CALTRANS CLIMATE CHANGE

VULNERABILITY ASSESSMENT SUMMARY REPORT

DISTRICT 3

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 describe climate change effects in District 3. 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.

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

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

1 - American Association of State Highway and Transportation Officials (AASHTO) resilience definition
2 - "Global Warming in the Western United States," Union of Concerned Scientists, last accessed July 12, 2019, http://www.ucsusa.org/global_warming/regional_information/ca-and-western-states.html#.WMwOFm_yvIU

TABLE OF CONTENTS

OVERVIEW OF METHODOLOGY

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

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

This assessment uses or references:

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

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

EVACUATION PLANNING

Among the things that Caltrans must consider when planning for climate change is the role of the State Highway System when disaster strikes. The State Highway System 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 State Highway System 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 State Highway System.

FLOODING ON SR-162 IN GLENN COUNTY | WILLOWS REST AREA

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 how to best use the most recent data. Discussions with professionals from various engineering disciplines helped identify the measures presented in this report.

The information in this Summary Report outlines the potential vulnerabilities to Caltrans' District 3 portion of the State Highway System and it illustrates the types of climate stressors that may affect how highways are planned, designed, built, operated, and maintained. This report does not identify projects to be implemented, nor does it present the costs associated with such projects—these items will be addressed in future studies. The intent of the current study is to add clarity regarding climate change in the region served by District 3 (which is a subject with many unknowns) and begin to define a subset of assets on the State Highway System on which to focus future efforts.

THE STATE HIGHWAY SYSTEM IN CALTRANS DISTRICT 3 IS CRITICAL FOR SUPPORTING FREIGHT TRAFFIC, WHICH MOVES GOODS FROM CENTRAL VALLEY FARMS TO URBAN AREAS.

DISTRICT 3 CHARACTERISTICS

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

The district maintains and operates 1,491 centerline miles of State Highway System. The primary north-south routes of the network are Interstate (I) 5 and State Routes (SR) 99, 70, and 149. SR-99 has been identified as the "Farm to Market" corridor of the region, as it connects agricultural areas south of Bakersfield to the Sacramento area. State Routes 70 and 149 are "focus routes," meaning they are high-priority routes for goods movement and link rural and urban areas. The primary east-west routes are US Route (US) 50, I-80, and SR 20. I-80 is part of a national freight corridor coordination effort due to its high truck volumes and difficult winter driving conditions. District 3 is also home to the Port of West Sacramento, which specializes in agricultural and construction cargo. The existing State Highway System in District 3 is critical for moving agricultural goods between rural and urban areas. It supports freight transportation to the Port for subsequent movement to the Bay Area, international markets, and to the east over the Sierra Nevada mountains.

KEY STATE POLICIES ON CLIMATE CHANGE

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

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

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

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

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4 - California Governor's Office of Planning and Research, "Planning and Investing for a Resilient California," March 13, 2018, http://opr.ca.gov/planning/icarp/resilient-ca.html
5 - California Legislative Information, "Assembly Bill No. 1482," October 8, 2015, https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201520160AB1482
6 - California Legislative Information, "Assembly Bill No. 2800," September 24, 2016, http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160AB2800
7 - Climate-Safe Infrastructure Working Group, "Paying it Forward: The Path Toward Climate-Safe Infrastructure in California," September, 2018, http://resources.ca.gov/climate/climate-safe-infrastructure-working-group

RECENT EXTREME EVENTS AND DIRECTOR'S ORDERS IN DISTRICT 3

Extreme weather events already disrupt and damage District 3 infrastructure. Below are some examples in the recent past that Caltrans District 3 has addressed through Director's Orders (orders for emergency response funds)—these examples show how weather events can impact the State Highway System and how the district responds. As temperatures rise, precipitation becomes more volatile, wildfires become more extreme, and sea levels rise,[8] such impacts may become more prevalent.

- **Temperature** – In April of 2017, Governor Jerry Brown declared an end to a five-and-a-half-year drought. Between 2011 and 2017, California experienced its driest and warmest year (2014) since records began, it's second driest and warmest year (2015), and unprecedented low levels of Sierra Nevada snowpack (2013 – 2015).[9] Recent studies that incorporate projected higher temperatures suggest that droughts like this may become more common if current trends continue.[10]

  One of the greatest drought impacts for Caltrans was the resulting massive tree die-off. The Governor proclaimed a state of emergency, and required Caltrans and other agencies to "identify areas of the State that represent high hazard zones for wildfire and falling trees" and "remove dead or dying trees in those high hazard zones."[11] In response, from 2015 to 2018, Caltrans District 3 removed dead trees within 100 feet of highway centerlines along SR-20, US-50, I-80, and US-89 in Nevada, El Dorado, and Placer Counties. The program felled over 5,500 trees for an estimated cost of over ten million dollars.

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

- **Wildfire** – Wildfire area and severity increase as temperatures rise. The recently released Fourth National Assessment of Climate Change reported that climate change factors alone roughly doubled the area burned by wildfire in the West between 1984 and 2015.[12] District 3 has been affected by several wildfires in recent years—most notably, the Camp Fire. Given its significance and devastation, the Camp Fire and Caltrans' response are highlighted in a separate section (see pages 23 and 24).

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

- **Sea Level Rise and Storm Surge** – To date, there have been no major events in District 3 for which sea level rise and storm surge are known causes. However, evidence suggests that there is ample room for concern. One major concern is that sea level rise in the Sacramento-San Joaquin Delta could result in upstream impacts in the Sacramento area. A recent analysis completed by Climate Central found that there are approximately 3,000 acres in Sacramento under three feet of elevation at the local high tide line that could be flooded by that level of sea level or storm surge. Three feet of sea level rise could affect over 22,000 people and 10,000 homes.[13]

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8 - Louise Bedsworth, Dan Cayan, Guido Franco, Leah Fisher, Sonya Ziaja. (California Governor's Office of Planning and Research, Scripps Institution of Oceanography, California Energy Commission, California Public Utilities Commission), "Statewide Summary Report," California's Fourth Climate Change Assessment, Publication number: SUMCCCA4-2018-013,

9 - "California Drought 2011 to 2016," Climate Signals, December 4, 2018, http://www.climatesignals.org/headlines/events/california-drought-2012-2016

10 - Louise Bedsworth, Dan Cayan, Guido Franco, Leah Fisher, Sonya Ziaja. (California Governor's Office of Planning and Research, Scripps Institution of Oceanography, California Energy Commission, California Public Utilities Commission), "Statewide Summary Report," California's Fourth Climate Change Assessment, Publication number: SUMCCCA4-2018-013,

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

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

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

SR-20 | TREE MORTALITY


SR-49 | SLIP OUT IN SIERRA COUNTY


US-50 | MUDSLIDE NEAR LATROBE ROAD, EL DORADO HILLS


US-89 | EMERALD FIRE


FARAD FIRE

VULNERABILITY AND THE STATE HIGHWAY SYSTEM

CALTRANS EFFORTS

Informed by 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 issuance of Addressing Climate Change Adaptation in Regional Transportation Plans (2013) which serves as a how-to guide for California Metropolitan Planning Organizations (MPOs) and Regional Transportation Planning Agencies (RTPAs).
- The signing of an agreement with the California Coastal Commission and its Integrated Planning Team to ensure effective collaboration between agencies—including planning for sea level rise impacts.[14]
- The release of Guidance on Incorporating Sea Level Rise (2011) to advance effective design and programmatic considerations that incorporate sea level rise projections.
- The reporting of adaptation goals and progress to OPR through the State Sustainability Roadmaps, Adaptation Chapters.[15]

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 those using the system for nationwide commerce.

ADDRESSING CONCERNS IN DISTRICT 3

Caltrans District 3's State Highway System portion serves critical functions for communities, commerce, and more. Given the importance of the system, understanding the potential impacts of climate change and extreme weather on system performance is a key step in creating a resilient highway system.

"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 climate change or other stressors. Caltrans' approach focuses on the system's vulnerability to extreme weather and climate-related 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 that may be affected by expected future weather or climate conditions, including permanent inundation from sea level rise, temporary flooding from storm surge, or a wide range of disruptions from wildfire.
- **Consequence** – determining potential damage to system assets in terms of loss of use or costs of repair.
- **Prioritization** – determining how to make effective capital programming decisions to address identified risks (including system use and timing of expected exposure).

Implementing this approach requires the participation of a wide range of Caltrans professionals from planning, asset management, operations and maintenance, design, emergency response, and economics and will require coordination with environmental and social resource agencies. An agency-wide effort will be necessary to implement this approach successfully. This vulnerability assessment is the first stage of implementing this approach; it identifies the portions of the State Highway System 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 enhanced system resiliency when identifying project stakeholders, objectives, projects, assets, and designs. In District 3, this will require implementing projects to help address the expected wildfire, precipitation, increased temperature, sea level rise, and surge effects. Following are some general strategies that District 3 could employ to address future climate change impacts:

- Identify local and regional evacuation routes and prioritize those highways for further assessment of climate change impacts. District 3 can prepare those routes to better serve demand in the event of an evacuation.
- Perform detailed, asset-level analyses to understand if District 3 roadways, bridges, and drainage infrastructure will be significantly affected by rising seas and flood events. Where adaptations are needed, the district may consider elevating bridges or roadways, protecting bridge abutments, and increasing the size and/or number of drainage infrastructure.
- Continue to adapt irrigation systems to reduce water use, even when not in a drought emergency. During the drought from 2011 to 2017, District 3 installed new irrigation systems, SMART controllers (which adjust sprinkler runtime based on weather conditions), and bubbler systems in place of conventional sprinkler systems to reduce water use. These can also be utilized in non-drought conditions.

These are just some of the strategies that Caltrans can leverage to prepare for future climate change. Caltrans must be proactive and make capital investments now to secure the long-term viability of the transportation system, and advance the general benefits of reducing heat, flooding, and drought for the greater District 3 area. These efforts will require Caltrans to be proactive and invest in the long-term viability of the transportation system.

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

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

CONSEQUENCE

Identify the implications of extreme weather or climate change on Caltrans assets. Key variables include estimates of 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):

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

OTHER DISTRICT 3 EFFORTS TO ADDRESS CLIMATE CHANGE

Caltrans recognizes that outside of its efforts and statewide efforts, there are also regional projects underway in District 3 to mitigate and address the effects of climate change. Ongoing coordination with local governments and stakeholders will be critical to ensure that methodologies and adaptation strategies are not redundant with other efforts. Regional coordination will be especially important to combat the broad effects of stressors like rising seas and temperatures that will necessitate a collective response. Here are several regional stakeholders and projects that are instrumental to addressing the impacts of climate change in District 3:

LOCAL GOVERNMENT COMMISSION

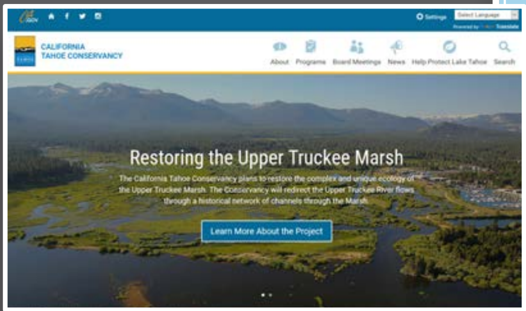
The Local Government Commission (LGC) is a Sacramento-based nonprofit that facilitates communication between the California leadership to support resilient, sustainable, and healthy communities. One of LGC's major focus areas is addressing the impacts of a changing climate by exchanging ideas and best practices. They host the biennial California Adaptation Forum to bring together the state's key stakeholders in addressing climate change to foster knowledge exchange and teamwork. LGC also hosts the CivicSpark program (an AmeriCorps program dedicated to building local government capacity to address climate change), and the Capital Region Climate Readiness Collaborative (CRC)—see below for more information.[16]

CAPITAL REGION CLIMATE READINESS COLLABORATIVE

The CRC is an LGC program and a member of the Alliance of Regional Collaboratives for Climate Adaptation (ARCCA). It is a multidisciplinary collaborative focused on building climate resilience in California's Capital Region which includes Yolo, Sacramento, Sutter, Yuba, Placer, and El Dorado counties. CRC is focused on achieving a common understanding of regional climate vulnerabilities and issues, identifying local strategies to address climate impacts, providing a voice for the Capital Region and its stakeholders, and communicating climate change issues across the state and nation. They provide resources to their members and the public, including fact sheets on climate change impact and response, a monthly newsletter with current news and resources for the Capital Region, and quarterly meetings that are open to the public.[17]

