CALTRANS CLIMATE CHANGE

VULNERABILITY ASSESSMENT SUMMARY REPORT

DISTRICT 12

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 12. This document provides a high-level review of potential climate impacts to the district's portion of the State Highway System, while the Technical Report presents detail on the technical processes used to identify these impacts. Similar reports are being prepared for each of Caltrans' 12 districts.

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

Climate change is expected to expose District 12 and its transportation assets to:

- More severe droughts, extreme temperatures, and changes in water availability; a concern affecting all of Orange County
- Rising sea levels, more severe storm impacts, and coastal erosion affecting the coast, especially around Newport Beach, Seal Beach, and Laguna Beach
- Longer and more severe wildfire seasons affecting areas such as Cleveland National Forest, Chino Hills State Park, Laguna Canyon, and Wood Canyon

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

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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). 32 different GCMs have been downscaled to a regional level and refined so they can be used specifically for California. Of those, 10 were identified by California state agencies to be the most applicable to California. This analysis used all ten of these representative GCMs, but only the median model (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 State Highway System when disaster strikes. The State Highway System is the backbone of most county-level evacuation plans and often provides the only high-capacity evacuation routes from rural communities. In addition, state highways also serve as the main access routes for emergency responders, and may serve as a physical line of defense (a firebreak, an embankment against floodwaters, etc.). As climate-related disasters become more frequent and more severe, this aspect of State Highway System usage will assume a greater importance that may need to be reflected in design. The upcoming studies of climate change adaptation measures will take these factors into account when identifying measures appropriate to each situation.

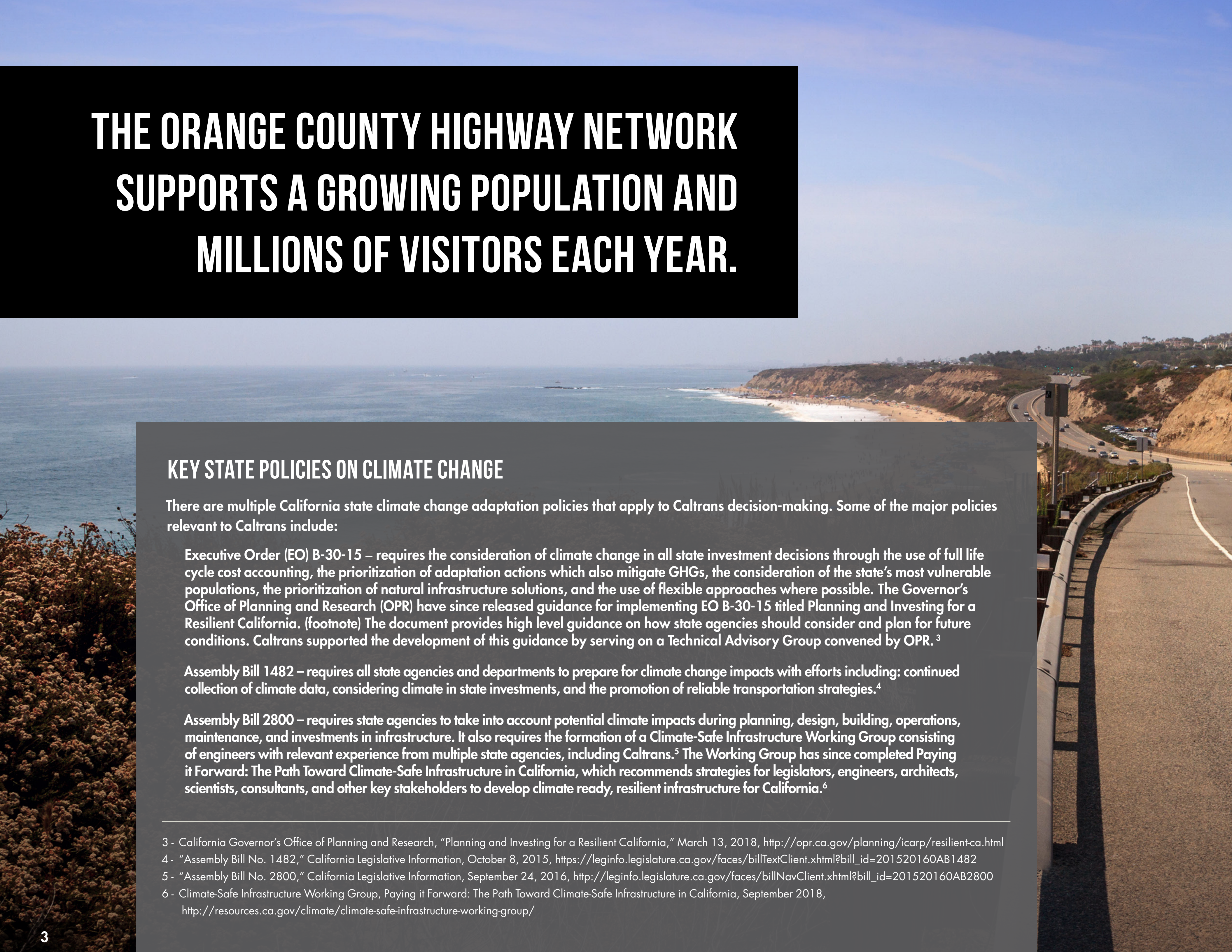
BACKGROUND AND APPROACH

Caltrans is making a concerted effort to identify the potential climate change vulnerabilities of the State Highway System.[2] The information presented in this report is the latest phase of this effort. It identifies portions of the State Highway System that could be vulnerable to different climate stressors and Caltrans processes that may need to change as a result.

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

This report does not identify projects to be implemented, nor does it present the costs associated with such projects. These issues will be addressed in future studies. The information in this Summary Report outlines the potential vulnerabilities to Caltrans' District 12 portion of the State Highway System and illustrates the types of climate stressors that may affect how highways are planned, designed, built, operated, and maintained. The intent of the current study is to add clarity regarding climate change impacts in the region served by District 12 and begin to define a subset of assets on the State Highway System 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.



THE ORANGE COUNTY HIGHWAY NETWORK SUPPORTS A GROWING POPULATION AND MILLIONS OF VISITORS EACH YEAR.

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. (footnote) 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 12 CHARACTERISTICS

Caltrans District 12, headquartered in Santa Ana, encompasses the entirety of Orange County, which lies between California's two largest cities—Los Angeles and San Diego. To the west, District 12 extends to the coast and to the east it meets the Cleveland National Forest. The jurisdictional boundaries of the district include a metropolitan area of 794 square miles, including 34 cities and a countywide population of 3.2 million people in 2016. Orange County is also home to 11 major universities and 10 private colleges/universities, two major military installations and numerous tourist attractions.

These attractions, and Orange County's status as one of the fastest growing regions in California, draws 50 million visitors annually and often result in high traffic volumes and congestion levels on the 17 state highway routes that cross District 12. To try to reduce this congestion, District 12 maintains the most complete High Occupancy Vehicle (HOV), or carpool, network in California, which spans 279 route miles of highway and 244 directional miles of full-time HOV lanes. Over the past 20 years, the district and its transportation partners have also greatly increased freeway lane-miles in the county.

District 12 has two types of highways in its system: freeways and conventional highways. Freeways are divided highways with full control of access and uninterrupted flow. Conventional highways have no control of access and traffic functions like it would on a local street (e.g., there are signals, crosswalks, places to park, etc.). A conventional highway offers direct access to local roadways, businesses, and residences along the corridor.

District 12's state highways play an important role in providing mobility and connectivity for the region, and the state,[7] and several are summarized below:

- Interstate 5 (I-5) is a major north-south freeway. It connects Orange County with Los Angeles County in the north and with San Diego County on the south.
- State Route (SR) 1 is a conventional highway that runs along the coast from Seal Beach to Dana Point and is used by many residents and visitors alike to access Orange County's beaches and coastal cities.
- SR 57 and SR 55 form a major north-south spine, linking nine east-west freeways from SR 73 in Orange County to Interstate 210 (I-210) east of Los Angeles.
- Interstate 405 (I-405) begins at the I-5 interchange in Irvine and runs northwest, parallel to the ocean until it terminates and connects back to I-5 in the San Fernando Valley.
- SR 74 is a major east-west arterial that offers interregional access between Orange County and Riverside County.
- SR 91 is a major east-west freeway in the county, linking Riverside and San Bernardino Counties to Orange and Los Angeles Counties. It is heavily travelled as a commuter and freight corridor that offers interregional access.[8]
- SR 22 is another east-west highway in the county stretching from the City of Seal Beach in the west to the City of Orange in the east.
- SR 73 connects the I-5 corridor in San Juan Capistrano to the I-405 corridor in Costa Mesa. SR 73 runs through the Laguna Coast Wilderness Park and the University of California, Irvine. The southernmost 12 miles of the highway operate as a toll road known as the San Joaquin Hills Transportation Corridor.

7 - Caltrans, District 12, "Corridor System Management Plan (CSMP) Final Report Orange County SR 55," March 27, 2014, http://www.dot.ca.gov/d12/planning/pdf/SR-55%20CSMP%20Final%20Technical%20Report.pdf

8 - Caltrans District 12 Division of Planning, "Route Concept Report: State Route 91," October 1999, https://district12.onramp.dot.ca.gov/downloads/district12/files/planning/system_planning/route91.pdf

RECENT EXTREME EVENTS IN DISTRICT 12

While the examples of past events described below were not necessarily caused by the changing climate, and the impacts of future events are difficult to predict, they do provide examples as to the types of challenges Caltrans District 12 could face more frequently in the future.

- **Temperature** – Temperatures in Orange County have historically been relatively mild, but extreme heat waves during the past decade have resulted in triple-digit temperatures that in some cases have set historical records. September 2017 saw week-long triple-digit highs of 107 degrees Fahrenheit in Yorba Linda, 105 degrees in Lake Forest and 103 degrees in Fullerton. In October 2017, Fullerton recorded 107 degrees, which is considered the hottest single temperature recorded anywhere in the United States so late in the year. The July 2018 heat wave resulted in the hottest recorded month in the history of California. Extreme temperatures, especially when occurring in consecutive days, can affect highway construction materials, expose system users (and Caltrans contractors and staff) to dangerous levels of heat, damage landscaping, and lead to drought and wildfires.
- **Precipitation** – Climate change can cause large fluctuations in precipitation, with dry years becoming dryer and wet years wetter. A lack of precipitation can lead to dangerous droughts. In January 2014, Governor Jerry Brown declared a drought State of Emergency that lasted in most of the state until April 2017. Officials had declared Orange County to be in 'extreme drought'. On the other hand, high intensity storms can cause transportation disruptions. Storms in January 2017 caused widespread flooding and power outages in Orange County. Several streets and pedestrian ways were closed due to flooding, downed trees, and rockslides. In Laguna Beach, after a three-day downpour, one major road had accumulated 24 inches of rain, resulting in its closure.
- **Wildfire** – Wildfires in California have become more frequent and widespread in recent years, partially due to multi-year, severe droughts.[9] In Southern California in particular, Santa Ana winds drive fires in October through April (Santa Ana fires), which affect urban areas like Orange County. A recent study found that these Santa Ana fires led to 80% of economic losses from wildfire between 1990 and 2009. As climate-driven drought becomes more common and weather conditions change, area burned from Santa Ana fires is projected to increase by 64%.[10]

  Recent wildfire events in Orange County have had major impacts to the surrounding region and Caltrans infrastructure. The Freeway Complex Fire burned over 30,000 acres, and a fire in October 2017 burned 9,200 acres and destroyed 25 structures in Orange County. In 2018, the Holy Fire closed SR 74 in Orange County, which caused issues for commuters, evacuees, and nearby residents. Wildfires can increase the likelihood of road closures even after the fire is extinguished, as damaged trees could fall and cause roadblocks or driver safety threats. Additionally, smoke from ongoing fires can decrease visibility for drivers. This was a concern on SR 74 after the Holy Fire, as firefighters, utility workers, and heavy equipment repairing the highway were clouded by smoke. Drivers were urged to drive slowly to avoid collisions.[11]
- **Sea Level Rise and Storm Surge** – While sea level rise alone has not yet had any major impact to District 12, storm surge impacts have affected the SR 1. High surf events coinciding with storm surges and/or extreme high tides have resulted in closures of the PCH in Bolsa Chica, Surfside, Seal Beach, and Laguna Beach. Roadbed erosion in Bolsa Chica has required emergency repairs. Portions of state highway in the Cities of Seal Beach, Surfside, Bolsa Chica, Huntington Beach, Newport Beach, Laguna Beach, and Dana Point are less than 2 meters above mean high tide levels and could be at risk if a substantial increase in sea level occurs. Sea level rise will exacerbate the effects of these coastal storm surge impacts, as water and waves will reach higher on shore and hit with more force. These storm events could lead to erosion, scour, and washouts underneath the highway itself.

