CALTRANS CLIMATE CHANGE

VULNERABILITY ASSESSMENT SUMMARY REPORT

DISTRICT 5

2019

Caltrans | wsp

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

This Summary Report and its associated Technical Report describe climate change effects in District 5. 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 available for each of Caltrans 12 districts.

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

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

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

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

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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 greenhouse gas (GHG) 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 of precipitation and temperature used all ten of these representative GCMs, but only the median model (50th percentile result) 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 GHG emission concentrations under varying global economic forces and government policies. The four scenarios are RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5.

This assessment uses or references:

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

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

EVACUATION PLANNING

Among the things that Caltrans must consider when planning for climate change is the role of the SHS when disaster strikes. The SHS is the backbone of most county-level evacuation plans and often provides the only high-capacity evacuation routes from rural communities. In addition, state highways also serve as the main access routes for emergency responders, and may serve as a physical line of defense such as 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. The upcoming studies of climate change adaptation measures will take these factors into account when identifying measures appropriate to each situation.

SR 154 | PLUGGED CULVERT PUMPING

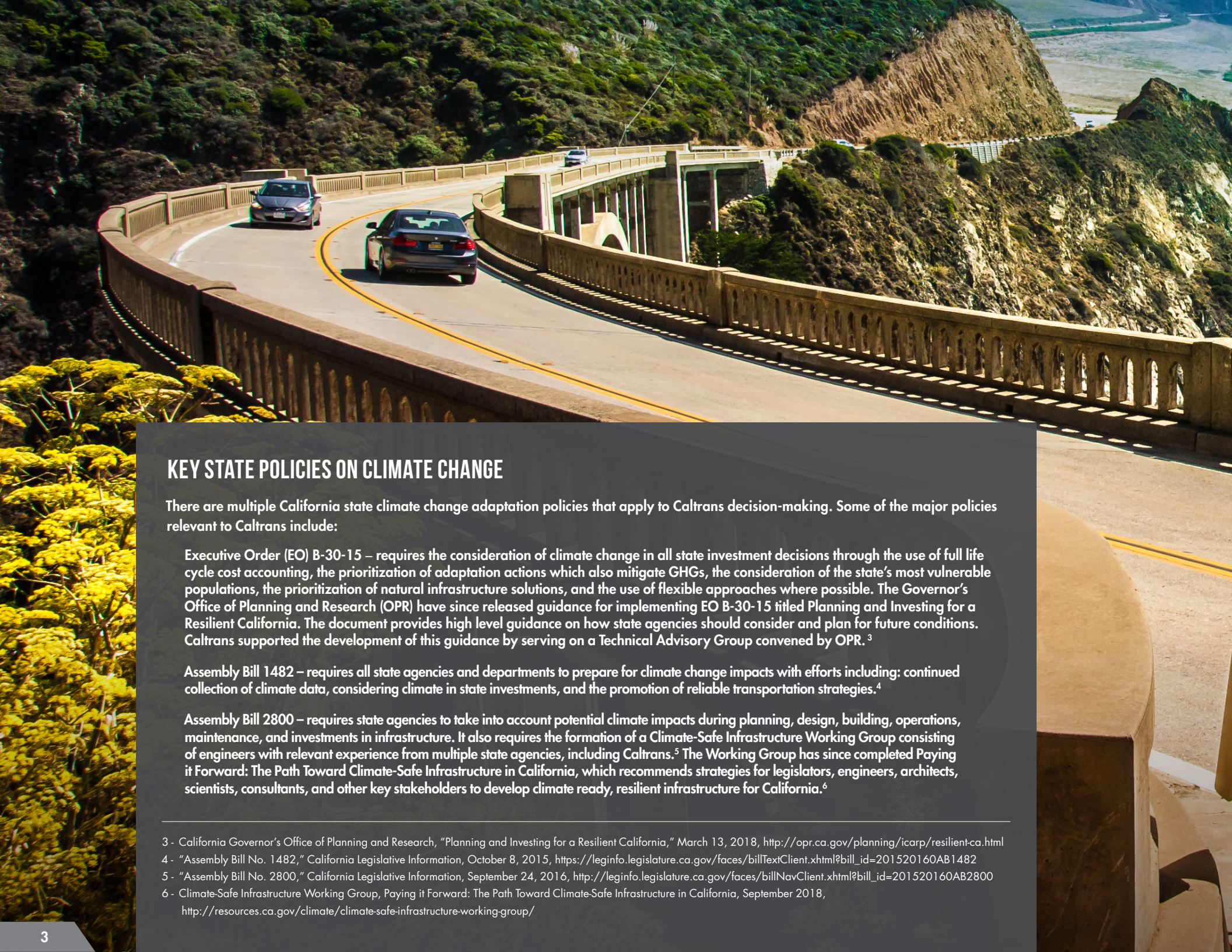
BACKGROUND AND APPROACH

Caltrans is making a concerted effort to identify the potential climate change vulnerabilities of the SHS.[2] 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 the best use of the most recent data. Discussions with professionals from various engineering disciplines helped identify the measures presented in this report.

This Summary Report presents information on potential vulnerabilities to the Caltrans District 5 portion of the SHS. It outlines various climate stressors and their potential effects on how highways are planned, designed, built, operated, and maintained. Specific projects and their potential costs are not identified—future studies will address these topics. This study's intent is to help explain potential climate change impacts in District 5 and begin to identify a subset of assets on the SHS on which to focus future efforts.

2 - Caltrans is also responsible for other assets, including those related to rail and mass transit, which are not the focus of this specific assessment.



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.[5] 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]

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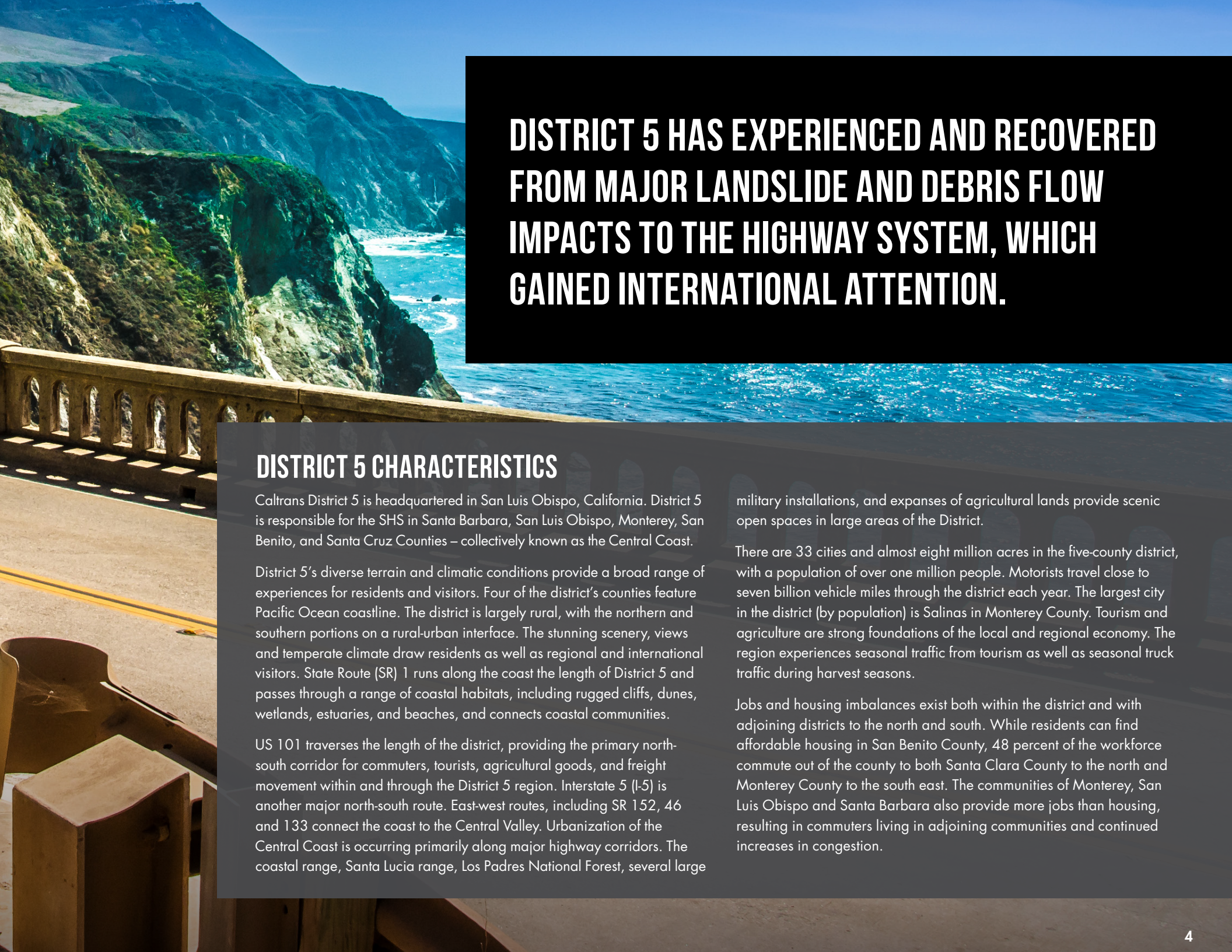
3 - California Governor's Office of Planning and Research, "Planning and Investing for a Resilient California," March 13, 2018, http://opr.ca.gov/planning/icarp/resilient-ca.html

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

5 - "Assembly Bill No. 2800," California Legislative Information, 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/



DISTRICT 5 HAS EXPERIENCED AND RECOVERED FROM MAJOR LANDSLIDE AND DEBRIS FLOW IMPACTS TO THE HIGHWAY SYSTEM, WHICH GAINED INTERNATIONAL ATTENTION.

DISTRICT 5 CHARACTERISTICS

Caltrans District 5 is headquartered in San Luis Obispo, California. District 5 is responsible for the SHS in Santa Barbara, San Luis Obispo, Monterey, San Benito, and Santa Cruz Counties – collectively known as the Central Coast.

District 5's diverse terrain and climatic conditions provide a broad range of experiences for residents and visitors. Four of the district's counties feature Pacific Ocean coastline. The district is largely rural, with the northern and southern portions on a rural-urban interface. The stunning scenery, views and temperate climate draw residents as well as regional and international visitors. State Route (SR) 1 runs along the coast the length of District 5 and passes through a range of coastal habitats, including rugged cliffs, dunes, wetlands, estuaries, and beaches, and connects coastal communities.

US 101 traverses the length of the district, providing the primary north-south corridor for commuters, tourists, agricultural goods, and freight movement within and through the District 5 region. Interstate 5 (I-5) is another major north-south route. East-west routes, including SR 152, 46 and 133 connect the coast to the Central Valley. Urbanization of the Central Coast is occurring primarily along major highway corridors. The coastal range, Santa Lucia range, Los Padres National Forest, several large military installations, and expanses of agricultural lands provide scenic open spaces in large areas of the District.

There are 33 cities and almost eight million acres in the five-county district, with a population of over one million people. Motorists travel close to seven billion vehicle miles through the district each year. The largest city in the district (by population) is Salinas in Monterey County. Tourism and agriculture are strong foundations of the local and regional economy. The region experiences seasonal traffic from tourism as well as seasonal truck traffic during harvest seasons.

Jobs and housing imbalances exist both within the district and with adjoining districts to the north and south. While residents can find affordable housing in San Benito County, 48 percent of the workforce commute out of the county to both Santa Clara County to the north and Monterey County to the south east. The communities of Monterey, San Luis Obispo and Santa Barbara also provide more jobs than housing, resulting in commuters living in adjoining communities and continued increases in congestion.

EXTREME EVENTS IN DISTRICT 5

In recent years, extreme weather events in District 5 have caused millions of dollars of damage. These events are examples of what the district could increasingly face in the future as California's climate changes.

- **Temperature** – District 5 has a Mediterranean climate, with cooler climatic conditions along the coastline and in the mountainous areas to the east. California's July 2017 heatwave not only set daily and monthly temperature records statewide, but also established a record-breaking streak of 100+ degree Fahrenheit days across much of the Central Coast. San Luis Obispo reached 108 degree Fahrenheit in October 2017, shattering the record of 103 set in 1959. Santa Maria reached 102 degrees, passing its record of 97 set in 1965.
- **Precipitation** – For decades, District 5 has experienced heavy precipitation events followed by flash floods, landslides, and debris flows. Flooding along coastal roads (such as SR 1) have disrupted traffic, and landslides and debris flows caused by heavy rainfall have significantly impacted the district's roads. The Mud Creek landslide (2017) closed SR 1 for over a year and necessitated $54 million in reconstruction and adaptation costs. In February 2017, heavy rains caused major rock slides which damaged the SR 1 Pfeiffer Canyon Bridge beyond repair and cut off access to Big Sur from both directions. A $24 million emergency project was required to replace the previous two-column bridge with a single-span steel girder structure. These two examples alone show how damaging and expensive heavy precipitation and associated slides can be.
- **Wildfire** – As temperatures rise and precipitation patterns become more unpredictable, wildfire risk is expected to increase. California's Fourth Climate Change Assessment states that, "by 2100, if greenhouse gas emissions continue to rise… the frequency of extreme wildfires burning over approximately 25,000 acres would increase by nearly 50%, and the average area burned statewide would increase by 77% by the end of the century."[7] In 2010, approximately 12% (6,883 acres) of San Benito County's total population of around 55,269 lived in fire hazard zones rated at medium to very high risk.[8] In 2018 alone, wildfires burned over 6,100 acres in District 5, and three people died as a result.
- **Sea Level Rise** – District 5 is already facing challenges associated with sea level rise. The City of Santa Cruz on the northern edge of Monterey Bay is developing an Adaptation and Management Plan for its most famous coastal roadway, West Cliff Drive. West Cliff Drive has become increasingly unstable as it erodes into the sea. The city's Climate Adaptation Plan notes that sea walls and riprap currently help protect the cliffs, but such protection will be an ongoing challenge as sea levels rise over the coming century. The Association of Monterey Bay Area Governments (AMBAG) is also conducting a resiliency study for the Moss Landing/Elkhorn Slough Corridor of SR 1. This assessment aims to understand the risks associated with cliff retreat and sea level rise in this area, with the end goal of identifying adaptation alternatives that meets transportation needs, while promoting healthy coastal habitats.

  Since 1920, sea levels have risen by about 0.06 inches (1.57 millimeters)[9] per year in Monterey Bay and around 0.04 inches (one millimeter)[10] per year in Port San Luis. By the end of the century, Central Coast sea levels will likely rise by anywhere from 0.7 to 9.9 feet above current levels (for more detail on projections, see the Sea Level Rise section).

7 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.
8 Ibid.
9 NOAA, "Relative Sea Level Trend: 9413450 Monterrey, California," NOAA Tides and Currents, Last accessed August 23, 2019 from https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=9413450
10 NOAA, "Relative Sea Level Trend: 9412110 Port San Luis, California," NOAA Tides and Currents, Last accessed August 23, 2019 from https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=9412110

TORO CANYON CREEK | BRIDGE REPLACEMENT | SANTA BARBARA COUNTY

TORO CANYON CREEK | BRIDGE DAMAGE | SANTA BARBARA COUNTY

PFEIFFER CANYON BRIDGE | DESTABILIZED BY LANDSLIDE | MONTEREY COUNTY

SR 1 | ROCKY CREEK SLIPOUT | MONTEREY COUNTY

SR 154 | FIRE DAMAGE | SANTA BARBARA COUNTY

VULNERABILITY AND THE STATE HIGHWAY SYSTEM

CALTRANS EFFORTS

Caltrans has been addressing climate change concerns over the last decade and has now developed guidance for effectively incorporating climate change considerations into project design and other functional responsibilities. Activities include:

- Issuing Addressing Climate Change Adaptation in Regional Transportation Plans (2013) which serves as a how-to guide for California Metropolitan Planning Organizations (MPOs) and Regional Transportation Planning Agencies (RTPAs).
- Releasing Guidance on Incorporating Sea Level Rise (2011) to advance effective design and programmatic considerations that incorporate sea level rise projections.
- Signing 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.[11]
- Reporting adaptation goals and progress to OPR through the State Sustainability Roadmaps, Adaptation Chapters.[12]

Caltrans ongoing efforts include developing a stronger understanding of the risks to the state's transportation system and taking the actions necessary to ensure the resiliency of California's transportation system.

ADDRESSING CONCERNS IN DISTRICT 5

Caltrans District 5's portion of the SHS serves important functions for commerce, communities, and more—which makes understanding the potential impacts of climate change and extreme weather on its performance a key part of creating a resilient highway system.

"Vulnerability" often describes the degree to which facilities, assets, and even the entire transportation system, might be disrupted by climate change or other stressors. Caltrans is focusing on the system's vulnerability to extreme weather and climate-related hazards—and it recognizes that many Caltrans units are critical assets for developing a resilient state transportation system.