16 - For more on LGC, visit: https://www.lgc.org/

17 - For more on CRC, visit: http://climatereadiness.info/



CALIFORNIA TAHOE CONSERVANCY

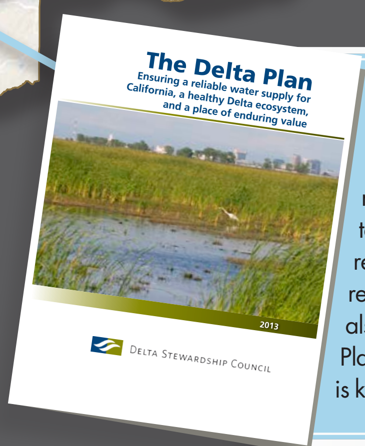
The California Tahoe Conservancy was formed to sustain a healthy balance between the natural environment and human use in the Lake Tahoe Basin. One of their recent efforts is to collaboratively lead the development of the Lake Tahoe Climate Adaptation Action Plan (CAAP). The CAAP uses downscaled climate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

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

SACRAMENTO AREA COUNCIL OF GOVERNMENTS

The Sacramento Area Council of Governments (SACOG) is an association of local governments in the Sacramento region—it includes El Dorado, Placer, Sacramento, Sutter, Yolo, and Yuba Counties. SACOG provides transportation planning and funding for the region and addresses other regional issues such as land use, air quality, and affordable housing.[18] SACOG has also been working to identify and address climate change impacts on their network. In 2015, SACOG released a Sacramento Region Transportation Climate Adaptation Plan, which summarized potential climate stressors that may pose risks, such as temperature rise, heavy rain events, wildfires and landslides, and drought.[19] SACOG is currently in the process of assessing the vulnerability and criticality of the region's transportation network.

S A C O G



DELTA STEWARDSHIP COUNCIL

The Delta Stewardship Council was created to advance the state's goals for the Delta, including creating a more reliable water supply and protecting the Delta ecosystem. Toward this goal, the Council created a long-term management plan called the Delta Plan which identifies policies and recommendations, some of which relate to climate change and sea level rise, to protect and improve the Delta. For example, the plan includes recommendations to restore the Tule habitat, which would help reduce greenhouse gas emissions. The plan also recommends increasing water storage to reduce Delta flood risk and lessen drought impacts. The Delta Plan emphasizes the need to consider long-term sea level rise in planning, and that coordination with Caltrans is key to understanding the risks to the State Highway System (see recommendation DP R6 of the Delta Plan).[20]

18 - For more on SACOG, visit: https://www.sacog.org/

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

20 - Delta Stewardship Council, "Delta Plan Executive Summary," Last amended April 26, 2018, http://deltacouncil.ca.gov/sites/default/files/documents/files/Delta_Plan_Executive_ Summary_2013.pdf.

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 State Highway System.

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 State Highway System. This step includes an examination of the range of climatic stressors and where, due to terrain or climatic region, portions of the State Highway System might be vulnerable to future disruptions.

IDENTIFY EXPOSURE OF CALTRANS HIGHWAYS TO POSSIBLE CLIMATE CHANGE DISRUPTIONS:
Identifying locations where Caltrans' assets might be exposed to extreme weather-related disruptions provides an important foundation for 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 State Highway System.

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

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

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 shows 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."[21] Given California's size and its many highly varied climate zones, it is expected that temperatures will rise to various extents across the state.

The figure on the following page shows the change in the average maximum temperature over seven consecutive days using the median temperature model (CMCC-CMS) compared to current temperatures (1975 to 2004). These temperatures are an important element of determining pavement mix for long-term performance. Generally, US studies have found that rising temperatures could impact the transportation system in several ways, including:

DESIGN

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

OPERATIONS AND MAINTENANCE

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

TEMPERATURE CHANGE IN DISTRICT 3

As shown in the mapped projections in Figure 1, the average maximum temperature over seven days is expected to increase through the end of the century. These projections are averaged for three periods: 1) 2010 to 2039, represented by the year 2025, 2) 2040 to 2069, represented by the year 2055, and 3) 2070 to 2099, represented by the year 2085. In the 2025 period, the temperature increase is estimated to be between 2 and 5.9 degrees Fahrenheit, depending on location. Temperatures are projected to rise by 4 to 7.9 degrees Fahrenheit by 2055, and by 8 to 11.9 degrees Fahrenheit by 2085. Increases in the average maximum temperature will have a range of impacts for District 3, including those related to design, operations, and maintenance listed above. Some examples include more rapid deterioration of pavements, expansion and contraction of bridge joints and other materials, and potential heat stress and health impacts for Caltrans employees.

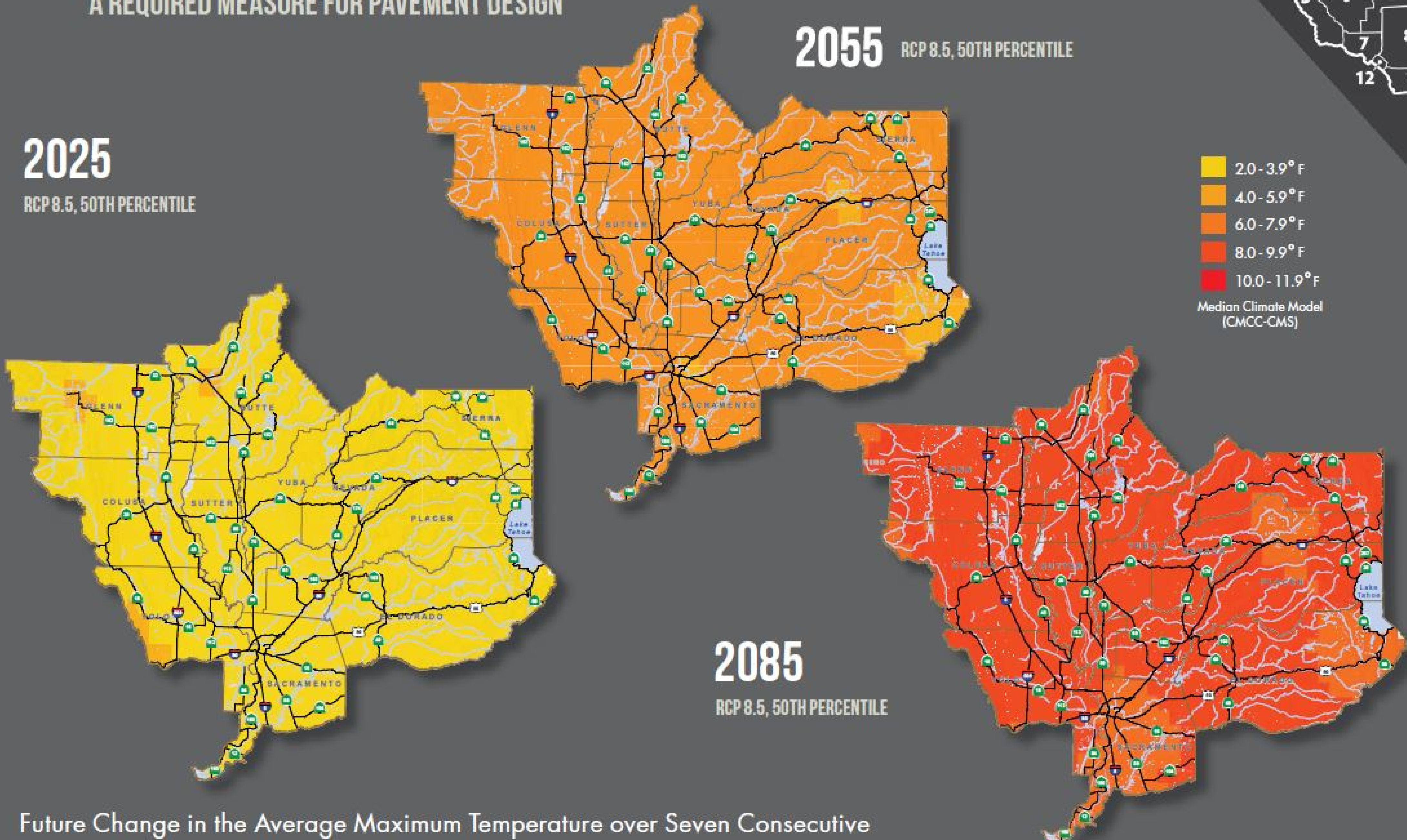
21 - "Extreme Weather," U.S. National Climate Assessment, accessed April 29, 2019, http://nca2014.globalchange.gov/report/our-changing-climate/extreme-weather

DAMAGE IN #2 LANE SOUTH OF SUTTERVILLE

Fig.1

INCREASE IN THE AVERAGE MAXIMUM TEMPERATURE OVER SEVEN CONSECUTIVE DAYS

A REQUIRED MEASURE FOR PAVEMENT DESIGN



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

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

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

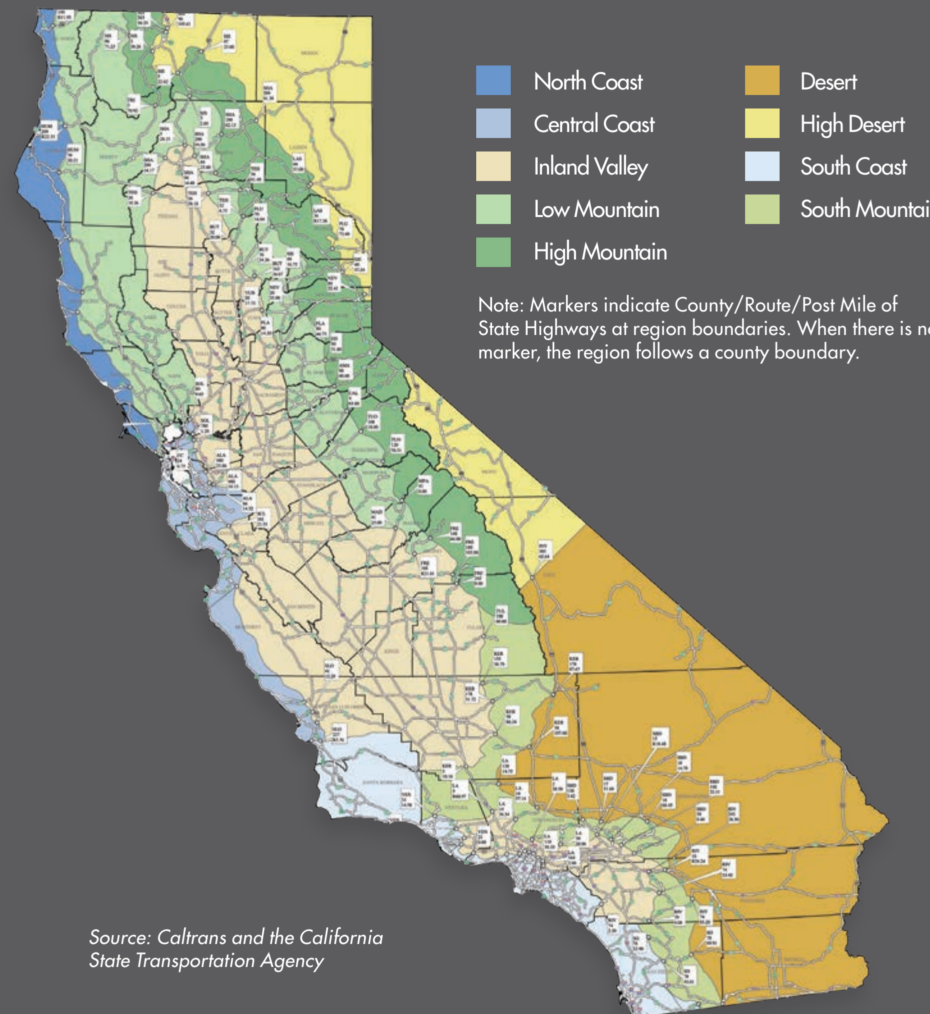
Pavement durability is affected by how it was designed and is an important component of Caltrans' highway asset management strategy. Ensuring that highway pavements maintain their durability and good ride quality under various conditions is an important responsibility of every state transportation agency.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