9 - Joseph Crockett, Leroy Westerling, "Greater Temperature and Precipitation Extremes Intensify Western US Droughts, Wildfire Severity, and Sierra Nevada Tree Mortality," UC Merced, 2017, retrieved from https://escholarship.org/uc/item/3t39d8jq

10 - Jin Yufang et al.,"Identification of Two Distinct Fire Regimes in Southern California: Implications for Economic Impact and Future Change," Environ. Res. Lett. 10 094005. (2015). http://iopscience.iop.org/article/10.1088/1748-9326/10/9/094005/meta;jsessionid=647F82C403F0D389C114345864FAA3D1.c1

11 - Beatriz Valenzuela, "Ortega Highway Reopens; Holy Fire Containment at 64 Percent," The Orange County Register, August 14, 2018, https://www.ocregister.com/2018/08/14/firefighters-hold-holy-fire-line-overnight-containment-at-59-percent/

SR 91 | ROCK SLIDE

SR 91 | ROCK SLIDE

SR 91 | ROCK SLIDE

SR 91 | ROCK SLIDE

CANYON FIRE 2 | CROSSED SR 241

VULNERABILITY AND THE STATE HIGHWAY SYSTEM

CALTRANS EFFORTS

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

- The formation of a Climate Change Branch under the Caltrans Division of Transportation Planning.
- The issuance of *Addressing Climate Change Adaptation in Regional Transportation Plans* (2013) which serves as a how-to guide for California Metropolitan Planning Organizations (MPOs) and Regional Transportation Planning Agencies (RTPAs).
- The signing of an agreement with the *California Coastal Commission and its Integrated Planning Team* to ensure effective collaboration between agencies—including planning for sea level rise impacts.[12]
- The development of an Adaptation Planning Grant Program following the signing of Senate Bill 1 in 2017, which issues $6 - 7 million each year to prepare transportation infrastructure for the impacts of climate change.[13]

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

ADDRESSING CONCERNS IN DISTRICT 12

Caltrans District 12's portion of the State Highway System serves critical functions for communities, commerce, and more. Given the importance of the system, understanding the potential impacts of climate change and extreme weather on system performance is a key step in creating a resilient highway system.

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 climate change or other stressors. Caltrans' approach focuses on the system's vulnerability to extreme weather and climate-related hazards and recognizes that many Caltrans units have important roles in supporting a resilient state transportation system.

SR 91 | ROCK SLIDE

The approach outlined on the following page describes a process consistent with Caltrans practices and is focused on the assessment of impacts from climate change on the transportation system. The approach focuses on three issues:

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

Implementing this approach requires the participation of a wide range of Caltrans professionals from planning, asset management, operations and maintenance, design, emergency response, and economics and will require coordination with other relevant state agencies. For example, the California Coastal Commission should be consulted regarding coastal projects to ensure that Caltrans responses protect beaches and shoreline access. It will take a collaborative effort to implement this approach successfully.

ENSURING SYSTEM RESILIENCY

Once system vulnerabilities are identified, Caltrans will begin considering enhanced system resiliency when choosing projects and project designs. In District 12, this will require the consideration of projects that address potential impacts of wildfire, intense precipitation, prolonged extreme temperatures, and those that mitigate sea level rise, storm surge, and coastal erosion. These strategies might include:

- Realigning or raising existing roadways to avoid flooding from sea level rise and storm surge, and designing new roadways outside of areas that may flood.
- Managing sea level rise, storm surge, and coastal erosion in a manner that avoids the negative impacts of coastal armoring (e.g. sea walls, rip rap, erosion control structures) such as beach loss and increased erosion on neighboring properties.[14]
- Assessing the sizing of existing drainage infrastructure to understand if modifications are needed given projections of precipitation events.

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

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

13 - 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

14 - Molly Loughney Melius and Margaret R. Caldwell, "California Coastal Armoring Report: Managing Coastal Armoring and Climate Change Adaptation in the 21st Century," Environment and Natural Resources Law & Policy Program Working Paper, (June 2015), https://law.stanford.edu/publications/california-coastal-armoring-report-managing-coastal-armoring-and-climate-change-adaptation-in-the-21st-century/

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:

1. **CONDUCT A VULNERABILITY ASSESSMENT OF ALL CALTRANS ASSETS**

   INCLUDING EXPECTED TIMING OF IMPACTS

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

3. **DETERMINE THE CONSEQUENCE OF IMPACTS ON CALTRANS ASSETS**

   DAMAGE/LOSS
   DURATION

4. **PRIORITIZE ACTIONS**

   BASED ON TIMING AND CONSEQUENCE OF IMPACTS

CURRENT STAGE

EXPOSURE

Define the components and locations of the highway system (roads, bridges, culverts, etc.) that may be exposed to changing conditions caused by the effects of climate change such as sea level rise, storm surge, wildfire, landslides, and more. 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:

- Timing – how soon can the impacts be expected?
- Impacts – what are the projected costs to repair or replace? What is the likely time of outage? What are the likely impacts on travel and goods movement?
- Safety – who will be directly or indirectly affected? How can impacts to vulnerable populations be avoided? How will worker safety be affected?

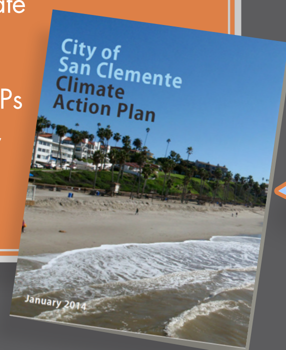
BY USING THIS APPROACH, CALTRANS CAN CAPITALIZE ON ITS INTERNAL CAPABILITIES TO IDENTIFY PROJECTS THAT INCREASE STATE HIGHWAY SYSTEM RESILIENCY.

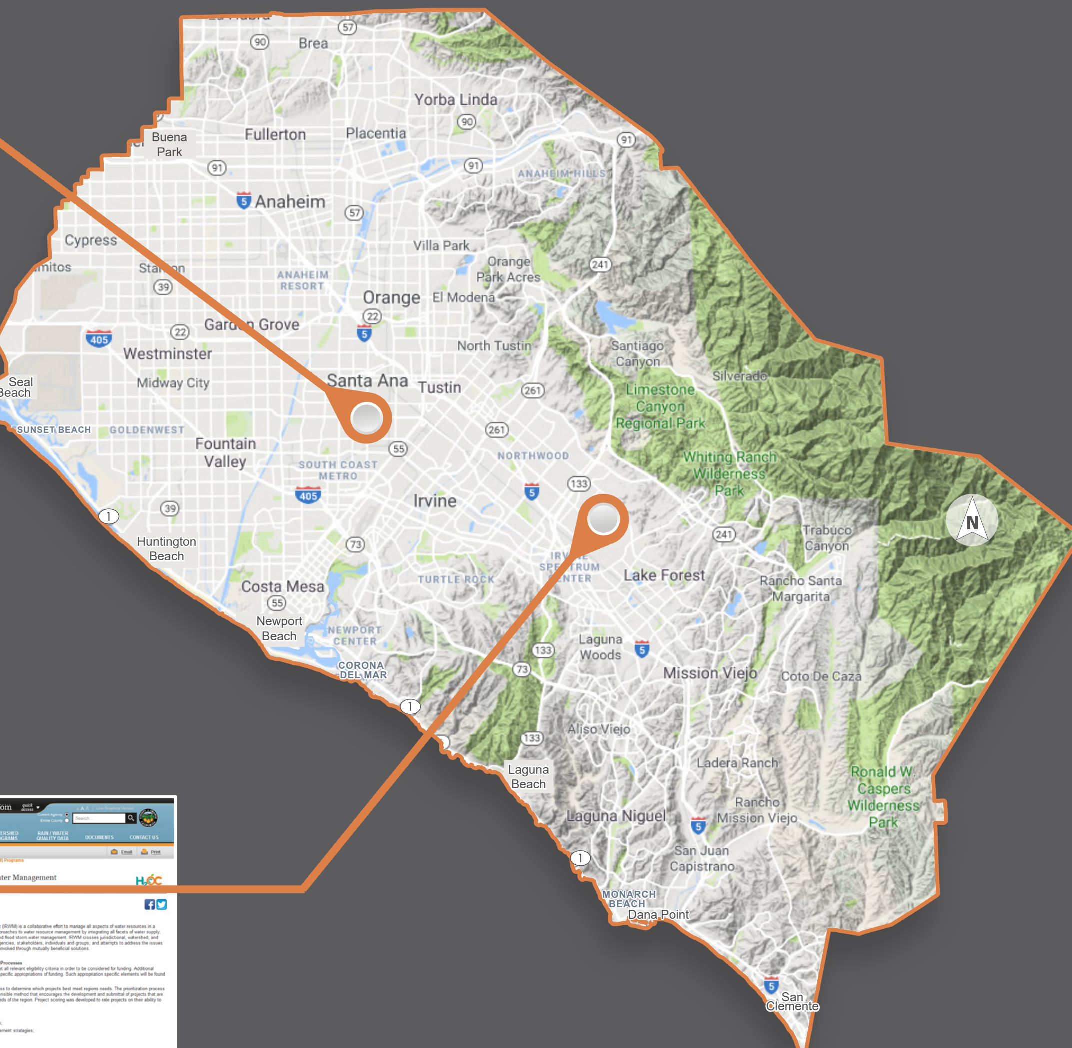
OTHER EFFORTS IN DISTRICT 12 TO ADDRESS CLIMATE CHANGE

Caltrans recognizes that other regional efforts are underway in District 12 to mitigate the effects of climate change. Ongoing coordination with local governments and stakeholders will be critical to ensure that methodologies and adaptation strategies are not redundant with other efforts. Regional coordination will be especially important to combat stressors, such as rising seas, that will affect everyone and require a collective response.

