CALTRANS CLIMATE CHANGE

VULNERABILITY ASSESSMENT SUMMARY REPORT

DISTRICT 4

2018

This Summary Report is one of two documents prepared to outline climate change effects in District 4, the San Francisco Bay Area, the other being the Technical Report. This is the first of 12 such studies that will eventually cover each region in the State.

A database containing geospatial data indicating the current and future locations of various natural hazards and their impacts to Caltrans roadways was also developed as part of this project. The maps included in this report and the Technical Report draw upon data contained in this database. Using this data, Caltrans intends to help evaluate the vulnerability of other transportation modes through partnership and data sharing with local and regional agencies. This database is expected to be a valuable resource for ongoing Caltrans resiliency efforts and coordination with stakeholders.

This document represents a general summary of identified impacts, while the Technical Report presents detail on the technical processes that were employed to identify these climate impacts.

THE WORK UNDERTAKEN FOR THIS STUDY INCLUDED COORDINATION WITH THE FOLLOWING AGENCIES, AMONG OTHERS:

- California Coastal Commission
- California Department of Forestry and Fire Protection
- California Department of Transportation –
- California Department of Water Resources
- California Energy Commission
- California Geological Survey
- Climate Central
- Federal Emergency Management Agency
- Federal Highway Administration
- Metropolitan Transportation Commission
- National Oceanic and Atmospheric Administration
- Pacific Gas and Electric Company
- Point Blue
- San Francisco Bay Conservation and Development Commission
- United States Geological Survey
- University of California, Berkeley
- University of California, Davis
- University of California, San Diego Scripps Institution of Oceanography
- US Army Corps of Engineers

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CLIMATE CHANGE AND EXTREME WEATHER EVENTS HAVE RECEIVED INCREASING ATTENTION WORLD-WIDE AS POTENTIALLY ONE OF THE GREATEST CHALLENGES FACING MODERN SOCIETY.

Climate change has various implications worldwide. In California and the west, the following general climate trends are expected[1]:

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

The data analysis presented in this report is largely based on global climate data compiled by the Intergovernmental Panel on Climate Change (IPCC), and subject to scientific analysis that estimates the response of the earth's natural systems to increasing carbon emissions. The IPCC represents future conditions through a set of Representative Concentration Pathways (RCPs) that reflect four separate scenarios of changes in greenhouse gas emission concentrations given different global economic forces and/or government policies. These RCPs include four scenarios – RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 – which assume that emissions would start to decline in the near term, by 2040, by 2080, or will continue unabated to the end of the century.

1 - "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, (n.d.)

BACKGROUND AND APPROACH

Caltrans is making a concerted effort to be a leader in identifying vulnerabilities and assessing the impacts of climate change on the State Highway System. The information presented in this report is the latest phase of this effort, completed to assess infrastructure that may be at risk, or other processes that may need to be changed, given possible future climatic conditions.

The effort for this project involved applying available climate data to refine the understanding of potential climate risks. Caltrans coordinated with various state and federal agencies and academic institutions on the best use of latest data for this study. Discussions with professionals from various engineering disciplines helped identify the measures that are presented in this report.

This report does not identify projects to be implemented, nor present costs associated with those changes. Caltrans plans to resolve these vulnerabilities in subsequent planning and design. The overall intent of this project is to add some definition to a subject with many unknowns (climate change), and begin to define a subset of assets from along the State Highway System that will be addressed in future efforts.

The information in this Summary Report outlines the potential vulnerabilities to Caltrans' District 4 State Highway System, to illustrate the types of climate stressors that may affect how highways are planned, designed, built, operated and maintained.

THE TRANSPORTATION SYSTEM IS ONE OF THE MOST CRITICAL FOUNDATIONS OF A RESILIENT COMMUNITY, ENABLING MANY OF THE ACTIVITIES THAT DEFINE MODERN SOCIETY.

STATE HIGHWAY SYSTEM USERS AND A RESILIENT SYSTEM

The benefits of a resilient State Highway System will be provided to the users — the customers of Caltrans services. The mobility provided by a resilient State Highway System ensures the economic and social well-being of the District's communities and residents.

Caltrans District 4 is a major population and employment center in California, covering the 9 Bay Area counties and including the cities of San Francisco, Oakland, San Jose, Rio Vista, and Santa Rosa. District 4 is also a major freight hub, with major ports, air cargo facilities, freight distribution centers and warehouses. The Metropolitan Transportation Commission (MTC) has identified that "the regional goods movement infrastructure includes the nation's fifth-largest container port (the Port of Oakland) and several specialized seaports; two of the most active air cargo airports in the Western U.S. (San Francisco International Airport and Oakland International Airport); major rail lines and rail terminals; and highways that carry some of the highest volumes of trucks in California."[1] This freight system and the requirements for modal connectivity can be particularly vulnerable to disruptions caused by extreme weather events. Assuring a resilient network will be a critical strategy for maintaining regional viability.

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

Executive Order B-30-15
requires the consideration of climate change in all state investment decisions through the use of full life cycle cost accounting, the prioritization of adaptation actions which also mitigate greenhouse gases, the consideration of the state's most vulnerable populations, the prioritization of natural infrastructure solutions, and the use of flexible approaches where possible.[2]

Assembly Bill 1482
requires all state agencies and departments prepare for climate change impacts through (among others): continued collection of climate data, considering climate in state investments, and the promotion of reliable transportation strategies.[3]

Assembly Bill 2800
requires state agencies to take into account climate impacts during planning, design, building, operations, maintenance, and investments in infrastructure. It also requires the formation of a Climate-Safe Infrastructure Working Group represented by engineers with relevant experience from multiple state agencies, including the Department of Transportation.[4]

1 - MTC, San Francisco Bay Area Goods Movement Plan, March 2016. Accessed at, http://mtc.ca.gov/sites/default/files/RGM_Exec_Summary.pdf
2 - "Governor Brown Establishes Most Ambitious Greenhouse Gas Reduction Target in North America," Office of Governor Edmund Brown, https://www.gov.ca.gov/news.php?id=18938, April 29, 2015
3 - "Assembly Bill No. 1482," https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201520160AB1482, October 8, 2015
4 - "Assembly Bill No. 2800," http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160AB2800, September 24, 2016

RECENT EXTREME STORM EVENTS IN DISTRICT 4

On a yearly basis, Caltrans invests millions of dollars in repair and maintenance of the State Highway System. During a normal year, these funds are used to replace aging infrastructure and to maintain adequate travel conditions. But in years when extreme climate events occur, the damage and resulting costs of repairing transportation infrastructure can be extensive. In the last year alone, Caltrans has sustained approximately $1 billon in storm-related damages. Hillsides that burned during wildfires last year crumbled during the winter's record-breaking rain and snow storms. Between January and May of 2017, District 4 experienced weather-related damages in 110 locations, with a cumulative cost over $250 million in repairs, largely from heavy precipitation and strong coastal storms. Although this year's weather events are "extreme" as compared to historic weather, Caltrans expects events of this scale to increase in frequency, due to climate change. It will be important that actions taken to respond to these events and similar future events increase system resiliency and address potential future conditions.


Keep Off

EFFORTS IN DISTRICT 4 TO ADDRESS CLIMATE CHANGE

The San Francisco Bay may be one of the most studied water bodies in the world with regard to the effects of climate change on sea levels. The volume of studies generates active discussion on how this information may be used to provide policy and planning guidance. Various efforts have been undertaken by a range of agencies to define the potential impacts of higher water levels on the communities and infrastructure that borders the Bay.

One of the primary partners of Caltrans in determining these long term risks on the highway system is the San Francisco Bay Conservation and Development Commission (BCDC). In addition to BCDC's regulatory duties, the BCDC has been leading the sea level rise (SLR) studies in the region. In 2011, BCDC published Living with a Rising Bay, which presented the results of an initial vulnerability assessment of the Bay Area using two SLR projections: 16 inches (40 centimeters) by mid-century and 55 inches (140 centimeters) by the end of the century.[5] The assessment was focused on three planning areas: shoreline development, the Bay ecosystem, and governance. Conclusions and recommendations focused on several areas that could be strongly affected by SLR, including the San Francisco and Oakland Airports, critical natural habitats that need preservation, and the change in jurisdictional boundaries as SLR progresses.

BCDC also co-founded the Adapting to Rising Tides (ART) Program, which supports cross-jurisdictional projects in the Bay Area studying SLR and adaptation implementation. ART has partnered with other key stakeholders such as the Metropolitan Transportation Commission (MTC), the California Coastal Conservancy, and the San Francisco Public Utilities Commission, amongst others.[6] The ART Program provides online tools and reference reports that serve as a resource for other jurisdictions planning to address climate change and sea level rise. BCDC, in collaboration with MTC and the Bay Area Regional Collaborative (BARC), is conducting a project funded through a Caltrans grant to complete a vulnerability assessment for the Bay Area. This vulnerability assessment will include transportation assets,vulnerable and disadvantaged communities, Priority Development Areas and Priority Conservation Areas vulnerable to SLR. The grant also provides funding to develop initial adaptation strategies.[7] BCDC has a history of addressing SLR across the Bay Area and will continue to be an important partner for District 4 as concerns specific to the State Highway System are defined and addressed.

BCDC uses a methodology to determine flooding exposure that is different than that applied in this project. The BCDC method utilizes existing flood levels with sea level rise added to determine future flooding zones, whereas the assessment performed for this report utilized a hydrodynamic model to reflect future storm types, considering higher water levels associated with sea level rise. This model is called the Coastal Storm Modeling System (CoSMoS) and was developed by the United States Geological Survey (USGS). For more information on CoSMoS and the sea level rise data used in this vulnerability assessment, see the Sea Level Rise section on page 25.

Having multiple model representations of the future allows for a very robust assessment of future risk given that no model is perfect. Future efforts in the area will be able to utilize multiple data sets to establish a range of possibilities for planning and design efforts.

5 - The Bay Area Conservation and Development Commission, Living with a Rising Bay, http://www.bcdc.ca.gov/BPA/LivingWithRisingBay.pdf, 2011

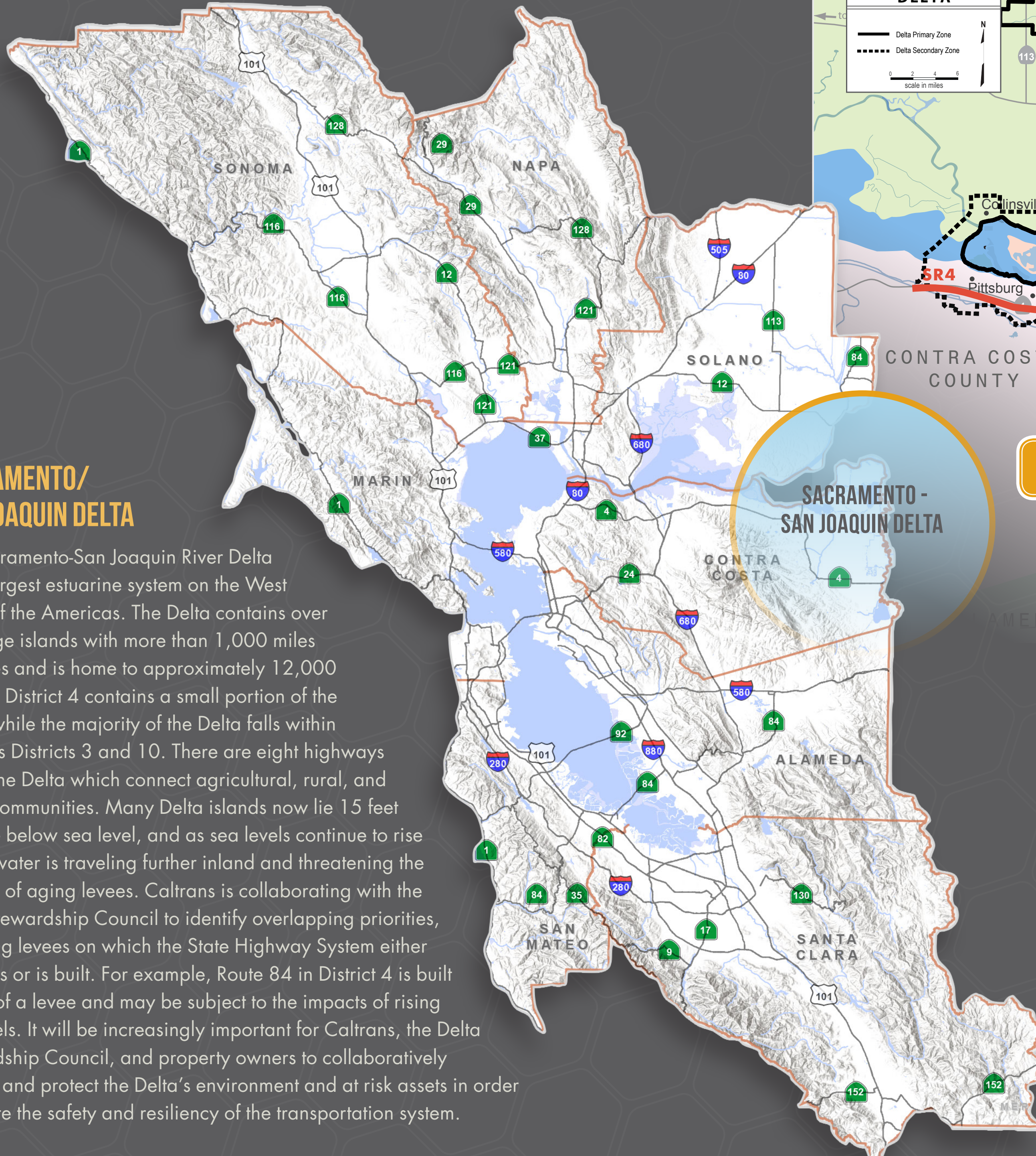
6 - Adapting to Rising Tides, "Regional Sea Level Rise Mapping and Shoreline Analysis," http://www.adaptingtorisingtides.org/project/regional-sea-level-rise-mapping-and-shoreline-analysis/, n.d.