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

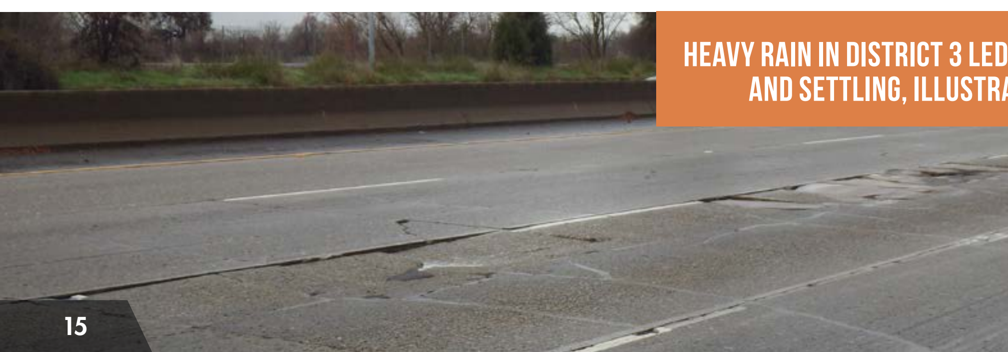
Caltrans has divided the state into nine pavement climate regions (as shown in Figure 2) to help determine the recommended pavement types for each area. Pavement design considers two primary criteria: average maximum temperature over seven consecutive days, and the change in absolute minimum air temperature.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

Fig. 2

CALTRANS PAVEMENT REGIONS



Source: Caltrans and the California State Transportation Agency




HEAVY RAIN IN DISTRICT 3 LED TO PAVEMENT SLABS BREAKING AND SETTLING, ILLUSTRATING PAVEMENT IMPACTS

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, are replaced around every 20-40 years while others, like bridges, are built which the expectation of a useful life of 50 years or longer.

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

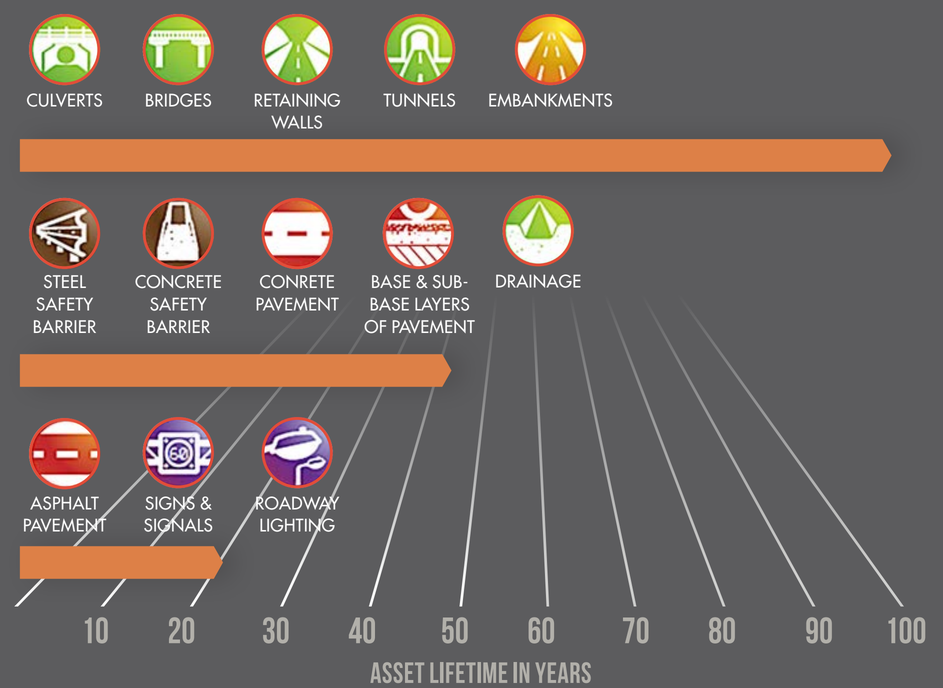
Fig. 4

TRANSPORTATION INFRASTRUCTURE ASSETS

SOME CALTRANS ASSETS, LIKE BRIDGES, ARE BUILT WITH THE EXPECTATION OF A USEFUL LIFE OF 50 YEARS OR LONGER.

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

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

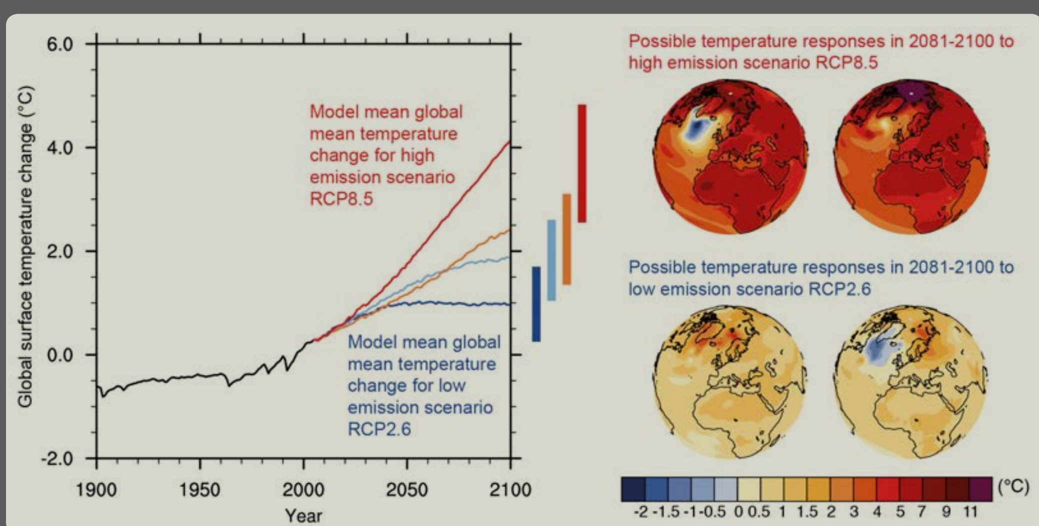


The graphic above shows how assets maintained by Caltrans will require different considerations for planning and design. All decisions should be forward-looking instead of based on historic trends, because all future scenarios show changing conditions. These future conditions must be considered when 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

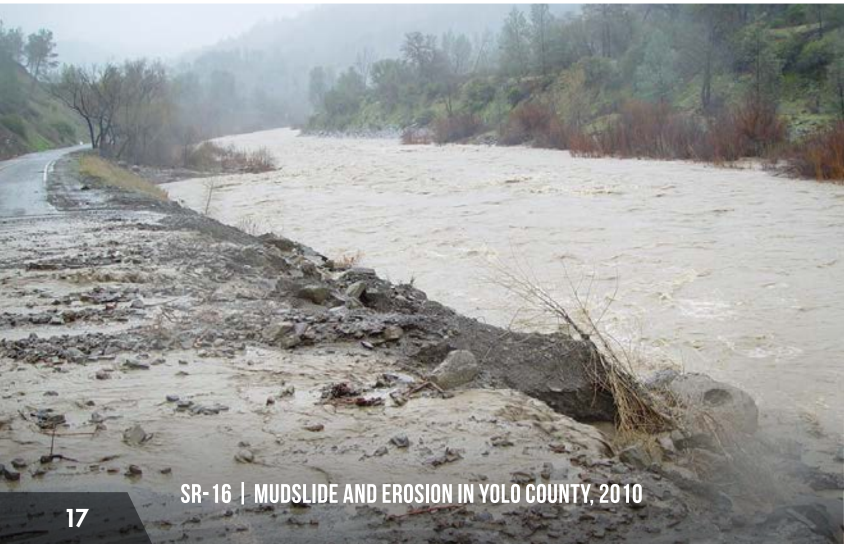
The increase in moisture and energy in the atmosphere caused by increasing temperatures is expected to change the nature of precipitation events in California. More intense storms, combined with other changes in land cover and land use, can increase the risk of damage or loss from flooding. Precipitation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

The Scripps Institution of Oceanography at the University of California, San Diego has projected future rainfall data to the year 2100 using two different GHG emission scenarios and several different models. The "100-year storm event" is one useful way to examine this data—it is defined as a storm with a likelihood of occurring once every 100 years (or a one percent chance of occurring in any given year). A storm of this magnitude could cause significant damage, so it is a good design standard for infrastructure projects. Understanding how the 100-year storm may change in the future can help Caltrans to build more resilient infrastructure, designed to accommodate heavier storm events. See the figure on the following page for the percentage increase in the 100-year storm depth across District 3.

PRECIPITATION CHANGE IN DISTRICT 3

As shown in Figure 5, the depth of a 100-year precipitation event is expected to increase over time in District 3, using the median precipitation model (HadGEM2-CC). Projections vary by location, with some of the most significant changes projected in the Sierra Nevada and parts of Sutter and Yuba counties. In the 2025 period (mean of the years 2010 to 2039), 100-year precipitation depths are expected to increase by 0 to 9.9% with the greatest change in the Sierra Nevada and in the western edges of Glenn and Colusa counties (5 to 9.9%). In the 2055 period (mean of the years 2040 to 2069), the range increases from 0 to 14.9%, and by 2085 (mean of the years 2070 to 2099) the range increases to 0 to 19.9%, depending on location. Modeling future precipitation is still an uncertain practice, and these projections show some of the wide ranges that appear in model outputs. Generally, storms like the 100-year event are expected to become more severe, while droughts between periods of rain become longer and more extreme. Decadal to multi-decadal megadroughts are expected to become more likely in the west as temperatures rise, despite the increased frequency of heavy downpours.[22]

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



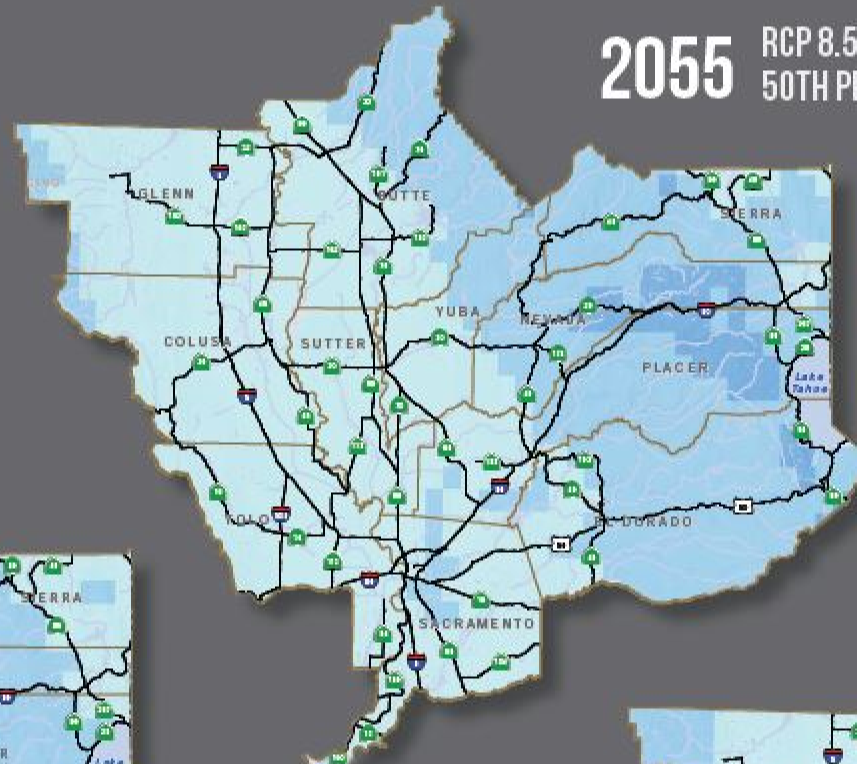
SR-16 | MUDSLIDE AND EROSION IN YOLO COUNTY, 2010