CLIMATE ACTION PLANS

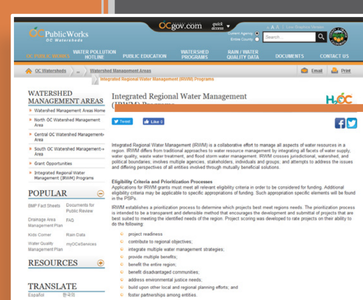
Many communities and county-wide agencies in District 12 have either adopted Climate Action Plans (CAPs) designed to mitigate GHG emissions and reduce the impacts of climate change to their communities or have included such plans as part of their comprehensive plan. Some of the communities that have adopted CAPs include the cities of Fullerton, Huntington Beach, La Habra, Laguna Beach, Laguna Woods, Mission Viejo, San Clemente and Santa Ana.





INTEGRATED REGIONAL WATER MANAGEMENT PLAN FOR NORTH AND CENTRAL ORANGE COUNTY

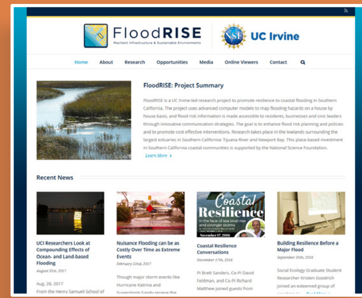
Orange County Public Works recently completed an Integrated Regional Water Management Plan for the north and central regions. In the plan, sea level rise, warmer temperatures, changing mountain snowpack runoff, changes in precipitation (and temperature affecting average runoff volume), changes in drought persistence, higher water temperatures in streams and reservoirs, potential increase in water demands for landscape use, damage to trees, and increased risk of wildfire and erosion were identified as having the greatest impact on hydrological conditions in the county.[15]



15 - South Orange County Watershed Management Area, "Integrated Regional Water Management (IRWM) Plan," July 2013, http://prg.ocpublicworks.com/DocmgmtInternet/Download.aspx?id=1059

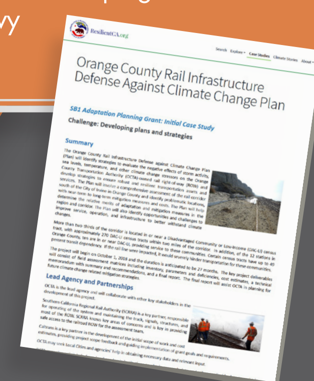
UNIVERSITY OF CALIFORNIA, IRVINE | FLOODRISE PROGRAM

Researchers at the University of California, Irvine have developed new computer modeling technology built to help communities manage flood risk. The model provides parcel-level information about the depth and extent of flooding under a variety of conditions. As noted in the program's website, the general approach "involves: (1) setting up and running metric resolution hydrodynamic flood models to simulate various flooding scenarios that are relevant to these communities, and (2) post-processing model scenario results to produce maps that visualize flood hazard information in ways that end-users find useful." The researchers rely on community surveys and consultations to corroborate results.[16]



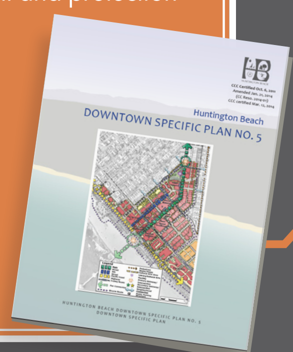
ORANGE COUNTY RAIL INFRASTRUCTURE DEFENSE AGAINST CLIMATE CHANGE PLAN

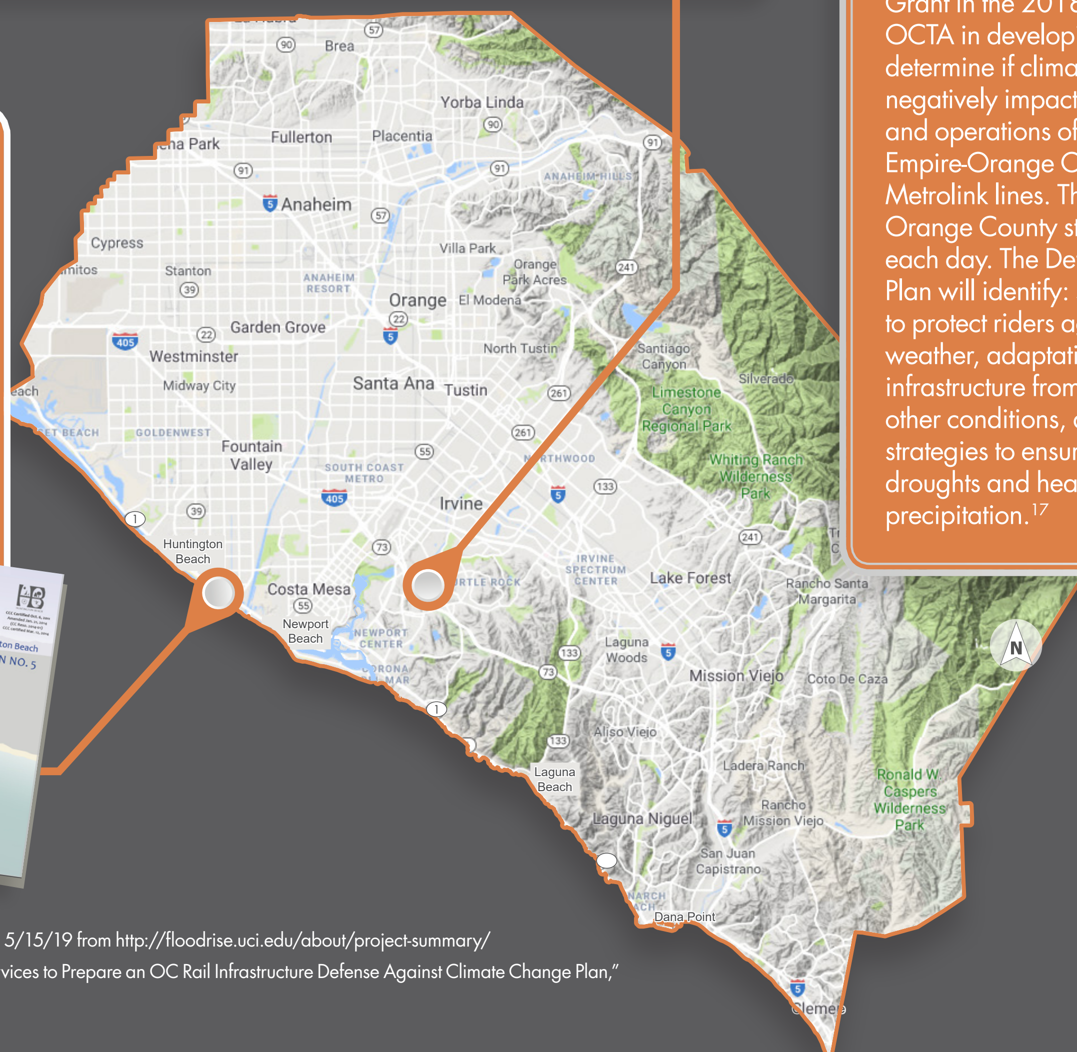
Passenger and freight rail services parallel some of the major highway corridors in Orange County (i.e. I-5 and SR 91). One of the efforts to address climate change on these alternate corridors is the Orange County Rail Infrastructure Defense Against Climate Change Plan. The Orange County Transportation Agency (OCTA) was awarded a Caltrans Adaptation Planning Grant in the 2018-19 grant cycle, to support OCTA in developing the study. The plan will determine if climate change conditions will negatively impact rail infrastructure, service, and operations of the Orange County, Inland Empire-Orange County, and 91/Perris Valley Metrolink lines. These three lines service 11 Orange County stations and over 40,000 riders each day. The Defense Against Climate Change Plan will identify: station amenity improvements to protect riders against high heat and extreme weather, adaptation strategies to protect rail infrastructure from flooding, landslides and other conditions, and vegetation management strategies to ensure landscaping can withstand droughts and heavy precipitation.[17]



LOCAL COASTAL PROGRAMS

The California Coastal Commission is working with a number of cities in Orange County, including Seal Beach, Huntington Beach, San Clemente, and Dana Point to update their Local Coastal Programs (LCPs) to account for climate change impacts—especially from sea level rise. These LCPs are tools used by local governments to plan the development and protection of the coastal zone. Once updated, they will also include strategies to reduce infrastructure impacts from sea level rise, storm surge, and other climate stressors.





16 - "FloodRISE," University of California, Irvine, last accessed 5/15/19 from http://floodrise.uci.edu/about/project-summary/

17 - Orange County Transportation Authority, "Consultant Services to Prepare an OC Rail Infrastructure Defense Against Climate Change Plan," Request for Proposals 8-2072, February 21, 2019

PHASES FOR ACHIEVING RESILIENCY

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

PREDICT CLIMATE CHANGE EFFECTS:

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

UNDERSTAND POSSIBLE TRANSPORTATION IMPACTS:

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

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.

SCOPE OF THIS STUDY

INITIATE VULNERABILITY ASSESSMENT:

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

IDENTIFY EXPOSURE OF CALTRANS HIGHWAYS TO POSSIBLE CLIMATE CHANGE DISRUPTIONS:

Identifying locations where Caltrans' assets might be exposed to extreme weather-related disruptions provides an important foundation for decision-making to protect and minimize potential damage. The exposure assessment examines climate stressors such extreme temperatures, heavy precipitation, sea level rise, and more, and relates the likely consequences of these stresses to disruptions to the State Highway System.

IDENTIFY PRIORITIZATION METHOD FOR CALTRANS INVESTMENTS:

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

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

DEVELOP ACTION PLANS FOR EACH CALTRANS FUNCTIONAL AREA

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

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

INCORPORATE RESILIENCY PRACTICES THROUGHOUT CALTRANS:

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

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

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

PRIORITIZE A SET OF PROJECTS AND ACTIONS FOR ENGINEERING ASSESSMENTS:

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

ADVANCE PROJECTS AND ACTIONS TO APPROPRIATE INVESTMENT PROGRAMS:

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

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

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

TEMPERATURE

As GHGs rise in the atmosphere, so do global temperatures. The US National Climate Assessment notes that the "number of extremely hot days is projected to continue to increase over much of the United States, especially by late century. Summer temperatures are projected to continue rising, and a reduction of soil moisture, which exacerbates heat waves, is projected for much of the western and central US in summer."[18] Given the size of California and its many highly varied climate zones, it is expected that temperatures will rise in varying degrees across the state.

The figure on the following page compares the change in the average maximum temperature over seven consecutive days (an important element for determining the best pavement mix for long-term performance) for three time periods to data from 1975 to 2004. In general, US studies have found that increasing temperatures could impact the transportation system in several ways, including:

DESIGN

- Materials exposed to high temperatures over long periods of time can deform (including pavement heave or track buckling). The design of pavements must consider high temperatures to mitigate future deterioration.
- Ground conditions and water saturation levels can affect foundations and retaining walls.