The approach outlined on the following page describes a process consistent with Caltrans practices. It focuses on:

- **Consequence** – determining what damage might occur to system assets in terms of loss of use or cost of repair.
- **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 damages from wildfire.
- **Prioritization** – determining how to make effective capital programming decisions to address risks (including the consideration of system use and timing of expected exposure).

Implementing this approach requires the efforts of a wide range of Caltrans professionals from asset management, planning, operations and maintenance, design, emergency response, and economics. It also requires coordination with environmental and social resource agencies. The success of this approach requires an agency-wide effort.

ENSURING SYSTEM RESILIENCY

After identifying system vulnerabilities, Caltrans will begin the next phase of this assessment which will include prioritizing the district's most vulnerable assets for facility-level assessment and developing adaptation responses as necessary. Protecting the highway network's most critical and vulnerable assets will enhance overall system resiliency. Some potential adaptation strategies for District 5 include:

- Adapting the Caltrans Highway Design Manual's drainage and flood protection design criteria for assets along the coast or in low-lying areas to ensure that adequate flood protection. For example, Caltrans could increase bridge freeboard requirements or culvert drainage capacities.
- Managing the retreat of the portions of the SHS that are vulnerable to sea level rise and coastal erosion and cannot be protected or saved.
- Siting any new roadways in locations outside of vulnerable areas for the life of the roadway, to the greatest extent possible.
- Identifying and prioritizing protection of assets in poorer condition, that may be more susceptible to climate stressor impacts.
- Exploring strategies for beneficial reuse of sediment from flood basins, landslides, projects, and other activities. This may include beach replenishment and could be coordinated with stakeholders like the California Coastal Sediment Management Workgroup.
- Creating plans that are flexible and allow for the continued adaptation of assets and systems as certain triggers and thresholds are reached.

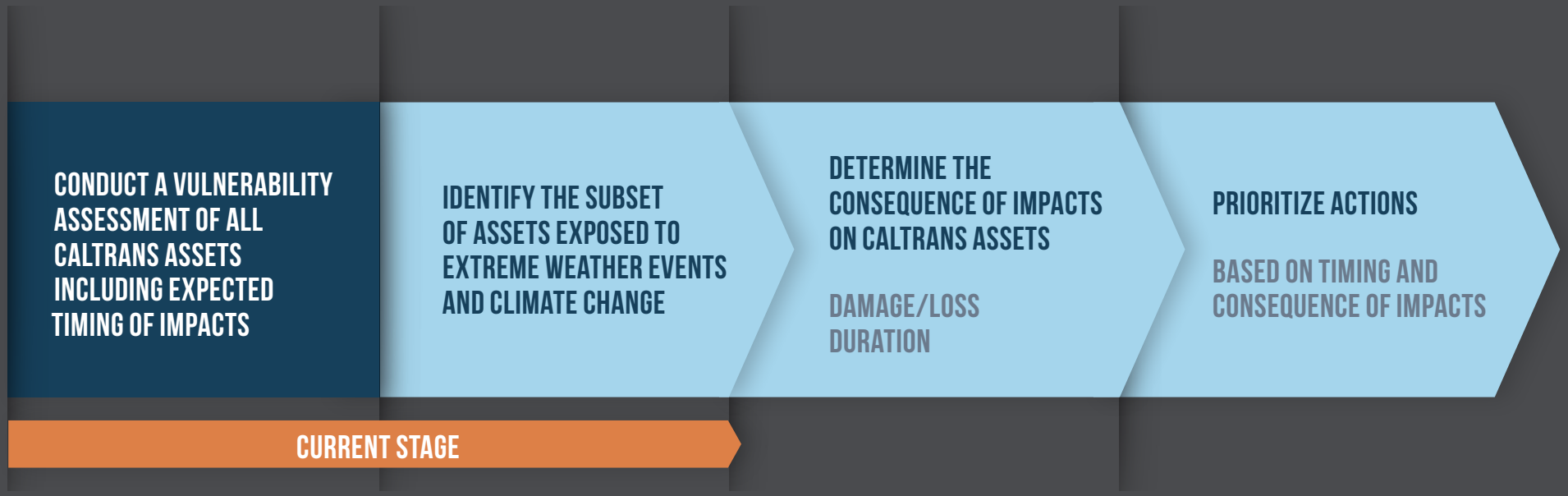
These efforts will require Caltrans to be proactive and invest in the long-term viability of the transportation system—but building a more resilient system now may help reduce maintenance and repair costs later.

11 - Plan for Improved Agency Partnering: Caltrans and California Coastal Commission," December 21, 2016, https://dot.ca.gov/-/media/dot-media/programs/environmental-analysis/documents/iaccc-improved-agency-partnering-agreement-a11y.pdf

12 - 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:



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. One key indicator for this measure is the potential timing of impact (e.g. the year or time frame a potential condition is expected 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 SHS resiliency.

EFFORTS IN DISTRICT 5 TO ADDRESS CLIMATE CHANGE

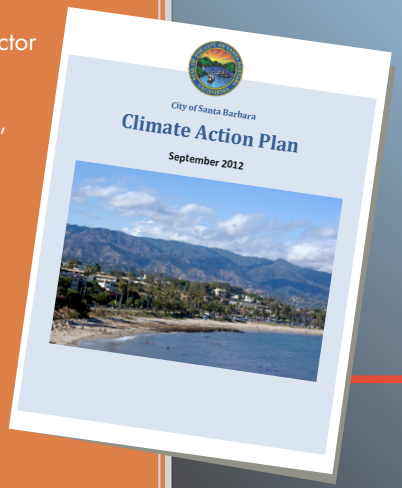
Caltrans recognizes that other regional efforts to mitigate the effects of climate change are underway in District 5. Ongoing coordination with local governments and stakeholders will be critical to ensuring that methodologies and adaptation strategies are not redundant with other efforts—this is especially important for combating the kinds of stressors that will affect large numbers of people and require a collective response, such as wildfires, landslides, and rising seas.

CITY OF SANTA BARBARA CLIMATE ACTION PLAN

The City of Santa Barbara developed a Climate Action Plan in 2012 that focuses on strategies to, 1) reduce carbon emissions in energy consumption, travel and land use, vegetation, waste reduction, and water conservation, and 2) adapt to expected climate change impacts.[13] The potential climate change-related impacts that City officials identified include:

- Increased frequency and severity of heatwaves, droughts, and wildfires
- Larger storms and associated flooding and erosion
- Increased air and water pollution, and changes in pest and vector transmission
- Sea level rise effects on storm damage, inundation, beach loss, and coastal cliff erosion
- Changes to water, agriculture, and food supplies
- Increased energy demand
- Effects on wildlife and habitats
- Changes to local economies such as tourism and fisheries.

Santa Barbara's Climate Action Plan identifies some specific responses and needs including a local vulnerability assessment of future climate change effects, identification of options for local adaptation projects, incorporation of climate change into the city's emergency response strategies, and continued pursuit of grant funding for studies and adaptation planning.



13 - City of Santa Barbara, "Climate Action Plan," 2012, Last accessed August 23, 2019, https://www.santabarbaraca.gov/civicax/filebank/blobdload.aspx?BlobID=17720

CITY OF SANTA CRUZ CLIMATE ADAPTATION PLAN

The City of Santa Cruz adopted an updated Climate Adaptation Plan (CAP) in 2018, which includes:

- The city's first sea level rise vulnerability assessment, with climate hazard map projections for 2030, 2060, and 2100
- The city's first social vulnerability assessment, with maps of the census blocks deemed most vulnerable socially due to their intersection with climate hazard projections,
- An updated assessment of noncoastal impacts,
- Details on progress since the 2011 CAP which show that Santa Cruz's adaptation effort is one of the most active of any community in the nation.

Some of the plan's strategies include:

- Addressing climate change effects through changes in land use and building codes for low-lying areas that may experience flooding from increasing sea levels and greater storm intensity,
- Identifying areas that should be protected from the combined forces of sea level rise and increased storm intensity, and considering policies to more safely align roads and utility infrastructure,
- Developing policies that establish effective review processes for proposed capital improvement projects to help minimize risk and maximize capital investment within existing and future hazard zones,
- Relocating or upgrading facilities or infrastructure that increased storm events, sea level rise, coastline or cliff erosion, flooding, or saltwater intrusion may impact.[14]

CENTRAL COAST CLIMATE COLLABORATIVE

The Central Coast Climate Collaborative (4C) is a member of the Alliance of Regional Collaboratives for Climate Adaptation (ARCCA), which is a coalition of collaboratives across California that strive to build regional resilience to climate change impacts. The mission of 4C is to foster a network of local and regional partnerships for climate change mitigation and adaptation. In 2018, 4C held a series of workshops focused on topics such as building resilient communities and funding adaptation strategies in Central Coast communities. One of the presentations made the economic case for resilience, and suggested conducting full project-lifecycle cost accounting to achieve the triple bottom line (social, environmental, and financial). Other workshop topics focused on emergency preparedness, disaster response, fire suppression, and vulnerability assessment findings.[15] These presentations, along with other resources for Central Coast communities, are available on 4C's website, centralcoastclimate.org.

14 - City of Santa Cruz, "Climate Adaptation Plan Update: 2018 – 2023," October 9, 2018, http://www.cityofsantacruz.com/home/showdocument?id=73396

15 - "Resources, Central Coast Climate Collaborative, 2018, Last accessed August 24, 2019, http://www.centralcoastclimate.org/resources/

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.

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.

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

SCOPE OF THIS STUDY

UNDERSTAND POSSIBLE TRANSPORTATION IMPACTS:

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

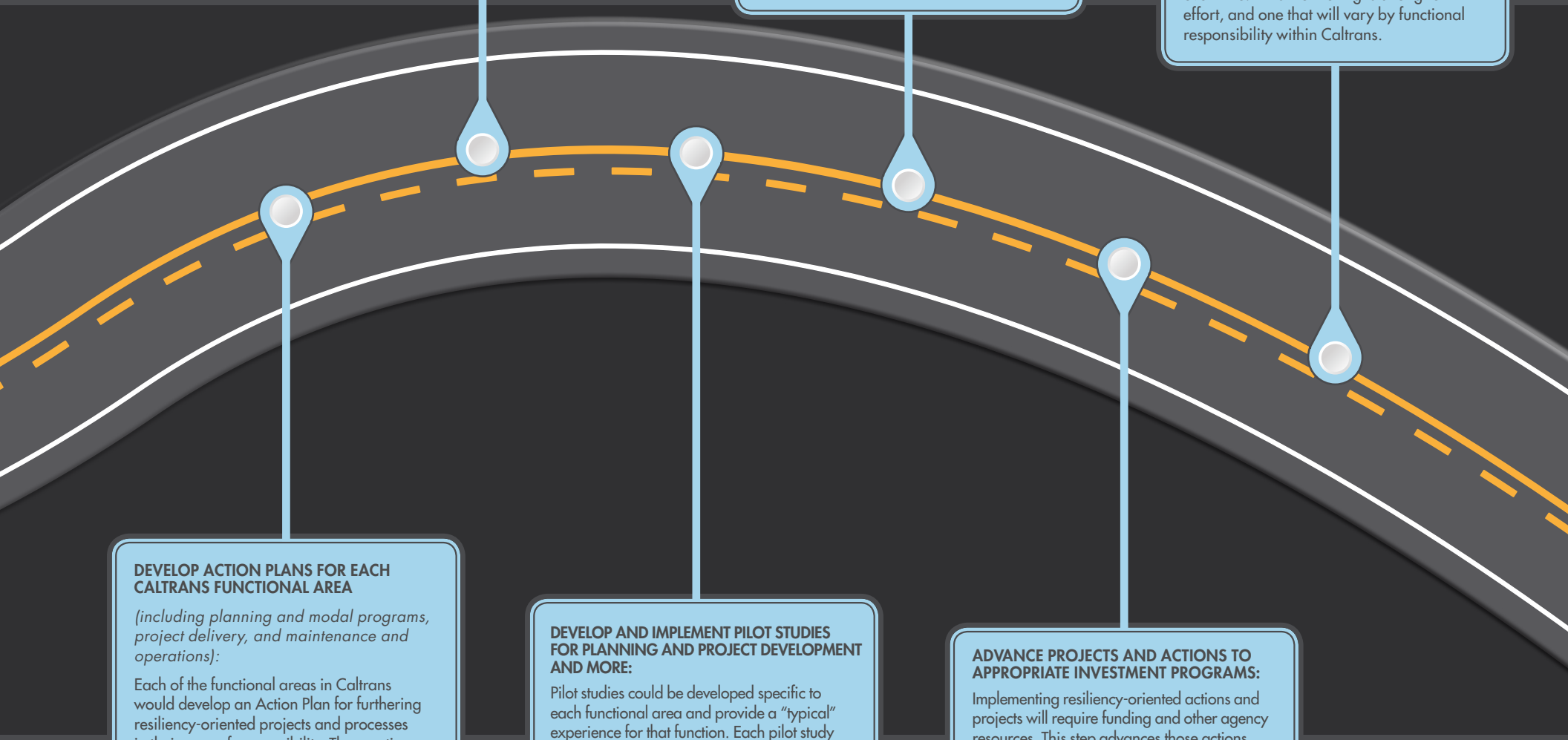
INITIATE VULNERABILITY ASSESSMENT:

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 PRIORITIZATION METHOD FOR CALTRANS INVESTMENTS:

This step identifies the process that Caltrans can use to prioritize projects and actions based on their likely system resiliency benefits through reduced impacts to system users.

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



INCORPORATE RESILIENCY PRACTICES THROUGHOUT CALTRANS:

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

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.

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.

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

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.

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.

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."[16] Because of 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 that compares the average maximum temperature change over the course of seven consecutive days (which is important for determining the best pavement mix for long-term performance) for three time periods, to data from 1975 to 2004. This figure demonstrates that under the median model applied (CMCC-CMS), temperatures are rising across District 5 and will through the end of the century. US studies generally show that rising temperatures could impact the transportation system in several ways, including:

DESIGN

- 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.
- Ground conditions and water saturation levels can affect retaining walls and foundations.

OPERATIONS AND MAINTENANCE

- Higher temperatures could cause expansion that deteriorates bridge joint seals, which could accelerate replacement schedules, and even affect bridge superstructure.
- Extreme heat could affect employee health and safety, especially for those working long hours outside.
- 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.

EFFECTS OF TEMPERATURE CHANGE IN DISTRICT 5

Figure 1 shows rising average maximum temperatures over seven consecutive days across District 5 compared to historical averages. By 2025 (which represents 2010 to 2039), temperatures are expected to rise by anywhere from 0 to 5.9 degrees Fahrenheit. By 2055 (representing 2040 to 2069), the projected rise is 4 to 7.9 degrees Fahrenheit. Finally, by 2085 (representing 2070 to 2099), the expected temperature rise is 6 to 11.9 degrees Fahrenheit. These values are the added temperature rise above the current average maximum temperatures, meaning that the hottest hot days in District 5 could be up to 11.9 degrees warmer—this has implications for the health and comfort of people living, working, and traveling in District 5. It also has implications for the design of the SHS because high temperatures can affect materials and roadside landscaping.

