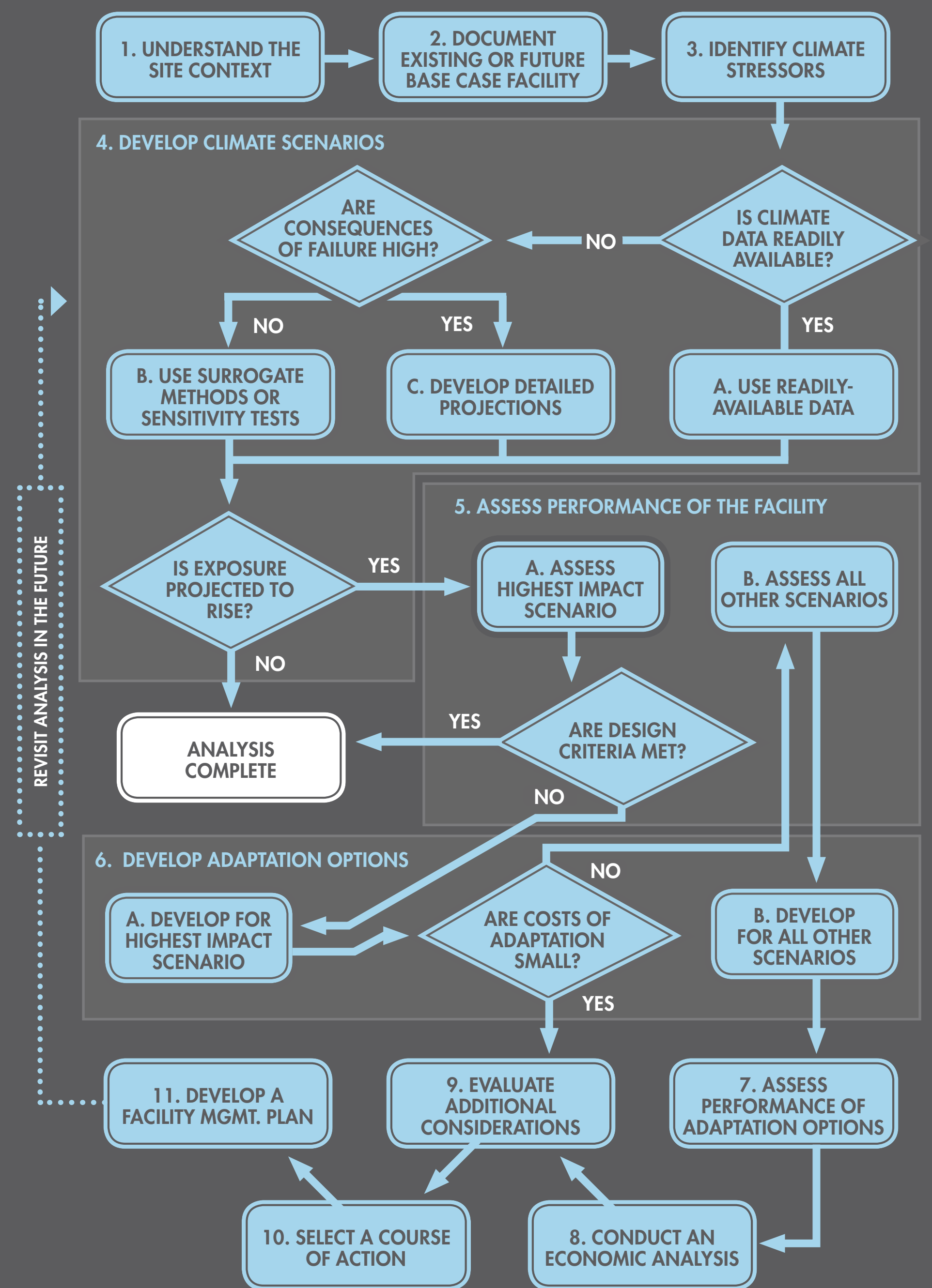
Located in one of the most remote parts of California, SR 190 is the gateway to Death Valley National Park for visitors from all over the world. SR 190 is classified as an interregional, two-lane minor arterial, and elevations vary from 5,200 feet near Darwin Road to 245 feet below sea level in Death Valley. The area's combination of unusual topography, dry landscape, and monsoonal rains can produce annual flash flooding. In October 2015, a major flash flood severely damaged SR 190, utilities, and historic buildings at Scotty's Castle in the park. Flash floods such as this often affect highways and create multiple hazards for travelers. To mitigate flash flood impacts on SR 190, District 9 improved culverts to increase their flash flood capacity. In other areas, District 9 has constructed new culverts, channeled water flows in sediment basins, installed drains and catchment basins, and captured debris flow in an effort that also assisted national park staff in restoring water and habitats. The projected changes in the district's precipitation profile will likely make such projects more common in the future.