OPERATIONS AND MAINTENANCE

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

TEMPERATURE CHANGE IN DISTRICT 12

Average and extreme temperatures across District 12 are expected to warm by the year 2100, which may necessitate a review of roadway pavement design and other Caltrans activities. The average maximum seven-day moving average temperature in the third period (represented by 2085) could be anywhere from 8 to 9.9 degrees Fahrenheit higher in most of Orange County; some portions of eastern Orange County could see an increase of 10 to 11.9 degrees Fahrenheit. For both metrics, temperature changes are generally greater moving farther inland due to the increased distance from the moderating influence of the Pacific Ocean.

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

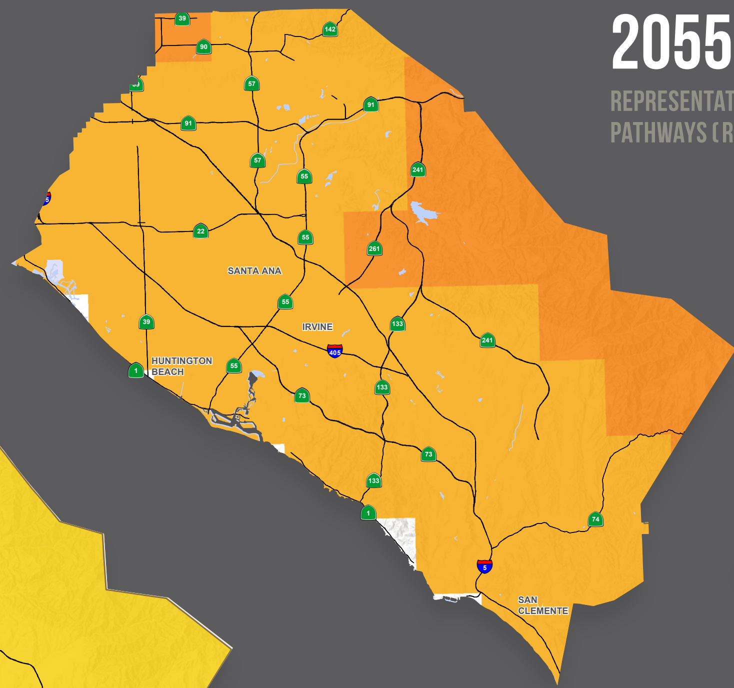
HIGH TEMPERATURES MAY AFFECT PAVEMENT QUALITY

ROADSIDE LANDSCAPING MAY BE SUSCEPTIBLE TO HIGHER TEMPERATURES AND DROUGHT CONDITIONS

Fig. 1

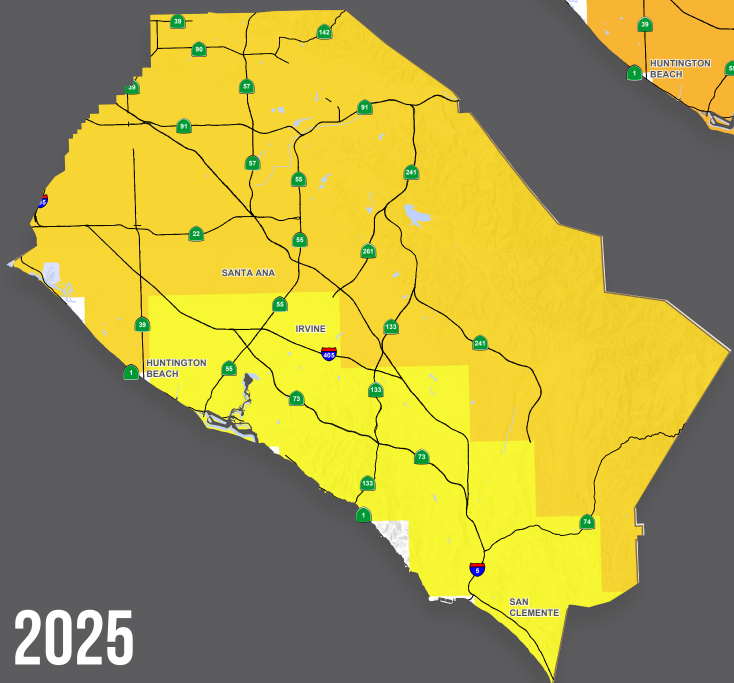
INCREASE IN THE AVERAGE MAXIMUM TEMPERATURE OVER SEVEN CONSECUTIVE DAYS

A REQUIRED MEASURE FOR PAVEMENT DESIGN



2055

REPRESENTATIVE CONCENTRATION PATHWAYS (RCP) 8.5, 50TH PERCENTILE



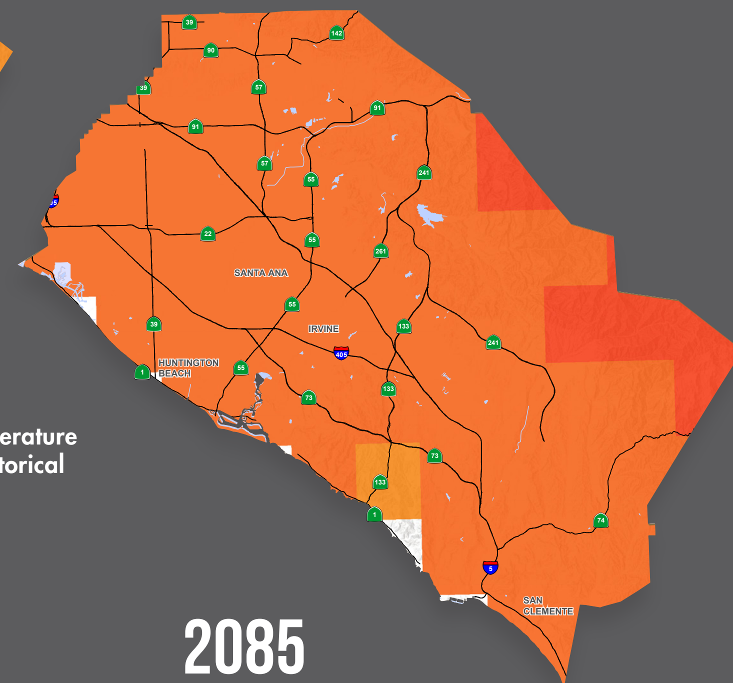
2025

REPRESENTATIVE CONCENTRATION PATHWAYS (RCP) 8.5, 50TH PERCENTILE

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)



2085

REPRESENTATIVE CONCENTRATION PATHWAYS (RCP) 8.5, 50TH PERCENTILE

Future change in the Maximum Average Temperature Over Seven Consecutive Days within District 12, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 12. 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

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

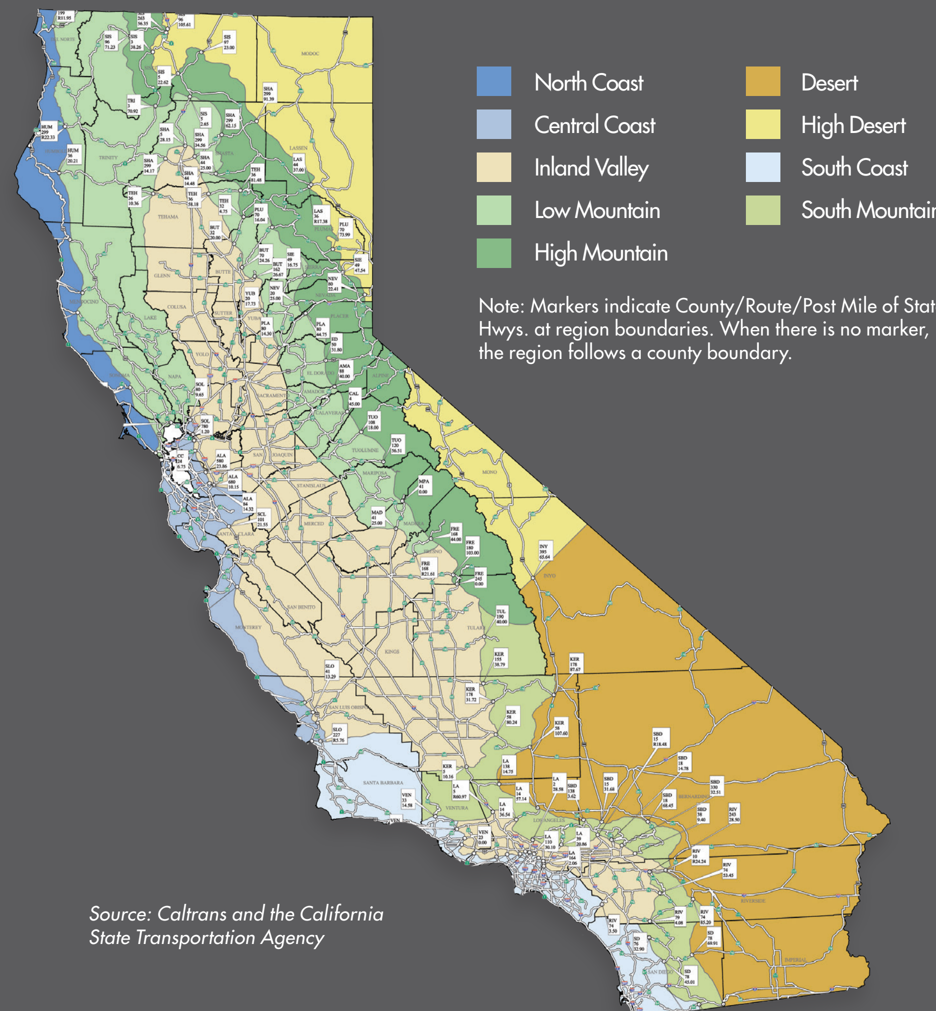
Preparing for climate change is different for pavement design than for other assets. Many of Caltrans' assets, including tunnels, bridges, and culverts, will likely be in place for 50 years or longer, so decisions made for them today need to consider their longer design life. Asphalt pavement is replaced more frequently—approximately every 20-40 years depending on the pavement's purpose.

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

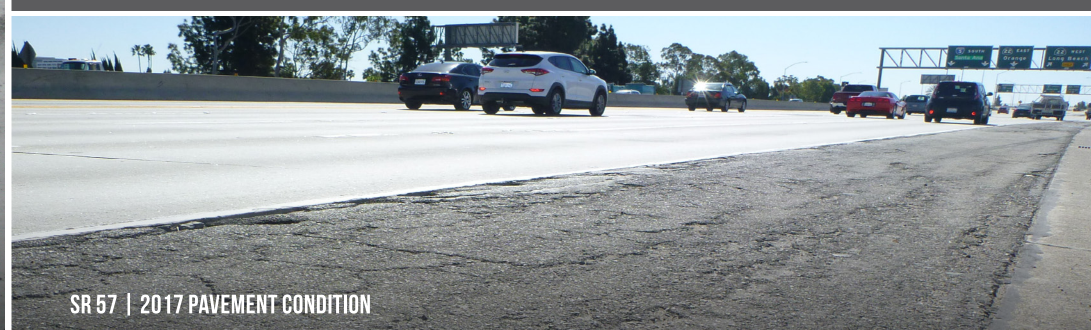
SR 1 | 2010 PAVEMENT CONDITION

Fig. 2

CALTRANS PAVEMENT REGIONS



Source: Caltrans and the California State Transportation Agency



SR 57 | 2017 PAVEMENT CONDITION

TIMEFRAMES AND ASSET DECISION-MAKING

Transportation assets have varying lifetimes, or design lives, that depend upon factors such as its design make-up, use, and the level of maintenance and rehabilitation it receives. Some assets managed by Caltrans, like asphalt pavement, are replaced around every 20-40 years while others, like bridges, are built with the expectation of a useful life of 50 years or longer. Many assets will exceed their intended design life, if the resources are not available to replace them.