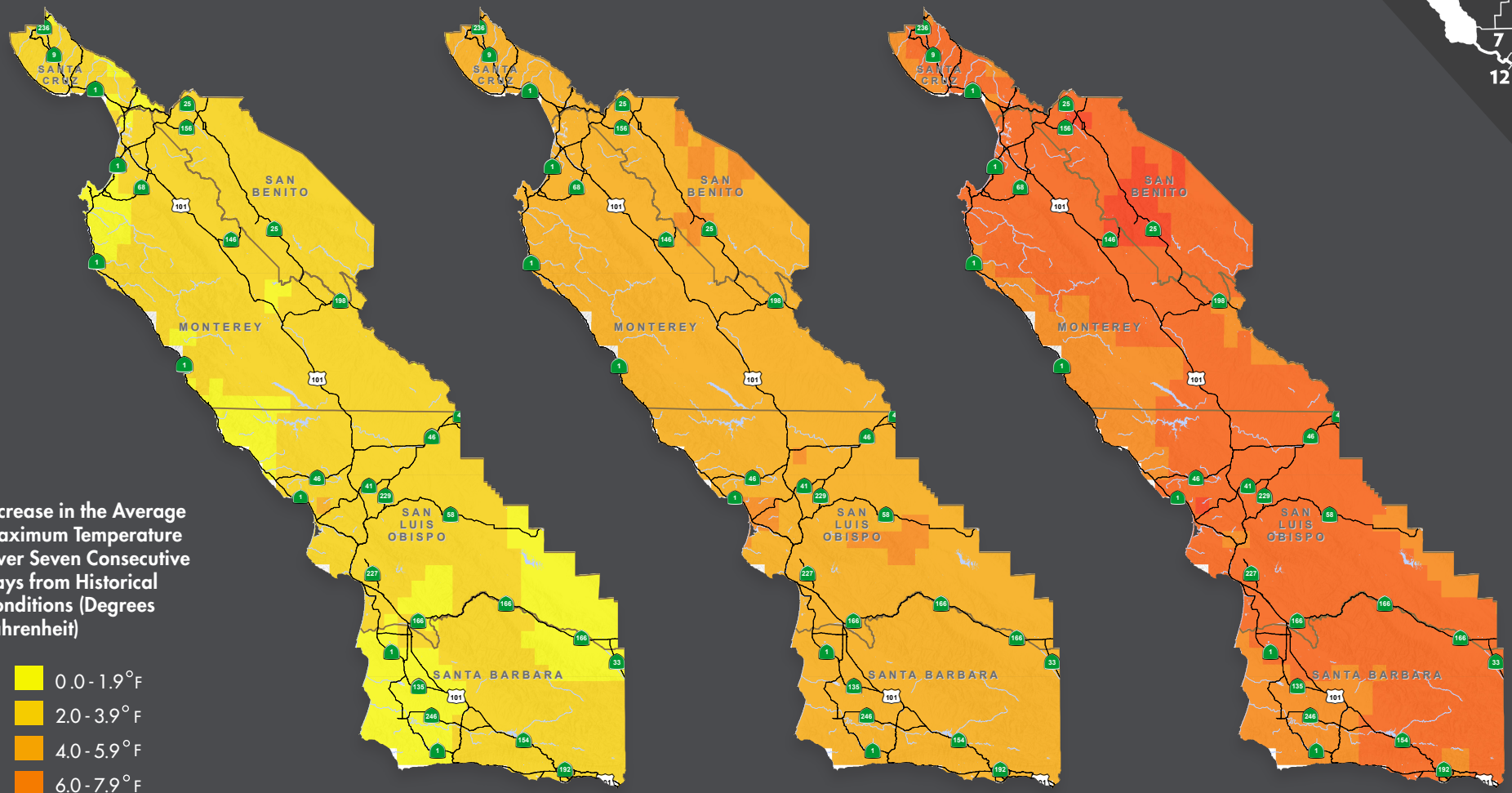
16 - "Extreme Weather," U.S. National Climate Assessment, accessed April 29, 2019, http://nca2014.globalchange.gov/report/our-changing-climate/extreme-weather

SR 58 | PAVEMENT DAMAGE FROM HEAT | SAN LUIS OBISPO COUNTY

Fig. 1

INCREASE IN THE AVERAGE MAXIMUM TEMPERATURE OVER SEVEN CONSECUTIVE DAYS

A REQUIRED MEASURE FOR PAVEMENT DESIGN



Increase in the Average Maximum Temperature Over Seven Consecutive Days from Historical Conditions (Degrees Fahrenheit)

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

Median Model (CMCC-CMS)

2025

RCP 8.5, 50TH PERCENTILE

2055

RCP 8.5, 50TH PERCENTILE

2085

RCP 8.5, 50TH PERCENTILE

Future Change in the Average Maximum Temperature Over Seven Consecutive Days within District 5, Based on RCP 8.5.

Caltrans Transportation Asset Vulnerability Study, District 5. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown were 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

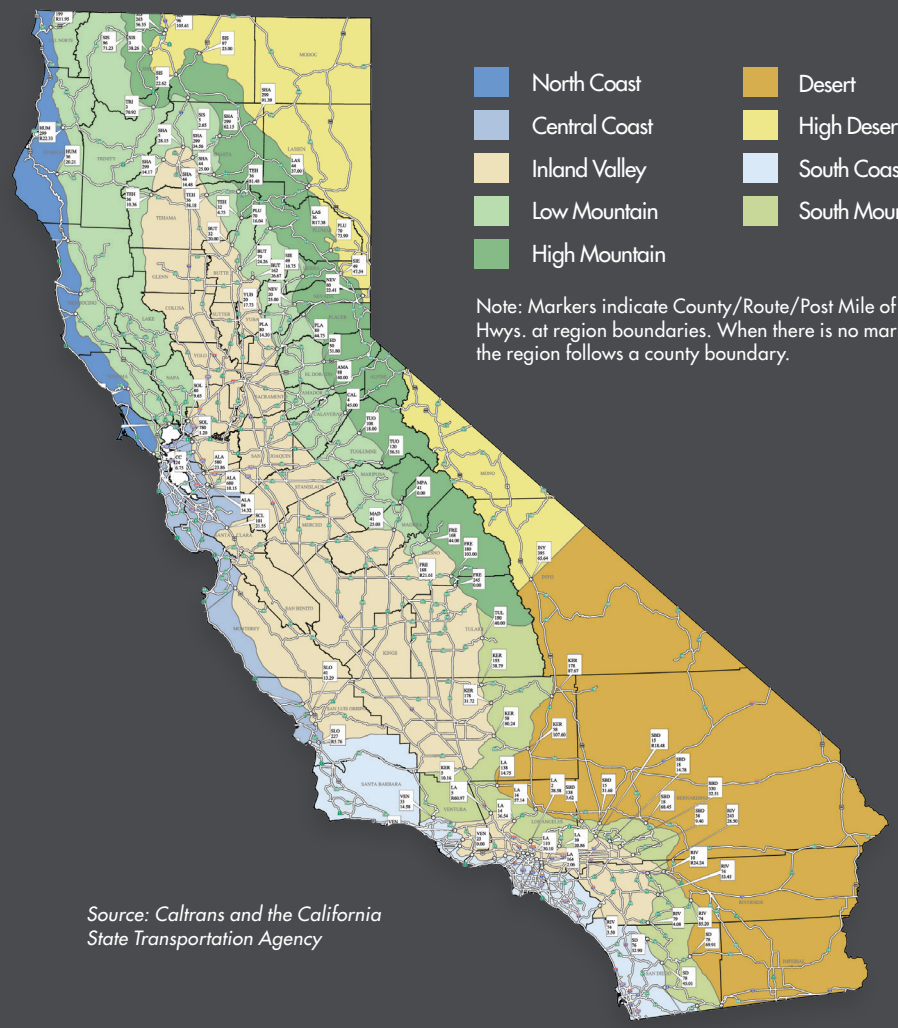
Every state transportation agency has the responsibility to ensure the good ride quality and durability of highway pavements under various conditions. Pavement design affects its durability, which is an important component of Caltrans' highway asset management strategy. Various factors help determine if highway pavement should be a concrete or an asphalt mix—for asphalt mixes, the project area's temperature conditions help determine the best pavement binder, which is a critical for durability.

Because of pavement's shorter design life, preparing it for climate change is different than for other assets. Caltrans' bridges, roadways, culverts, and many other assets will likely be in place for a long time, so decisions made for them today need to consider those timespans. Depending on its purpose, asphalt pavement is replaced relatively frequently—often every 20-40 years.

To help determine pavement type recommendations for different areas, Caltrans has divided the state into nine pavement climate regions (as shown in Figure 2). The two primary considerations in pavement design are 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. Caltrans and its pavement design engineers will need to consider whether the boundaries of these climate regions could shift as a result of climate change, or whether regional pavement design parameters might need to change due to climatic changes.

Fig. 2

CALTRANS PAVEMENT REGIONS



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

Source: Caltrans and the California State Transportation Agency

PAVEMENT QUALITY MAY BE AFFECTED BY LONG TERM CHANGES IN TEMPERATURE

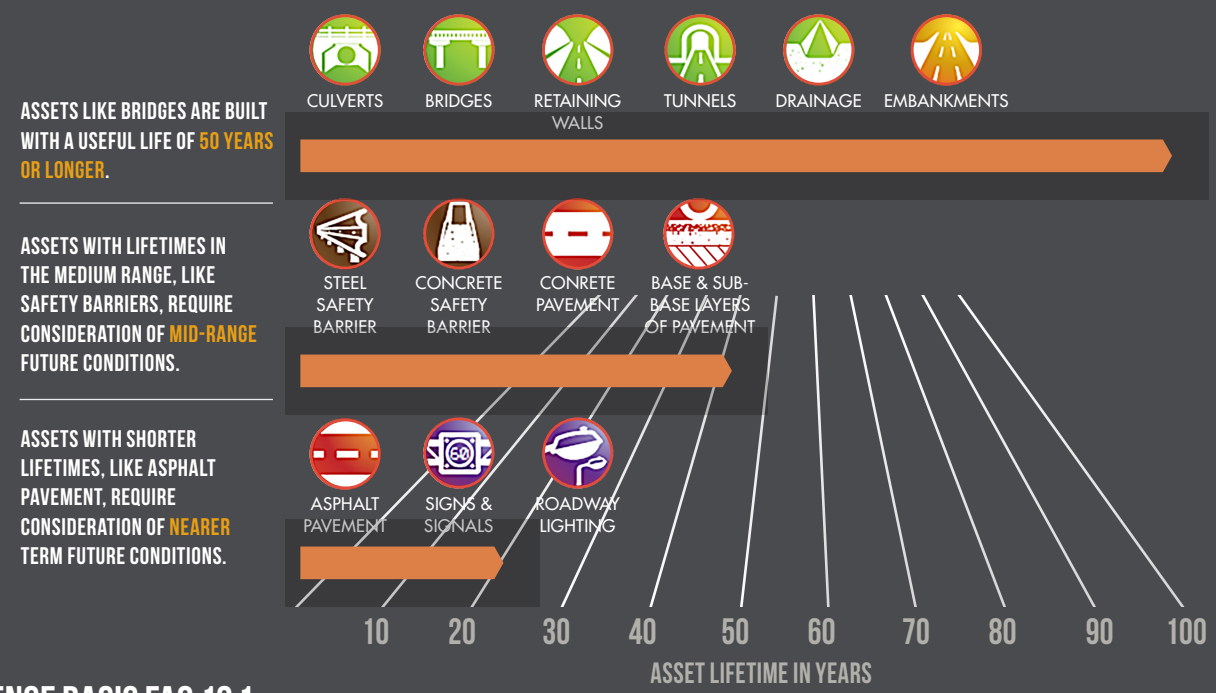
TIMEFRAMES AND ASSET DECISION-MAKING

Transportation asset decision-making must incorporate many factors, including the asset's design life (or useful life)—which is how long the asset will be in place. Some Caltrans assets, such as asphalt pavement, are replaced every 20-40 years, while others, such as bridges, can last more than 50 years. Road alignments can last over a century, as did the first national highway (as it was then defined). It was built to connect settlers to the Ohio Valley and the west and is still in use today.

Design-life considerations are critical in transportation investment planning. Figure 3 illustrates how emission levels and global response may significantly affect temperature scenarios in the future. Through around 2050, temperature conditions are fairly consistent—but then they begin to more significantly diverge. This indicates that investment decisions for the end of the century must include a much wider range of uncertainty.

Fig. 4

TRANSPORTATION INFRASTRUCTURE ASSETS

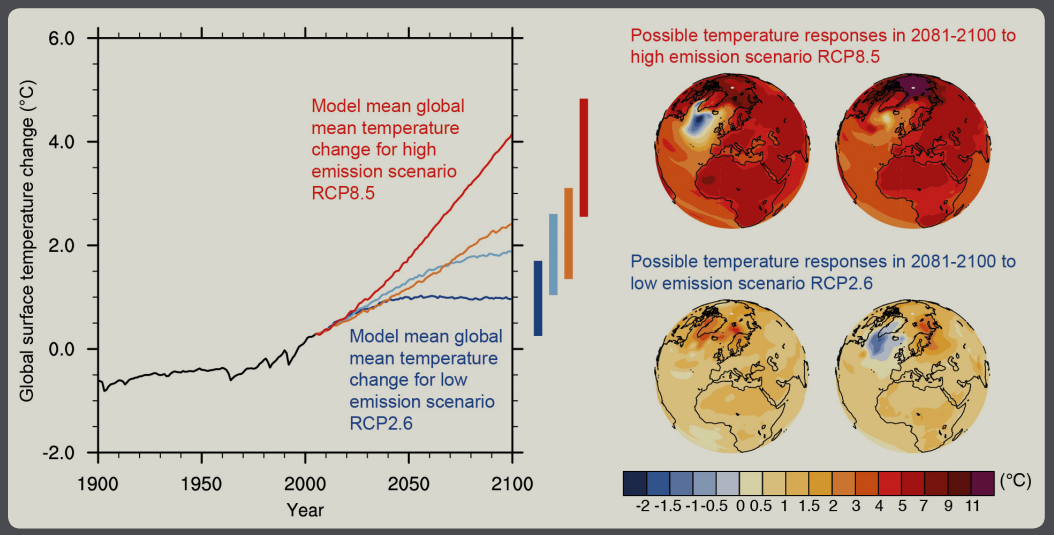


The graphic above was prepared to show how assets maintained by Caltrans will require different considerations for planning and design. All decisions should be forward-looking instead of based on historic trends, because all future scenarios show changing conditions. These future conditions must be considered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

Source: UK Highways Agency

Fig. 3

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



Source: IPCC

PRECIPITATION

Rising temperatures will increase atmospheric moisture and energy—which is expected to change the nature of precipitation events in California. More intense storms, combined with other changes in land cover and land use, can raise the risk of damage or loss from flooding. Precipitation affects transportation assets in California in many ways, including through landslides, flooding, washouts, erosion, and debris flows. The main threat is larger and more frequent storm events and their resulting damage to the SHS.

The Scripps Institution of Oceanography at the University of California, San Diego has projected future rainfall data to the year 2100 using two different emission concentration pathways and a variety of models. A storm with a likelihood of occurring once every 100 years (or a one percent chance of occurring in any given year) is called a "100-year storm event," and it is one good way to examine this data. Such storms are a useful design standard for infrastructure projects, because they could cause major damage. Understanding how the 100-year storm may change can help Caltrans build more resilient infrastructure to accommodate heavier storm events. The percentage increase in the 100-year storm depth across District 5 is shown in the figure on the following page. The median model for precipitation change was applied (HadGEM2-CC) in this analysis and model results show that the 100-year storm depth is expected to increase in the future. It is important to note that the 100-year storm event represented here is not associated with the event discussed in the storm surge section. These projections account for changes in precipitation rather than coastal flooding.

PRECIPITATION CHANGE EFFECTS IN DISTRICT 5

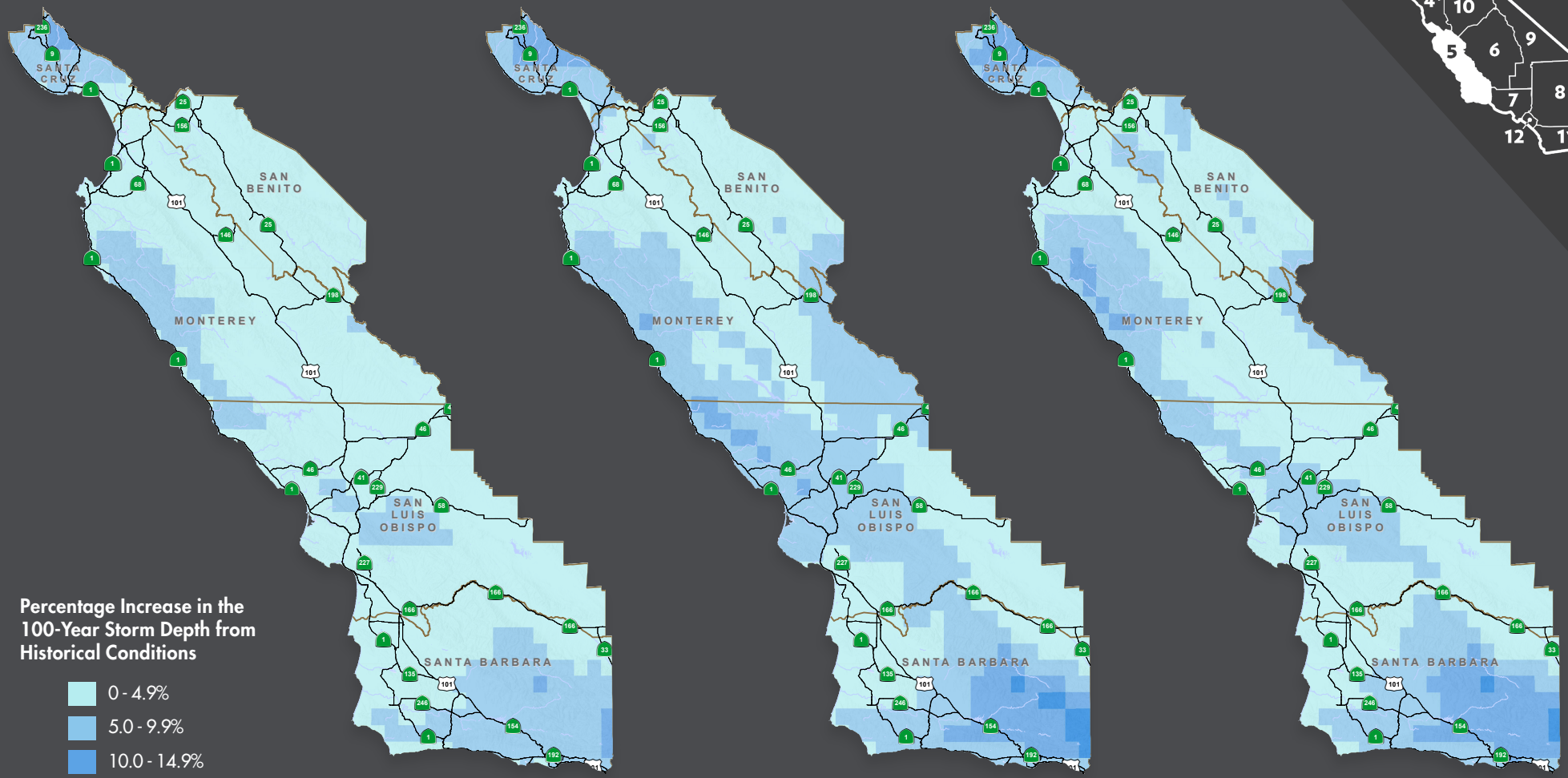
As seen in Figure 5, the 100-year storm depth is expected to increase by anywhere from 0 to 19.9% over the coming century. The greatest increases are projected for the years 2055 (representing 2040 to 2069) and 2085 (representing 2070 to 2099). There are some regional differences in the precipitation projections, with Santa Cruz and Santa Barbara counties showing the greatest overall increases in precipitation. This information is useful for planning-level studies, but the district will still need to conduct hydrologic analyses to better understand risks to bridges, culverts, and other assets affected by runoff and river flows. These analyses should consider future precipitation projections to ensure effective asset design for future conditions. This analysis does not consider the effects of changing floodplains, which may also affect SHS assets.