SR-193 | SLIP OUT REPAIR, 2016

Fig. 5

PERCENT CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH

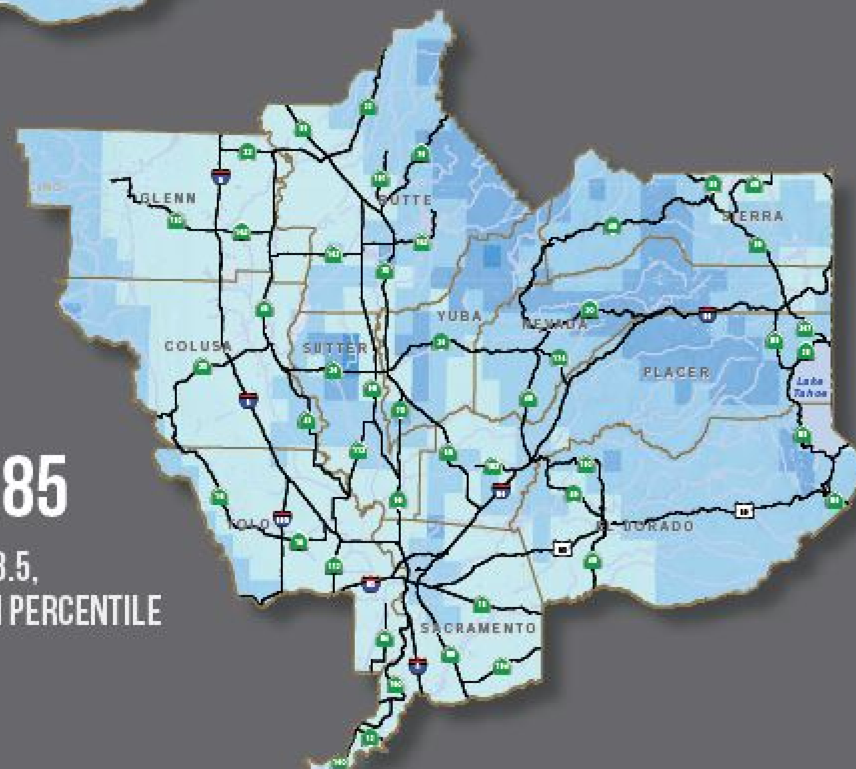
2055 RCP 8.5, 50TH PERCENTILE



	0.0 - 4.9%
	5.0 - 9.9%
	10.0 - 14.9%
	15.0 - 19.9%

Median Climate Model (HadGEM2-CC)

2025 RCP 8.5, 50TH PERCENTILE



2085 RCP 8.5, 50TH PERCENTILE

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

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

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

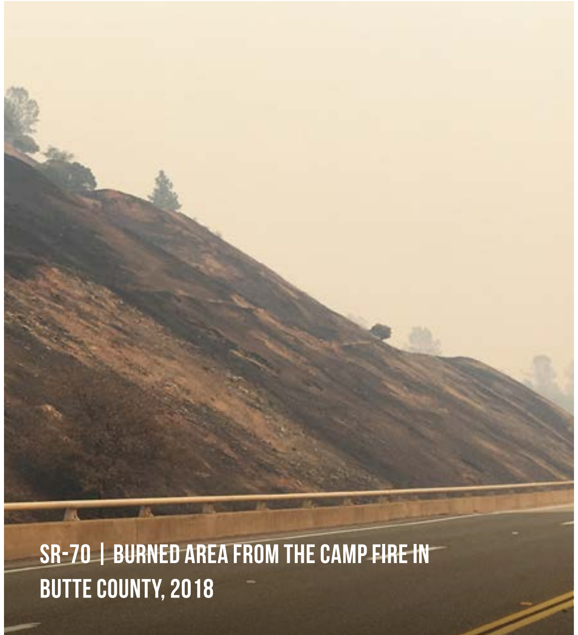
The areas shaded in red in Figure 6 indicate an increased likelihood of wildfires based on projected percentages of area burned over time. These projections are from data generated by the MC2 – EPA (from the United States Forest Service), MC2 – Applied Climate Science Lab (University of Idaho), and the Cal-Adapt 2.0 (UC Merced) wildfire models. Each model was paired with three downscaled GCMs to produce nine future scenarios. Starting with three different wildfire models was a conservative methodology because final data shows the highest wildfire risk categorization of all model results. The results for RCP 8.5, the high-emissions scenario, are provided in Figure 6 and Table 1. See the associated Technical Report for results processed for RCP 4.5.

WILDFIRE EFFECTS IN DISTRICT 3

Figure 6 shows modeled wildfire concern areas under RCP 8.5, with medium wildfire concern being an expected 15 to 50% of that area burning, high concern being 50 to 100%, and very high being over 100% (a greater than 100% burn can occur when the same area is projected to burn multiple times over the given time period). A summary of exposure for RCP 4.5 is in the associated District 3 Technical Report. The mileage of State Highway System exposed does not change over time, but the level of wildfire risk does. For example, there are portions of the Sierra Nevada range that show medium projections of risk in the 2025 period (mean of the years 2010 to 2039) that change to high concern by the middle of the century, and very high concern by the end of the century. The projected wildfire risk for the district overall is very high, given that a large portion of the district consists of forested foothills and mountain ranges. Urban areas and agricultural lands do not have the same level of risk as forested areas, though there is inherently some wildfire risk wherever there is fuel. These lower-risk areas can be observed in Figure 6, shown as the white portions of Glenn, Butte, Colusa, Sutter, Yolo, and Sacramento counties. Wildfires in District 3 could lead to road closures, and damages to State Highway System infrastructure such as signs, guardrails, culverts, and asphalt. They could also lead to indirect impacts such as landslides on steep slopes.

TABLE 1:
TOTAL CENTERLINE MILEAGE EXPOSED TO MEDIUM TO VERY HIGH WILDFIRE CONCERN BY END OF CENTURY, UNDER RCP 8.5

DISTRICT 3 COUNTY	YEAR 2085
BUTTE	101
COLUSA	25
EL DORADO	159
GLENN	35
NEVADA	127
PLACER	120
SACRAMENTO	41
SIERRA	85
YOLO	22
YUBA	27
TOTAL MILES EXPOSED	743



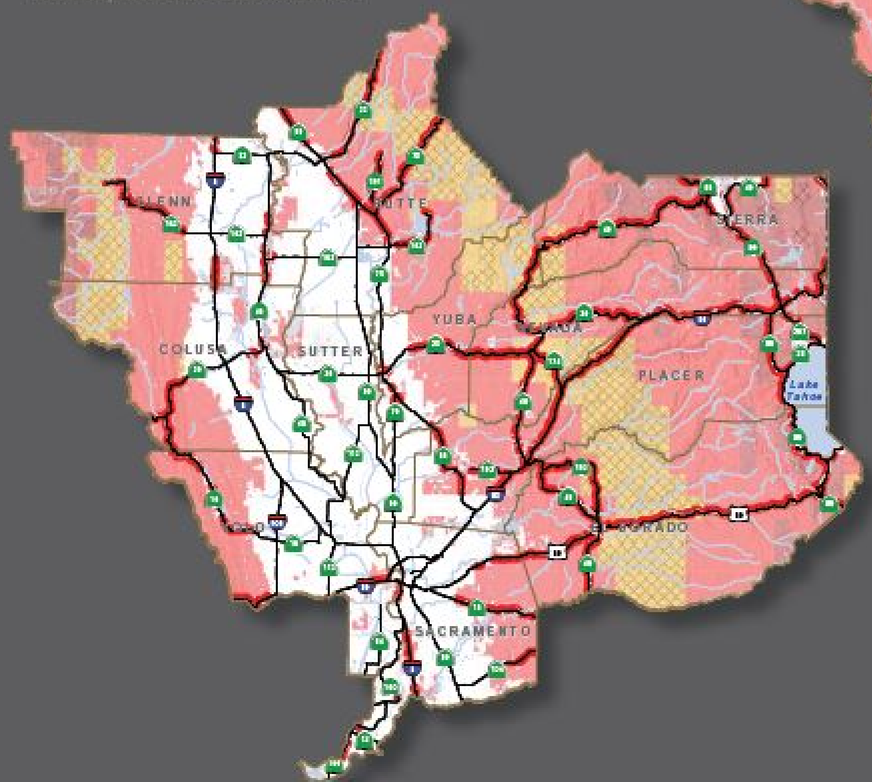
SR-70 | BURNED AREA FROM THE CAMP FIRE IN BUTTE COUNTY, 2018

Fig. 6

LEVEL OF WILDFIRE CONCERN

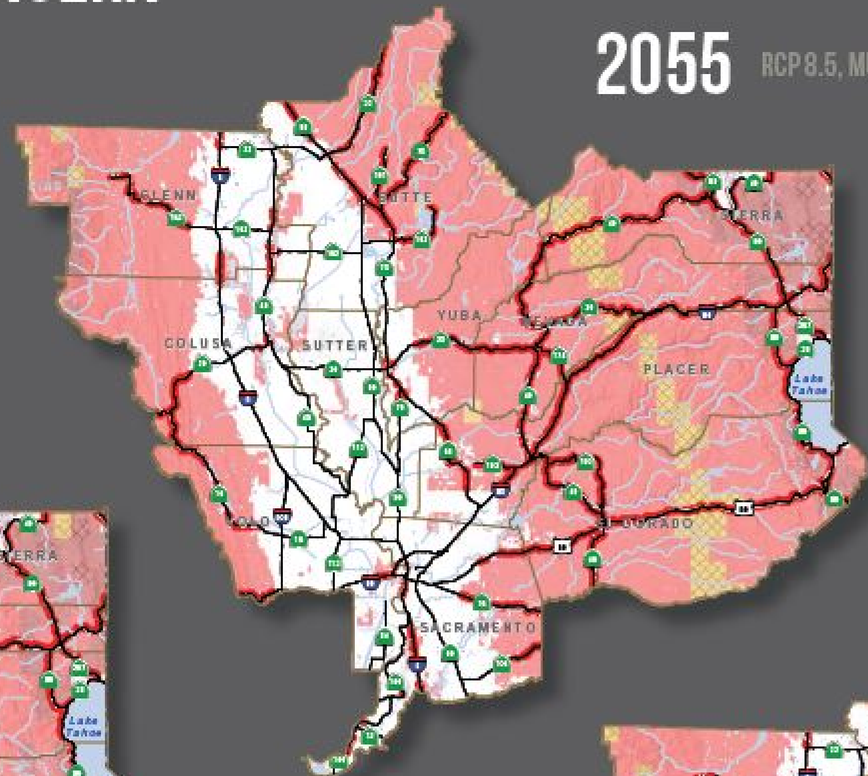
2025

RCP 8.5, MULTI-MODEL MAXIMUM



2055

RCP 8.5, MULTI-MODEL MAXIMUM



2085

RCP 8.5, MULTI-MODEL MAXIMUM

Levels of Concern

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

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

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

*The hashing shows areas where 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 moderate. More information on models used and the classifications for levels of concern can be found in the associated Technical Report.