The two graphics provided on this page highlight how design lives are critical elements of planning transportation investments. Figure 3 below shows how future temperature scenarios may vary widely depending on emission levels and global response. Conditions are somewhat consistent through around 2050, after which they begin to diverge more significantly. This means that decisions made on investments nearing the end of century need to include a much wider range of uncertainty regarding future temperatures. Assets with shorter design lives will not need to consider such a wide range of projections and investment decisions can be made with greater certainty.

SOME ASSETS MANAGED BY CALTRANS, LIKE ASPHALT PAVEMENT, ARE REPLACED AROUND EVERY 20-40 YEARS WHILE OTHERS, LIKE BRIDGES, ARE BUILT WITH THE EXPECTATION OF A USEFUL LIFE OF 50 YEARS OR LONGER.

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

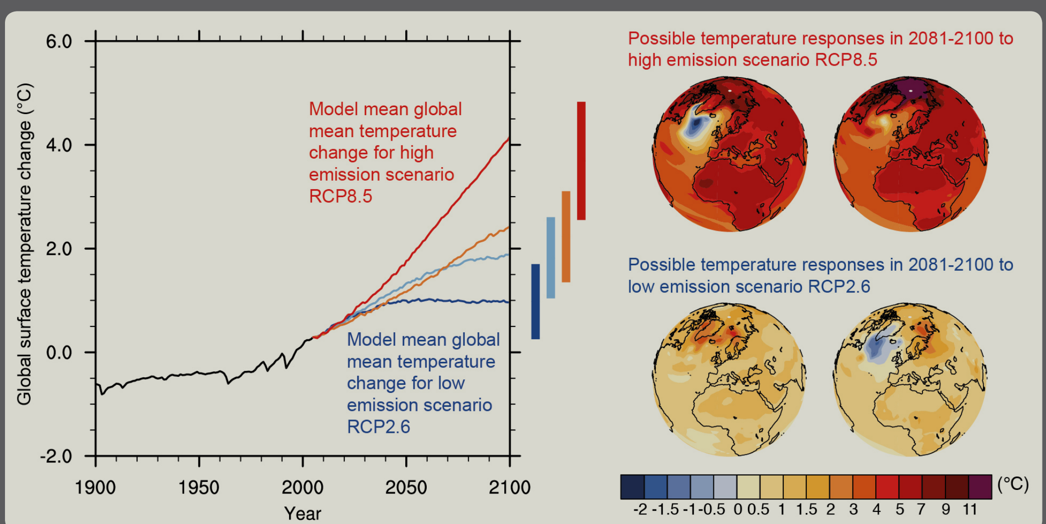
ASSETS WITH SHORTER LIFETIMES, LIKE ASPHALT PAVEMENT, REQUIRE CONSIDERATION OF NEARER TERM FUTURE CONDITIONS.

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

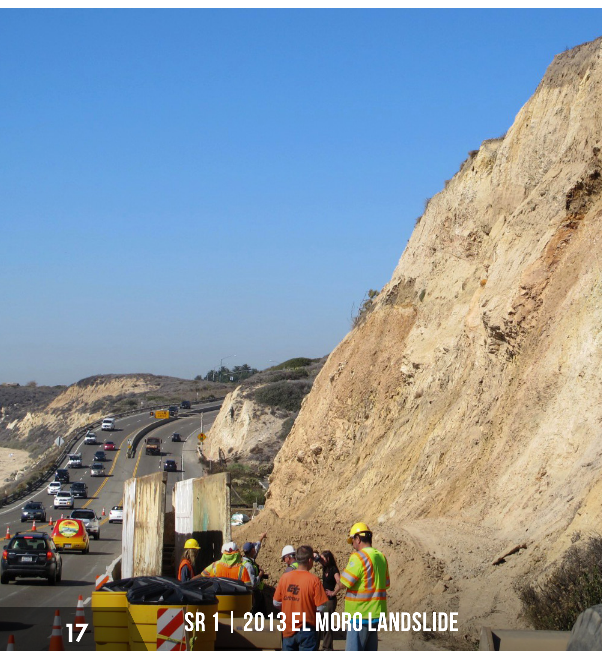
PRECIPITATION

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

The Scripps Institution of Oceanography at the University of California, San Diego has projected future rainfall data to the year 2100 using two different GHG emission scenarios and a variety of models. The "100-year storm event" is one useful way to examine this data—it is defined as a storm with a likelihood of occurring once every 100 years (or a one percent chance of occurring in any given year). A storm of this magnitude could cause significant damage and is therefore a good design standard for infrastructure projects.

PRECIPITATION CHANGE IN DISTRICT 12

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 12 for each of the three analysis periods noted (assuming RCP 8.5). The maps represent a relative midpoint of predicted precipitation increase. For the period represented by 2085, most of District 12 will likely experience a relatively small (less than a 5%) increase in the precipitation depth from a 100-year storm. The pattern is relatively consistent over time. Changes are generally expected to be greater in the eastern sections of the district due to the tendency for the coastal mountains to squeeze moisture from eastward-moving storm systems.



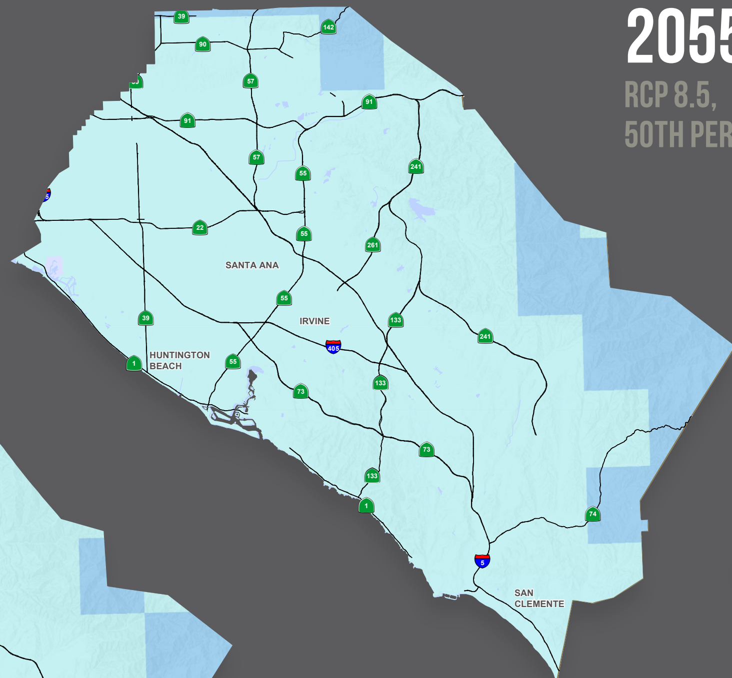
SR 1 | 2013 EL MORO LANDSLIDE

SR 39 | 2017 ROSECRANS SINKHOLE

SANTA ANA RIVER CHANNEL

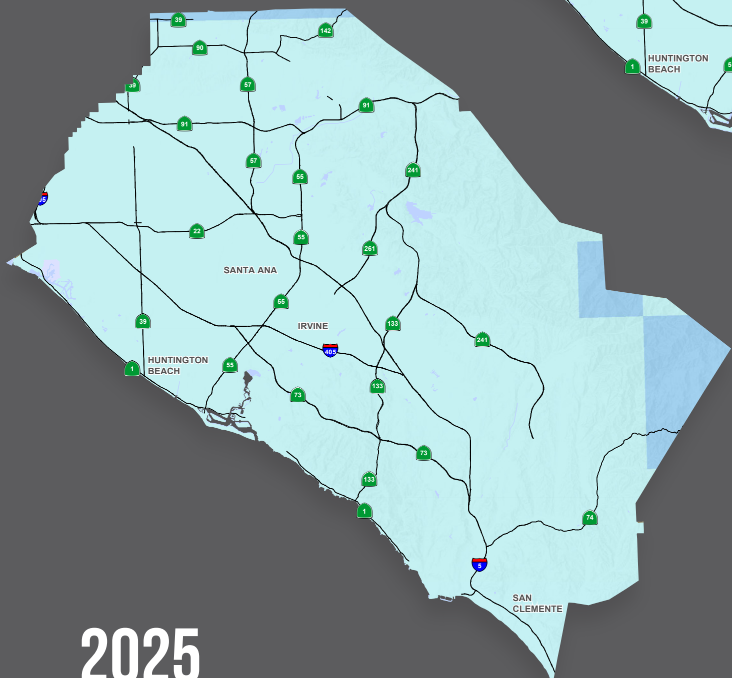
Fig. 5

PERCENT CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH



2055

RCP 8.5,
50TH PERCENTILE



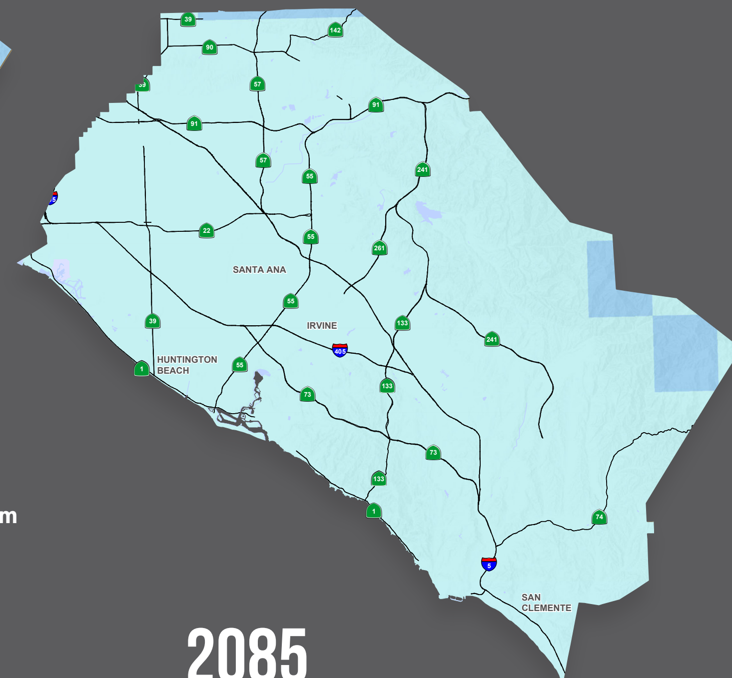
2025

RCP 8.5,
50TH PERCENTILE

Percentage Increase in the 100-Year Storm Depth from Historical Conditions

- 0 - 4.9%
- 5.0 - 9.9%

Median Model (HadGEM2-CC)



2085

RCP 8.5,
50TH PERCENTILE

Future Percent Change in 100-year Storm Precipitation Depth within District 12, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 12. 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.

WILDFIRE

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

WILDFIRE IS A DIRECT CONCERN FOR:

- Driver safety
- System operations
- Caltrans infrastructure

WILDFIRES CAN INDIRECTLY CONTRIBUTE TO:

- Landslide and flooding exposure, by burning off soil-stabilizing land cover and reducing the capacity of the soils to absorb rainfall.
- Wildfire smoke, which can impact visibility and the health of the public and Caltrans staff.