PFEIFFER CANYON | DAMAGED BRIDGE

MUDCREEK | MUD SLIDE

Fig. 5

PERCENT CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH



Future Percent Change in 100-year Storm Precipitation Depth within District 5, Based on RCP 8.5.

Caltrans Transportation Asset Vulnerability Study, District 5. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown were 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.

The 100-year storm precipitation depth represented here is not necessarily associated with the 100-year storm surge event in the "Storm Surge" section. These projections account for changes in precipitation rather than coastal flooding.

WILDFIRE

Higher temperatures and changing precipitation patterns are expected to affect both the intensity and scale of wildfires. Increases in temperatures decrease the moisture in vegetation and soils and lead to a higher risk of wildfire. In addition, wildfires can contribute to flooding and landslides because they burn off protective land cover and reduce the ability of the underlying soil to absorb rainfall. California is already prone to serious wildfires—and future climate forecasts suggest that this condition 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 later issued Executive Order N-05-19 to create a task force to develop a community resilience and education campaign and provide immediate, mid-, and long-term suggestions to prevent deadly and destructive wildfires.

Figure 6 shows the increased likelihood of wildfires in District 5 based on projected area burned. These projections incorporate 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. Three downscaled GCMs were paired with each model to produce nine future scenarios. Using three different wildfire models was a conservative approach because final data shows the highest wildfire risk categorization of all model results. These results were split up into different levels of wildfire likelihood (or "concern") ranging from very low to very high. See the associated District 5 Technical Report to learn more about how these levels of concern were determined. The results of the assessment using the high-emissions pathway (RCP 8.5) are shown in Figure 6 and Table 1. The associated District 5 Technical Report includes the RCP 4.5 results.

WILDFIRE EFFECTS IN DISTRICT 5

Wildfires are a major risk in District 5—Figure 6 shows that by as early as 2025 (which represents the years 2010 to 2039) most of the SHS will lie in areas of medium to very high wildfire concern. Some portions of District 5's highway network lie outside these concern areas, such as the section of US 101 that traverses agricultural areas between Salinas and King City. Note that areas of medium concern in 2025 become high or very high concern in 2055 (representing 2040 to 2069) and 2085 (2070 to 2099). The hatch marks on each map show where the models agree on the level of wildfire concern—this means that there is a higher level of confidence for the projections for those locations. Areas without hatch marks show the highest projected wildfire concern identified by the models. Table 1 shows the centerline mileage of the SHS that passes through the medium to very high concern areas. See the associated District 5 Technical Report for a more detailed breakdown of the mileage.

Table 1: Centerline Miles of State Highways in Medium to High Wildfire Concern Areas under the RCP 8.5 Scenario

County	Year		
	2025	2055	2085
Monterey	**154**	**178**	**189**
Santa Barbara	**165**	**174**	**174**
San Benito	**64**	**64**	**64**
Santa Cruz	**44**	**81**	**98**
San Luis Obispo	**334**	**340**	**349**

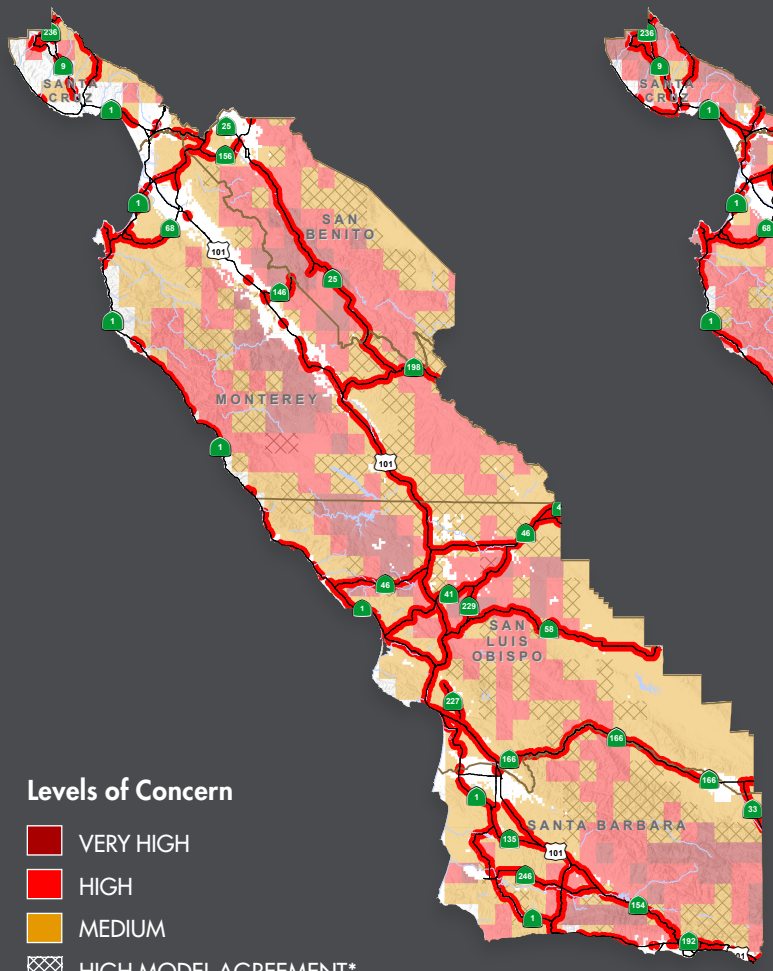
Note: Data does not include other state roads or local streets and roads.

2017 THOMAS FIRE EVACUATIONS | PHOTO BY SALVADOR LOPEZ-ZAMORA

SR 192 - 2017 THOMAS FIRE EVACUATIONS | PHOTO BY SALVADOR LOPEZ-ZAMORA

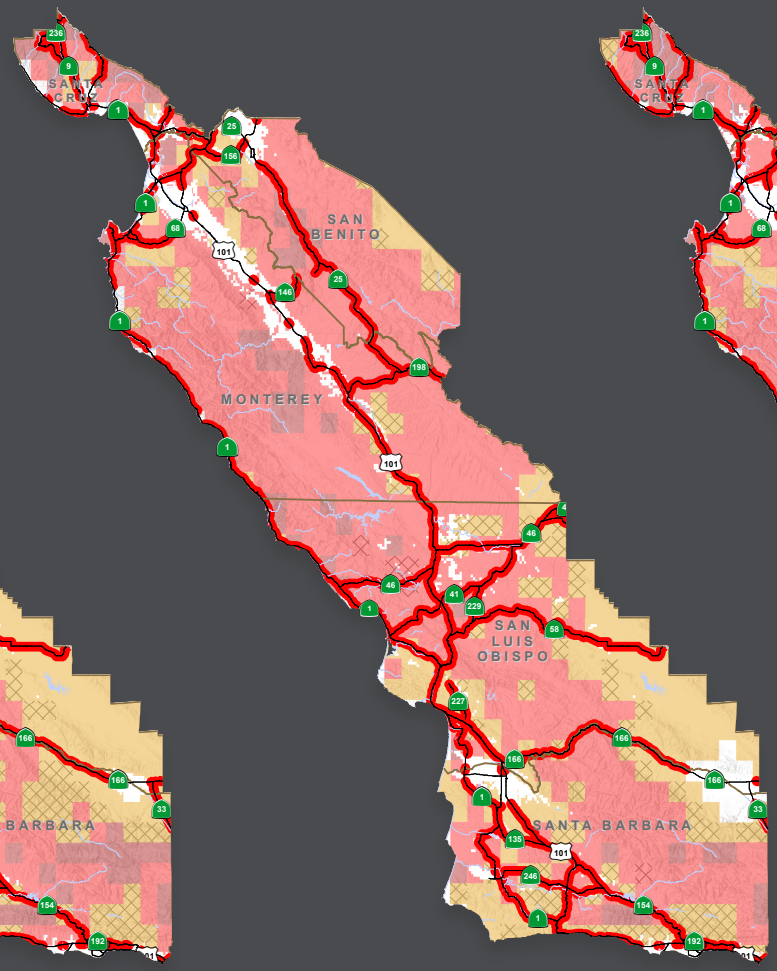
Fig. 6

LEVEL OF WILDFIRE CONCERN



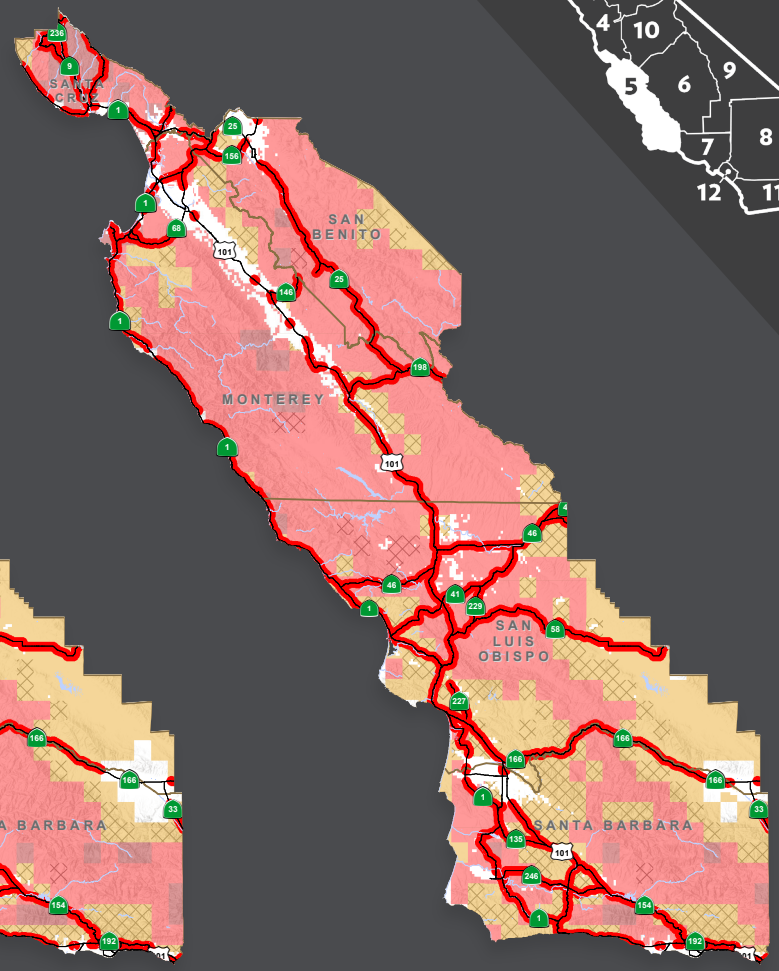
2025

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 SHS within District 5, Based on RCP 8.5.

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 Global Climate Models: (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.

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.

* The hashing shows areas where 5 or more of the 9 models fall under the same cumulative % burn classification as the one shown on the map.

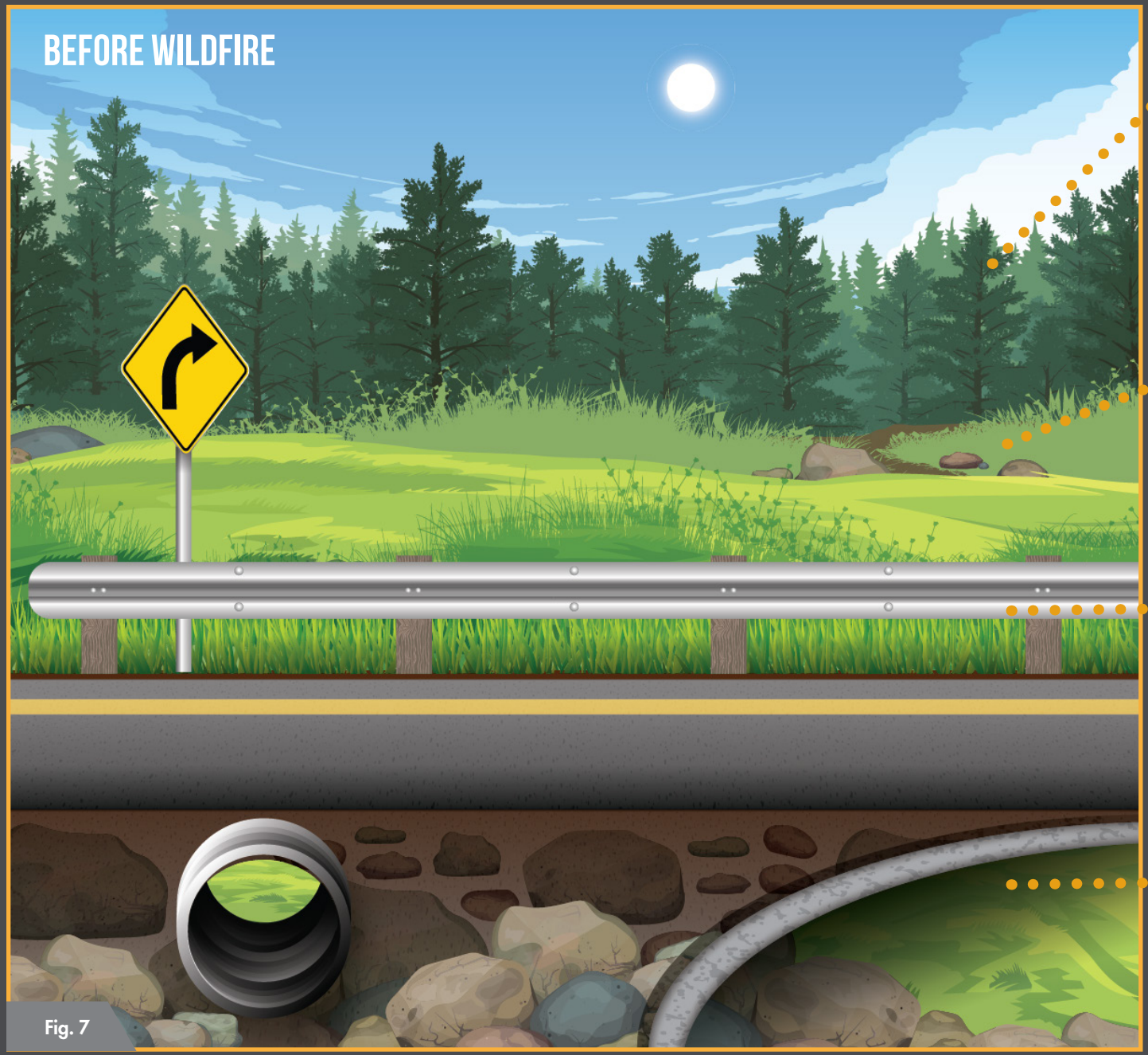


Fig. 7

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 services contributing to precipitation infiltration and soil stabilization. These natural systems help prevent potential damage to roadways, bridges, and culverts by mitigating flooding 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