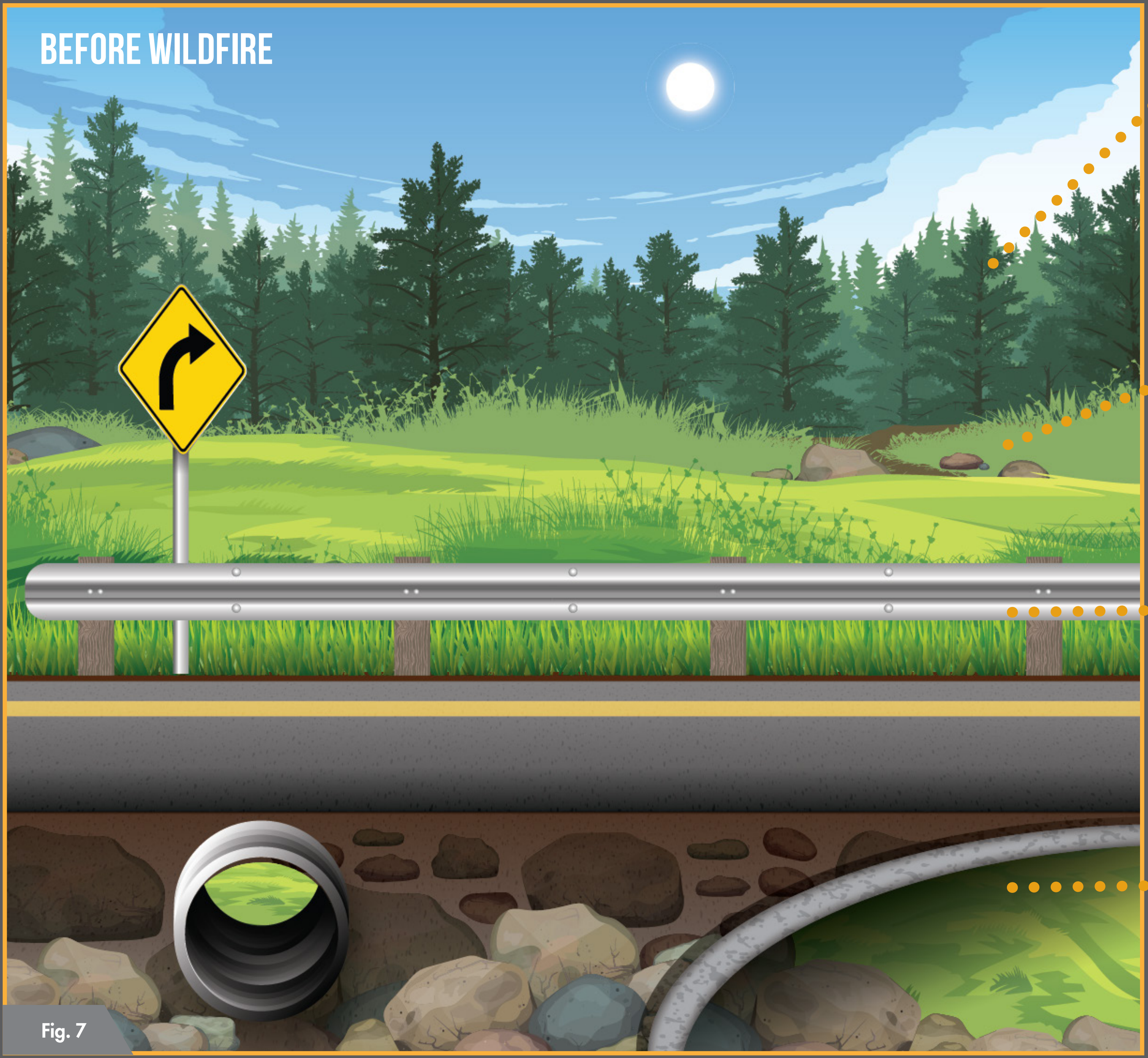


Fig. 7

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

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

LOSS OF FOREST COVER RESULTS IN MORE EROSION OF SOILS

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

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

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

DESTROYED SIGNS AND GUARDRAILS REDUCE DRIVER SAFETY

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

Fig. 8

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

THE CAMP FIRE AND IMPACTS TO THE STATE HIGHWAY SYSTEM

On November 8, 2018, the Camp Fire started near the town of Pulga on SR-70 and quickly spread westward toward the town of Paradise, causing mass evacuations and the closure of local streets and highways. Overnight, the fire burned 70,000 acres, including 2,000 structures in the towns of Paradise, Magalia, Concow, and Yankee Hill. By the time the Camp Fire was over, it had killed 86 people and burned 153,336 acres and 18,804 structures. It is now known as the deadliest and most destructive fire in California's history.[23] The town of Paradise was nearly destroyed, leaving tens of thousands of residents in need of shelter.

As of November 15th, 2018, 42 miles of the State Highway System were in the Camp Fire perimeter, and major damages occurred on State Routes 32, 70, 88, 149, and 191 in Butte County. Thousands of burned trees stood in highway right-of-way which presented an imminent threat to roadways and exposed mountainous slopes to erosion and debris-flow threats. Roadside infrastructure such as retaining walls, drainage systems, metal beam guardrails, and signage was damaged. The photos throughout this section show some of the damages to Caltrans District 3.

In response to the Camp Fire, Caltrans initiated a Director's Order for emergency funds totaling over $26,000,000 to repair damage and mitigate threats from erosion, debris flows, and falling trees. Caltrans District 3 staff removed and chipped hazardous trees and installed protections such as mesh drapery and Rock Slope Protection on steep, barren slopes.[24] The district used debris racks, which are structures typically created from fallen or dead trees from the wildfire, to stop or deflect debris away from culvert entrances and protect streams. Caltrans staff also replaced or repaired damaged roadside infrastructure such as guardrails, fencing, signage, and electrical equipment.

These repairs were authorized just one day after the start of the fire and were undertaken immediately. This was critical because state routes needed to be available for evacuations and emergency services, and the coming rainy season posed threats for slope failure and further damages. When the rainy season came a month after the fire, flooding, rockslides, and debris flows closed portions of SR-99 and SR-70 in Butte County.

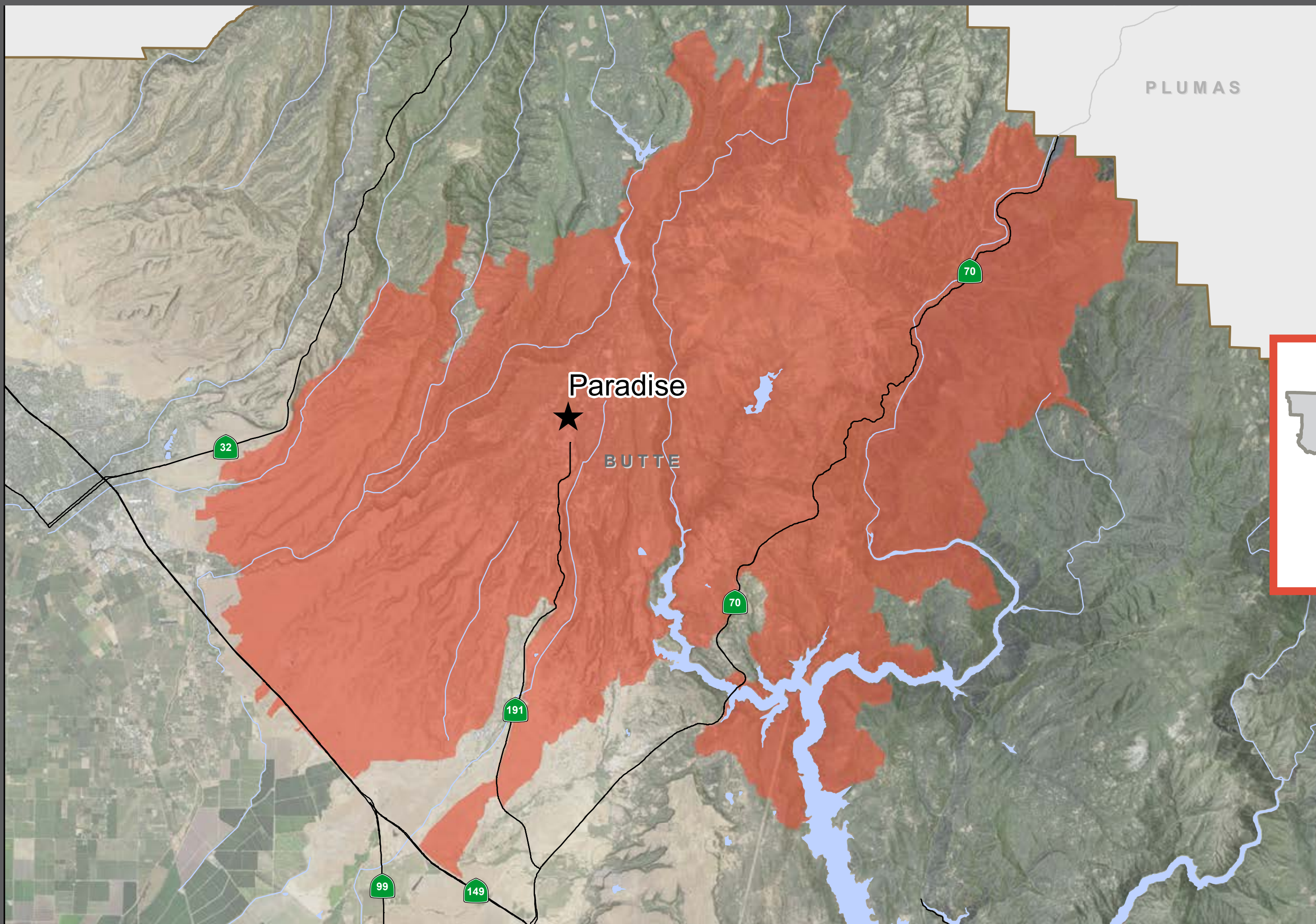
Climate change, along with other anthropogenic factors, has already contributed to more frequent and severe wildfires in the west.[25] Other human factors contribute to wildfires (e.g., fire suppression), but a recent study of the western US estimated that factors attributable to climate change were more influential in burns from 1916 to 2003.[26] As time goes on and temperatures continue to rise, California may experience a 77% increase in mean area burned (compared to 1961 to 1990) under the RCP 8.5 scenario. Large fires (greater than 24,710 acres), like the Camp Fire, are projected to occur 50% more frequently under the RCP 8.5 scenario.

23 CalFire, "Top 20 Most Destructive California Wildfires," December 12, 2018, http://www.fire.ca.gov/communications/downloads/fact_sheets/Top20_Destruction.pdf
24 For more information on RCP, see page 29.
25 Louise Bedsworth, et al., "Statewide Summary Report," California's Fourth Climate Change Assessment, Publication number: SUMCCCA4-2018-013, 2018, accessed from http://climate.calcommons.org/bib/california%E2%80%99s-fourth-climate-change-assessment-statewide-summary-report
26 Patrick Gonzalez, et al., "In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]," U.S. Global Change Research Program, doi: 10.7930/NCA4.2018.CH25, (2018): 1101–1184, accessed from https://nca2018.globalchange.gov/chapter/25/

SR-70 | BURNED AREA BY BRIDGE AND LAKE | CAMP FIRE IN BUTTE COUNTY, 2018

Fig. 9

THE CAMP FIRE PERIMETER IN BUTTE COUNTY



Perimeter boundary was retrieved from the CalFire 2019 Statewide Incidents Map

SR-191 | CAMP FIRE, 2018

SR-191 | CAMP FIRE, 2018

SEA LEVEL RISE IN THE DELTA

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

As subsidence continues and sea levels rise, there are greater concerns surrounding flood impacts in the Delta. The levees have promoted agriculture, community-building, and infrastructure development in flood-prone areas. But they are aging, and in some cases, outdated. Flood-prone areas of the Delta are largely reliant on the levee system for flood protection, but recent estimates find that protection is adequate for only about half of the Delta.

The levee system is also important to the State Highway System, which traverses the Delta and connects Sacramento, Stockton, and other neighboring cities. The State Highway System sits atop levees in parts of the Delta and is elevated on viaducts in others, but there is a significant network that extends through low-lying farmland and suburban neighborhoods. These areas could be increasingly vulnerable to flooding and its associated damage, especially considering the potential for subsidence and sea level rise. Portions of State Routes 160, 12, 4, and I-5, among others, traverse levee-protected areas. These routes are critical for transporting agricultural products and providing Bay Area access for residents and other travelers. Given the importance of the State Highway System in the Delta, Caltrans analyzed sea level rise impacts to the network as part of the District 3 vulnerability assessment. This assessment will help Caltrans identify which routes may be vulnerable to inundation, scour, erosion, or other effects due to higher water levels.

This analysis used a model developed by Climate Central, which identifies potential flooding conditions if levees and flood control barriers[27] remain resilient, and if they do not. The following sections show the results of this analysis for 1.64, 3.28, and 5.74 feet of sea level rise (0.5, 1.00, and 1.75 meters respectively). Two types of inundation are presented, "sea level rise inundation extent," which assumes that levees and other barriers are strong enough to effectively stop the flow of water, and "levee protected areas," which identifies land areas at risk if levees and other barriers were to fail. Note that the sea level rise inundation extent data received from Climate Central was clipped to be consistent with the storm surge data described in the next section. Sea level rise risks posed to the State Highway System are highlighted in Figure 10 and are summarized below.

SEA LEVEL RISE INUNDATION IN DISTRICT 3

If all levees and flood control structures provide adequate flood protection, SR-12 would be the primary District 3 route vulnerable near term sea level rise. Segments of SR-160, I-5, and I-80 may also be at risk.