The areas shaded in red in Figure 6 indicate increased likelihood of wildfires based on projected percentages of area burned over time. These projections are from data generated by the MC2 – EPA (from the United States Forest Service), MC2 – Applied Climate Science Lab (University of Idaho), and the Cal-Adapt 2.0 (UC Merced) wildfire models. Each model was paired with three downscaled global climate models to produce nine future scenarios. Starting with three different wildfire models was a conservative methodology, as final data shows the highest wildfire risk categorization of all model results.

WILDFIRE EFFECTS IN DISTRICT 12

Large portions of District 12 are projected to be exposed to increased wildfire risk. The extent of wildfire risk does not expand from the beginning to the end of century, but the level of risk increases over time in these areas (from moderate to high, for example). The eastern portions of Orange County are most vulnerable to increased wildfire concern, compared to coastal areas where the wildfire risk is limited.

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
Orange	**71.5**	**71.6**	**72.5**

SR 91 | FREEWAY COMPLEX FIRE

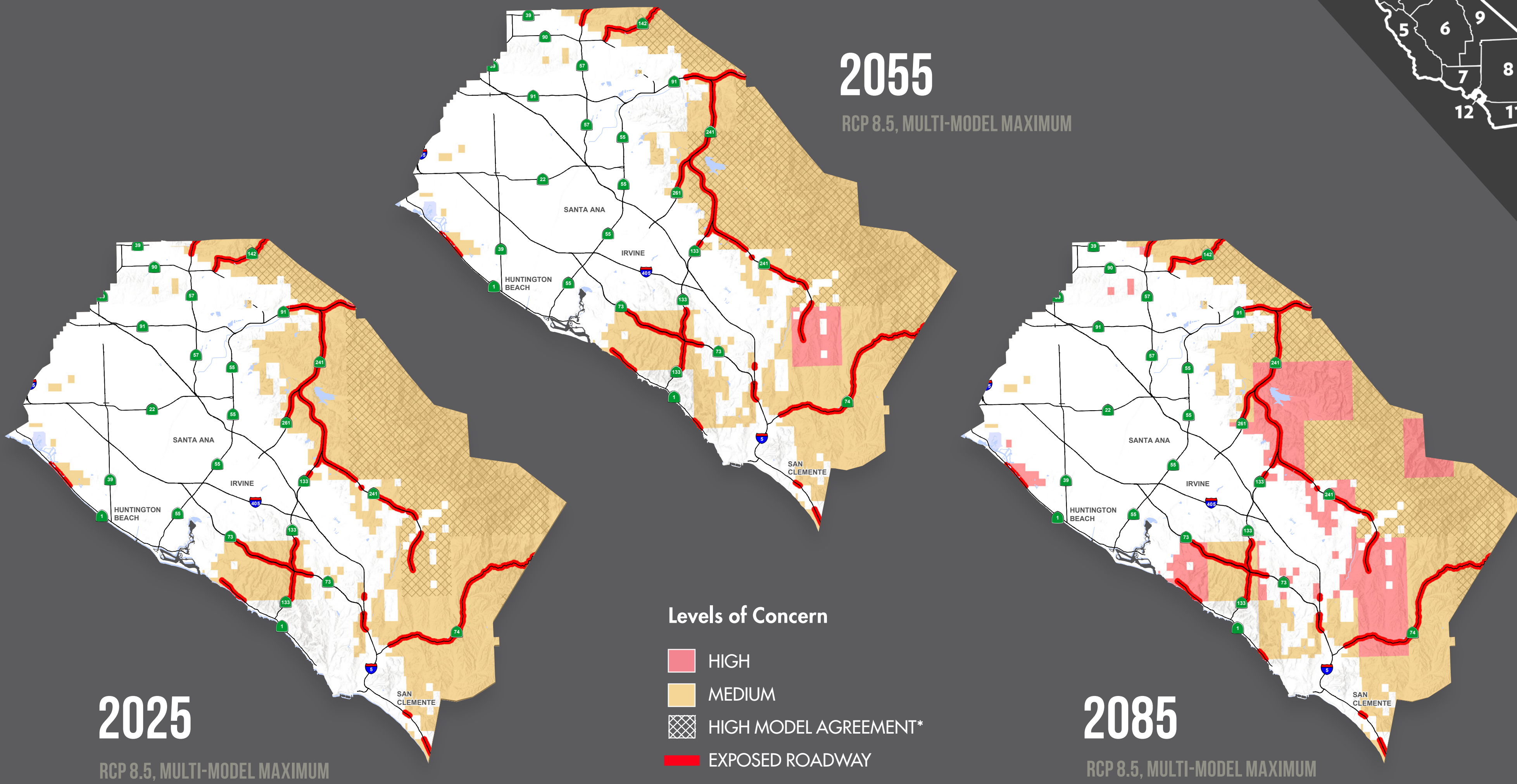
photo by Bluedv | CC

TRIANGLE COMPLEX FIRE | NOVEMBER 2018

photo by jstanden | CC

Fig. 6

LEVEL OF WILDFIRE CONCERN

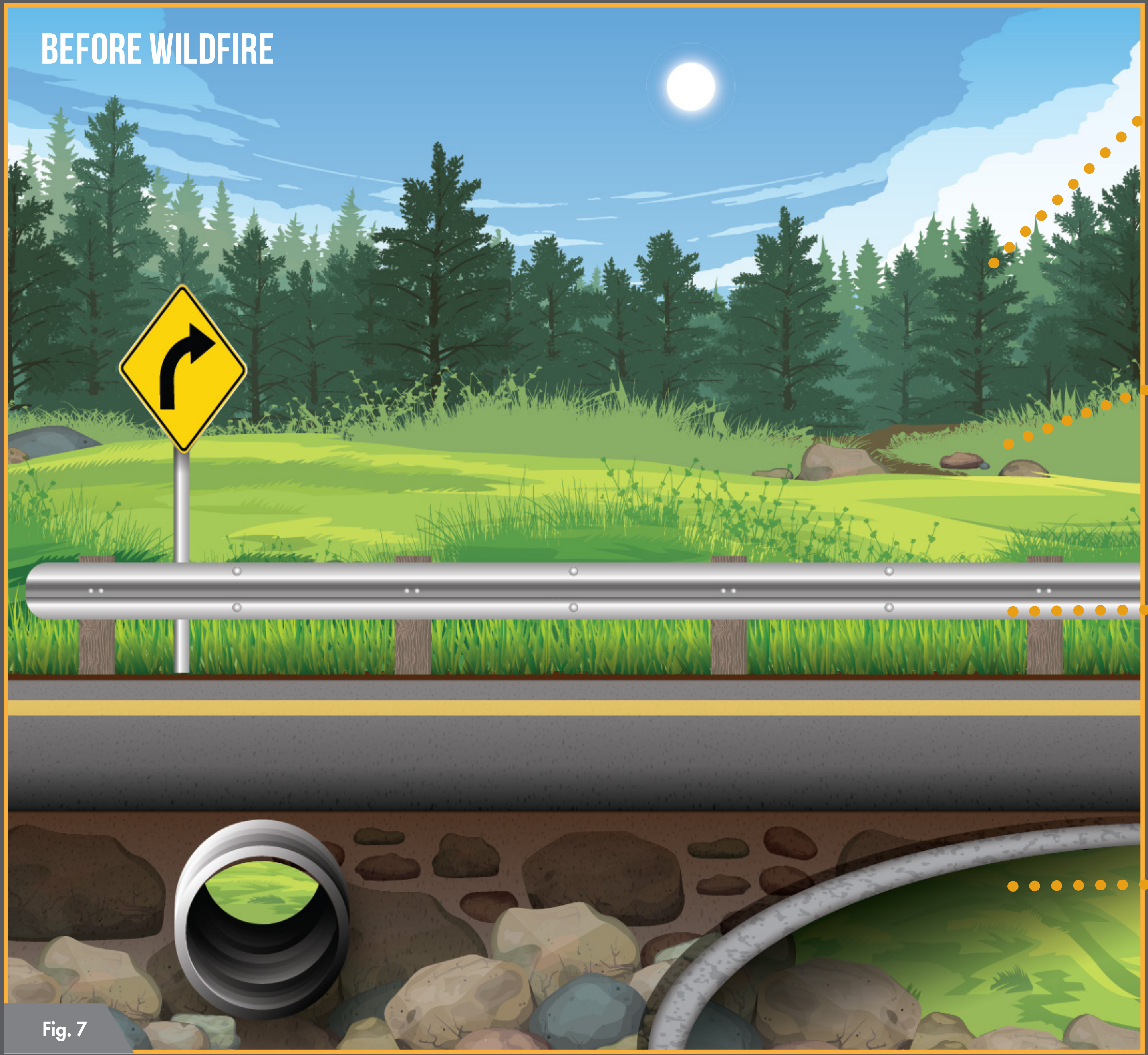


Future Level of Wildfire Concern for the Caltrans State Highway System within District 12, Based on the RCP 8.5 Emissions Scenario.

The fire model composite summaries shown are based on wildfire projections from three models: (1) MC2 - EPA Climate Impacts Risk Assessment, developed by John Kim, USFS; (2) MC2 - Applied Climate Science Lab at the University of Idaho, developed by Dominque Bachelet, University of Idaho; and (3) University of California Merced model, developed by Leroy Westerling, University of California Merced. For each of these wildfire models, climate inputs were used from three 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 moderate. 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.



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 12

Multiple climate stressors could potentially impact District 12's State Highway System, but the effects of rising sea levels on the coast are of primary concern. 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, which are already problems in District 12. Orange County residents are taking steps to limit the impacts of flooding and erosion: Newport Beach is raising the height of their Balboa Island sea wall,[19] and Orange County installed riprap and barriers along what remains of Capistrano Beach to protect it from being further washed away.[20]

The following sections provide a high-level overview of the District 12 assessments for sea level rise, storm surge, and cliff retreat. Each analysis encompasses the entire coastline—the District 12 Technical Report includes the full results. Modeling results showed notable State Highway System vulnerabilities in Seal Beach, Newport Beach, and a stretch of cliffs near Moro Canyon—the following section highlights these areas. Figure 9 shows these locations and photos of recent coastal impacts. Zoomed in maps highlight the modeling results in these locations and mileage summaries are provided for the entire District 12 coastline.