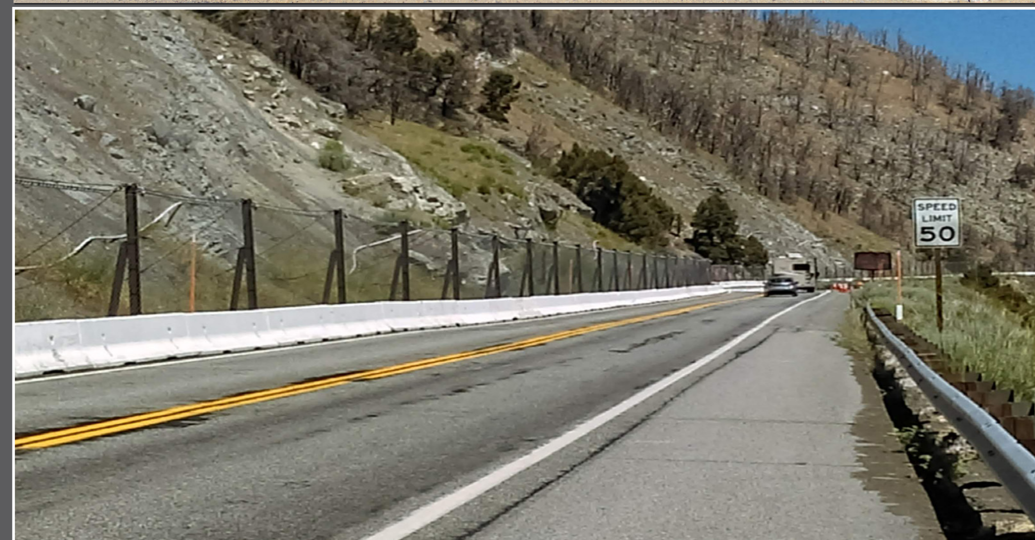
15 - Adaptation Decision-Making Assessment Process," FHWA, last modified January 12, 2018, https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/teacr/adap/index.cfm

SR 190 | DEATH VALLEY | FLOODING

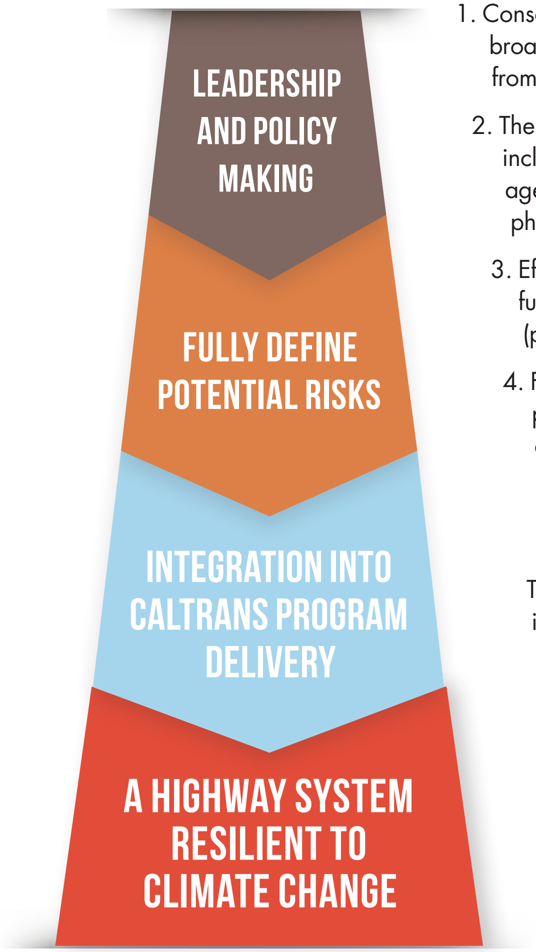
Fig. 10

FHWA'S ADAP DESIGN PROCESS





WHAT DOES THIS MEAN TO CALTRANS?



GENERAL CONCLUSIONS

Recent extreme weather events in District 9 offer an opportunity to address many of the potential climate change impacts described in this report. Caltrans can draw these conclusions:

1. Consequence costs should factor into redesign to assess broader economic measures and the potential cost savings from adaptation (page 8 – vulnerability approach)
2. The development of updated design approaches, which includes best available climate data from state resource agencies, should be a part of event response (page 11 – phases for achieving resiliency)
3. Efforts to build or repair District 9 facilities should consider future conditions as opposed to historical conditions (page 4 – state policies)
4. FHWA's ADAP process should be applied when planning or designing assets and facilities. This will help account for uncertainties in climate data and provide a benefit-cost assessment methodology that considers long-term costs to guide decisions (page 25 – Adaptive Design, Response, and Risk Management)

The SHS is at risk from many climate stressors, as outlined in this report. Effective risk management will require a response that prioritizes the system's most vulnerable and critical assets. Addressing these climate concerns will also require:

FULLY DEFINING RISKS

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

INTEGRATION INTO CALTRANS PROGRAM DELIVERY

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

LEADERSHIP

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

COMMUNICATION AND COLLABORATION

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

A STATE HIGHWAY SYSTEM RESILIENT TO CLIMATE CHANGE

The systematic and comprehensive consideration of climate change (using this report as a guide for the first steps) will lead to a SHS that is more resilient to extreme events and climate change.