If certain levees and flood barriers failed or provided inadequate protection, sea level rise could also flood large portions of SR-220 and SR-84, and affect a larger span of I-5. These areas are at risk from just 1.64 feet (0.5 meters) of sea level rise given levee failure—the state's "likely range" projections show a 66% chance of this happening by 2060. Using more conservative estimates, 1.64 feet of sea level rise could happen sooner—sometime between 2040 and 2050 (see Figure 11). It is important to note that this scenario assumes that ALL levees and flood barriers fail, which is highly unlikely. However, it is also important to identify the worse-case scenarios so actions can be taken to determine and mitigate the potential risks and adequately protect the highway network.

Table 2 summarizes the centerline mileage of the SHS in District 3 that sea level rise could inundate or otherwise impact (e.g., through erosion or washouts).[28]

Table 2: Centerline Miles of Highways Inundated by Sea Level Rise in the Delta

County	Sea Level Rise Height		
	1.64 ft (.5 m)	3.28 ft (1 m)	5.74 ft (1.75 m)
Sacramento	**1**	**1**	**10**
Yolo	**0**	**0**	**1**

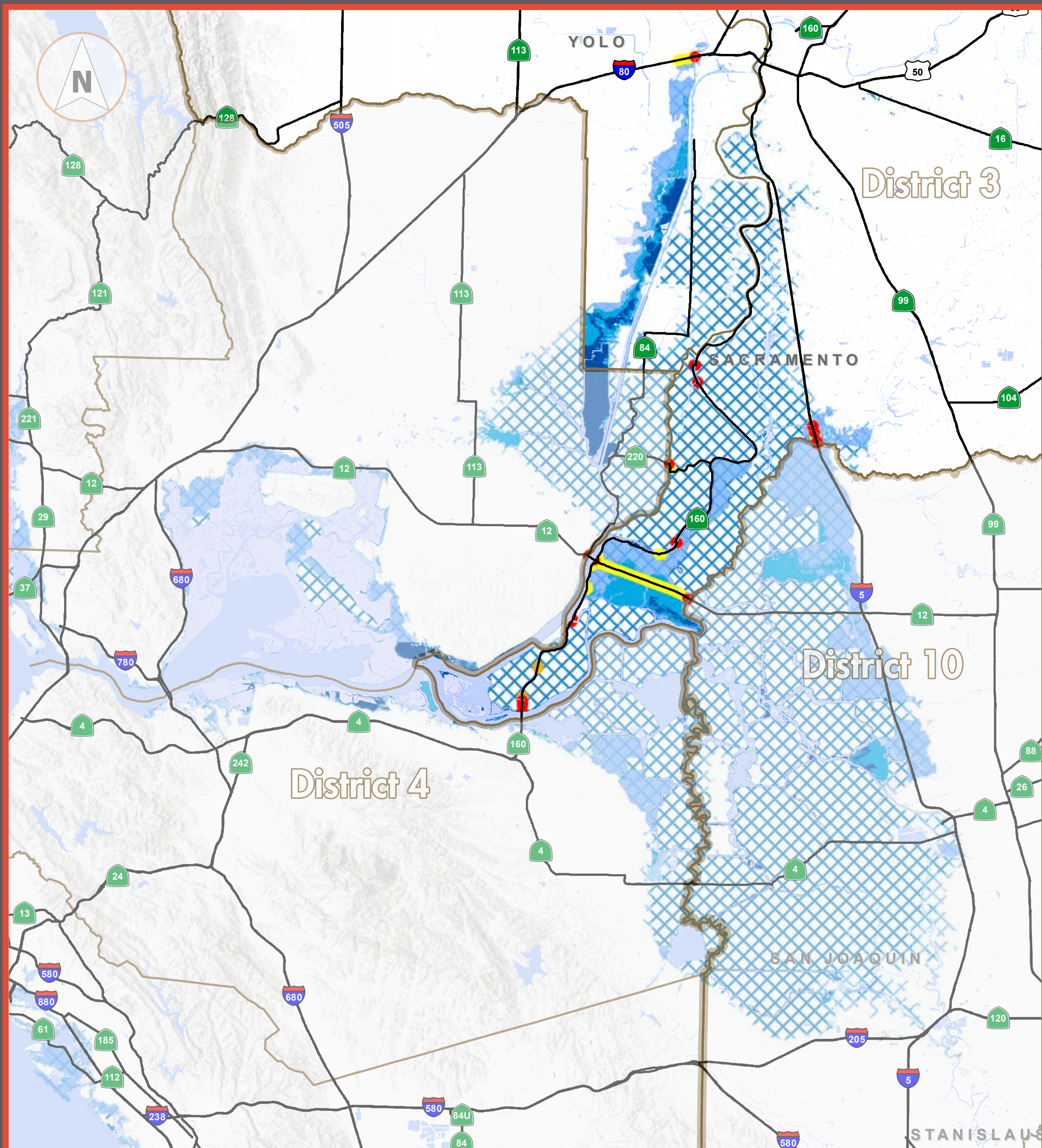
Note: There are very short segments of highway in Yolo County that are affected by lower sea level rise heights.

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

28 - This data assumes that levee protection is adequate to protect against higher water levels. This mileage summary includes bridges on the State Highway System that may be overtopped or otherwise exposed to conditions that could affect their long-term viability, including increased scour and erosion, and a higher water table. These areas may require additional analysis to determine whether the bridges are at risk.

Fig. 10

SEA LEVEL RISE INUNDATION IN THE DELTA



Impacts to District 3 State Highway System by Sea Level Rise Inundation Extent

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

Sea Level Rise Height

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

Levee Protected Areas

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

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

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

STORM SURGE IN THE DELTA

As seas rise and move inland over low-lying areas, there is a greater potential for storm surge caused by meteorological events to become more devastating. Storm surge is defined as a rise of water "generated by a storm, over and above the predicted astronomical tide."[29] Surges are caused primarily by strong winds during a storm event which cause "vertical circulation" by pushing water forward. In deep water the effect is minimal, but when the storm reaches shallower water or coastline, the disrupted circulation pushes water onshore.[30] Figure 11, developed by the National Oceanic and Atmospheric Administration (NOAA), shows how wind-driven events create a surge at the coastline and inland.

An analysis of the potential effects of sea level rise, combined with storm surge in the Delta, was completed using data from the 3Di model developed by John Radke (et al.) of University of California, Berkeley.[31] 3Di is a three-dimensional hydrodynamic model that simulates water movement during flood events based on observed water levels from a past near-100-year storm event.[32] Three future water levels associated with sea level rise were used as the baseline water elevation and combined with the identified storm event to determine future surge levels. The levels used were 1.64, 3.28, and 4.62 feet (or 0.50, 1.00, and 1.41 meters, respectively), and, except for the highest, they align with the sea level rise data used in the previous section. The different methodologies and inputs used in each model result in different outcomes for which parts of the State Highway System may be exposed, and when.

FLOODING ON HIGHWAY 162 IN GLENN COUNTY

STORM SURGE FLOODING IN DISTRICT 3

The model results indicate that for water levels associated with 1.64 feet of sea level rise, combined with a 100-year storm, small segments of SR-160, SR-12, I-80, and I-5 may temporarily flood and suffer storm surge damage. These affected areas expand as sea level rises, and under the highest scenario modeled (4.62 feet) large portions of SR-160 and SR-12 may flood or be otherwise impacted. See Figure 11 for mapped storm surge projections in District 3.

Table 3 identifies the centerline miles of the District 3 State Highway System that could be flooded by a 100-year storm event. This mileage summary includes bridges on the State Highway System that may be overtopped or otherwise exposed to conditions that could affect their long-term viability, including increased scour and erosion, and a higher water table. See Figure 13 for more on bridge impacts from sea level rise and surge. For more information on the analysis completed see the associated District 3 Technical Report.

Table 3: Centerline Miles of Highways Flooded by Sea Level Rise and Surge in the Delta

County	Sea Level Rise Height		
	1.64 ft (.5 m) + 100-Yr Storm	3.28 ft (1 m) + 100-Yr Storm	4.62 ft (1.41 m) + 100-Yr Storm
Sacramento	**2**	**2**	**11**
Yolo	**0**	**0**	**0**

Note: There are very short segments of highway in Yolo County that are affected by sea level rise and surge.

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

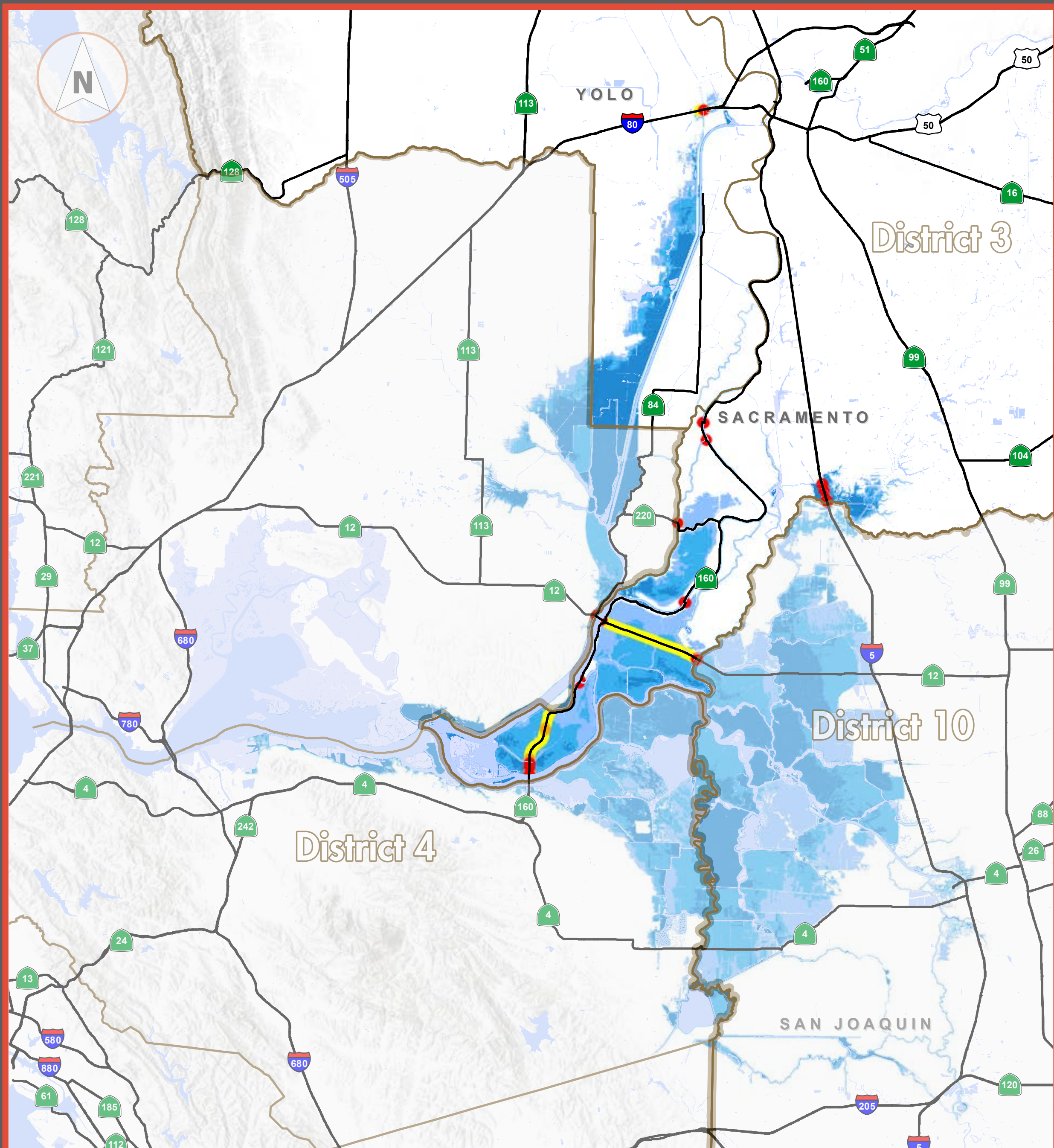
30 - Ibid.