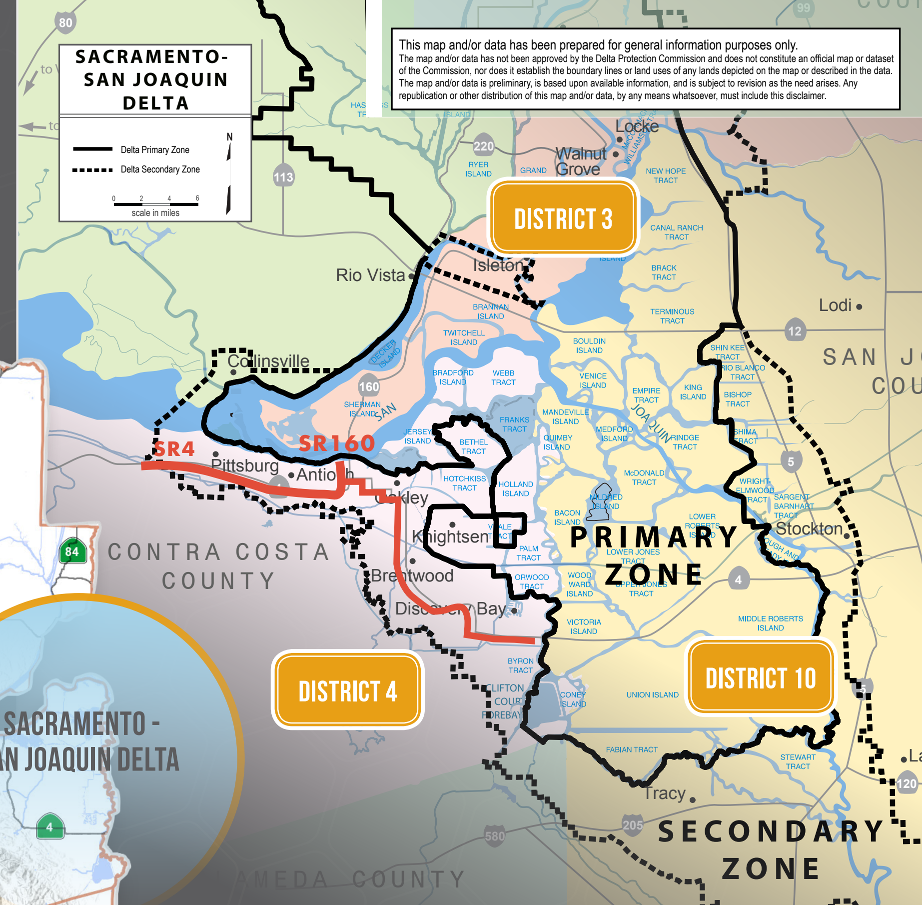
7 - Adapting to Rising Tides, "New Grant from Caltrans," http://www.adaptingtorisingtides.org/new-grant-from-caltrans/, 2016

THE CALIFORNIA COASTAL COMMISSION (CCC) ADOPTED THE CALIFORNIA SEA LEVEL RISE POLICY GUIDANCE DOCUMENT IN 2015, WHICH RECOMMENDED THE 2012 NRC REPORT AS THE BEST AND MOST CURRENT AVAILABLE SLR SCIENCE FOR CALIFORNIA.

THE CALIFORNIA OCEAN PROTECTION COUNCIL (OPC) RELEASED ITS OWN GUIDANCE IN 2011, WHICH WAS UPDATED IN 2013 AND RECOMMENDED THE SAME SLR PROJECTIONS AS THE CCC. "RISING SEAS IN CALIFORNIA: AN UPDATE ON SEA-LEVEL RISE SCIENCE" WAS RELEASED BY AN OPC WORKING GROUP IN APRIL 2017, WHICH WILL FEED INTO AN UPDATE OF THE OPC STATE SEA-LEVEL RISE GUIDANCE DOCUMENT.

Fig.1





SACRAMENTO/ SAN JOAQUIN DELTA

The Sacramento-San Joaquin River Delta is the largest estuarine system on the West Coast of the Americas. The Delta contains over fifty large islands with more than 1,000 miles of levees and is home to approximately 12,000 people. District 4 contains a small portion of the Delta, while the majority of the Delta falls within Caltrans Districts 3 and 10. There are eight highways within the Delta which connect agricultural, rural, and urban communities. Many Delta islands now lie 15 feet or more below sea level, and as sea levels continue to rise ocean water is traveling further inland and threatening the stability of aging levees. Caltrans is collaborating with the Delta Stewardship Council to identify overlapping priorities, including levees on which the State Highway System either depends or is built. For example, Route 84 in District 4 is built on top of a levee and may be subject to the impacts of rising sea levels. It will be increasingly important for Caltrans, the Delta Stewardship Council, and property owners to collaboratively identify and protect the Delta's environment and at risk assets in order to ensure the safety and resiliency of the transportation system.

VULNERABILITY AND THE STATE HIGHWAY SYSTEM

The Caltrans District 4 highway system provides critical accessibility and mobility to those living in, visiting and passing through the District, enabling commuting, commerce, social interactions, and a myriad of other activities. Given the importance of this system, understanding the potential impacts of climate change and extreme weather on system performance becomes a key step in creating a resilient highway system.

The term "vulnerability" is often used to describe the degree to which assets, facilities and even the entire transportation system might be subject to disruption due to weather-related stressors. Transportation agencies like Caltrans require a definition and approach that recognizes the various business practices of a transportation agency. The approach outlined on the following page outlines a process that fits transportation agency practices and has been defined for the purposes of this vulnerability assessment. The approach includes the following actions:

- **Exposure** – the identification of Caltrans assets exposed to damage or reduced service life from expected future conditions.
- **Consequence** – a determination of what might occur to system assets – in terms of loss of use or costs of repair.
- **Prioritization** – developing a method by which capital programming decisions will be made to address identified risks, including considerations of system use and/or timing of expected exposure.

Contributions to this method would require the participation of a wide range of Caltrans professionals from planning, asset management, operations/maintenance, design, emergency response and economics among others. It will take an agency-wide effort to implement successfully.

Caltrans over the past few years has been addressing concerns associated with climate change by developing guidance on how it can be incorporated into project design. In 2011, Caltrans released the Guidance on Incorporating Sea Level Rise document for use by Caltrans Planning staff and Project Development Teams. The guidance provides initial criteria for consideration to determine whether or not sea level rise needs to be incorporated into project programming and design. Factors that should be considered include: the project design life, the existence of alternative routes, anticipated travel delays, evacuations, traveler safety, and environmental constraints. Sea level rise projections for this guidance are adopted from the Ocean Protection Council's (OPC) 2011 guidance for the state.[8]

In addition, Caltrans developed a guide for California Metropolitan Planning Organizations (MPO) and Regional Transportation Planning Agencies (RTPA) which outlined methods on how to incorporate adaptation into Regional Transportation Plans. This guide provides an overview of climate science and the state of the practice in California, and how the broad subject of climate change relates specifically to transportation. Caltrans recommends in this document that every MPO and RTPA follow the basic evaluation steps of: assessing the effects of climate in their region, considering how their five most importation transportation assets could be affected, and developing adaptation strategies for further study and inclusion into the Regional Transportation Plan.[9]

8 - Caltrans, Guidance on Incorporating Sea Level Rise, http://www.dot.ca.gov/ser/downloads/sealevel/guide_incorp_slr.pdf, May 16, 2011

9 - Caltrans, Addressing Climate Change Adaptation in Regional Transportation Plans, http://www.dot.ca.gov/hq/tpp/offices/orip/climate_change/documents/FR3_CA_Climate_Change_Adaptation_Guide_2013-02-26_.pdf#zoom=65, February 2013

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

THE APPROACH INCLUDES THE FOLLOWING KEY ELEMENTS:

CONDUCT A VULNERABILITY ASSESSMENT OF ALL CALTRANS ASSETS

INCLUDING EXPECTED TIMING OF IMPACTS

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

DETERMINE THE CONSEQUENCE OF IMPACTS ON CALTRANS ASSETS

DAMAGE/LOSS
DURATION

PRIORITIZE ACTIONS

BASED ON TIMING AND CONSEQUENCE OF IMPACTS

CURRENT STAGE

EXPOSURE

Define the elements and locations of the highway system (roads, bridges, culverts, etc.) that may be exposed to changing conditions caused by climate change, including sea level rise, storm surge, wildfire, landslides, etc. Key indicators for this measure include the value and timing of expected changes (at what year could you expect these conditions to occur).

CONSEQUENCE

Identify the implications of extreme weather or climate change on Caltrans assets. Key variables include estimates of cost of damage, and the duration of closure to repair or replace the asset. The consequence of failure from climate change would include such concerns as (among others):

- Sea levels and storm surge inundating roadways and bridges forcing their closure, which could affect goods movement and the traveling public.
- Wildfire primary and secondary effects (debris loads/ landslides) on roadways, bridges and culverts.
- Precipitation changes, and other effects such as changing land use, that combined could increase the level of runoff and flooding.

PRIORITIZATION

Develop a method to support investment decisions among multiple options that each reflect future climate risk, including such considerations as:

- Timing – how soon can the impacts be expected?
- Impacts – what are the likely costs to repair/replace? What is the likely duration of outage? What are the likely impacts on travel/goods movement?
- Safety – Who will be directly or indirectly impacted? How can impacts to vulnerable populations be avoided?

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

PHASES FOR ACHIEVING RESILIENCY

California has been a national leader in responding to extreme climatic conditions (see Executive Order B-30-15). Successful adaptation to climate change includes a structured approach which anticipates likely disruptions, while also institutionalizing changes in agency operating procedures. The steps shown below outline an approach to achieve resiliency at Caltrans and show how work performed on this this study fit within that framework.

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

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

UNDERSTAND POSSIBLE TRANSPORTATION IMPACTS:
Higher precipitation levels could cause more flooding and landslides. Sea level rise and/or storm surge could inundate or damage low-lying coastal roads and bridges. Higher temperatures could effect maintaining the state's highways and contribute to wildfire risk for highways. Understanding these potential impacts provides an impetus to study ways to enhance the resiliency of the State Highway System.

SCOPE OF THIS STUDY

COORDINATE WITH FEDERAL/STATE RESOURCE AGENCIES ON APPLICABLE CLIMATE DATA:
Many state agencies have been actively engaged in predicting more specific future climate conditions for various purposes (i.e. water supply, energy impacts, and environmental impacts). Federal agencies have also been studying change for other purposes (coastal erosion, wildfires, etc.)

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

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

IDENTIFY PRIORITIZATION METHOD FOR CALTRANS INVESTMENTS:
This step identifies the process that can be used by Caltrans to prioritize projects and actions from the perspective of their likely system resiliency benefits, through reduced impacts to system users.

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

DEVELOP ACTION PLANS FOR EACH CALTRANS FUNCTIONAL AREA *(E.G., PLANNING AND MODAL PROGRAMS, PROJECT DELIVERY, MAINTENANCE & OPERATIONS, ETC.)*:

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

INCORPORATE RESILIENCY PRACTICES THROUGHOUT CALTRANS:

Each Caltrans functional area will be responsible for incorporating those actions that are outlined in the Action Plan, while reporting progress regularly to agency leadership.

DEVELOP AND IMPLEMENT PILOT STUDIES FOR PLANNING, PROJECT DEVELOPMENT, ETC.:

Pilot studies could be developed specific to each functional area and provide a "typical" experience for that function. Each pilot study would be assessed from the perspective of lessons learned and how this experience can feed into guidance on implementing more projects or actions similar to those in the pilot studies.

PRIORITIZE A SET OF PROJECTS/ACTIONS FOR ENGINEERING ASSESSMENTS:

The prioritization method described above would be used to identify those projects and actions that show the most benefit in terms of enhancing system resiliency. This prioritization could focus on those projects whose primary benefits relate to system resiliency, or on others whose estimated benefits include enhanced resiliency as just one component of total project benefits.

ADVANCE PROJECTS/ACTIONS TO APPROPRIATE INVESTMENT PROGRAMS:

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

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

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

TEMPERATURE

The U.S. National Climate Assessment notes that the "number of extremely hot days is projected to continue to increase over much of the United States, especially by late century. Summer temperatures are projected to continue rising, and a reduction of soil moisture, which exacerbates heat waves, is projected for much of the western and central U.S. in summer."[10] Given the size of California and the many different climate regimes that exist, it is expected that the range of temperature increases throughout the State will vary dramatically.

The figure on the following page shows the change in the average seven-day maximum temperature for three time periods compared to a base year of 2004, which is an important element in determining the right pavement mix for long term performance. In general, the potential impacts of increasing temperatures on the transportation system that have been identified in other studies in the U.S. include:

DESIGN

- Materials exposed to high temperatures over long periods of time will deform (such as pavement heave or track buckling). Pavements, in particular, consider high temperatures in their design to avoid deterioration.
- Ground conditions and more/less water saturation can affect foundations and retaining walls.