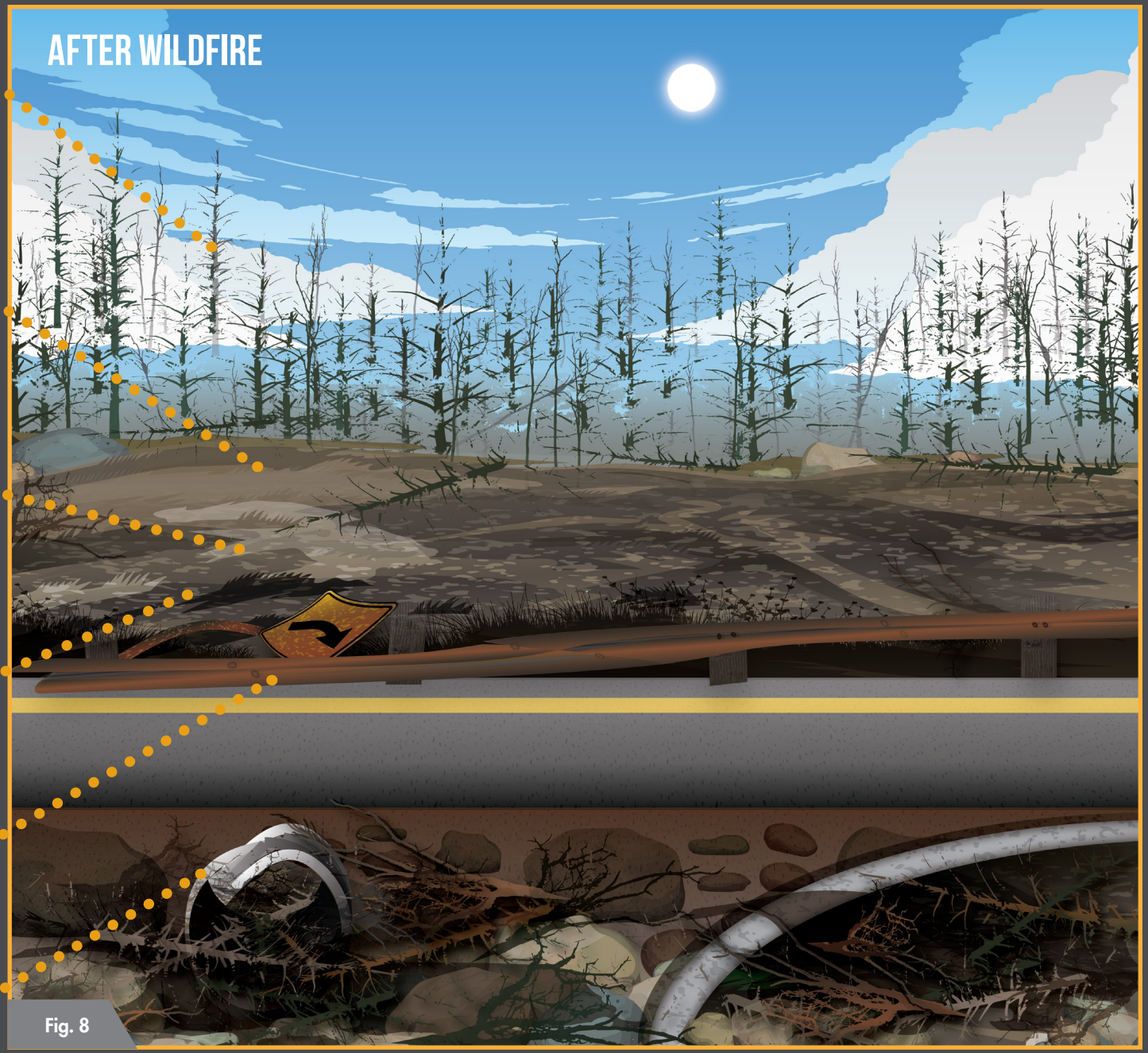


Fig. 8

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

COASTAL IMPACTS IN DISTRICT 5

Multiple climate stressors could impact District 5's SHS, but the effects of rising sea levels on the coast are a notable concern for coastal communities. Rising seas at high tide can temporarily flood roadways and cause inconvenience, safety concerns, and roadway deterioration and closures. Previously, only major storm events would cause inland flooding, but higher coastal sea levels have made flooding more common. Eventually, rising seas may permanently inundate low-lying areas along the coast and accelerate both cliff retreat and beach erosion.

The following sections provide a high-level overview of the District 5 assessments for sea level rise, storm surge, and cliff retreat. Each analysis encompasses the entire coastline—the District 5 Technical Report includes the full results. Sea level rise impacts are expected in Santa Barbara Santa Cruz, and San Luis Obispo counties, but most SHS impacts are anticipated to be in Monterey County. Modeling results showed notable SHS vulnerabilities near Castroville, south of Monterey Bay near Camel-By-The-Sea, and along the cliff sides near Big Sur—the following sections highlights these areas. Figure 9 shows these locations and photos of recent coastal impacts in these areas. Zoomed-in maps highlight the modeling results in these locations and mileage summaries are provided for the entire District 5 coastline.

These assessments are the first stage of analyzing and understanding the SHS's vulnerability to sea level rise, storm surge, and cliff retreat. With this information, Caltrans can begin to 1) identify the most critical and vulnerable locations on District 5's SHS, 2) understand the current conditions at those locations, and 3) if necessary, employ further in-depth, site-specific analyses. In collaboration with stakeholders, Caltrans can also leverage these study results to deploy collective responses to coastal impacts.

SR 1 | MUD CREEK SLIDE

SR 1 | MUD CREEK SLIDE

Fig. 9

COASTAL IMPACT FOCUS AREAS

ELKHORN SLOUGH NEAR CASTROVILLE

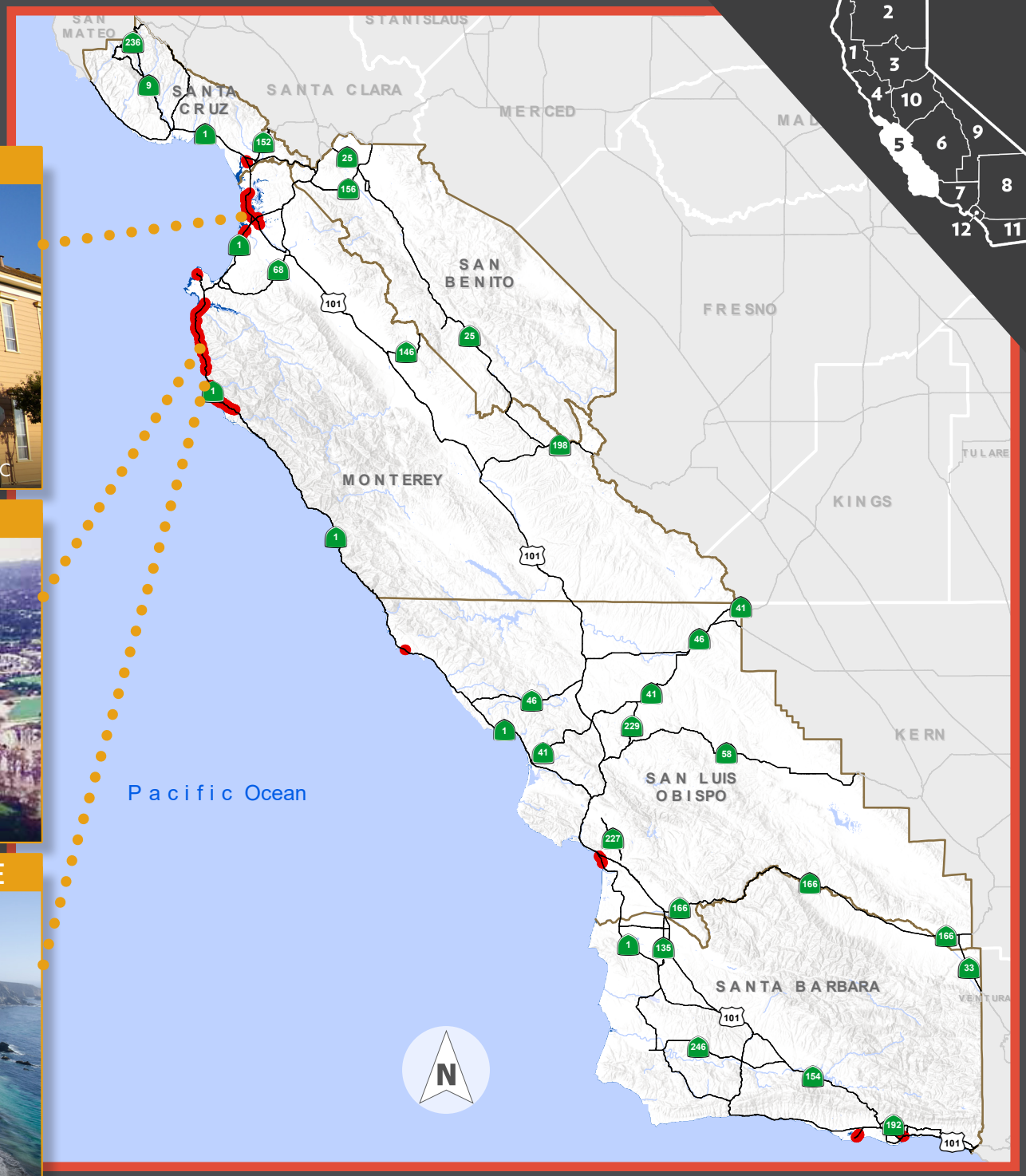
Castroville Sign and La Scuola "The Schoolhouse" | Photo: Dana Panye, CC

SOUTH OF CARMEL-BY-THE-SEA

Carmel River Watershed | Photo: Carmel Pine Cone
Monterey County Water Resources Agency

SR 1 IN MONTEREY COUNTY NEAR BIXBY CREEK BRIDGE

Bixby Creek Bridge | 2013



SEA LEVEL RISE

Sea level rise represents a long-term threat to coastal areas. The effects of thermal expansion of ocean water combined with glacial and ice sheet melting is leading to higher sea levels around the world. District 5 includes an extensive coastline and Caltrans facilities provide access to bayshore and coastal areas. Sea level rise will exacerbate the flooding and inundation that could occur in these areas during regular tidal or storm events. For Caltrans, this means that many of its coastal roads, bridges, and supporting facilities face risk of permanent inundation, meaning they could be consistently below the high tide line.

Like other forecasted changes in climate, future projections of sea level rise vary, depending in part on the assumptions made regarding future concentrations of GHGs and how the Earth's systems will respond. The State of California Sea Level Rise Guidance: 2018 Update provides the most recently developed sea level rise scenarios for locations across the California coastline.[17] This guidance document also provides direction on how to use these new projections in project planning and decision-making. A selection of these scenarios and how to use them is shown and explained further in Figure 11.

These projections were used and paired with sea level rise heights modeled by the National Oceanic and Atmospheric Administration (NOAA). NOAA developed their own sea level rise model to project potential inundation from sea level rise ranging from 1 to 10 feet (0.30 to 3.0 meters) above the average daily high tide.[18] NOAA produced results for both US coasts, including California's Central Coast. Given limited regional sea level rise data for the Central Coast, the national NOAA data was applied for the sea level rise assessment of District 5. All available sea level rise heights from NOAA were assessed, but due to space limitations maps were only created for 2, 3, and 6 feet (0.61, 0.91, and 1.83 meters) of sea level rise.[19] Figure 10 shows a zoomed-in example of one location in the district that will be affected by sea level rise – district-scale figures are available in the District 5 Technical Report.

This assessment of sea level rise, and the surge and cliff retreat assessments on the following pages, include bridges on the SHS. Bridges don't necessarily need to be inundated to be affected by sea level rise. Figure 12 is provided to illustrate some of the risks posed to bridges due to sea level rise.

SEA LEVEL RISE EFFECTS IN DISTRICT 5

Table 2 shows the centerline miles of District 5 SHS inundated by sea level rise based on three modeled NOAA increments: 2, 3, and 6 feet. Figure10 zooms in on the most vulnerable section of the SHS in District 5 identified by the NOAA data, which is in a low-lying area between Moss Landing and Castroville. The model results show increasing flood risks to SR 1 and 183 in this area. Given its location between the Elkhorn Slough, coastline, and Salinas River, this area may be particularly vulnerable to inundation and District 5 should consider further assessment and monitoring.

17 - 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

18 - "Sea Level Rise Viewer, NOAA Digital Coast, Last accessed August 26, 2019, https://coast.noaa.gov/digitalcoast/tools/slr.html

19 - The NOAA model analyzes sea level rise impacts based on the current shoreline and does not account for shoreline retreat. For this reason, some impacts may be missed in modeled results.

Table 2: Centerline Miles of State Highways in District 5 Inundated by Sea Level Rise

County	Sea Level Rise Height		
	2 ft (.6 m)	3 ft (.91 m)	6 ft (1.83 m)
Monterey	**0.3**	**0.4**	**2.0**
Santa Barbara	**0.0**	**0.0**	**0.1**
Santa Cruz	**0.0**	**0.0**	**0.0**
San Luis Obispo	**0.0**	**0.0**	**0.3**

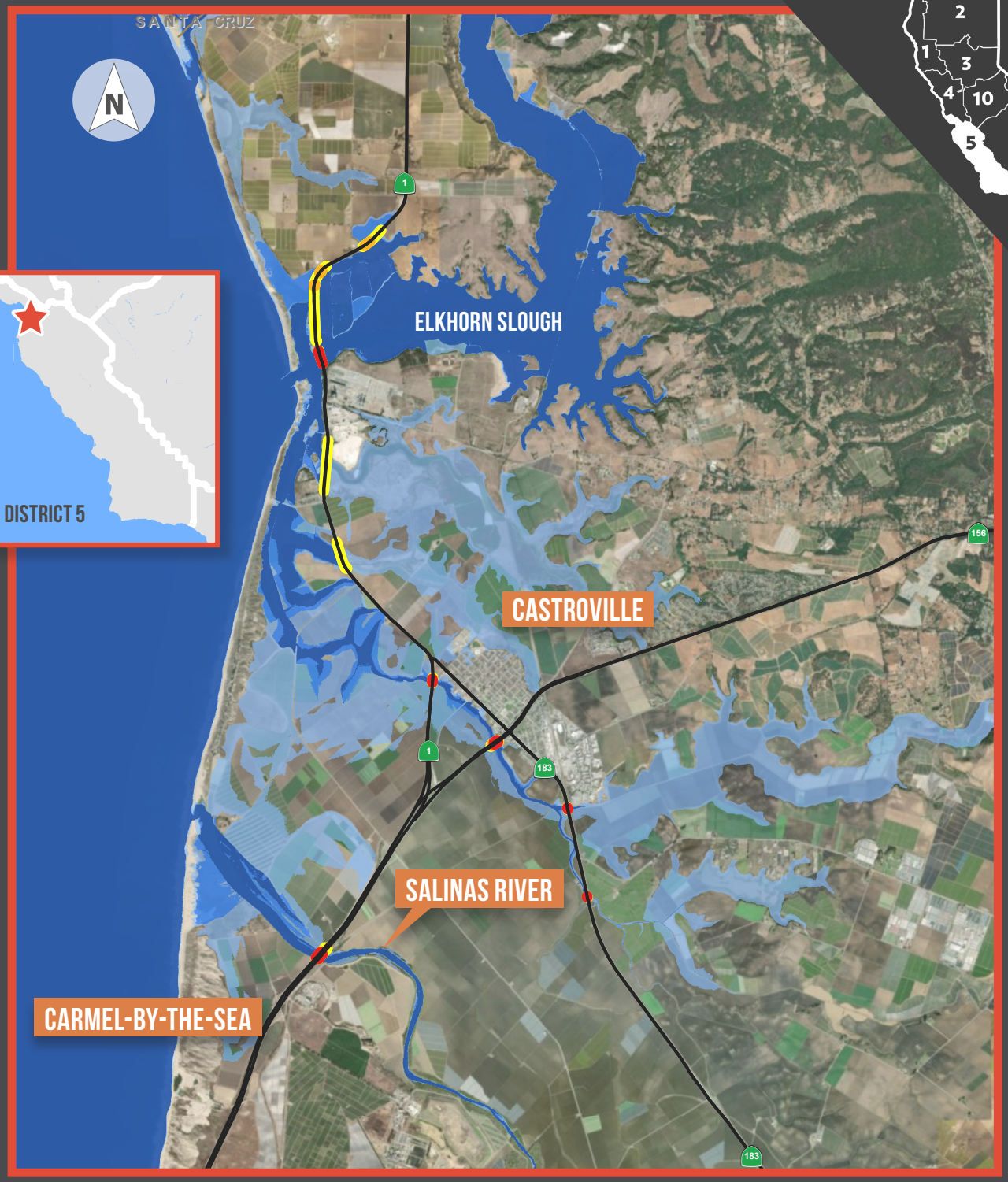
Note: Very small portions of the highway system are vulnerable to sea level rise in Santa Barbara, Santa Cruz, and San Luis Obispo counties. Data does not include other state roads or local streets and roads.