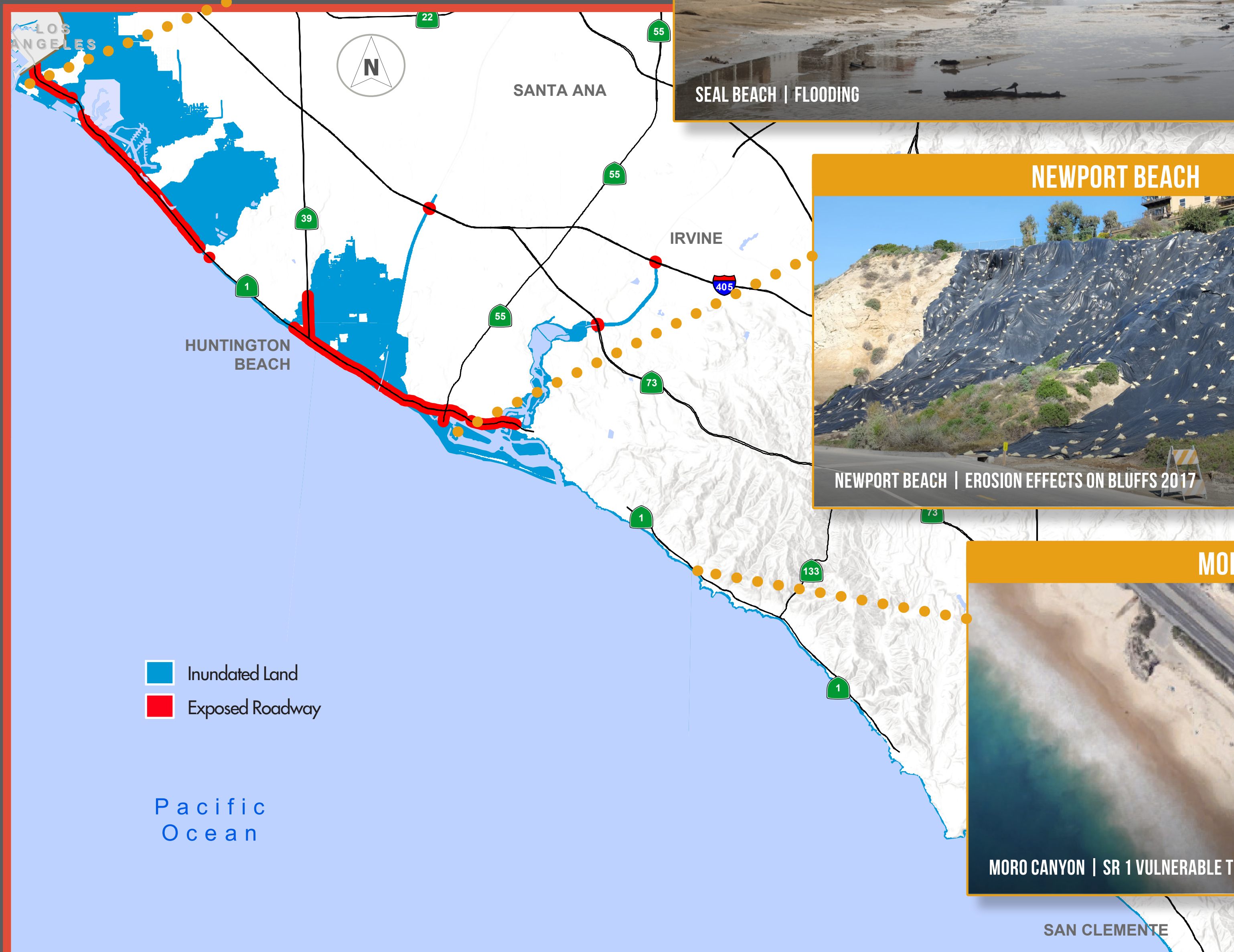
These assessments are the first stage of analyzing and understanding the State Highway System's vulnerability to sea level rise, storm surge, and cliff retreat. With this information, Caltrans can begin to 1) identify the most critical and vulnerable locations on District 12's State Highway System, 2) 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.

19 - "Balboa Island Seawalls Rehabilitation Project," City of Newport Beach, updated May 4, 2017, https://www.newportbeachca.gov/trending/projects/balboa-island-seawalls-rehabilitation.

20 - "Can 475 'sand cubes' protect Capo Beach from further erosion?" The Orange County Register, updated April 4, 2019, https://www.ocregister.com/2019/04/03/can-475-sand-cubes-protect-capo-beach-from-further-erosion/.

Fig. 9

RECENT COASTAL IMPACTS



SEAL BEACH

SEAL BEACH | FLOODING

NEWPORT BEACH

NEWPORT BEACH | EROSION EFFECTS ON BLUFFS 2017

MORO CANYON

MORO CANYON | SR 1 VULNERABLE TO CLIFF RETREAT

SEA LEVEL RISE

Sea level rise is one of the most threatening impacts of climate change for coastal areas. The effects of ocean water's thermal expansion and glacial and ice sheet melting are leading to higher sea levels around the world. District 12 includes an extensive coastline for which Caltrans facilities provide access, and sea level rise will exacerbate flooding that could occur in these areas during regular tidal or storm events. Eventually, some areas may become permanently inundated. For Caltrans, this means that many of its coastal roads, bridges, and supporting facilities face risk of future flooding, permanent inundation, or other damages.

Like other forecasted changes in climate, projections for 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.[21] It also provides direction for using these new projections in project planning and decision-making. A selection of these scenarios, and their use are explained further in Figure 11.

These projections were paired with sea level rise heights modeled by the Coastal Storm Modeling System (CoSMoS) for this study. CoSMoS was developed by the United States Geological Survey (USGS) to model the potential inundation from sea level rise and storm surge given certain heights of sea level ranging from 1.64 feet (0.50 meters) to 16.40 feet (5 meters). This data was developed to model sea level rise and storm surge above the average daily high tide for most of the California coast and within the San Francisco Bay. The District 12 analysis also includes cliff retreat data created by the CoSMoS model for portions of Southern California.

The assessments of sea level rise, surge, and cliff retreat on the following pages include bridges that may also be subject to sea level rise, but not necessarily overtopping, because the rise alone can pose risks. Figure 12 illustrates some of these risks to bridges from sea level rise.

SEA LEVEL RISE EFFECTS IN DISTRICT 12

Rising seas will exacerbate tidal flooding[22] and storm surge conditions along the California coastline, and may eventually lead to permanent inundation in some areas. This could impact coastal infrastructure along the shoreline.

Table 2 shows the miles of District 12 State Highway expected to by inundated by sea level rise for three modeled CoSMoS increments: 1.64, 3.28, and 5.74 feet. Some sections of the State Highway System will be more vulnerable than others. Figure 10, for example, shows the expected inundation of SR 1 in Newport Beach. As shown, a significant portion of SR 1 through this community may be inundated with sea level rise of up to 5.74 ft (1.75 m).

Poor conditions on coastal highways are expected to become more pronounced as sea level rises and Caltrans will need to develop strategies that address long-term permanent inundation. Options to consider include the creation of natural buffers, pumping water out of inundated areas, elevating roadways, and retreat.

21 - 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

22 - Tidal flooding refers to flooding caused by high tides, which get progressively higher as sea levels rise.

Table 2: Centerline Miles of State Highways in District 12 Inundated 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)
Orange	**2.8**	**5.2**	**8.7**

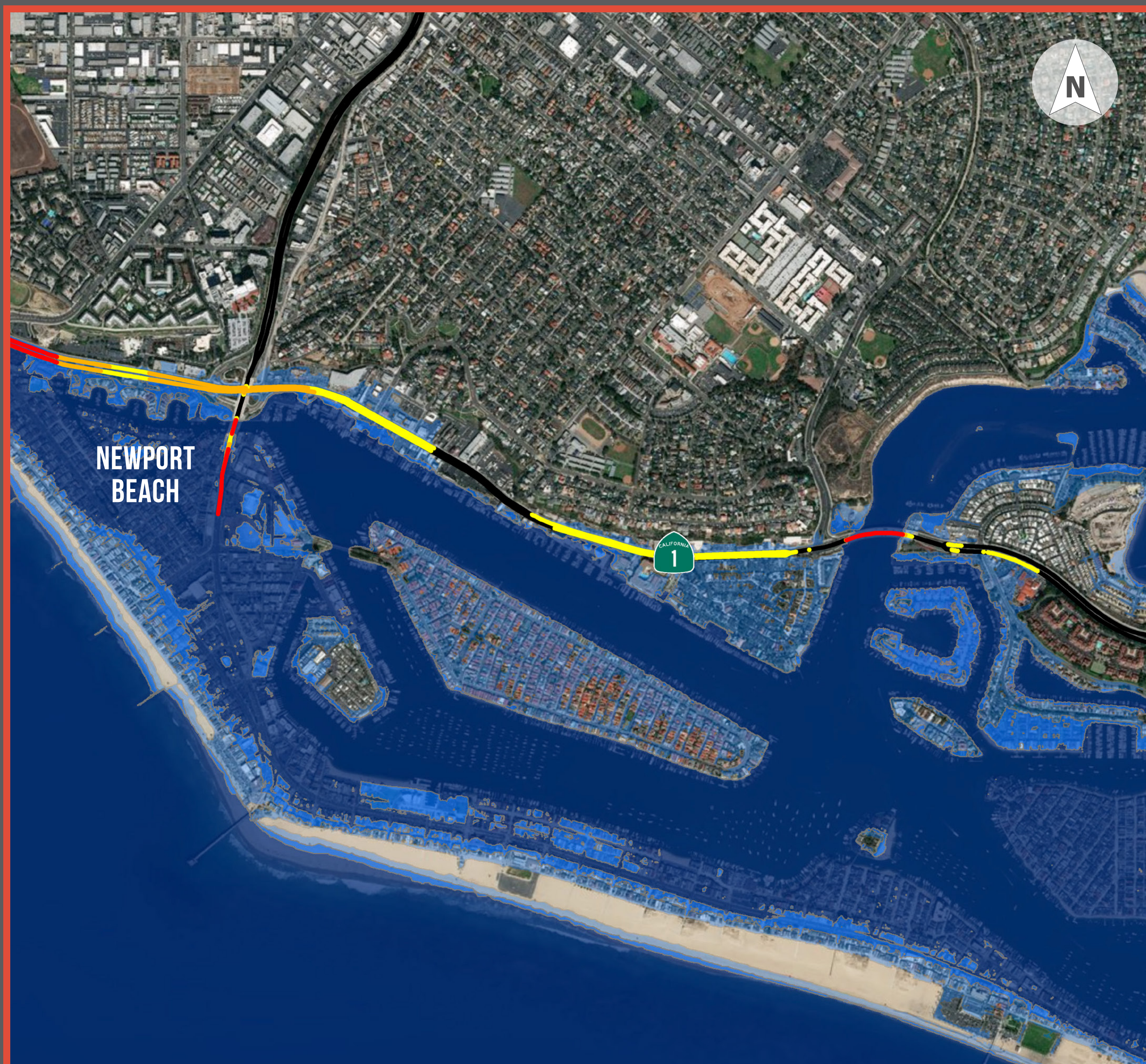
ANALYSIS FOR THIS REPORT WAS CONDUCTED ON THREE DISTINCT INCREMENTS OF SEA LEVEL RISE TO SHOW HOW CONDITIONS MAY CHANGE OVER TIME. THOSE INCREMENTS ARE 1.64 FEET (.5 METERS), 3.28 FEET (1 METER) AND 5.74 FEET (1.75 METERS)

APPROXIMATELY NINE MILES OF CALTRANS DISTRICT 12 HIGHWAYS AND BRIDGES MAY BE INUNDATED BY SEA LEVEL RISE UNDER 5.74 FEET OF SEA LEVEL RISE

SR 1 | 2008 FLOOD EVENT

Fig. 10

MODELED SEA LEVEL RISE INUNDATION IN AND AROUND NEWPORT BEACH



Impacts to SR 1 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)