OPERATIONS AND MAINTENANCE

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

RESPONDING TO TEMPERATURE CHANGE

Ensuring long-term pavement quality on Caltrans roadways requires a consideration of a number of factors, including high and low temperatures in the study area. The expectations are that temperatures are expected to warm considerably to the year 2100, requiring a review of pavement design parameters. The eastern area of District 4 is expected to show the greatest increase in temperatures, with the average high temperature for one week increasing by an estimated 4-5 degrees (°F) by 2025 and 8-9 degrees (°F) by 2055 This indicates that roads would need to consider increasing temperatures as a part of pavement design for any projects planned for these areas.

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

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

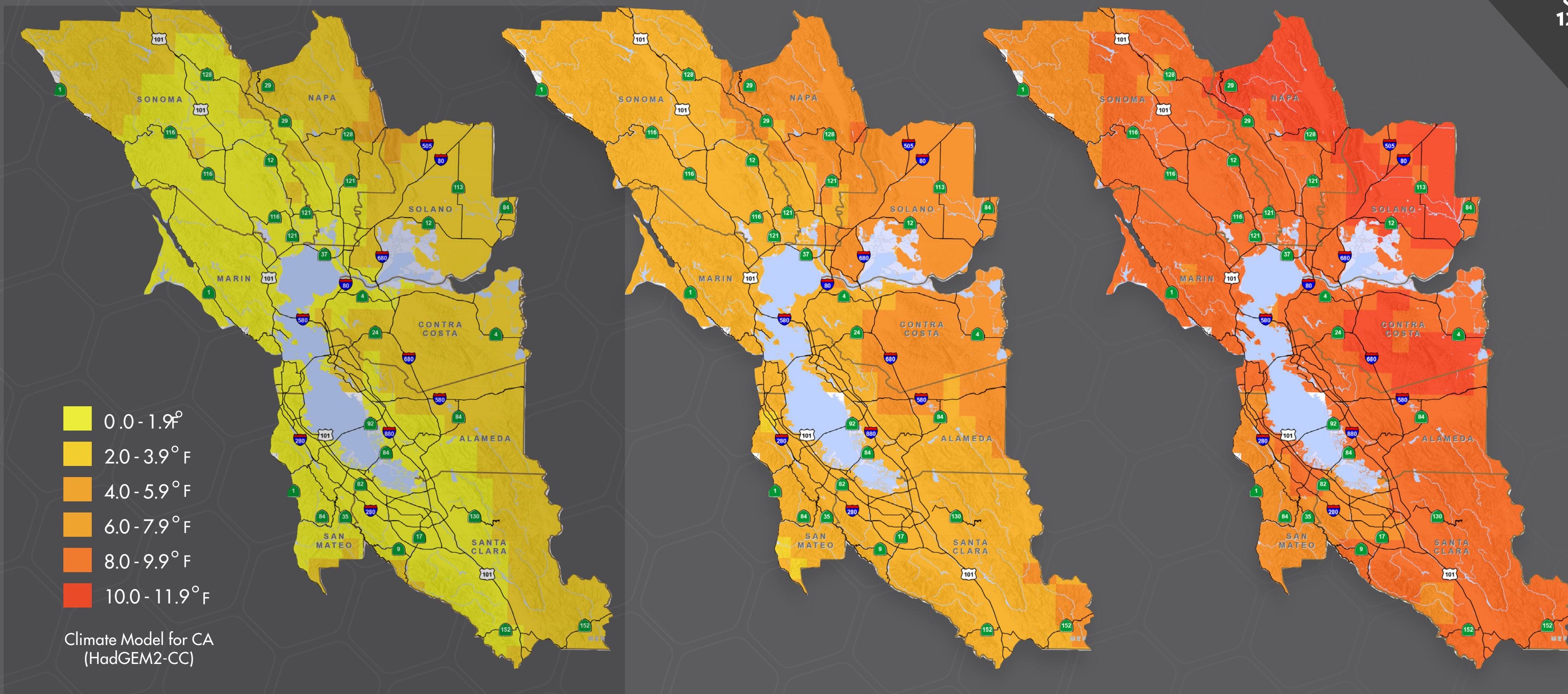
ROADSIDE LANDSCAPING WILL NEED TO SURVIVE LONGER PERIODS OF HIGH TEMPERATURES.

US101 IN MOUNTAINVIEW

Fig.2

CHANGE IN THE AVERAGE MAXIMUM 7 DAY MOVING AVERAGE TEMPERATURE

A REQUIRED MEASURE FOR PAVEMENT DESIGN



2025 REPRESENTATIVE CONCENTRATION PATHWAYS (RCP) 8.5, 50TH PERCENTILE[11]

2055 REPRESENTATIVE CONCENTRATION PATHWAYS (RCP) 8.5, 50TH PERCENTILE[11]

2085 REPRESENTATIVE CONCENTRATION PATHWAYS (RCP) 8.5, 50TH PERCENTILE[11]

Change in the Average 7-day Maximum Temperature, Worst Case Scenario for Future Greenhouse Gas Emission Concentrations, 2025, 2055, and 2085

11 - Caltrans Transpotation Asset Vulnerability Study, District 4. 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.

PAVEMENT DESIGN

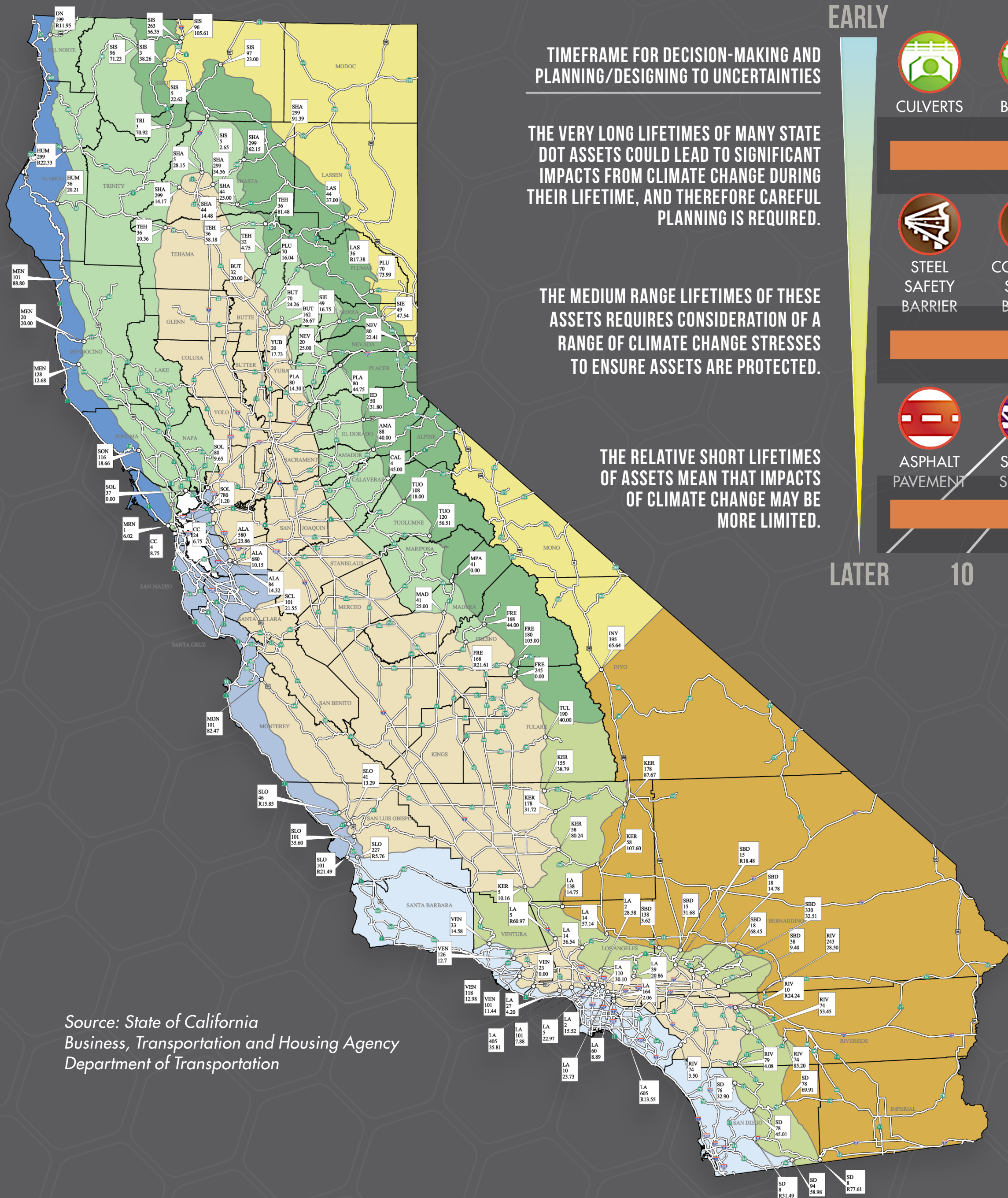
Pavement condition (which is related to how the pavement is designed) is one of the important components of Caltrans' highway asset management strategy. Ensuring that highway pavements remain durable and with good ride quality when exposed to various conditions is an important responsibility of every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

The consideration of the timing of climate change is a bit different for pavement design when compared to other assets. Many of Caltrans' assets, including roadways, bridges and culverts, will likely be in place for many decades or longer, and therefore decisions made today for these types of assets need to incorporate a longer view than is the case for asphalt pavement. Asphalt pavement is replaced approximately every 20-25 years, or sooner if quality degrades more rapidly.

The graphic on the following page identifies how various elements of the State Highway System may need to be considered as part of an adaptation assessment to adequately reflect agency decisions considering climate change. The graphic, originally developed by England's Highways Agency, identifies the expected lifetimes for various roadway assets, showing how decisions for each need to consider various timeframes. As noted, pavement design uses much shorter timeframes and therefore the relative short lifetime may mean impacts from climate change would be expected to be more limited.

Caltrans has divided the state into nine pavement climate regions, which help to define the types of pavement recommended for each area. Pavement design uses as two of its primary criteria "seven day average maximum temperature" and "average minimum temperature," the measures assessed by analyzing available climate data to determine whether decisions regarding pavement may change over time. An important issue for Caltrans and its pavement design engineers will be whether the boundaries of these climate regions could shift due to climate change, or whether the pavement design recommendations identified for each region may shift due to climatic changes in that region.

Fig. 3 CALTRANS PAVEMENT REGIONS



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

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

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

Fig. 4 TIMEFRAME FOR DECISION MAKING

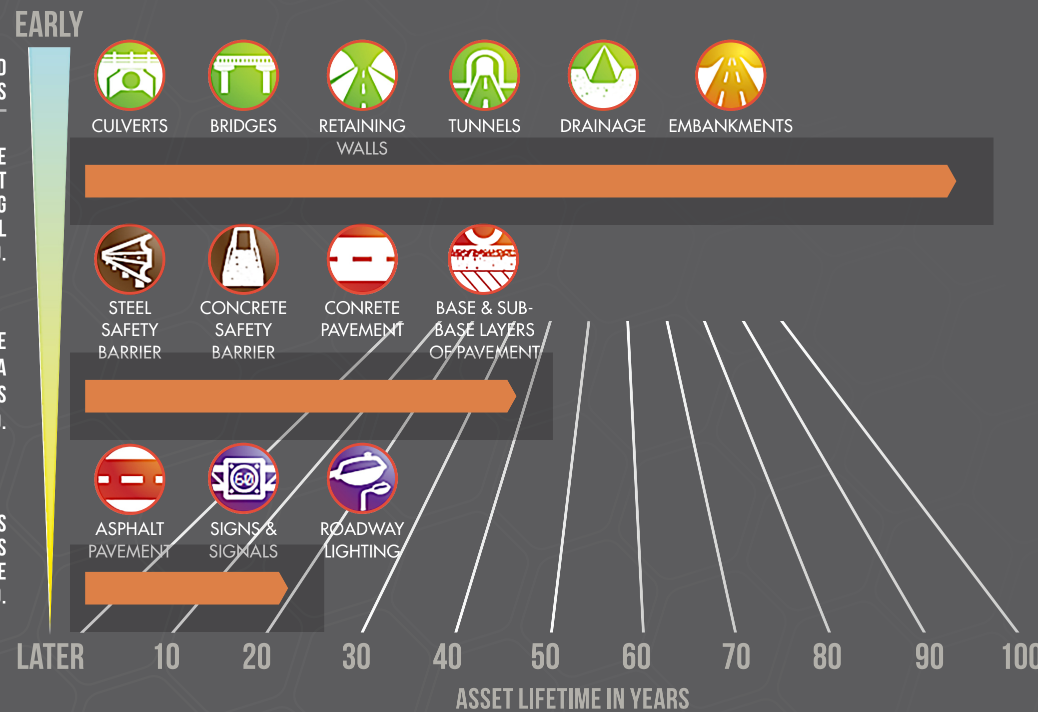
TRANSPORTATION INFRASTRUCTURE ASSETS

TIMEFRAME FOR DECISION-MAKING AND PLANNING/DESIGNING TO UNCERTAINTIES

THE VERY LONG LIFETIMES OF MANY STATE DOT ASSETS COULD LEAD TO SIGNIFICANT IMPACTS FROM CLIMATE CHANGE DURING THEIR LIFETIME, AND THEREFORE CAREFUL PLANNING IS REQUIRED.