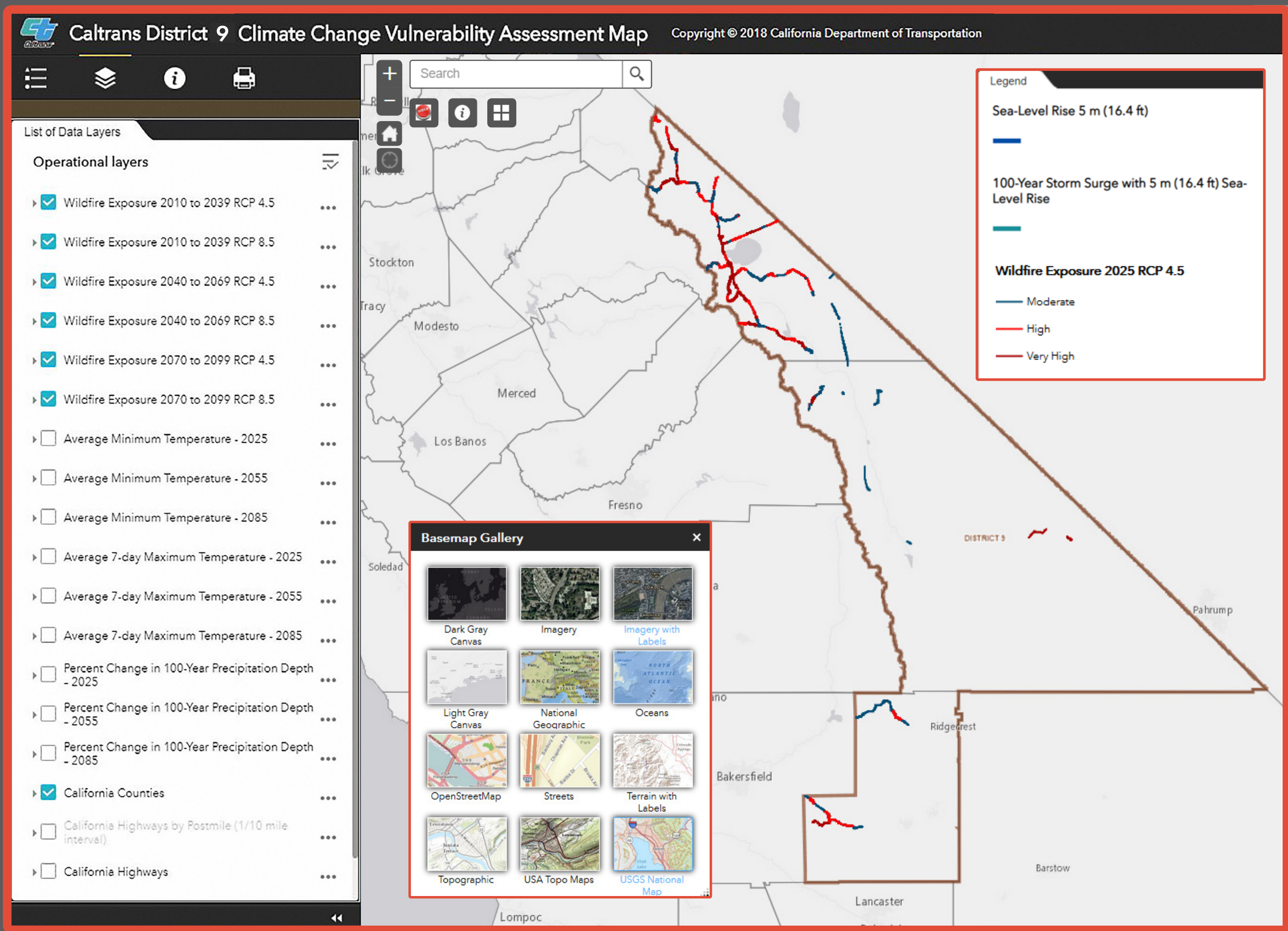
ONLINE MAPPING TOOL FOR DECISION-MAKING

Caltrans has created an online mapping program to provide information for users across the state, using data assembled for this project. The Caltrans Climate Change Vulnerability Assessment Map can be accessed here.[16]

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

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

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



Complex geospatial analyses were required to develop an understanding of Caltrans assets exposed to heavy precipitation, temperature, and wildfire. The general approach for each stressor's geospatial analysis went as follows:

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

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