31 - "Sea Level Rise CalFloD-3D," Cal-Adapt, last accessed May 21, 2019, http://cal-adapt.org/data/slr-calflod-3d/

32 - John Radke, et al., (University of California, Berkeley), "Assessment of Bay Area Natural Gas Pipeline Vulnerability to Climate Change," California Energy Commission, Publication number: CEC-500-2017-008, 2016, accessed from https://www.energy.ca.gov/2017publications/CEC-500-2017-008/CEC-500-2017-008.pdf

Fig. 11

FLOODING FROM STORM SURGE IN THE DELTA



Flooded District 3 State Highway System by Sea Level Rise and Storm Surge Extent

- 1.64 Ft (0.50 M)
- 3.28 Ft (1.00 M)
- 4.62 ft (1.41 m)

Sea Level Rise Height

- 1.64 Ft (0.50 M)
- 3.28 Ft (1.00 M)
- 4.62 ft (1.41 m)

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

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

PROJECTIONS OF SEA LEVEL RISE FOR SAN FRANCISCO

Sea level rise estimates, focused at locations where tidal data is regularly collected, have been developed for California by various agencies and research institutions. For the Delta, the San Francisco gauge was the closest tide gauge and was used in this analysis. Figure 12 shows the estimates recently developed for the San Francisco gauge by a scientific panel for the 2018 Update of the State of California Sea-Level Rise Guidance, an effort led by the Ocean Protection Council (OPC).[33] These projections were developed for gauges along the California coast based on global and local factors that drive sea level rise, including thermal expansion of ocean water, glacial ice melt, and the expected amount of vertical land movement.

Sea level rise projection scenarios presented in the OPC guidance identify several values or ranges, including:

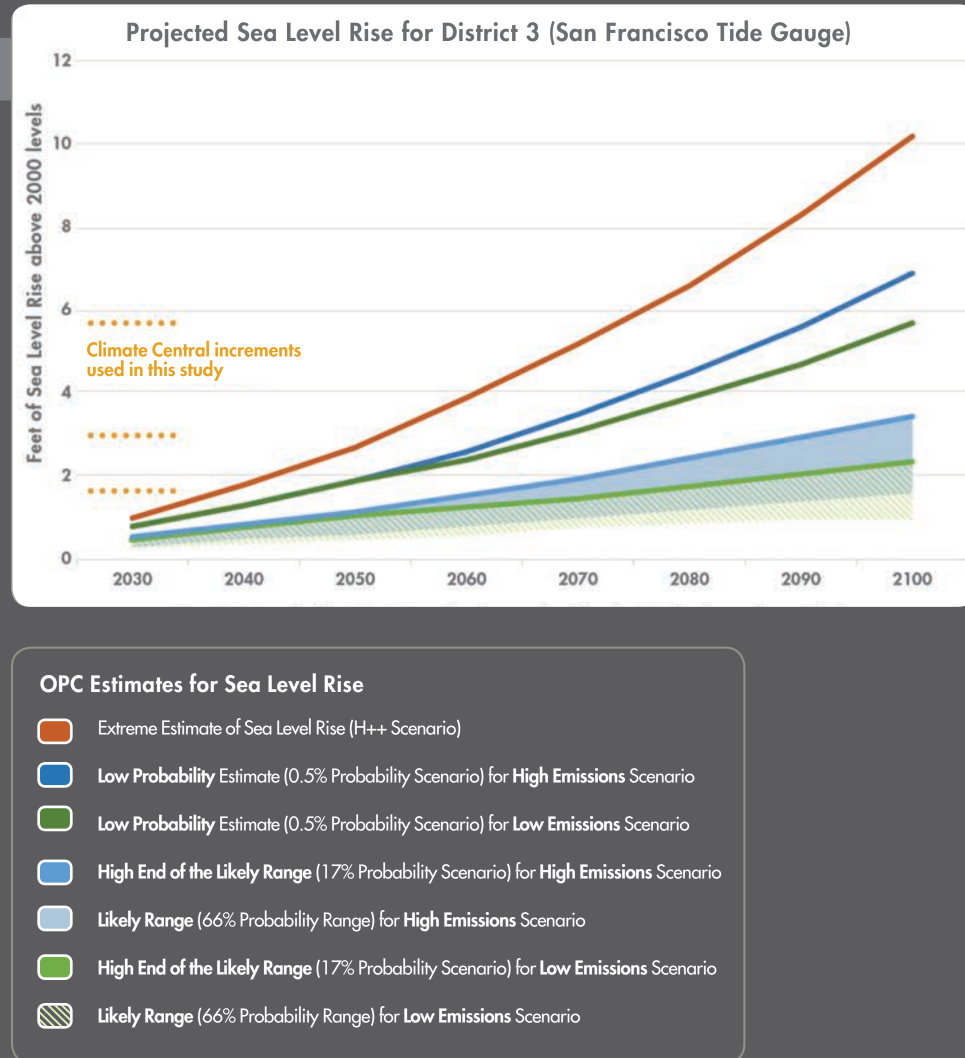
- A low (0.5%) probability scenario
- A 1-in-20 (5%) probability scenario
- A median (50%) probability scenario
- A likely (66%) probability scenario
- An extreme (H++) scenario to be considered when planning for critical or highly vulnerable assets with a long lifespan

Each of these values is presented below for both low (RCP 2.6) and high (RCP 8.5) emissions scenarios to show the full range of projections over time—though the assumptions for global emissions associated with the RCP 8.6 scenario are considered “business-as-usual.” The OPC guidance provides estimates derived for the RCP 8.5 scenario until 2050, and for both scenarios through 2150. Given the uncertainty inherent in any modeling result, the OPC recommends assessing a broad range of future projections through a scenario analysis before making investment decisions for projects. Guidance is provided for when it is best to consider certain projections for projects of varying risk aversion, since some projects have greater consequences and impacts if affected by sea level rise:

- For low-risk aversion decisions (for projects with few consequences, a short lifespan, or low cost), the OPC recommends using the likely (66%) probability sea level rise range estimate. This range is shown in light blue for the RCP 8.5 scenario and light green for RCP 2.6 in the graphic below.
- For medium to high-risk aversion decisions (for projects with higher potential risk, more significant consequences, a long lifespan, or high costs), the OPC recommends using the low (0.5%) probability scenario. This value is shown in dark green for RCP 2.6 and in dark blue for RCP 8.5 in the graphic below.
- For high-risk aversion decisions (for projects where risks are significant, and consequences could be catastrophic), the OPC recommends considering the extreme (H++) scenario. This projection is shown in dark orange in Figure 12.

The OPC guidance was developed to help state and local governments understand the potential future risks associated with sea level rise and incorporate this understanding into work efforts, investment decisions, and policy mechanisms. The OPC recognizes that the science surrounding sea level rise projections is still improving and anticipates updating their guidance at least every five years to incorporate the best current information. Accordingly, Caltrans will always use the best-available sea level rise projections and associated guidance and incorporate them into its policies to help ensure the best capital investment decisions for its projects.

Fig.12

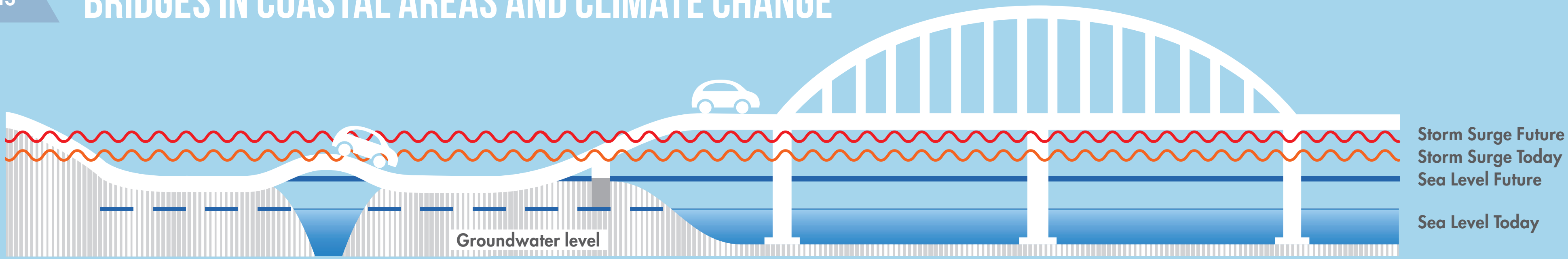


Identifying specific sea level rise height projections can be helpful when reviewing modeling results. Sea level rise heights of 1.64, 3.28, and 5.74 feet (0.5, 1.00, and 1.75 meters respectively) are shown in Figure 12. In referencing these specific heights, and the estimates for sea level rise in OPC’s guidance document, Caltrans can identify the full range of projections to consider for its capital projects. For example, 3.28 feet of sea level rise is projected to occur around mid-century (2060) under the H++ scenario, or around 2130 under the high-emissions median scenario. Given the uncertainty regarding the rate of sea level rise, especially after mid-century, a wide range of projections needs to be considered. Caltrans will be working over the coming months to develop a policy for how best to incorporate these estimates and OPC guidance into its processes and procedures.

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

Fig. 13

BRIDGES IN COASTAL AREAS AND CLIMATE CHANGE



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

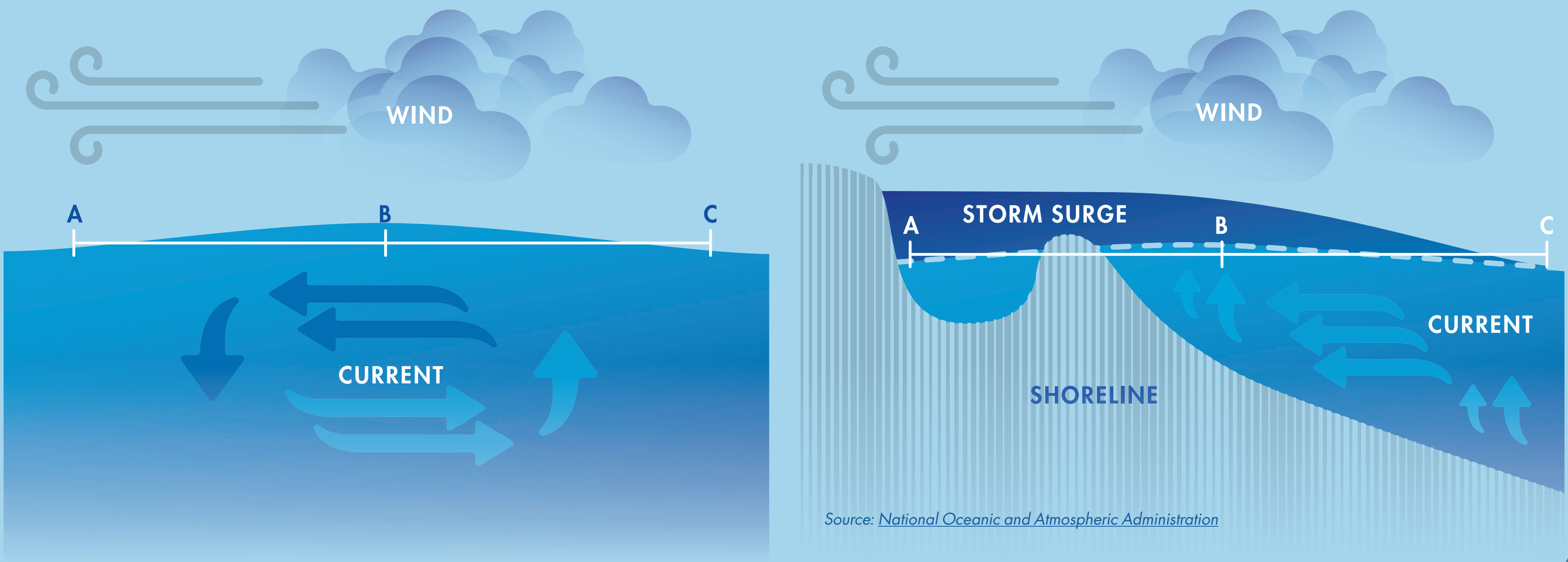
Some of bridge vulnerabilities include:

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

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

Fig. 14

VERTICAL CIRCULATION DURING A STORM EVENT



Source: National Oceanic and Atmospheric Administration

ADAPTIVE DESIGN, RESPONSE, AND RISK MANAGEMENT

Risk-based design strategies are one way of developing an effective adaptation response to climate stressors and dealing with the uncertainties of future climate conditions. A risk-based decision approach considers the broader implications of damage and loss in determining the design approach. The Federal Highway Administration has developed a framework for making design decisions that incorporates climate change: the Adaptation Decision-Making Assessment Process (ADAP)[34] process.