THE MEDIUM RANGE LIFETIMES OF THESE ASSETS REQUIRES CONSIDERATION OF A RANGE OF CLIMATE CHANGE STRESSES TO ENSURE ASSETS ARE PROTECTED.

THE RELATIVE SHORT LIFETIMES OF ASSETS MEAN THAT IMPACTS OF CLIMATE CHANGE MAY BE MORE LIMITED.



THE DESIGN LIFE (OR "USEFUL LIFE") OF TRANSPORTATION INFRASTRUCTURE IS THE ESTIMATED REMAINING TIME THAT AN ASSET WILL BE IN SERVICE.

Transportation assets have differing periods of useful life once put in place. These timeframes should be a factor when planning In areas with identified climate change concerns. Roadway alignments and embankments could be in place for a century or beyond, while other assets would have a less or much less useful life.

PRECIPITATION

Increasing temperatures are expected to result in changing precipitation events, due to an increase in energy and moisture in the atmosphere. Increased precipitation levels, combined with other changes in land use and land cover, can increase the risk of damage or loss from flooding. Transportation assets in California are affected by precipitation in a variety of ways, from inundation/flooding due to heavy rainfall events, to landslides and washouts or structural damage from heavy rain events. The primary concern with regard to transportation assets is not the overall volume of rainfall observed over an extended period, but rather the expectation of changing future conditions for heavy precipitation and the potential for increasing damage to the State Highway System.

The Scripps Institution for Oceanography at the University of California, San Diego has compiled an expected future rainfall database to the year 2100, an effort that incorporates different estimates for how much greenhouse gas might be emitted into the atmosphere. An important way to look at the level of change in precipitation in the future is to assess what happens to the so called 100-year precipitation event. In more commonly used terms, this is the type of storm that will likely happen once in every 100 years—a potentially very damaging storm and one that is often used in the design of highway infrastructure. The figure on the next page shows the percent change in the 100-year event (when compared to historic rainfall) precipitation depth in Caltrans District 4 for each of the three analysis periods noted. The maps represent a relative mid-point of predicted precipitation increase. As seen, for the period represented by 2085, some portions of District 4 will likely experience a 15% increase in the precipitation depth coming from a 100-year storm. In inches, this means an estimated additional 1" of rainfall in a day in southeast Marin County.

RESPONDING TO PRECIPITATION CHANGE

Indications of increased precipitation in District 4 means that Caltrans will need to plan differently for improvements to the State Highway System, assuming higher rainfall and associated flooding. This condition can be exacerbated by increased development which reduces the natural absorption capacity of the land in the drainage area. Complex conditions like these require that a long view be taken on design and responses to flood concerns for facilities in these areas to ensure that facilities will remain operational to the end of their design lives. Actions to improve long-term resiliency will require that Caltrans conduct a comprehensive assessment of future conditions, incorporating new values for precipitation. Assessing recent examples of flooding and the impact on the State Highway System will also provide benefits for how to ensure a higher level of resiliency to future precipitation effects.

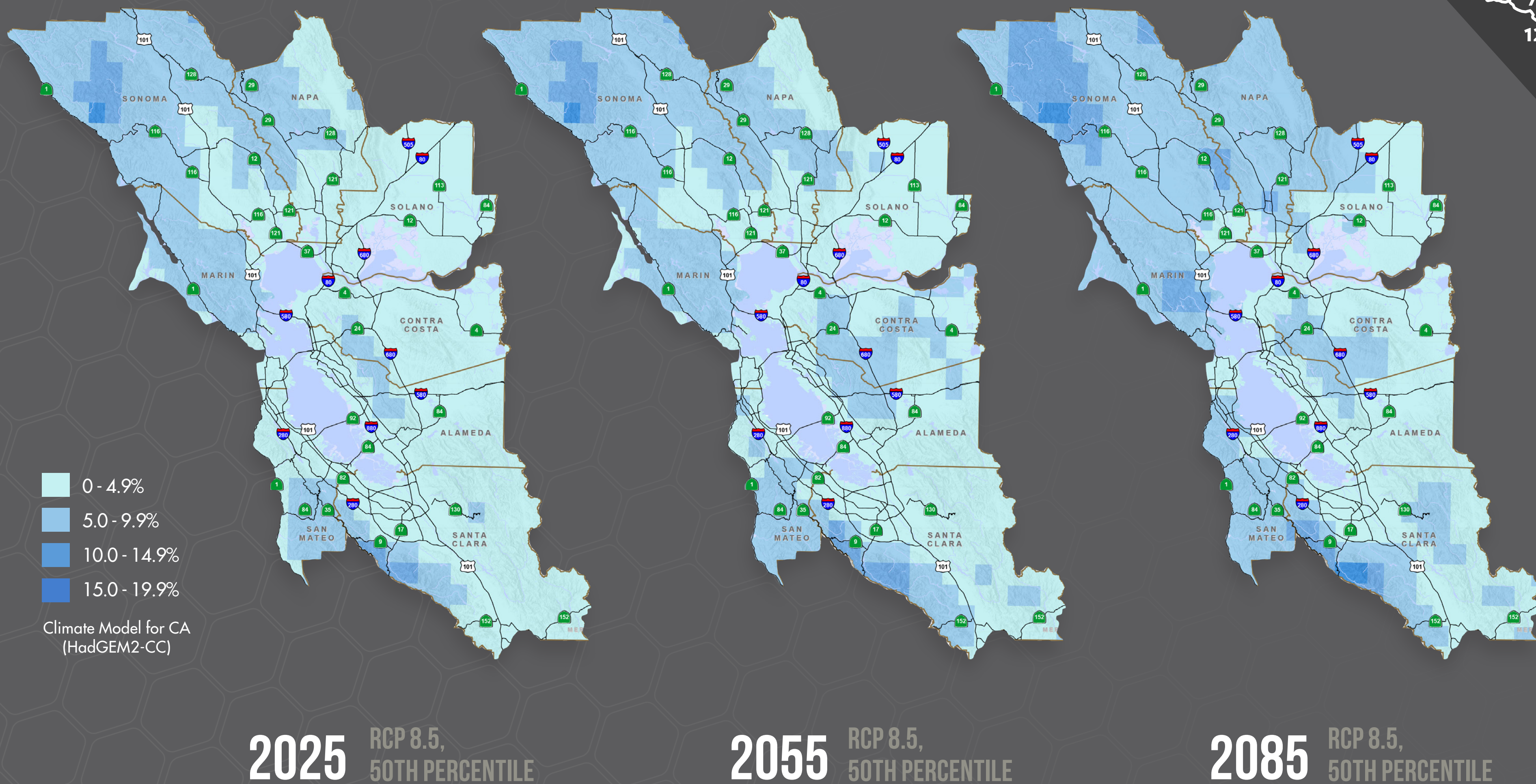

HIGHWAY 37 IN MARIN COUNTY

FLOODING IS EXPECTED TO INCREASE IN LOWLYING AREAS


HIGHWAY 12 NEAR THE NAPA RIVER

Fig. 5

CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH



Percent Change in 100-year Storm Precipitation Depth, Worst Case Scenario for Future Greenhouse Gas Emission Concentrations, Caltrans District 4, 2025, 2055, and 2085

Caltrans Transpotation Asset Vulnerability Study, District 4. 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.

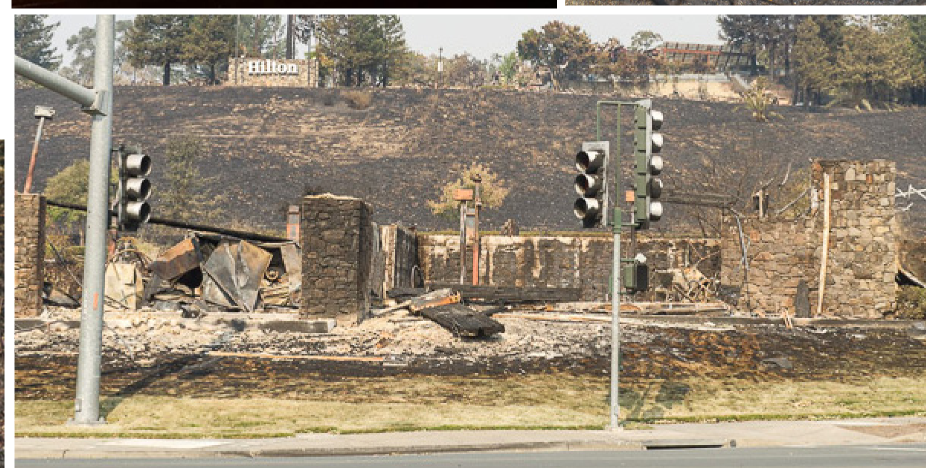
WILDFIRE

The year 2017 is noted as being one of the most destructive years in California wildfire history, particularly within Caltrans District 4. The Tubbs and Nuns fires in Sonoma County and the Atlas fire in Solano and Napa Counties represent three of the top 10 wildfires in recorded California history—with a combined 143,000 acres burned, 7,800 structures damaged or destroyed, and 29 lives lost[12] to fast moving wildfires with many of these being elderly residents. Caltrans employees were among the impacted, with four employees losing their homes and over 30 others having to leave their homes during the evacuation.[13] The wildfires displaced thousands and severely impacted many communities. The process of recovering from these events and rebuilding the impacted communities will take years and will require a coordinated effort among Federal, state and local agencies—all of which are committed to restoring the viability of these neighborhoods for California residents and businesses.

The conditions that contributed to the severity of the wildfires—a wet winter which fed vegetation growth followed by long periods with very low humidity and then the high velocity Diablo winds—were extreme weather conditions. The ignition source, still to be identified, is likely attributed to an influence associated with developed areas—electrical infrastructure or human factors—but it was the conditions created by changing climate and related extreme weather that contributed to the intensity and extent of the damaged caused by the wildfires.

Caltrans is responsible for the State Highway System which serves critical functions before, during and after extreme weather events like these wildfires. 42 miles of the highway system were within the areas impacted by these three fires in District 4, contributing to the total of 45 miles in areas affected by wildfires throughout 2017 in District 4. Various state highways were closed over 16 days during these events, including Routes 101, 121, 29, 128, and 12. Highway repairs in District 4 after

12 - http://www.fire.ca.gov/communications/downloads/fact_sheets/Top20_Destruction.pdf
13 - Internal report – October 18, 2017



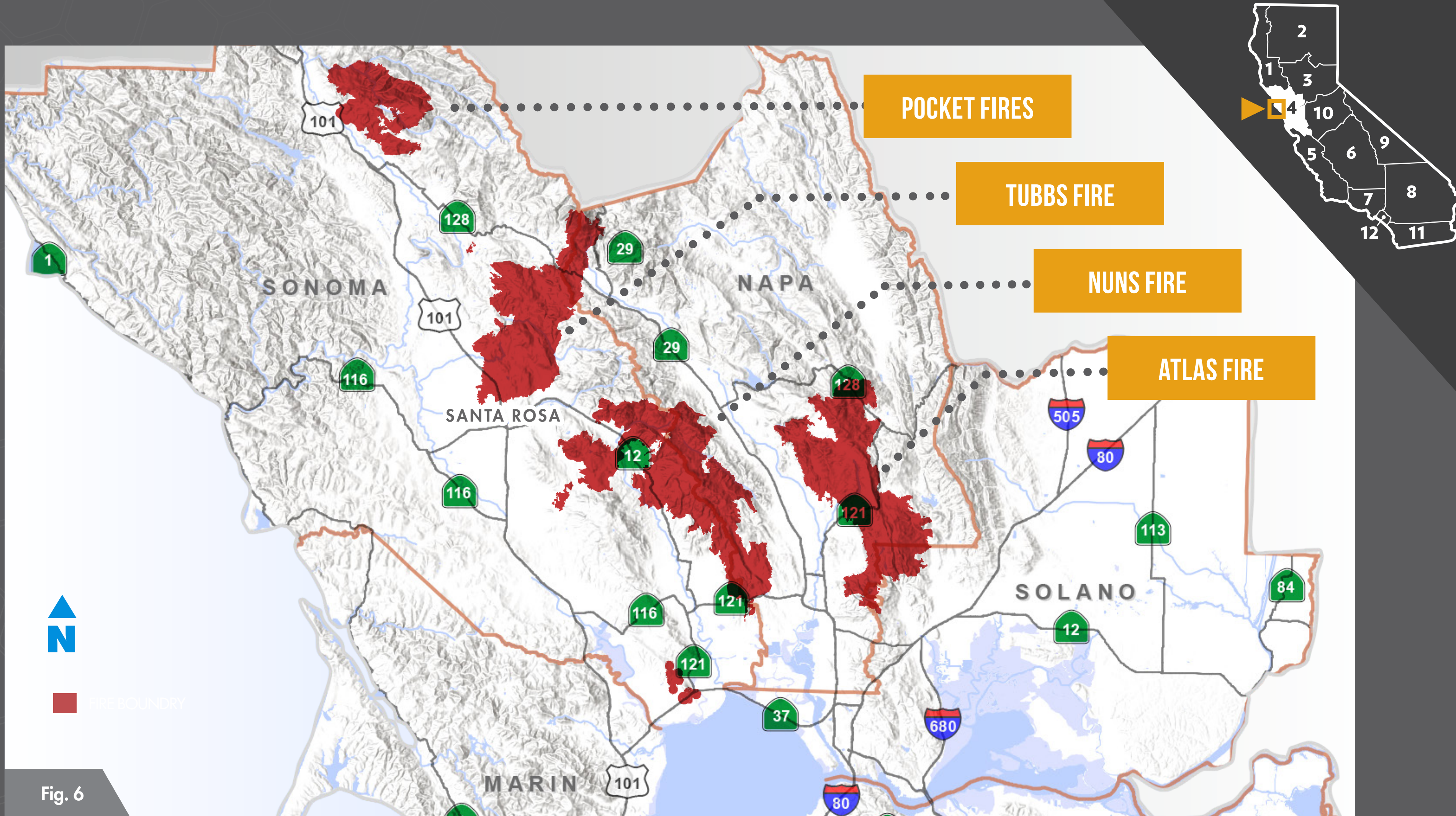


Fig. 6

fires were extinguished cost $14.4 million dollars, and extra personnel costs paid by Caltrans were $1.23 million for all fires statewide, for costs documented through November 29, 2017.