ANALYSIS FOR THIS REPORT WAS CONDUCTED ON THREE DISTINCT INCREMENTS OF SEA LEVEL RISE TO SHOW HOW CONDITIONS MAY CHANGE OVER TIME. THOSE INCREMENTS ARE 2 FEET (.6 METERS), 3 FEET (.91 METERS) AND 6 FEET (1.83 METERS)

APPROXIMATELY THREE MILES OF CALTRANS DISTRICT 5 HIGHWAYS AND BRIDGES MAY BE INUNDATED UNDER 6 FEET OF SEA LEVEL RISE.

Fig. 10

MODELED SEA LEVEL RISE INUNDATION



Impacts to State Highways by Sea Level Rise Increment

- 2 Ft (0.60 M)
- 3 Ft (.91 M)
- 6 Ft (1.83 M)

Sea Level Rise Increments

- 2 Ft (0.60 M)
- 3 Ft (.91 M)
- 6 Ft (1.83 M)

Sea level rise data are from NOAA. See the NOAA Sea Level Rise Viewer for more information. The term "inundation" is used to describe sea level rise impacts, as these areas could be permanently inundated by sea level rise.

Fig. 11

SEA LEVEL RISE ESTIMATED FOR DISTRICT 5

Estimates of sea level rise have been developed for California by various agencies and research institutions. The graph on the right reflects estimates recently developed for Port San Luis 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).[20] These projections were developed from gauges along the California coast based on global and local factors that drive sea level rise such as thermal expansion of oceans, water, glacial melt, and the expected amount of vertical land movement.

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

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

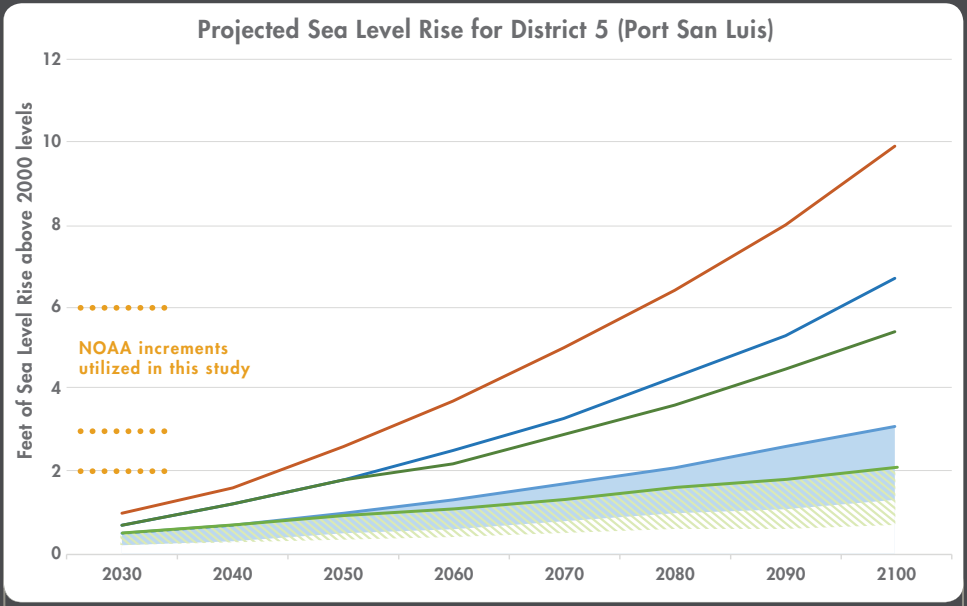
Each of these values are presented for low (RCP 2.6) and high (RCP 8.5) emissions scenarios to demonstrate a full range of potential projections over time. The OPC recommends using only RCP 8.5 for projects that have a lifespan to 2050, and using both scenarios for projects with longer lifespans. The OPC also recommends assessing a range of future projections before making decisions on projects, given the uncertainty inherent in modeling inputs. Guidance is provided for when it is best to consider certain projections, given the risks associated with projects of varying types:

- **For low risk aversion decisions,** the OPC recommends using the high end of the likely (66%) probability sea level rise range. In the graphic to the right, this range is shaded in light blue for the RCP 8.5 scenario and is shaded in light green for RCP 2.6. The low risk aversion scenario should be used for projects with limited consequences or a higher ability to adapt.
- **For medium to high risk aversion decisions,** 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 to the right. The medium-high risk aversion scenario should be used for projects with greater consequences and/or a lower ability to adapt. The medium-high risk aversion scenario should be used for projects with greater consequences and/or a lower ability to adapt.
- **For high risk aversion decisions,** the OPC recommends considering the extreme (H++) scenario. This projection is shown in dark orange in the graphic to the right. The extreme risk aversion scenario should be used for projects that would be irreversibly destroyed or significantly costly to repair and/or would have considerable health, safety, and environmental consequences. The extreme risk aversion scenario should be used for projects that would be irreversibly destroyed or significantly costly to repair and/or would have considerable health, safety, and environmental consequences.

This guidance was developed to help state and local governments understand future risks associated with sea level rise and incorporate these projections into work efforts, investment decisions, and policy mechanisms. In particular, local jurisdictions should update local coastal plans as well as local development plans with adaptation planning strategies. The OPC recognizes that the science surrounding sea level rise projections is still improving and anticipates updating the state guidance at least every five years. Given that new findings are inevitable, Caltrans will use best-available sea level rise modeling, projections, and guidance as the science evolves over time, and will be working towards defining how this data is incorporated into capital investment decisions.

COASTAL COMMISSION SEA LEVEL RISE GUIDANCE

The *California Coastal Commission Sea Level Rise Policy Guidance* document was adopted in August of 2015 and has since been updated given the 2018 sea level rise guidance released by the OPC. The guidance provides a step-by-step process using the latest science to determine a range of sea level rise projections in the project area, identify potential impacts, develop adaptation options, and incorporate strategies into Local Coastal Programs. Similar guidance applies to addressing sea level rise in Coastal Development Permits. Caltrans references this guidance in their emergency and day-to-day work in coastal areas to ensure that they are meeting Coastal Commission permitting requirements and correctly applying the latest science.[21]



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

OPC Estimates for Sea Level Rise

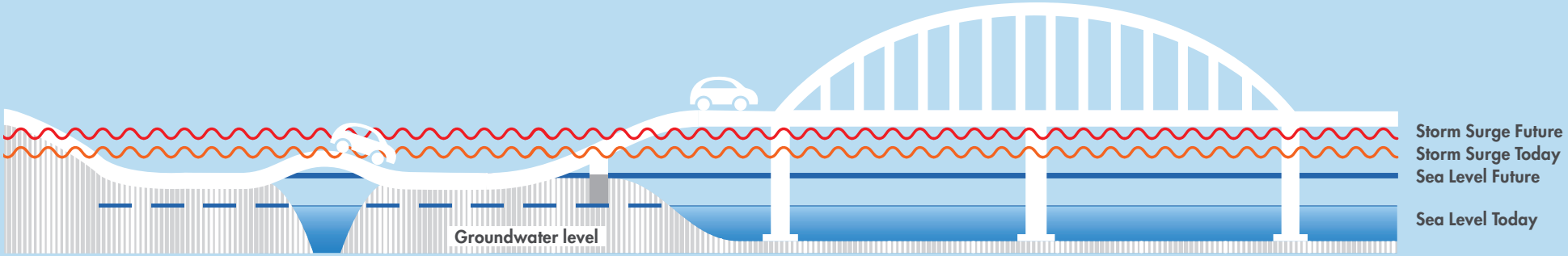
- Extreme Estimate of Sea Level Rise (H++ Scenario)
- **Low Probability** Estimate (0.5% Probability Scenario) for **High Emissions** Scenario
- **Low Probability** Estimate (0.5% Probability Scenario) for **Low Emissions** Scenario
- **High End of the Likely Range** (17% Probability Scenario) for **High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

20 - 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

21 - California Coastal Commission, "California Coastal Commission Sea Level Rise Policy Guidance: Interpretive Guidelines for Addressing Sea Level Rise in Local Coastal Programs and Coastal Development Permits," November 2018, https://www.coastal.ca.gov/climate/slrguidance.html

Fig. 12

BRIDGES IN COASTAL AREAS AND SEA LEVEL RISE



Climate change can impact infrastructure in multiple ways. Bridges in coastal areas, 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 to these facilities in the future.

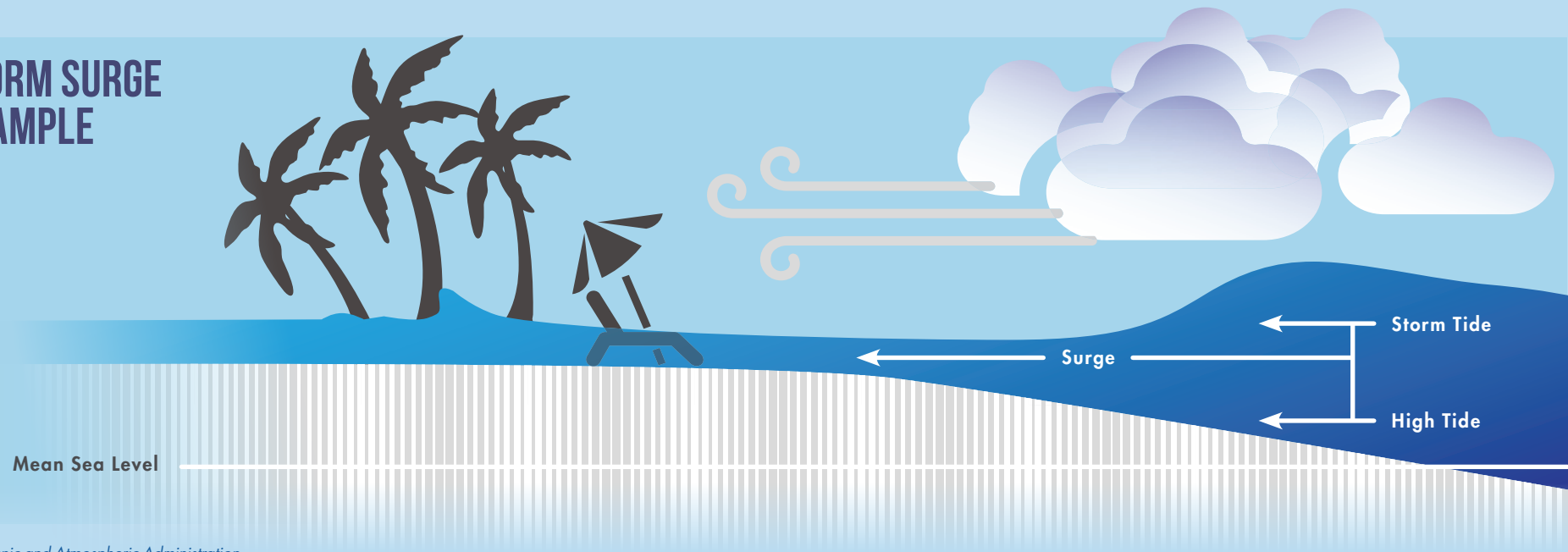
Some bridge vulnerabilities include:

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) becoming exposed to surge forces and sustaining damage from storms.
5. Surge and wave effects loosening or damaging portions of the bridge and requiring securing, re-attaching, or replacing of bridge parts.
6. Bridge use becoming limited due to the loss or damage of a roadway or minor bridges near the bridge approaches.

Most bridges are built with added safety factors during design so these concerns may not be realized—but they should be factored into decision-making to ensure that all Caltrans bridges can withstand conditions that will change over time.

Fig. 13

STORM SURGE EXAMPLE



Source: National Oceanic and Atmospheric Administration

STORM SURGE

Storm surge can significantly worsen the flooding of coastal areas during a storm event, and it is expected that storm frequency and intensity will increase over time. Even now, storm events expose coastal roads, bridges, and other infrastructure to higher forces, and greater surge effects will likely increase damage and reduce useful life. Higher levels of coastal erosion, landslides, shoreline retreat, and roadway flooding are all potential outcomes.

Data from the CalFloD-3D (or "3Di") model was used to assess sea level rise and storm surge impacts to the SHS in District 5. The model was developed by researchers at UC Berkeley to understand the risks posed by sea level rise and a 100-year storm event to the California coast, San Francisco Bay, and the Sacramento-San Joaquin Delta. The model applies real water level data from past, near 100-year storm events to better understand how storm surge occurs and flows inland.[22] The sea level rise heights provided by the model are: 1.64, 3.28, and 4.62 feet (0.50, 1.00, and 1.41 meters), combined with the surge associated with a 100-year storm. These heights are the only ones available from the model and were applied in this assessment. The highest increment of 4.62 feet is considerably lower than the projections provided by the state (see Figure 11). The US Geological Survey (USGS) is completing additional sea level rise and surge modeling for the Central Coast, which will include higher projections, and should be considered in future assessments of the district.

Figure 14 shows a zoomed-in portion of the SHS in District 5 that is at high risk of flooding due to sea level rise and surge from a 100-year storm. Full, district-scale maps of sea level rise and surge impacts are available in the District 5 Technical Report.

STORM SURGE EFFECTS IN DISTRICT 5

The areas most vulnerable to flooding from sea level rise and storm surge mirror the areas identified by NOAA data in the sea level rise analysis. The northern portion of the district, between Moss Landing and Castroville, is still identified as a vulnerable location in terms of SHS impacts. The 3Di model also suggests that there will be large, vulnerable portions of SR 1 south of Monterey Bay that were not revealed when assessing sea level rise alone. Figure 14 zooms in on this area to visualize potential flooding to this location and SR 1. A more detailed assessment of elevations in this location will be necessary to understand how SR 1 could be affected.

22 - "Sea Level Rise CalFloD-3D," Cal-Adapt, Last accessed August 26, 2019, https://cal-adapt.org/data/slr-calflod-3d/

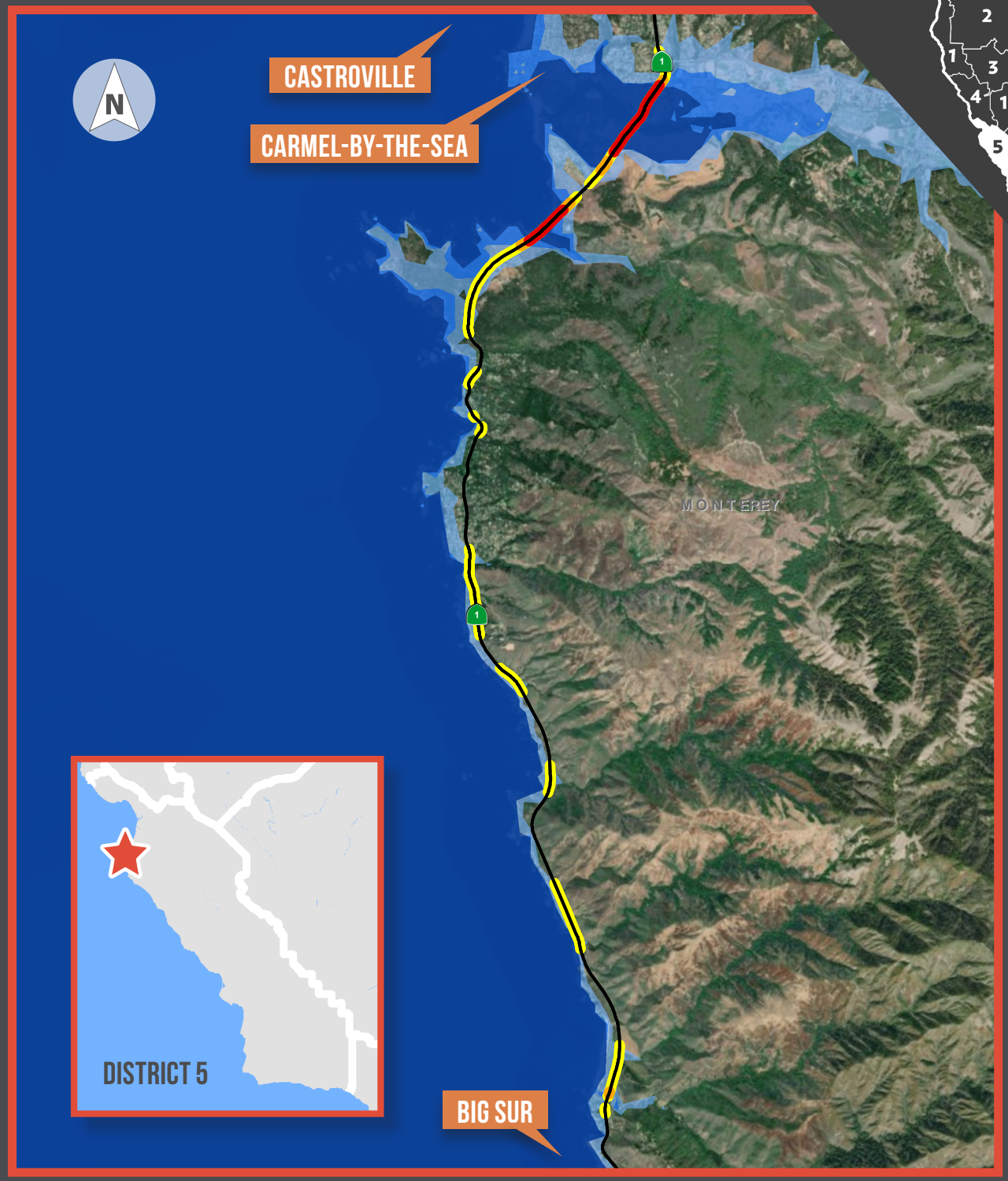
Table 3: Centerline Miles of State Highways in District 5 Flooded by Sea Level Rise and Surge During a 100-Year Storm

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
Monterey	**2.5**	**3.3**	**12.5**
Santa Barbara	**0.2**	**0.2**	**0.7**
Santa Cruz	**0.0**	**0.0**	**0.2**
San Luis Obispo	**0.0**	**0.1**	**0.5**

Note: Data does not include other state roads or local streets and roads.