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

34 - "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

DISTRICT 3 DESIGN RESPONSE – STATE ROUTES 16 AND 20 STABILIZATION

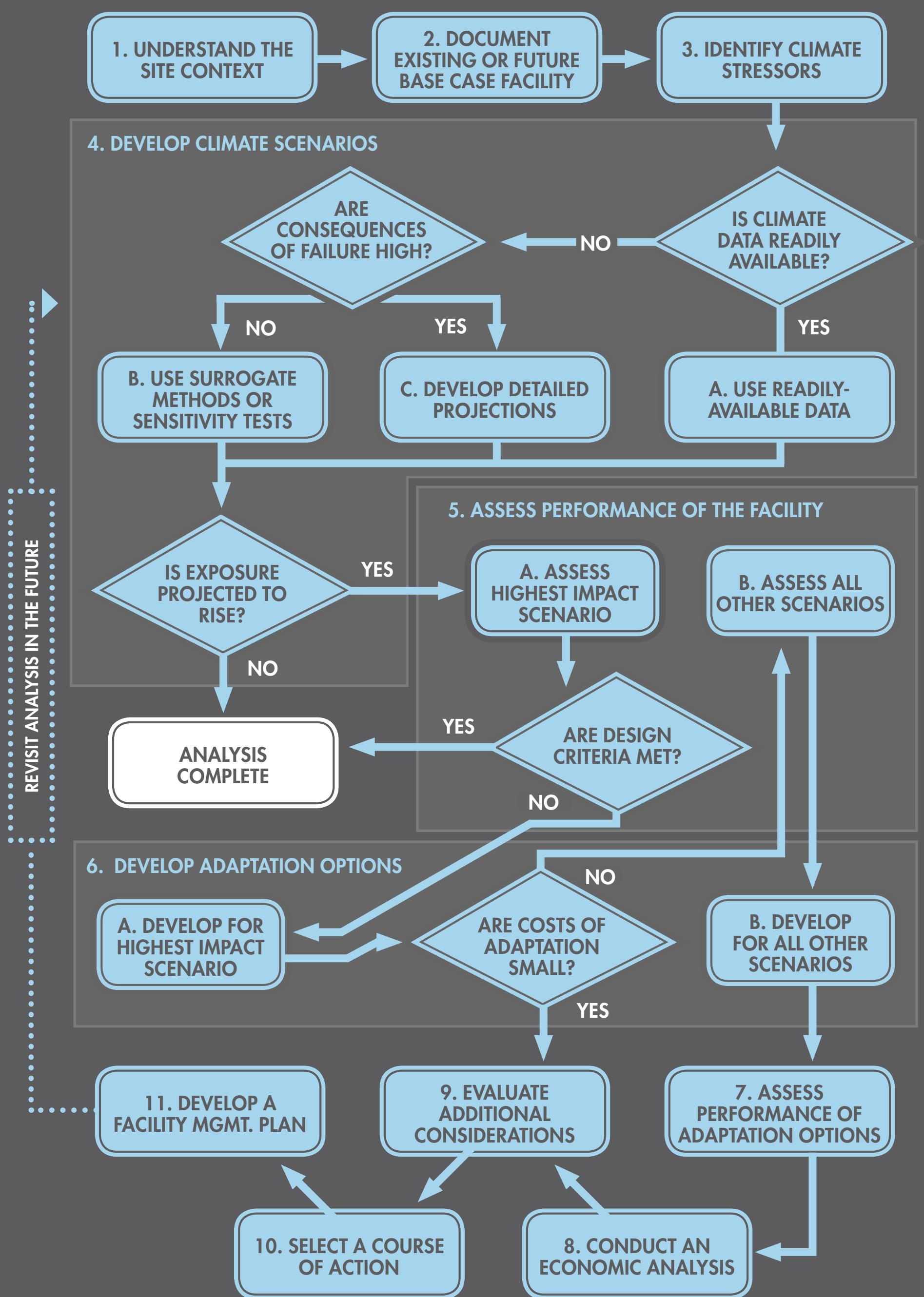
This vulnerability assessment is the first step in a multipart effort to identify State Highway System exposure to climate change, identify the potential impacts, and prioritize actions based on those impacts. The assets found to be at the greatest risk will undergo more detailed, ADAP-style assessments and risk-based design responses. While this effort is underway, District 3 will continue to respond to extreme weather impacts and take steps to increase the resiliency of its portion of the State Highway System wherever possible. Following is one example of a design response used to respond to damage on the District 3 State Highway System and prevent further impacts.

In 2015, the Rocky Fire in Colusa and Yolo counties burned nearly 70,000 acres and forced the closure of local highways, including SR-16 and SR-20. There was observed damage to both routes, including scorched slopes, burned vegetation, and minor roadway impacts. Given the potential for further impacts from rainfall, Caltrans District 3 initiated a Director's Order to respond before the winter season. This response involved armoring the eroded areas by recontouring and placing Rock Slope Protection (RSP), which included a fabric underlayment, drainage, a layer of rock, a soil mixture between rocks, and vegetation to stabilize the soils of the scorched slope. Vegetation, which typically includes shallow rooting plants like grasses, was applied through hydroseeding. The figures on the following page show some of the scorched slopes along SR-16 and SR-20, and some of the flooding and landslide impacts following the Rocky Fire on SR-16.

SLOPE STABILIZATION FOLLOWING THE ROCKY FIRE ON SR-16 AND SR-20

Fig. 15

FHWA'S ADAP DESIGN PROCESS

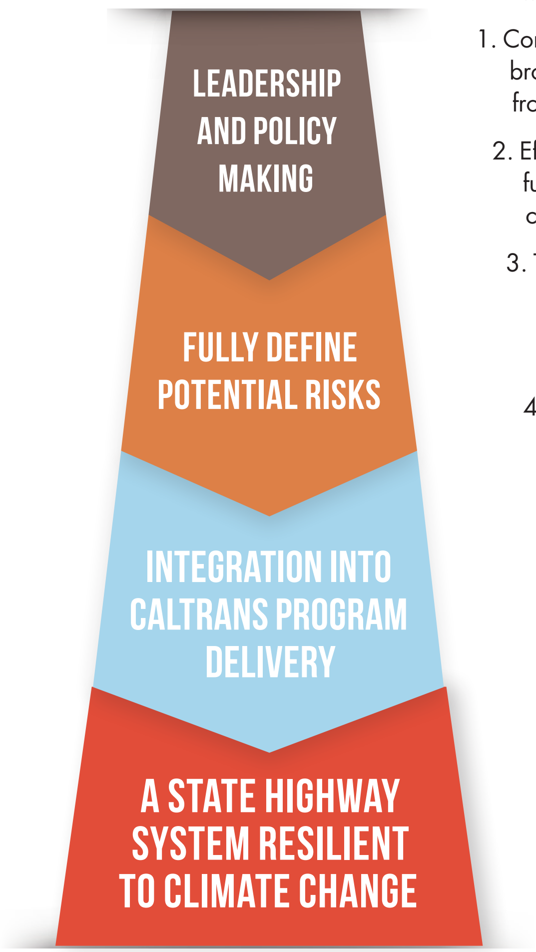


BURNED SLOPE FROM THE ROCKY FIRE

ARMOR RILL IN CUT SLOPE WITH RSP

HYDROSEED FILL SLOPE

WHAT DOES THIS MEAN TO CALTRANS?



GENERAL CONCLUSIONS

District 3's recent extreme weather events provide an opportunity to address many of the potential climate change impacts outlined in this report. Caltrans can draw the following conclusions:

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

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

FULLY DEFINE RISKS

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

INTEGRATION INTO CALTRANS PROGRAM DELIVERY

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

LEADERSHIP

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

COMMUNICATION AND COLLABORATION

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

A STATE HIGHWAY SYSTEM RESILIENT TO CLIMATE CHANGE

Considering climate change in a comprehensive and systematic way (using this report as a guide for the first steps) will lead to a State Highway System that is more resilient to extreme events and climate change.

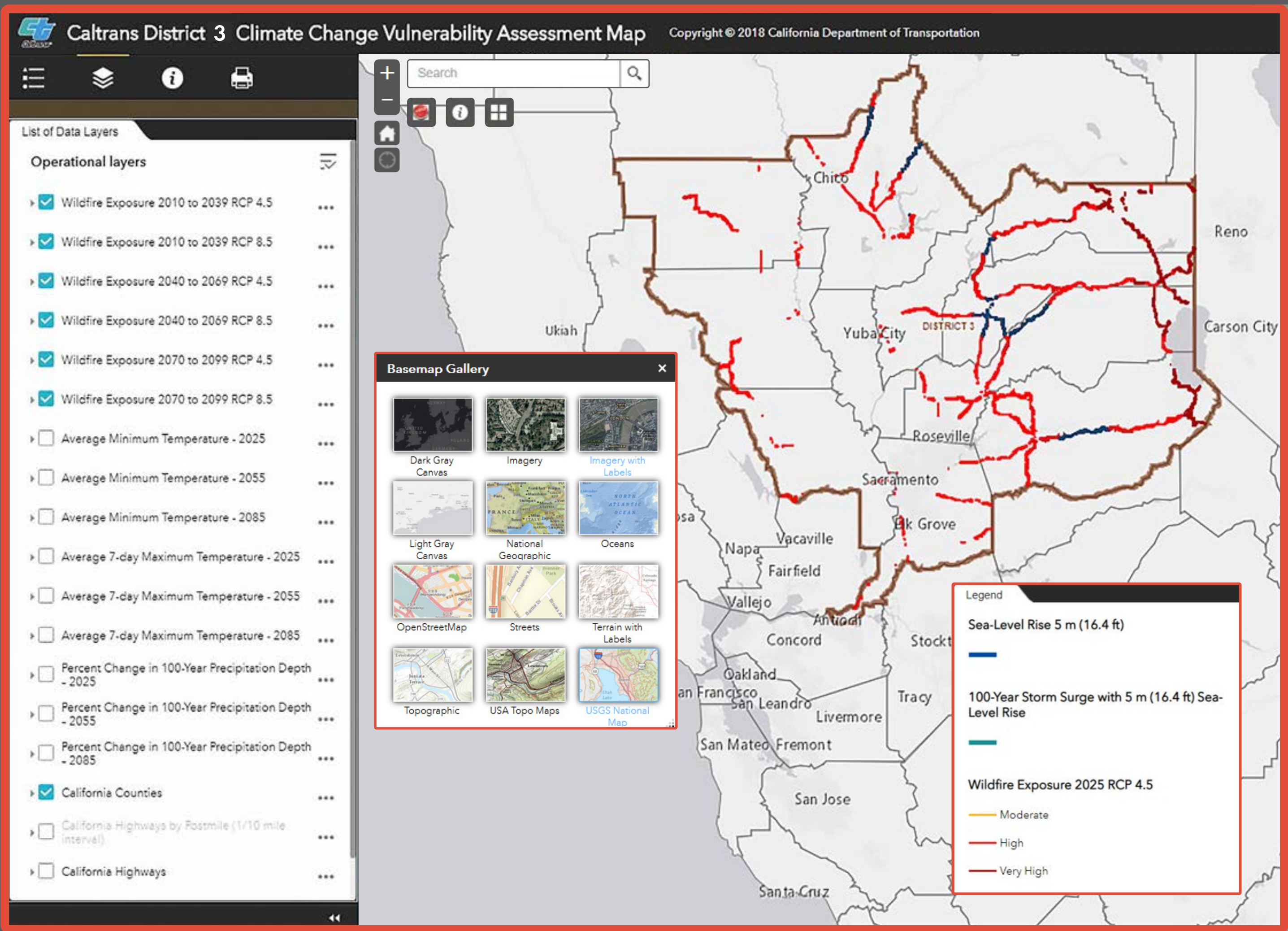
ONLINE MAPPING TOOL FOR DECISION-MAKING

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.[35]

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

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



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

- **Obtain/conduct stressor mapping:** The first step in each GIS analysis was to obtain or create maps showing the presence and value of a given climate stressor at various future time periods.
- **Determine critical thresholds:** To highlight areas affected by climate change, the geospatial analyses for certain stressors defined the critical thresholds for which the value of a hazard would be a concern to Caltrans.
- **Overlay the stressor layers with Caltrans 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.

Caltrans

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