These highways, as part of the statewide system, serve as evacuation routes for community members, critical access links for emergency responders, essential arteries required to move equipment and supplies needed to facilitate recovery efforts, and as important community assets as neighborhoods are restored.

Moving forward from these events, maintaining access along the impacted roadways will require a coordinated effort across various Caltrans divisions. This system will require effort to restore—to repair damage from the fires, to address higher maintenance needs resulting from debris in burned areas, and to monitor for heightened risks of flooding and landslides resulting from scorched shrubs, trees, and soil while surrounding sensitive natural systems also recover. There are lessons to be learned based upon what occurred and as Caltrans compiles recommendations for how to adapt based on these events.

Understanding how climate change may impact future wildfire risk and better defining the effects of climate change are topics of research by a few key agencies—including the US Forest Service and Environmental Protection Agency, and Calfire and the University of California Merced. Data from this research is being utilized by Caltrans to define actions that may need to be taken to address potential future impacts.

WILDFIRE AND CLIMATE CHANGE

The devastating wildfires that occurred recently in District 4 are a major concern to Caltrans and other state agencies. In the future, higher temperatures and changing precipitation patterns are expected to continue to influence the likelihood of wildfires and their extent throughout the state. A few agencies and institutions have been developing, testing and refining models to estimate future changing wildfire risks associated with climate change.

The US Forest Service has partnered with Oregon State University and the EPA to develop and update models (MC1 and MC2) which simulate changing soil moisture and vegetation conditions resulting from climate change to project how wildfires may change to the end of the century. The Sierra Nevada Research Institute at UC Merced has also recently developed a statistical model to estimate how wildfire risks may change over time to the future—holding groundcover assumptions constant but incorporating changing temperature and precipitation patterns projected from climate models.

Both efforts utilize the Locally Constructed Analogue (LOCA) downscaled climate data sets which have been developed by the Scripps Institute of Oceanography at the University of California, San Diego. The LOCA data provides a high resolution spatial and temporal set of information on changing temperature and precipitation patterns projected to occur in California. LOCA better simulates potential changes in extreme conditions and climate variability than many other techniques. This downscaled data enables an analysis of changes using more refined assumptions and for more specific geographic conditions than data provided by global climate models.

The information presented in this section utilizes the MC1 wildfire model outputs for two emissions scenarios and shows how the outputs of that model depict wildfire risks in forested areas changing over time. The MC2 model and UC Merced models were in the development/refinement stage at the time of the development of this report. The MC1 model results do not reflect the conditions present in the Sonoma/Napa fires which are the result of a series of extreme weather events as outlined in the previous section. The event was unanticipated by most researchers, and many of the hardest hit areas are noted as having moderate/little risk even within Cal Fire's Fire Hazard Severity Zones maps. This event will be the basis of research from this point forward, enabling a better understanding of future risks.

Caltrans, in its ongoing efforts to define how existing practices will need to change to reflect projected changes in future conditions—will be working over the next few years with the agencies tasked with developing these models to refine the understanding of future wildfire risk. This analysis will provide insight into how wildfire risks in the District can change, and support the development of actions and policies that address these changes in wildfire risk.

WILDFIRE EFFECTS

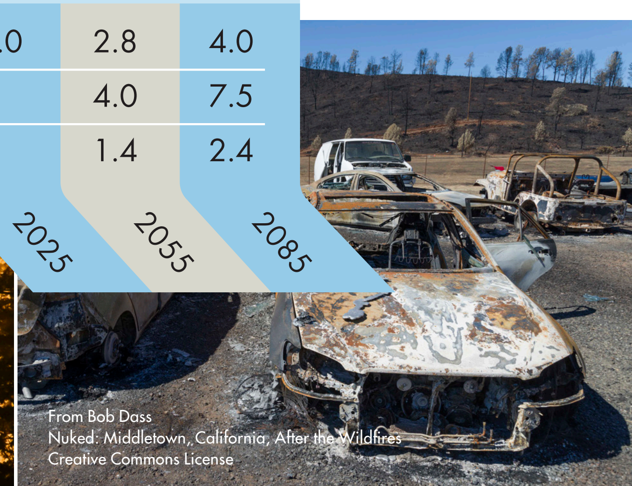
The maps shown in Figure 7 identify the areas of District 4 where long-term wildfire occurrence is projected based on the outputs of the MC1 model; the areas shaded in red indicate there is an increased likelihood of multiple wildfires for each analysis period.

Wildfire can be a direct risk to travelers on California roadways and, after the fire has scorched an area, can also exacerbate flooding by denuding hillsides of vegetation (which helps to retain rainfall) and reducing the permeability of soils. Both factors can contribute to dramatically higher runoff and the presence of debris that can clog culverts or bridge openings. The following pages show how these conditions can impact Caltrans facilities for extended periods.

Table 2: Miles of Roadways in Moderate to High Wildfire Exposure Areas (estimated)

County	Miles		
	2025	2055	2085
Santa Clara	1.0	2.8	4.0
Solano		4.0	7.5
Napa		1.4	2.4

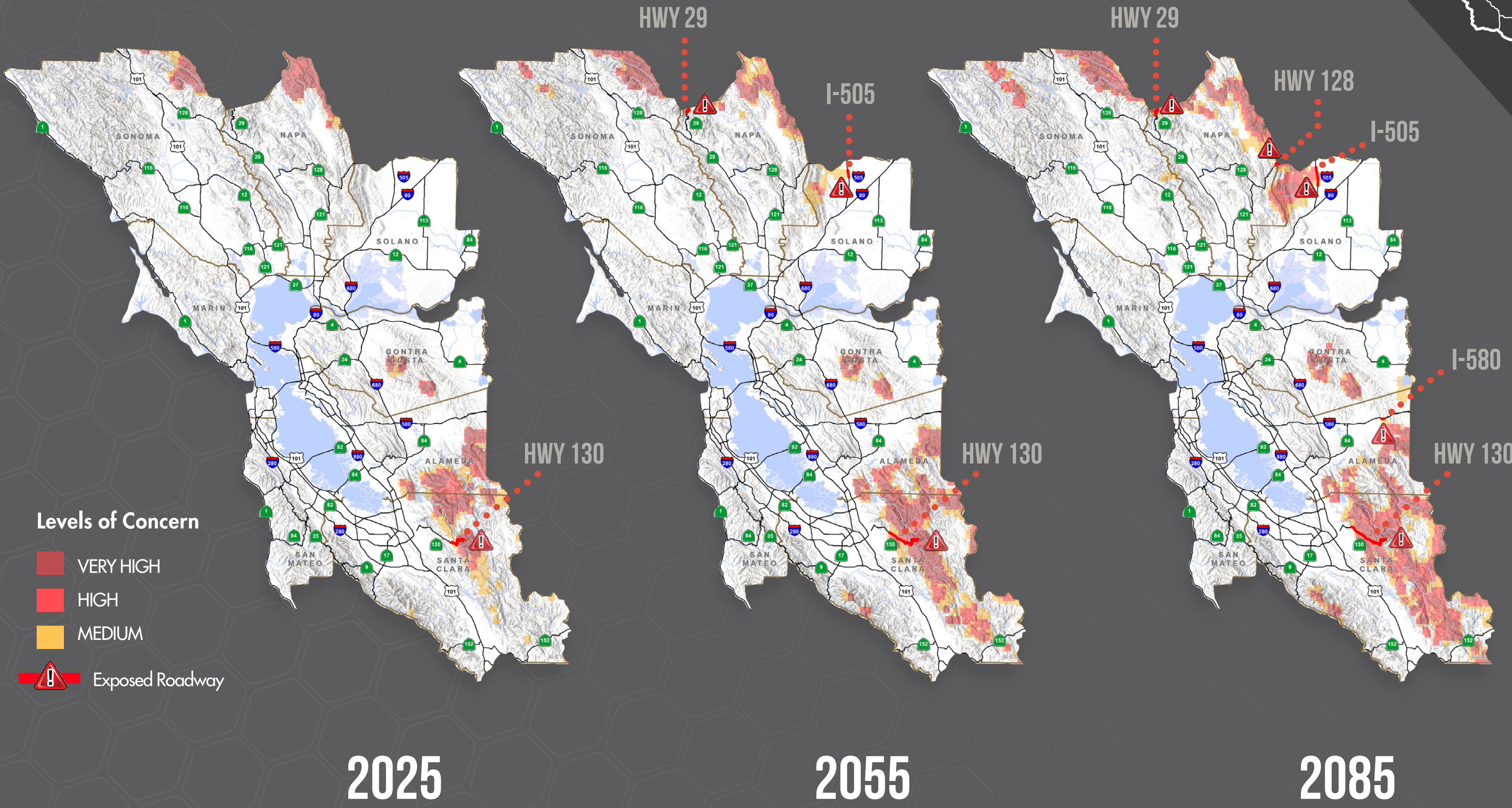
HIGHWAY 130 IN SANTA CLARA COUNTY IS THE DISTRICT 4 ASSET MOST AT RISK FROM WILDFIRE



From Bob Dass
Nuked: Middletown, California, After the Wildfires

Fig. 7

LEVEL OF WILDFIRE CONCERN



Level of Wildfire Concern for Caltrans State Highway System Exposed to Wildfires within District 4 in Future Years

Caltrans Transportation Asset Vulnerability Study, District 4. Caltrans No. 74A0737. Fire projections developed using the MC1 fire model by John B. Kim and Bear (G. Stephen) Pitts of the USDA Forest Service Pacific Northwest Research Station, displaying the A2 (or higher emissions) scenario.

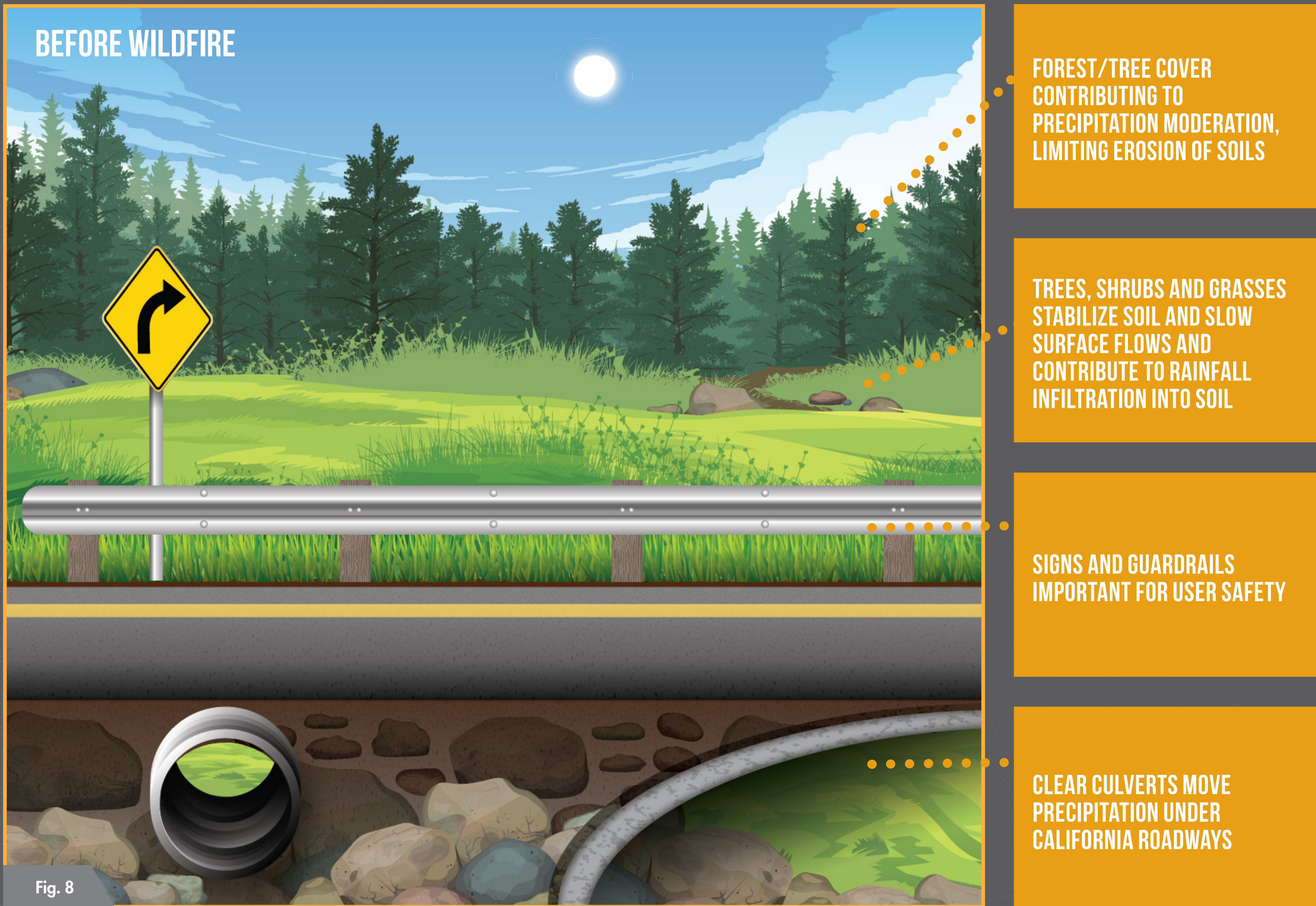


Fig. 8

Healthy vegetated areas provide various ecosystems services contributing to precipitation infiltration and soil stabilization. These natural systems help prevent potential damage to roadways, bridges and culverts by managing flood waters and preventing erosion.