Fig. 14

MODELED SEA LEVEL RISE AND STORM SURGE FLOODING



Impacts to State Highways by Sea Level Rise Increment

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

Sea Level Rise Increments

- 1.64 Ft (0.50 M) + 100-Yr. Storm
- 3.28 Ft (1.00 M) + 100-Yr. Storm
- 4.62 Ft (1.41 M) + 100-Yr. Storm

Sea level rise and storm surge data are from UC Berkeley and available on Cal-Adapt. See the Cal-Adapt sea level rise page for more information. The term "flooding" is used to describe sea level rise and storm surge impacts, as inland areas may flood temporarily, but not be permanently inundated like in the sea level rise analysis.

CLIFF RETREAT

The sea level rise and storm surge concerns noted in this report outline how higher water levels will directly impact transportation infrastructure. Changing water levels in the oceans will also create different forces at the shoreline, eroding beaches and causing cliff retreat along the 1,100-mile California coastline. Cliff retreat occurs when waves impact the base of a cliff and hydraulic action carves out a portion of the cliff face. This loss of rock and soil increases over time and undermines support for the cliff itself, eventually resulting in the collapse of the cliff face. Over time the cliff recedes, or "retreats", from its original position. Examples this effect are seen throughout California, most notably (as described in a recent study of historic cliff retreat rates) in San Onofre, Portuguese Bend, Palos Verdes, Big Sur, Martins Beach, Daly City, Double Point, and Point Reyes.[23]

Rates of cliff retreat will be dependent on several factors, including the rapidity of sea rise, the physical make-up of the cliffs, and the effectiveness of adaptation responses by state agencies and other stakeholders. The best strategies to address long-term concerns will likely consider the trade-offs between engineered solutions to protect the coastline, and physical retreat strategies where infrastructure and communities are relocated away from eroding areas.

The USGS Coastal Storm Modeling System (CoSMoS) model was applied for the District 5 analysis of cliff retreat to help determine the long-term changes from sea level rise. The CoSMoS model cliff retreat data is available for the Bay Area to Southern California (extending from San Francisco Bay to Imperial Beach in San Diego County).[24] The USGS CoSMoS cliff retreat data are provided in 0.82 feet (0.25 meter) increments from 0 to 6.56 feet (0 to 2 meters), and include a much higher 16.4 feet (5 meter) scenario. Each of these heights was applied in this assessment, but due to space limitations only three are shown here. The model also provides cliff retreat data with two different assumptions—one which assumes that coastal armoring will be 100% effective at preventing cliff retreat ("hold the line"), and one which assumes that coastal armoring is ineffective, and cliff retreat continues past current protections ("do not hold the line").[25] For this analysis, the "do not hold the line" scenario was applied to assess the full potential of cliff retreat impacts in District 5. Figure 15 shows these projections of cliff retreat for one portion of the highway system in District 5, the full, district-scale maps are available in the District 5 Technical Report.

CLIFF RETREAT EFFECTS IN DISTRICT 5

Cliff retreat is already an ongoing issue for Caltrans District 5, and rising seas will exacerbate it. When projecting 1.64 feet of sea level rise, large swaths of SR 1 are vulnerable to retreat in Monterey County. Projecting higher sea level rise reveals another vulnerable area in southern Santa Barbara County. Table 4 provides the centerline mileage of the SHS exposed to cliff retreat. Figure 15 shows a zoomed-in portion of the vulnerable area in Monterey County and how cliff retreat is expected to progress inland as sea levels rise using a "no armoring" (do not hold the line) scenario.

Table 4: Centerline Miles of State Highways in District 5 Vulnerable to Cliff Retreat Driven by Sea Level Rise

County	Sea Level Rise Height		
	1.64 ft (.5 m)	3.28 ft (1 m)	5.74 ft (1.75 m)
Monterey	**4.0**	**6.3**	**8.3**
Santa Barbara	**0.2**	**0.7**	**1.5**
Santa Cruz	**0.5**	**0.9**	**0.9**
San Luis Obispo	**0.8**	**1.2**	**1.7**

Note: Data does not include other state roads or local streets and roads.

23 - UC San Diego, "Study Identifies California Cliffs at Risk of Collapse," 2017, https://phys.org/news/2017-12-california-cliffs-collapse.html.

24 - These projections only model cliff retreat and not long-term shoreline change or beach erosion.

25 - "Coastal Storm Modeling System," ScienceBase-Catalog, Last modified July 12, 2019, https://www.sciencebase.gov/catalog/item/5633fea2e4b048076347f1cf

Fig. 15

MODELED CLIFF RETREAT IMPACTS

Impacts to State Highways by Sea Level Rise Increment

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

Sea Level Rise Eroded Area Increments

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

Cliff retreat data are from the US Geological Survey, Coastal Storm Modeling System (CoSMoS). This data applies the "do not hold the line" management option, which assumes that cliff retreat continues unimpeded. See Our Coast, Our Future and the USGS CoSMoS webpage for more information on the model. See the CoSMoS v3.0 Summary of Methods for more information on cliff retreat modeling for Southern California.

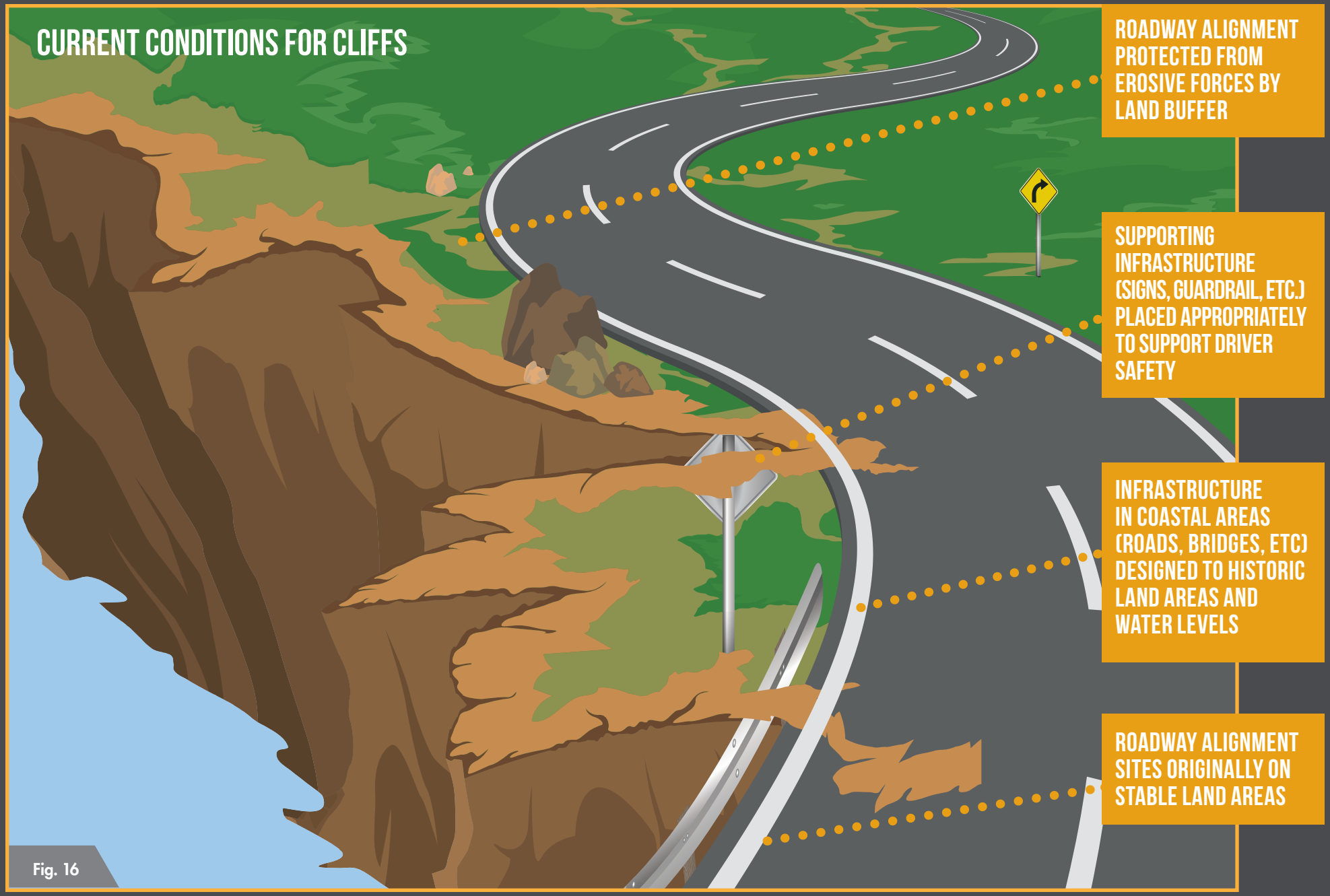


Fig. 16

The California coastline has been shaped in part by forces from ocean water and waves from past storm events.

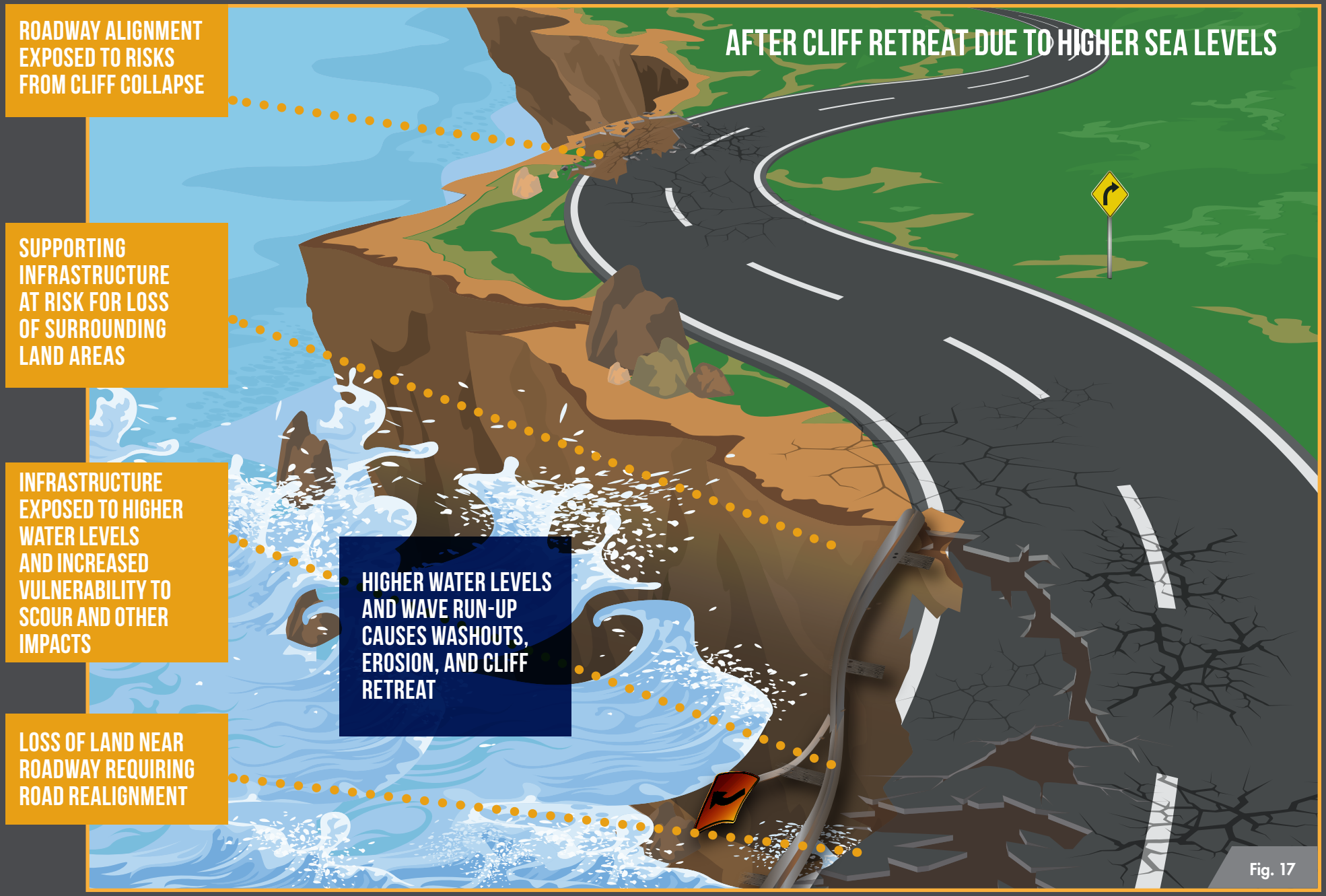
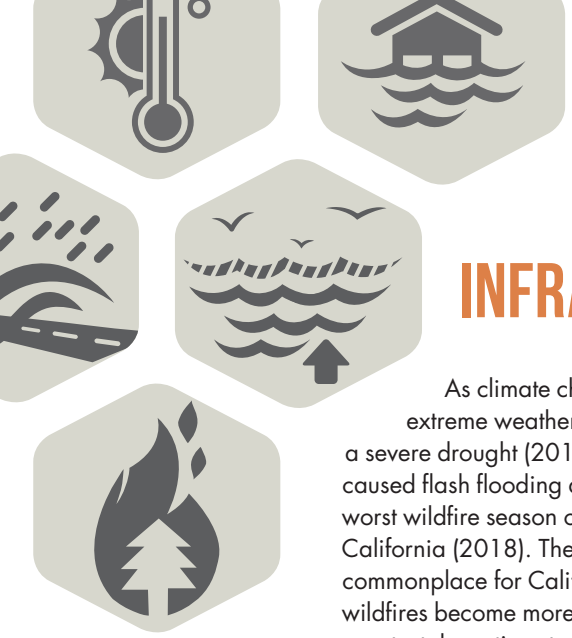


Fig. 17

Future conditions with higher water levels from sea level rise will extend flooding inland and impart more forces on the California coastline.



INFRASTRUCTURE IMPACT EXAMPLES

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

MONTECITO DEBRIS FLOWS

On January 9th, 2018, flooding and debris flows in Montecito, Summerland, and Carpenteria in Santa Barbara County[26] killed 23 people (21 confirmed, two are still missing), destroyed more than 100 homes, caused hundreds of millions of dollars in damage[27], and shut down US 101 for 12 days. The flows were caused by a combination of the Thomas Fire, which burned over 281,000 acres (including slopes on the Santa Ynez Mountains above Montecito) in December 2017[28], and later heavy rains which, due to the lack of vegetation caused by the fire, washed loose dirt and debris from the slopes down San Ysidro Creek and others into the neighboring cities.[29] See Figure 18 on the following page for a map of the affected areas in Montecito.