LOSS OF FOREST COVER REDUCING ABSORPTION OF RAINFALL AND ABILITY TO MODERATE WATER FLOW

BURNED SOILS REPEL WATER—LIMITED INFILTRATION OF RAINFALL AND LEADING TO MORE RAPID DELIVERY OF WATER TO CULVERTS/BRIDGES

LOSS OF GROUNDCOVER RESULTING IN LOOSER SOILS AND INCREASED LANDSLIDE RISK

DEBRIS ON THE GROUND, INCREASING RISKS OF CLOGGING RISK AT CULVERTS/BRIDGES

LOSS OF SAFETY SIGNS AND GUARDRAILS

DAMAGED AND/OR CLOGGED CULVERTS CONTRIBUTING TO RISK OF POTENTIAL DAMAGE DURING RAINFALL EVENTS DUE TO BREACHING OF EMBANKMENT AND/OR OVERWASH OF ROADWAYS

Fig. 9

After wildfires have impacted the land, new risks are posed to transportation assets in the area. In the immediate period following a fire, the loss of signs and guardrails present a danger for roadway users, requiring an immediate response to maintain traveler safety. Other impacts noted in the graphic above can exist as a potential risk to Caltrans assets for years after a wildfire event occurs.

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 4 has an extensive coastline, with Caltrans facilities providing access to bayshore and coastal areas. Sea level rise will exacerbate the flooding 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 could face risk of inundation or damage in the future.

Like other forecasted changes in climate, estimates of sea level rise vary, depending in part on the assumptions made regarding future concentrations of greenhouse gas concentrations in the atmosphere and how the earth's systems will respond. The California Coastal Commission Sea Level Rise Policy Guidance (2015) provides a good overview of how California has been estimating expected increases in sea level.

The State is currently finalizing an update to the Sea Level Rise Guidance, which will provide statistical ranges of sea level rise for future years based on the latest science outlined in Ocean Protection Council's 2017 report "Rising Seas in California." Figure 10 shows projections of sea level rise outlined in the current draft of this document, highlighting the potential future values for sea level rise when considering various contributing factors.

For the District 4 assessment of sea level rise and the following assessment of future storm surge (starting on page 27), these estimates, and estimates from other sources for District 4, were used to select data available as an output of the Coastal Storm Modeling System (CoSMoS). CoSMoS was developed by the United States Geological Survey (USGS) to model the potential impacts of sea level rise, and storm surge, along portions of the California coast and within San Francisco Bay. Table 3 shows the miles of District 4 State Highway exposed to sea level rise for three modeled CoSMoS increments: 1.64, 3.28, and 5.74 feet.

COASTAL EROSION

Increasing sea level rise will exacerbate tidal flooding and storm surge conditions along the California coastline, leading to coastal erosion and cliff retreat. This could impact coastal infrastructure along the Pacific shoreline as it did in the Devil's Slide area (see page 31 for more on Devil's Slide). Highway 1 near Half Moon Bay is a known area of concern for these coastal effects, which will potentially worsen as seas continue to rise. Erosion and landslide conditions along the coast will be impacted by sea level rise, coastal storms, and precipitation effects—California's recent rainy season after a five-year drought has caused severe flooding, landslides, and coastal erosion, totaling over $1 billion in highway damage for Caltrans. These conditions on coastal highways are expected to become more pronounced as sea level rises. Strategies that address long-term coastal erosion, increasing tidal flooding conditions, and increased storm surge will need to be developed.[14]

14 - Wamsley, Laurel, "'Mother of all Landslides' in Big Sur Buries Section of California's Highway 1," http://www.npr.org/sections/thetwo-way/2017/05/25/530025850/-mother-of-all-landslides-closes-section-of-california-s-highway-1, May 25th, 2017

Table 3: Miles of District 4 State Highway System Exposed to Sea Level Rise

County	Estimated Sea Level Rise		
	0.5 meter (1.64 ft): 2048 - 2100	1.0 meter (3.28 ft): 2064 - 2100	1.75 meters (5.74 ft): 2081 - 2100
Alameda	4.9	7.4	19.0
Contra Costa	2.1	2.3	3.6
Marin	5.9	11.8	17.2
Napa	0.1	0.1	0.4
Santa Clara	2.1	2.5	4.9
San Francisco	5.0	5.1	5.7
San Mateo	7.7	17.4	27.3
Solano	2.5	2.8	11.0
Sonoma	3.6	4.8	5.2

Miles of State Highway Exposed

ANALYSIS FOR THIS REPORT WAS CONDUCTED ON THREE DISTINCT INCREMENTS OF SEA LEVEL RISE TO SHOW HOW CONDITIONS MAY CHANGE OVER TIME. THOSE INCREMENTS INCLUDED 1.64 FEET (.5 METER), 3.28 FEET (1 METER) AND 5.74 FEET (1.75 METERS)

APPROXIMATELY 95 MILES OF CALTRANS DISTRICT 4 ROADS AND BRIDGES MAY BE EXPOSED TO SEA LEVEL RISE BY THE END OF THE CENTURY

Fig. 10

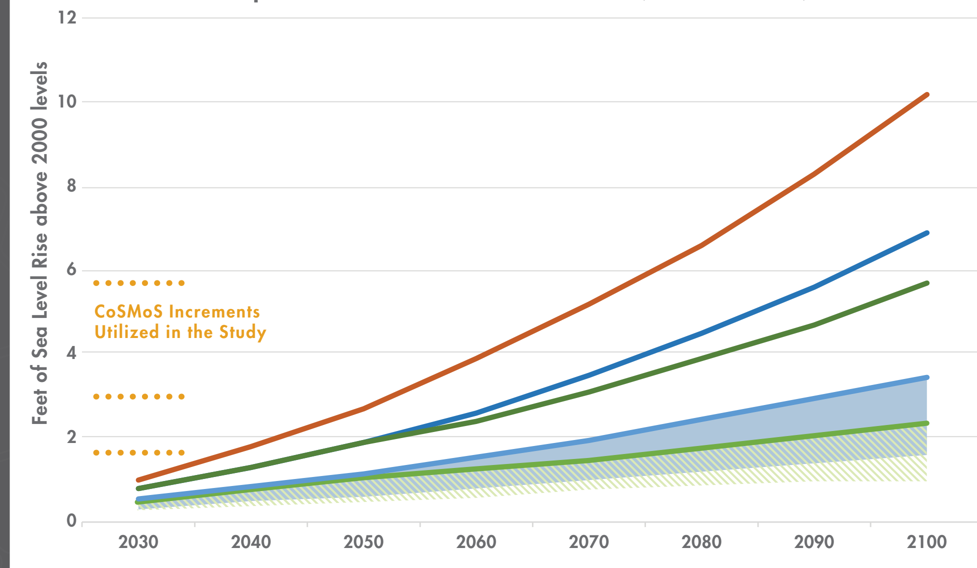
SEA LEVEL RISE ESTIMATED FOR DISTRICT 4

Estimates of sea level rise have been developed for California by various agencies and research institutions. The graph shown at right reflects estimates recently developed for San Francisco by a scientific panel for the 2018 Update of the State of California Sea-Level Rise Guidance (Draft), an effort led by the Ocean Protection Council (OPC). For more information on how to implement the guidance, see the OPC State Guidance Draft.[15]

Projections were developed for areas along the California coast based on global and local factors that drive sea level rise. Research on each of these factors is ongoing and estimating the timing and extent of sea level rise will remain a dynamic process. These estimated projections for California are expected to be updated in the future based on those assessments and will be utlized by Caltrans for programming efforts.

OPC Estimates for Sea Level Rise

- Extreme Estimate of Sea Level Rise (H++ Scenario) *Highest estimated value. This value is recommended when considering assets that will be in place long-term and are of a critical nature where impacts could be significant (for major airports, toxic storage sites, etc.)*
- Low Probability/High Estimate of Sea Level Rise (RCP 8.5) *High value for this emissions scenario. Recommended to be incorporated into decisions for long-term efforts where the potential impacts may be high.*
- Low Probability/High Estimate of Sea Level Rise (RCP 2.6) *High value for this emissions scenario.*
- Top End of the Likely Range of Sea Level Rise (RCP 8.5)
- Estimated Likely Range of Sea Level Rise (RCP 8.5) *The shaded area depicts a likely range of sea level rise for this emissions scenario, which assumes an increase in emissions to the end of century.*
- Top End of the Likely Range of Sea Level Rise (RCP 2.6) *This line represents the lowest value to be considered for any project.*
- Estimated Likely Range of Sea Level Rise (RCP 2.6) *The shaded area depicts a likely range of sea level rise for this emissions scenario, which assumes an unlikely decrease in emissions.*



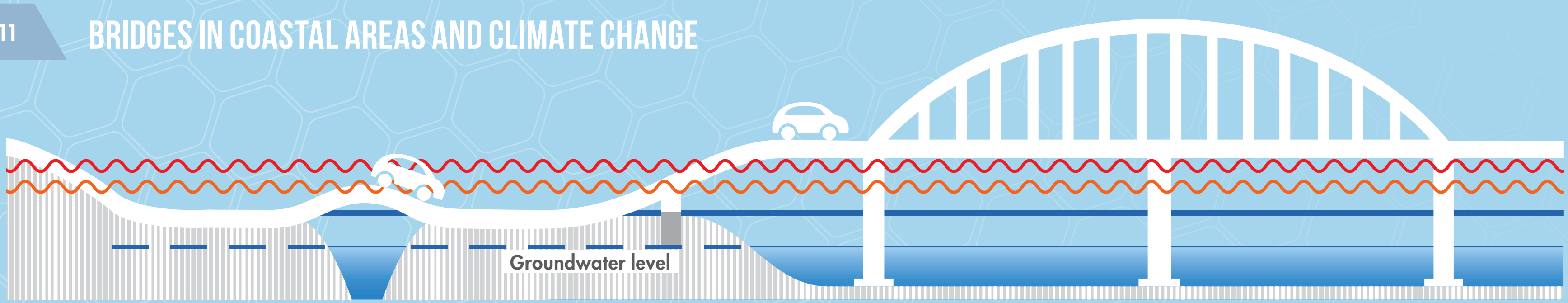
Note: RCP 2.6 values for 2030-2050 are linearly interpolated from the 2000 baseline, with interpolated values constrained to maximum of their equivalent RCP 8.5 values.

Note: The OPC guidance outlines an approach for incorporating sea level rise into planning, permitting, and investment decisions which recognizes the uncertainties for future SLR. The sea level rise estimates shown above are the values the guidance identifies that practitioners should consider. When making decisions, practitioners are advised to address the impacts of various water levels on project alternatives, identify possible adaptive designs that can be altered to adjust to changing future conditions, and consider the risk tolerance for assets. This approach is recommended for Caltrans assets, and a design approach that includes these considerations is outlined on page 32 of this document.

15 - http://www.opc.ca.gov/webmaster/_media_library/2017/11/State-of-California-Sea-Level-Rise-Guidance_draft-final_11.15.17.pdf

Fig. 11

BRIDGES IN COASTAL AREAS AND CLIMATE CHANGE



Climate change can impact infrastructure in a few ways. Bridges in coastal areas, for example, can be impacted by rising sea levels and storm surge effects. Bridges have been designed and built for today's tidal and surge conditions, so increasing water levels may increase the risk at these facilities in the future.

Some of the concerns for bridges could include:

1. A rising groundwater table may inundate supports on land that were not built for saturated soil conditions, leading to erosion of soils and loss of stability.
2. Higher sea levels means greater forces on the bridge during normal tidal processes, increasing scour effects on bridge structure elements.
3. Higher water levels means that storm surge will be higher and have more force than today. These forces would potentially impact scour on bridge substructure elements.
4. Bridge approaches where the roadway transitions to the bridge deck may become exposed to surge forces and may become damaged during storms.
5. Surge and wave effects may loosen or damage portions of the bridge - requiring securing, re-attaching or replacing those parts.
6. Bridge use may be impacted due to the loss/damage of a roadway or minor bridge near the bridge approaches

This may or may not be a concern as most bridges are built with added safety factors during design, but they should be assessed to be sure that they can withstand conditions that will change over time.

STORM SURGE

The inundation of coastal areas becomes even worse when combined with storm surge. Storm surge, in particular, can have powerful impacts on coastal infrastructure, causing extensive damage. Coastal infrastructure will be exposed to higher forces during storms, and it is likely that many coastal roads and bridges may now be exposed to greater surge effects, increasing damage and reducing useful life. Storm surge is also expected to increase coastal erosion and landslides, causing shoreline retreat and exposing roadways to increased effects from flooding (see Figure 12 on following page).

As sea level rises, one would expect more serious impacts from storm surge, and this is exactly what is shown in Table 4 where the number of miles of state highway inundated in District 4 under different scenarios are shown. The more significant the sea level rise, the larger the number of state highway miles under water during 100-year storm events.

Not surprisingly, the most affected roads will be those close to the coast. Figure 13 shows the sections of the State Highway System in the San Francisco Bay area of District 4 that are at high risk of future inundation due to sea level rise and storm surge from a 100-year storm assuming a one meter sea level rise. As can be seen, many of these state highways are critically important not only for the San Francisco Bay area, but also for serving intra-state travel and commerce.

Table 4: Miles of District 4 State Highway System Inundated Given Assumed Sea Level Rise with Storm Surge

County	Estimated Sea Level Rise with Storm Surge		
	0.5 meter (1.64 ft) 2048 - 2100	1.0 meter (3.28 ft) 2064 - 2100	1.75 meter (5.74 ft) 2081 - 2100
Alameda	5.6	10.0	25.3
Contra Costa	2.3	2.3	4.4
Marin	10.6	13.5	19.5
Napa	0.1	0.1	0.4
Santa Clara	2.3	4.3	5.4
San Francisco	5.1	5.1	6.7
San Mateo	15.9	25.7	30.4
Solano	2.6	2.9	11.7
Sonoma	4.7	5.0	6.4

Miles of State Highway Exposed

110 MILES OF ROADWAYS AND BRIDGES IN DISTRICT 4 ARE EXPOSED TO STORM SURGE BY THE END OF THE CENTURY, WITH 30 OF THOSE MILES IN SAN MATEO COUNTY

Fig. 12

STORM SURGE EXAMPLE

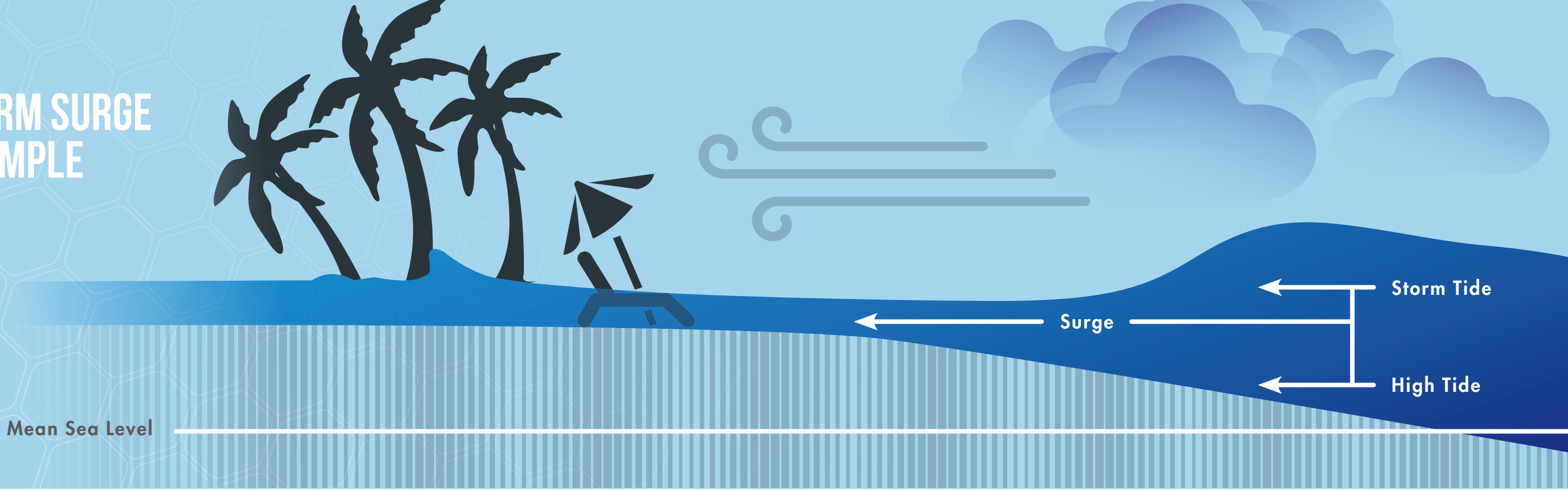
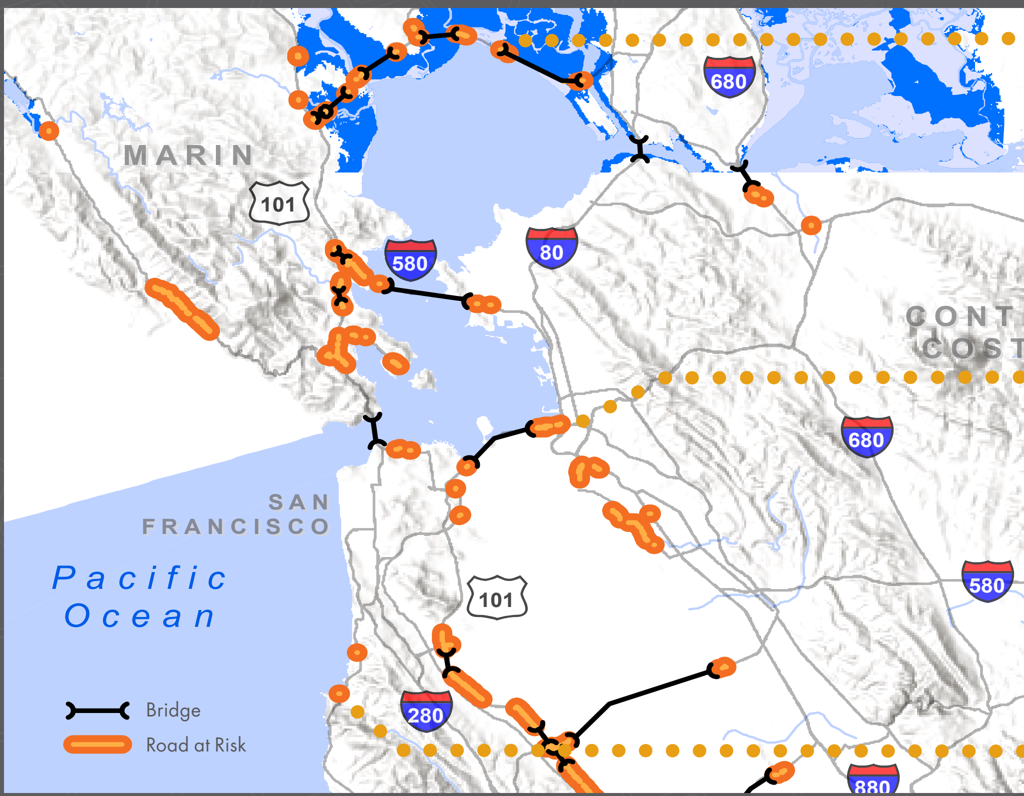


Fig. 13

ROADS AT RISK TO SEA LEVEL RISE

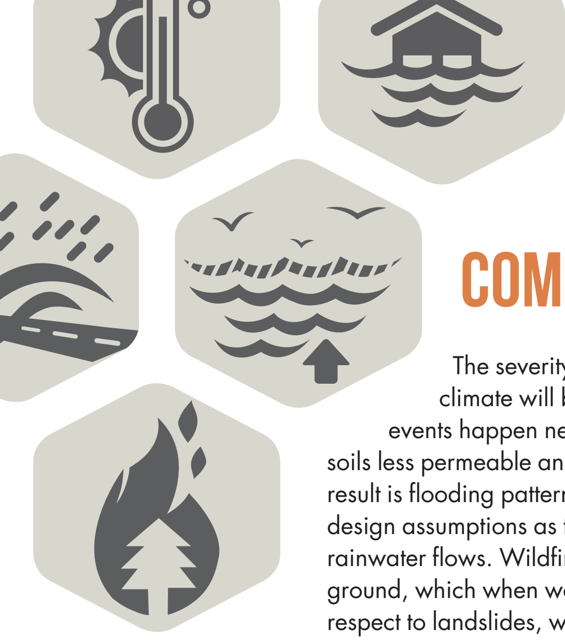


Roads at Risk of Flooding Due to Sea Level Rise and Storm Surge, San Francisco Bay Area.
3.28 ft (1 meter) Sea Level Rise 100-year Storm Surge

FLOODED BAYSHORE ROAD HIGHWAY 37

FLOODED BRIDGE ACCESS I-80 IN OAKLAND

ERODING COASTAL ROAD HIGHWAY 1



COMBINED EFFECTS

The severity of the impacts associated with a changing climate will be increased significantly when two or more events happen nearly at the same time. Wildfires can make soils less permeable and thus not able to absorb as much rainfall. The result is flooding patterns that are inconsistent with original roadway design assumptions as the land is no longer able to help control rainwater flows. Wildfires also increase the amount of debris on the ground, which when washed away, clogs culverts or bridges. With respect to landslides, wildfires remove land cover, resulting in soils with no vegetation providing stable slopes. This condition will likely increase the number of shallow landslides in these areas.

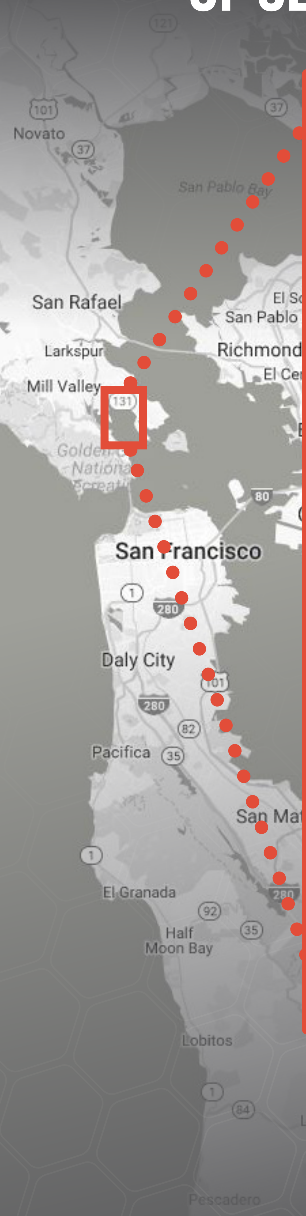
A DISTRICT 4 EXAMPLE

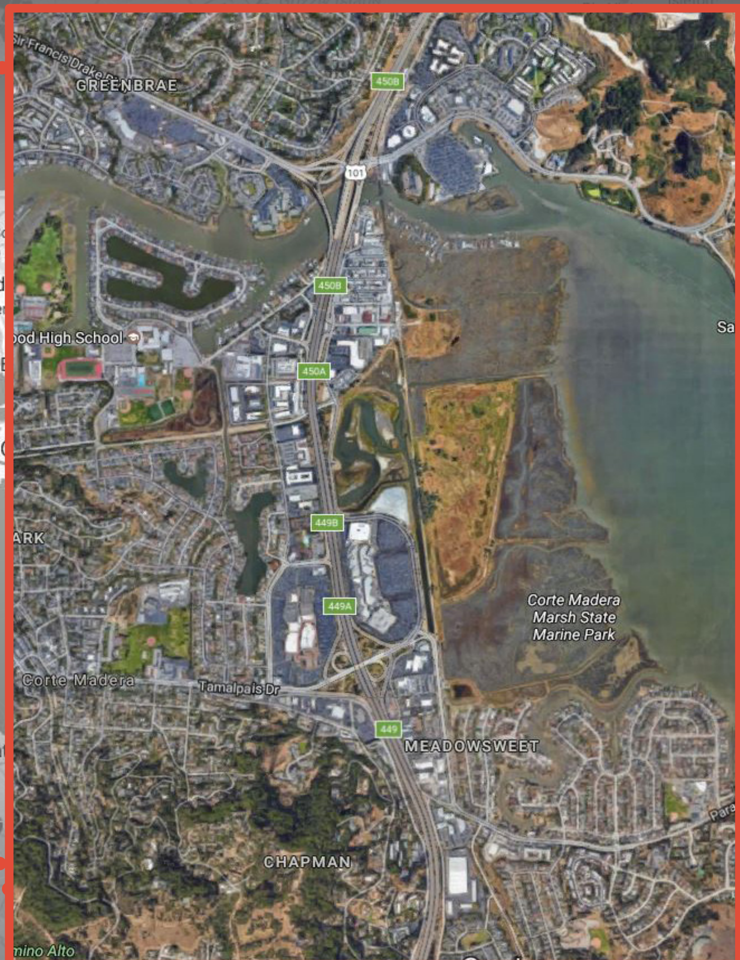
United States Route 101 (US 101) near Corte Madera Creek in Marin County was selected to highlight how climate change may impact a Caltrans facility. Sea level rise presents a real threat to this segment of US 101. A sea level rise of 1.0 meter will lead to inundation on portions of the roadway on a regular basis (specifically, a few times a month during typical spring tides). Storm surge, coupled with sea level rise, presents a nearer term, though less frequent, threat to the facility. As shown in the figure on the following page, the 100-year storm surge begins to overtop US 101 south of the Corte Madera Creek Bridge with 1.64 ft (0.5 meters) of sea level rise. This situation could occur during severe storm events as soon as mid-century, assuming worst case scenarios for future greenhouse gas concentrations in the atmosphere. Higher levels of sea rise lead to greater lengths of the roadway being inundated and to greater depths during storm events.