Caltrans District 5 responded to the US 101 shutdown by redirecting motorists, but at one point, a quarter-mile section of US 101 was under 12 feet of water and the necessary detours were lengthy. Caltrans and its contractors removed over 105,000 cubic yards of material from the highway with 40 pieces of equipment and 1,500 trucks. After clearing the water and debris, Caltrans and its contractors reinstalled or repaired guardrail, stabilized slopes and embankments, cleared major drainage facilities, replaced striping, and fixed minor pavement damage. Around 13,000 individual truck trips were required to restore US 101 to functionality.

PIEDRAS BLANCAS ROADWAY REALIGNMENT

SR 1, from Point Piedras Blancas to North of the Arroyo de la Cruz Bridge in northern San Luis Obispo County, has experienced severe coastal erosion (nearly five feet per year in some areas) resulting in numerous projects for rock slope protection and minor realignment over 20 years. Given that SR 1 is a State Scenic Route, a National Scenic Byway, an All-American Road and on the Pacific Coast Bicycle Route, these projects affected many users of the roadway. District 5 determined that the temporary shore armoring was not sufficient to protect the road—a long-term solution was needed. Approximately 2.8 miles of SR 1 was moved inland (at the maximum, about 475 feet from the existing road). This placed the new alignment outside of the area where erosion was predicted to be the most severe over the next 100 years. Caltrans explicitly considered future climate-related impacts of increased erosion in setting the anticipated 100-year erosion line.

The project also included enhancement of 12 acres of offsite state parkland sites to mitigate the impacts to areas disturbed by project construction. This is an element of an arrangement with neighboring property owners to allow for similar realignments at five locations along the 18-mile stretch of SR 1. The historic Hearst Scenic Conservation easements allow for highway realignments in vulnerable areas and includes the dedication of land to state parks.

26 - "Montecito Flooding/Mudflows," CalFire, Last accessed August 26, 2019, https://www.fire.ca.gov/incidents/2018/1/9/montecito-flooding-mudflows/

27 - Joseph Serna, "Montecito Mudslide Costs Insurance Companies More Than $421 Million in Claims," April 2, 2018, https://www.latimes.com/local/lanow/la-me-ln-montecito-mudslide-insurance-20180402-story.html

28 - "Thomas Fire," CalFire, Last accessed August 26, 2019, https://www.fire.ca.gov/incidents/2017/12/4/thomas-fire/

29 - Laris Karklis, Lauren Tierney, and Tim Meko, "Before and After the Mudslides in Montecito, The Washington Post, Last updated January 19 2018, https://www.washingtonpost.com/graphics/2018/national/montecito-before-after/?noredirect=on

Fig. 18

MONTECITO DEBRIS FLOW

Montecito (Santa Barbara County) Thomas Fire (12/4/2017) and Debris Flow (1/9/2018) Impacts to SR 192 and US 101

A SR 192 PM 12.49 Toro Creek Bridge

B 101 PM 10.5 looking northwest at the Olive Mill Road O/C from the southbound onramp to 101

C SR 192 (Valley Road) PM 8.8 at the signal with San Ysidro Rd (fire)

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)[30].

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 5 for existing and future roadways.

The following section highlights a district effort that demonstrates an adaptive design following a major disruption. The project did not apply ADAP specifically, but does provide a useful example of how Caltrans districts can respond to extreme weather and climate change triggered events. In the future, these types of responses can directly incorporate climate projections by using ADAP.

30 - 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

31 - Kathe Tanner, "Hwy 1 Will Reopen on Wednesday – and Travelers Can Once Again reach Big Sur," July 17, 2018, https://www.sanluisobispo.com/news/local/article215042145.html

MUD CREEK SLIDE ROADWAY REBUILD

There have been multiple landslides and erosion events on SR 1 along the Big Sur coast between Paul's slide and Mud Creek. In January 2017, rock, mud and debris slid down the Mud Creek mountainside about nine miles north of the Monterey-San Luis Obispo County line, which damaged SR 1. In May 2017, while efforts were underway to restore the highway, the Mud Creek slide completely buried 1,000 feet of SR 1 with over six million cubic yards of dirt and rock, leading to a 14-month closure along the Big Sur coast. Extensive and innovative analysis of the site determined that rebuilding SR 1 on top of the landslide was more efficient that removing the six million cubic yards of dirt and rock. Caltrans compacted the soil and installed embankments, berms, rocks, and nets to stabilize the area, and the highway was formally re-opened in July 2018.

The highway is open to traffic again, but efforts continue to monitor and manage the site. An automated total station (provides remote, optical survey monitoring) and Trimble T4D system (provides real-time movement analysis) continuously monitor the slide in near-real time. Mirrors track surface movement within and around the perimeter of the slide area. Solar arrays and satellite Wi-Fi enable on-site communications and relay the data back to the Caltrans District 5 Office. The project includes additional features to aid in future maintenance of the highway as well as to further protect the traveling public. For example, new protocols established include preemptive closures in advance of significant forecasted storms.

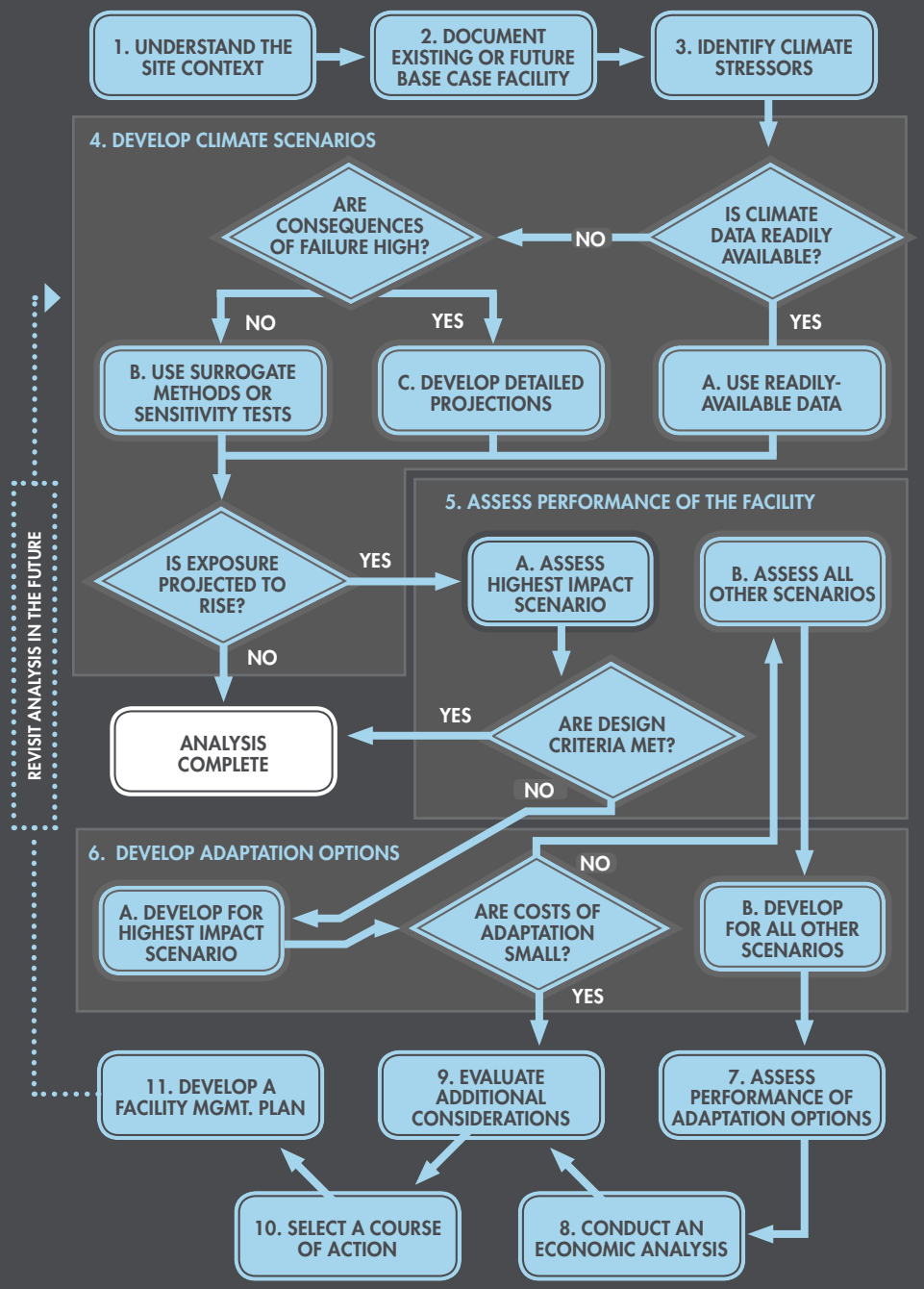
Caltrans and its contractor compacted the soil and installed embankments, berms, rocks, and nets to stabilize the area. Caltrans formally reopened SR 1 on July 18th, 2018.[31]

BEFORE

AFTER

Fig. 18

FHWA'S ADAP DESIGN PROCESS

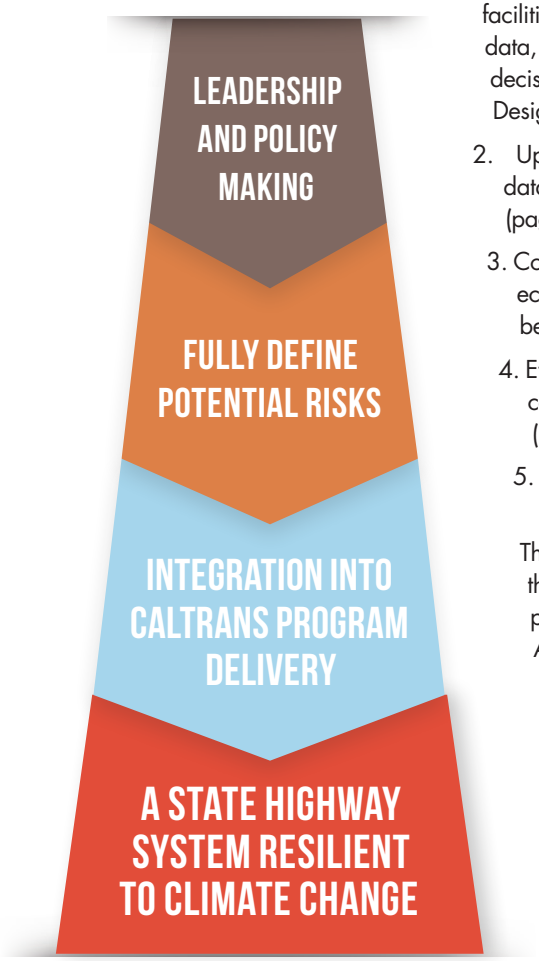


SR 1 | ROCKY CREEK SLIPOUT REPAIR

SR 1 | PAUL'S SLIDE | AFTER REPAIR

SR 9 | BROOKDALE SLIPOUT | FINISHED VIADUCT

WHAT DOES THIS MEAN TO CALTRANS?



GENERAL CONCLUSIONS

District 5's recent extreme weather events offer an opportunity to address many of the potential climate change impacts outlined in this report and suggest these conclusions:

1. FHWA's ADAP process should be used when planning or designing facilities and assets. This will help account for uncertainties in climate data, establish a benefit-cost assessment methodology, and enable decision-making guided by long-term costs (page 37 – Adaptive Design, Response, and Risk Management)
2. Updated design approaches that employ the best available climate data from state resource agencies should be a part of event response (page 11 – phases for achieving resiliency)
3. Consequence costs should factor into redesign efforts so broader economic measures and potential cost savings from adaptation can be assessed (page 8 – vulnerability approach)
4. Efforts to build or repair District 5 facilities should consider future conditions as opposed to focusing on historical conditions (page 4 – state policies)
5. Project prioritization and capital programming should consider extreme weather events and climate change impacts.

This report outlines the many climate stressors that pose risks to the SHS. Effective risk management will require a response that prioritizes the system's most vulnerable and critical assets first. Addressing these climate concerns will also require:

LEADERSHIP

Both transportation agency and state government leadership will be required. Transportation systems are often undervalued because inadequate consideration is given to the full economic implications of their damage, loss, or failure. Avoiding the possible impacts of extreme weather events and climate change on the SHS should be priorities for policy and capital programming.

Adapting to climate change challenges will require a proactive and collaborative approach. Caltrans recognizes that coordination with stakeholders is necessary for developing 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 improve decision-making and promote a collective response.

FULLY DEFINING RISKS

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

INTEGRATION INTO CALTRANS PROGRAM DELIVERY

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

A STATE HIGHWAY SYSTEM RESILIENT TO CLIMATE CHANGE

Using this report as a guide for the first steps to consider climate change in a comprehensive and systematic way will lead to a SHS that is more resilient to climate change and extreme events.

NEXT STEPS

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

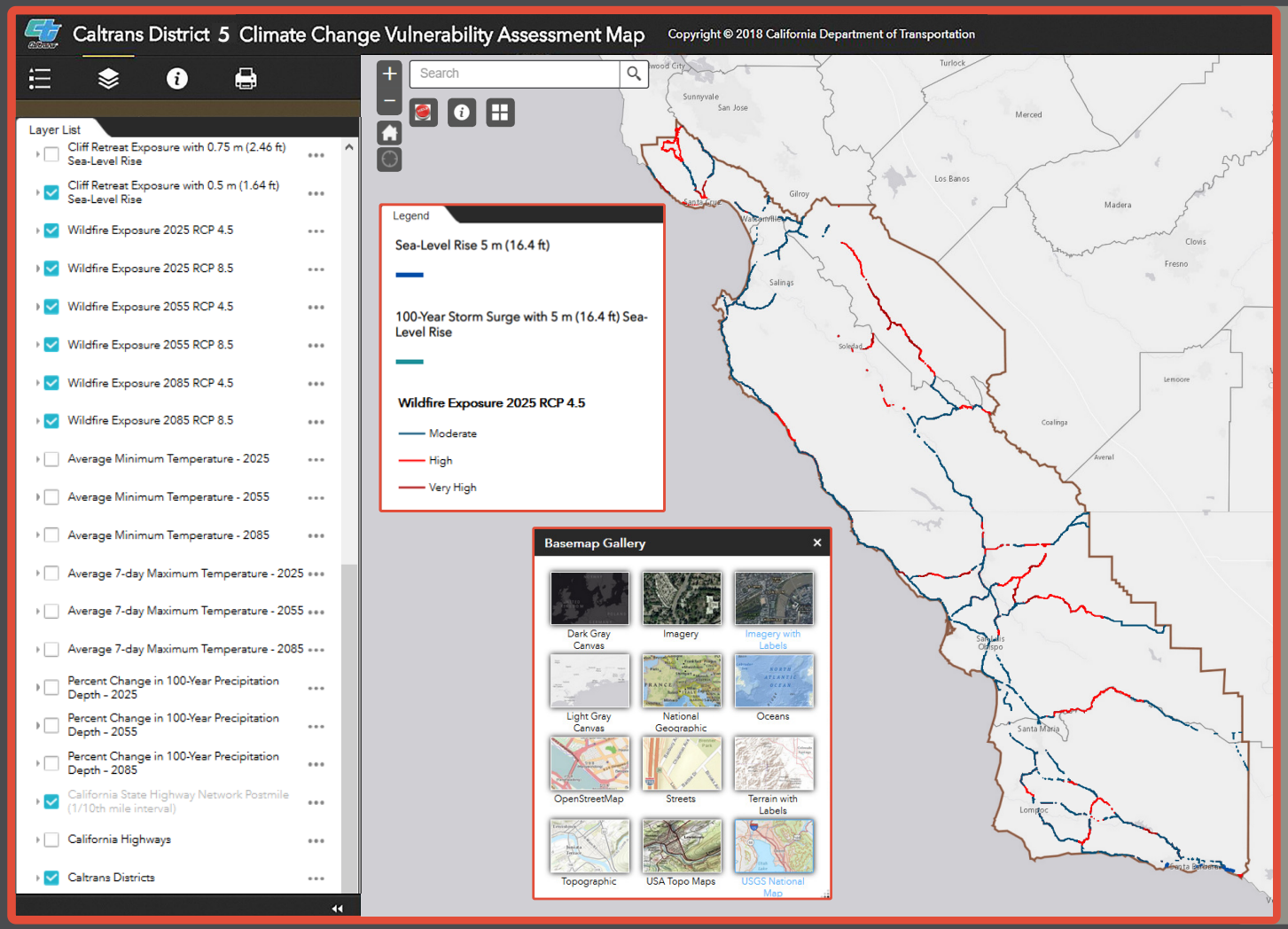
ON-LINE MAPPING TOOL FOR DECISION-MAKING

Caltrans has created an online mapping program to provide information for users across the state, using data assembled for this project. The Caltrans Climate Change Vulnerability Assessment Map can be accessed here.[32]

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

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

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



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

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

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

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