The Corte Madera Creek will likely experience higher peak flows in the future due to increasing precipitation totals during extreme rainfall events. By the end of the century, precipitation could increase over the watershed by up to almost 10 to 14%. This would likely lead to more serious flooding along Corte Madera Creek that could increase the likely inundation of US 101 and possibly cause scour issues for the Corte Madera Creek Bridge.

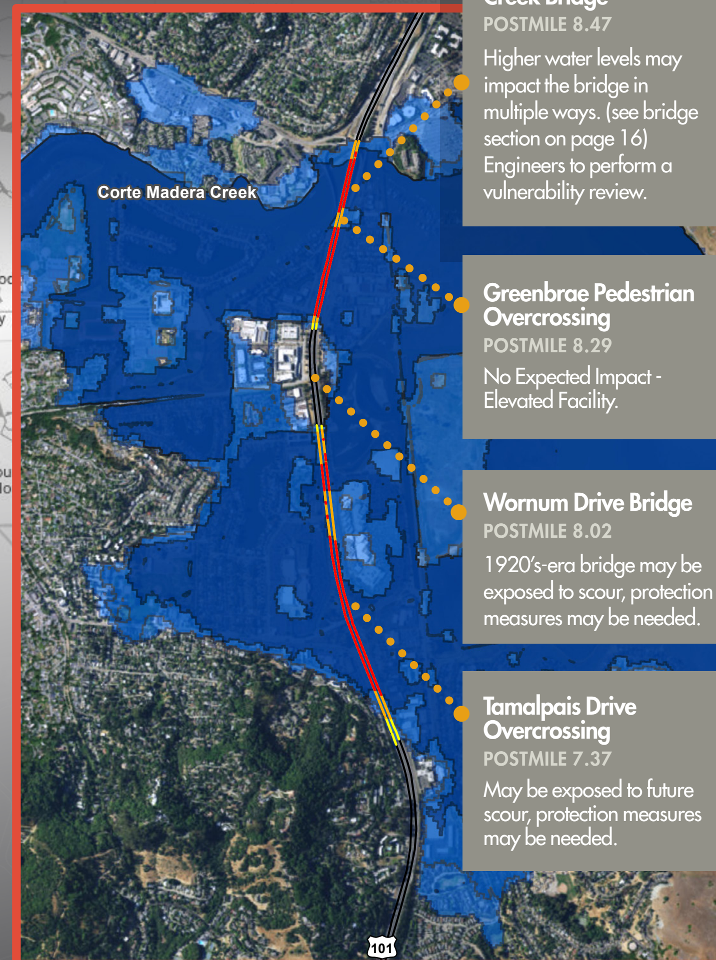
Fig. 14

CLIMATE CHANGE IMPACTS ON US 101 NEAR CORTE MADERA CREEK, MARIN COUNTY, 100-YEAR STORM SURGE WITH DIFFERENT ESTIMATES OF SEA LEVEL RISE





Current view



Corte Madera Creek Bridge
POSTMILE 8.47
Higher water levels may impact the bridge in multiple ways. (see bridge section on page 16) Engineers to perform a vulnerability review.

Greenbrae Pedestrian Overcrossing
POSTMILE 8.29
No Expected Impact - Elevated Facility.

Wornum Drive Bridge
POSTMILE 8.02
1920's-era bridge may be exposed to scour, protection measures may be needed.

Tamalpais Drive Overcrossing
POSTMILE 7.37
May be exposed to future scour, protection measures may be needed.

Impacts to State Highway System 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 Increments

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

AN ADAPTIVE DESIGN PROCESS

Many areas of District 4 experienced flood damage or extended periods of road closure due to recent heavy rainfall. Maintenance and design responses to similar events in the future should consider the findings in this report: that future extreme precipitation events will likely contain more rainfall and thus increase flood damage potential. The median climate model for California predicted increases in 100-year storm precipitation depths of up to 19% for parts of District 4 under RCP 8.5.[16] Addressing damage by rebuilding to previous design storms may not be the most appropriate strategy given information presented.

Risk-based design strategies can be one way of developing an effective adaptation response to flooding and dealing with the uncertainties of future climate. A risk-based decision approach considers the broader implications of damage and loss in determining the approach to design. The Federal Highway Administration has developed an approach to making design decisions that incorporates climate change: the Adaptation Decision-Making Assessment Process (ADAP)[17] process.

At its core, the ADAP process is a risk-based, scenario-driven design process. It incorporates broader economic and social costs, as well as projected future climate conditions into design decision-making. It can be considered a type of sensitivity test of Caltrans assets. It incorporates an understanding of the implications of failure on Caltrans system users, along with repair costs to the agency itself, as a factor when assessing the appropriate design response. The ADAP flowchart shows the basic elements of what could be included in the assessment of flooding in District 4, for existing roads. The same procedure could be used in planning and design of future projects so that climate change is appropriately considered.

DEVIL'S SLIDE PROJECT

A District 4 project that already incorporates the effects of climate change are the Tom Lantos tunnels. These northbound and southbound tunnels were built to bypass the "Devil's Slide" area, a steep and unstable cliff side. The previous section of Highway 1 along Devil's Slide had experienced long closures due to rockslides and land slippage, with one such closure lasting 158 days and costing over three million dollars to repair. The tunnels were constructed in 2013 to avoid the frequent maintenance associated with the Devil's Slide region and the old Highway 1 section was turned over to San Mateo County to serve as a pedestrian and bike trail.[18]

16 - Representative Concentration Pathways (RCP), https://sos.noaa.gov/Datasets/dataset.php?id=438

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

18 - "Caltrans District 4 Devil's Slide Project," Caltrans, http://www.dot.ca.gov/dist4/dslide/, n.d.

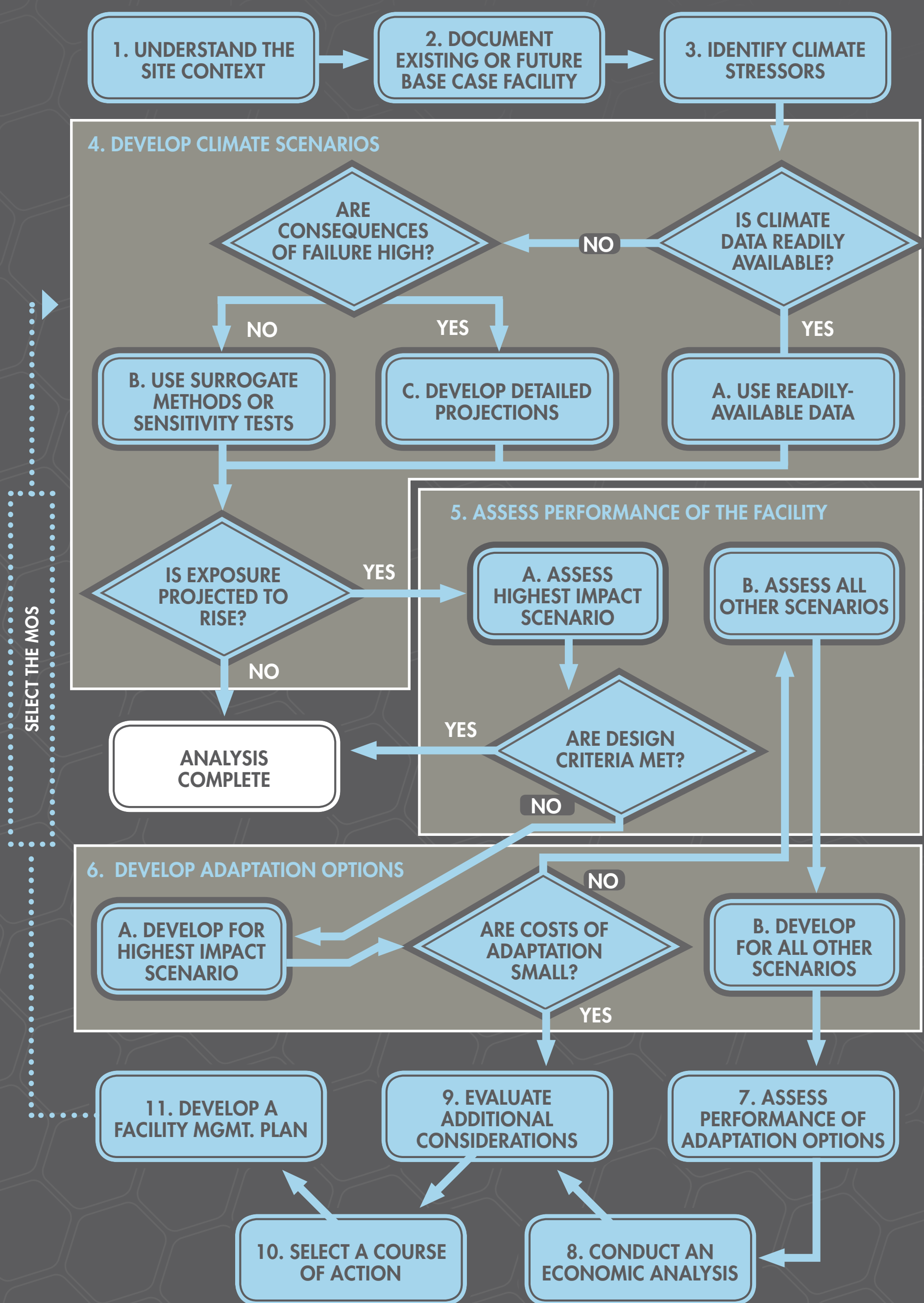
CALTRANS DISTRICT 4 DEVIL'S SLIDE PROJECT

From Jitze Couperus
Devil's Slide

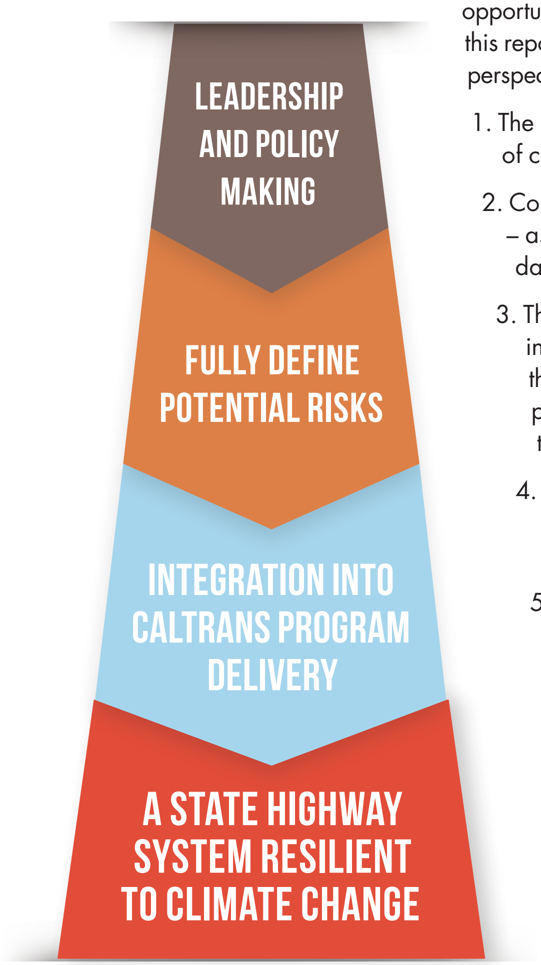
From Christopher Michel
Devil's Slide

Fig. 15

FHWA'S ADAP DESIGN PROCESS



WHAT DOES THIS MEAN TO CALTRANS?



GENERAL CONCLUSIONS

The recent Spring 2017 storms that occurred in District 4 caused extensive damage to the state highway system and closed roadways for extended periods. These events provide an opportunity to address many of the points contained throughout this report. Some conclusions that can be reached from the perspective of this report:

1. The repair of these facilities should include the consideration of climate change (page 4 – state policies)
2. Consequence costs should be a determinant in re-design – assessing broader economic measures than facility damage costs (page 10 – vulnerability approach)
3. The development of updated design approaches which includes data from state resource agencies – including the Scripps Institute which has developed downscaled precipitation data – should be a part of the response to these events (page 11 – phases for achieving resiliency)
4. The assessment of precipitation effects should include the higher estimated rainfall totals derived from the climate data (page 17 – Precipitation section)
5. FHWA's ADAP process should be applied in any potential re-design of the facility, to incorporate uncertainties in climate data and utilize a benefit-cost assessment methodology that considers long term costs to guide decisions (page 31 – An Adaptive Design Process)

The entirety of the Caltrans State Highway System is not at risk from climate change. However, there are some assets that could be affected as outlined in this report. Effective management of these risks will require a sustained effort on the part of Caltrans officials in that the methods for doing so are very different from those found in a typical state DOT. Most importantly, these methods focus on examining the potential of future risks, determined through a vulnerability assessment, rather than depending on historical data of environmental conditions to define the future.

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

LEADERSHIP

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

FULLY DEFINE RISKS

This report does not provide a full accounting of risks from changing climate conditions. Additional work will be required to identify risk at an asset by asset level from the full range of potential impacts. Sources of risk should include those assets outside of normal DOT control, but which could affect State Highway operation if they failed (e.g., dams, levees, etc.) in order to address risks effectively.

INTEGRATION INTO CALTRANS PROGRAM DELIVERY

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

A STATE HIGHWAY SYSTEM RESILIENT TO CLIMATE CHANGE

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