Sea level rise data are from the US Geological Survey, Coastal Storm Modeling System (CoSMoS). See Our Coast, Our Future and the USGS CoSMoS webpage for more information on the model. 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 PROJECTIONS FOR DISTRICT 12

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 Los Angeles 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).[23] These projections were developed for gauges along the California coast based on global and local factors that drive sea level rise such as thermal expansion of ocean water, glacial ice 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

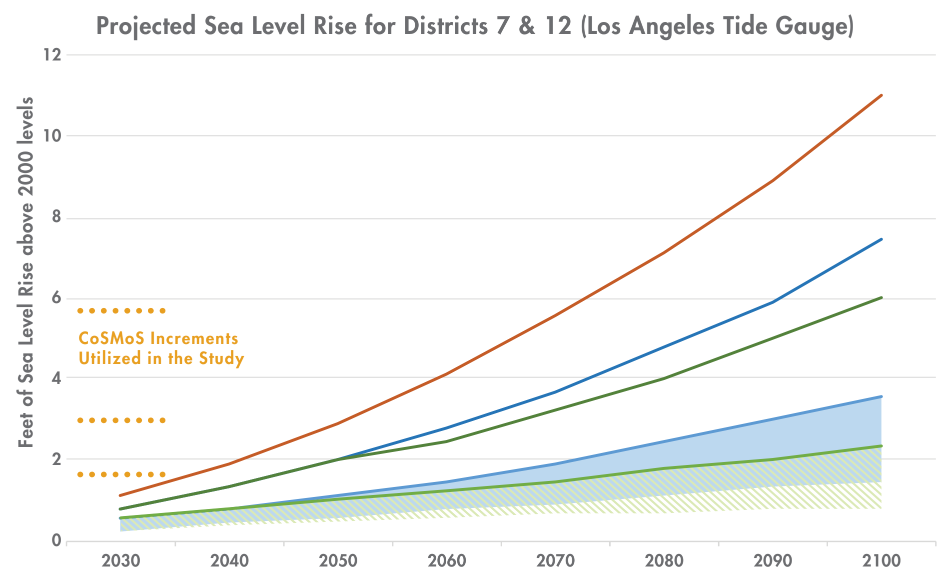
Each of these values are presented for low (RCP 2.6) and high (RCP 8.5) emissions scenarios to demonstrate a full range of potential projections over time. The OPC recommends using only RCP 8.5 for projects that have a lifespan to 2050, and using both scenarios for projects with longer lifespans. The 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 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.
- **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.
- **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.

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. 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.[24]



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

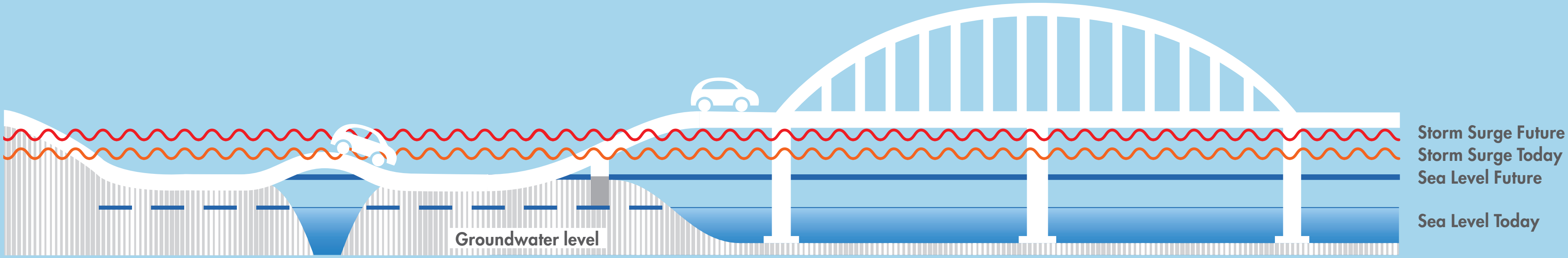
- Extreme Estimate of Sea Level Rise (H++ Scenario)
- **Low Probability** Estimate (0.5% Probability Scenario) for **High Emissions** Scenario
- **Low Probability** Estimate (0.5% Probability Scenario) for **Low Emissions** Scenario
- **High End of the Likely Range** (17% Probability Scenario) for **High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

23 -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

24 - 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," July 2018, https://documents.coastal.ca.gov/assets/climate/2018ScienceUpdate_website_7.20.18.pdf

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.

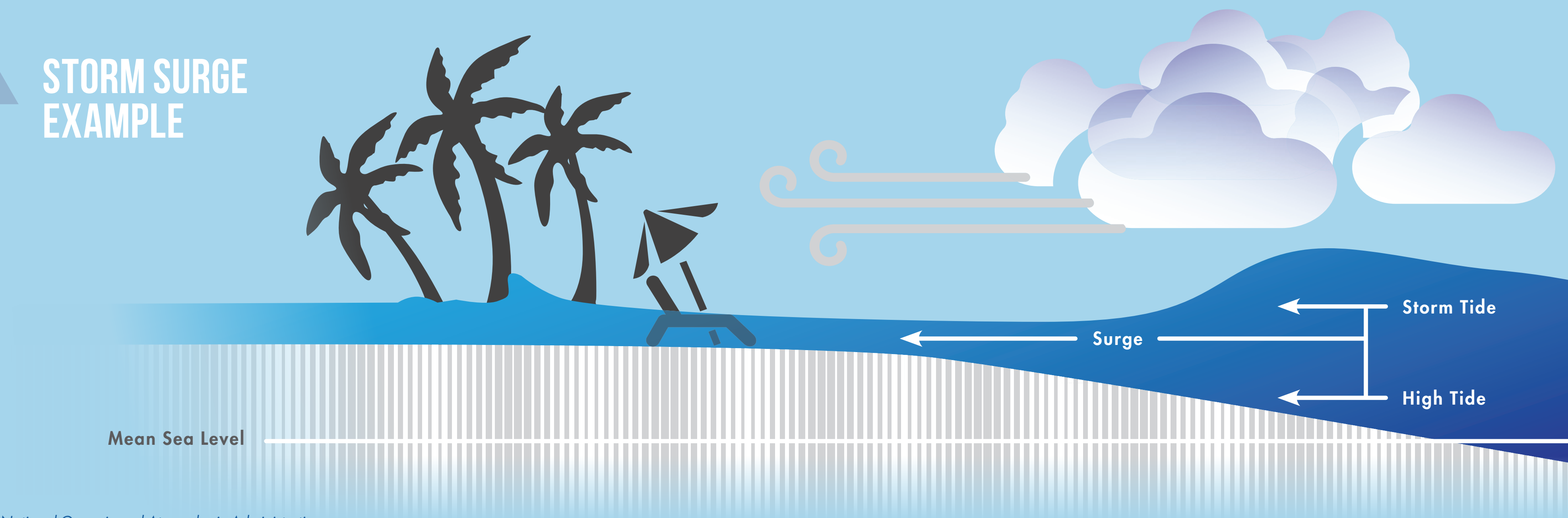
Some bridge vulnerabilities include:

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

The inundation of coastal areas becomes even worse when combined with storm surge, which refers to elevated sea levels during a storm event. It is likely that many coastal roads and bridges are already exposed to surge effects that can inflict damage and reduce their useful life. It is also likely that future storms will subject coastal infrastructure to even higher forces, due to higher than normal waves. Storm surge is expected to increase coastal erosion and landslides, cause shoreline retreat, and expose roadways to increased flooding (see Figure 14 on following page).

The CoSMoS data was used to assess sea level rise and storm surge impacts to the State Highway System in District 12. The model provides outputs for a variety of storm events, including an annual storm, a 20-year storm, a 100-year storm, and a King Tide.[25] The results from the 100-year storm analysis and three sea level rise heights are reported here.

Figure 14 shows a zoomed-in view of one part of SR 1 in District 12 that is at high risk of future flooding due to sea level rise and surge from a 100-year storm. This route is critically important for the local coastal communities and for tourists using the highway to access beaches and attractions.

25 - The King Tide is the highest high tide of the year.

STORM SURGE EFFECTS IN DISTRICT 12

Not surprisingly, the most-affected roads will be those close to the coast, with SR 1 the being the most-impacted highway. The District 12 Technical Report identifies all portions of the State Highway System in Orange County that will likely be affected by the combined effects of sea level rise and storm surge. Figure 14 shows SR 1 near Seal Beach, that may be flooded by a 100-year storm and various levels of sea rise. Major sections of SR 1 could be rendered unusable without a Caltrans response. Surrounding homes and businesses could also be inundated. Segments of SR 1 that are projected to be flooded by storm surge are those where District 12 currently faces the most extensive post storm clean-ups.

Table 3: Centerline Miles of State Highways in District 12 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	5.74 ft (1.75 m) + 100-Yr Storm
Orange	**3.7**	**6.2**	**11.9**

Fig. 14

MODELED SEA LEVEL RISE AND STORM SURGE FLOODING IN SEAL BEACH

Sea level rise and surge (100-year storm) data are from the US Geological Survey, Coastal Storm Modeling System (CoSMoS). See Our Coast, Our Future and the USGS CoSMoS webpage for more information on the model. 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 ocean water levels 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. Cliff retreat is 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.[26]

Rates of cliff retreat will depend 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 has adapted their CoSMoS model to incorporate projected changes in cliff retreat and shoreline erosion through a detailed topographic survey of the shoreline and application of erosion rates given future sea level rise. This data is available from Point Conception in Santa Barbara to Imperial Beach in San Diego County, and was applied for this analysis of District 12.

Figure 15 shows a detailed example of cliff retreat impacts in District 12. Note that this data estimates cliff retreat for a scenario, which assumes that no action is taken to maintain current armoring of the coastline. By using this data Caltrans can use a more conservative estimate of projected cliff retreat in decision-making for coastal infrastructure.

CLIFF RETREAT EFFECTS IN DISTRICT 12

The results for the entire District 12 cliff retreat assessment are presented in the District 12 Technical Report. Table 4 provides the full centerline mileage of affected highways in District 12. Impacted portions of SR 1 include a northern segment near Huntington Beach and several areas between Corona Del Mar and Monarch Beach. Figure 15 shows a section of SR 1 vulnerable to cliff retreat, near Crystal Cove. As shown, substantial portions of the beach, cliff face, and segments of SR 1 could be washed away as sea levels rise. Values used to determine these potential long-term effects are at the same increments as those used in the sea level and storm surge sections of this report – and specifically highlight assets at risk from sea level rise of 1.64, 3.28, and 5.74 feet (0.5, 1, and 1.75 meters).

District 12 has already faced ongoing issues with cliff retreat, which will only become more challenging as sea level rise increases the rate and severity of erosion. Cliff retreat is already threatening SR 1 near Seapoint Street in Huntington Beach, and District 12 staff have been forced to use extensive rip rap on the cliff face to protect the roadway. As described on page 7 of this report, there are negative repercussions to coastal armoring. Armoring is a temporary solution, it diminishes the availability of beaches and habitat, and can even increase erosion to neighboring properties.[27] To avoid these impacts, the California Coastal Commission recommends minimizing barrier construction and armoring in their *Sea Level Rise Policy Guidance*.[28]

Table 4: Centerline Miles of State Highways in District 12 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)
Orange	**0.3**	**0.7**	**1.0**

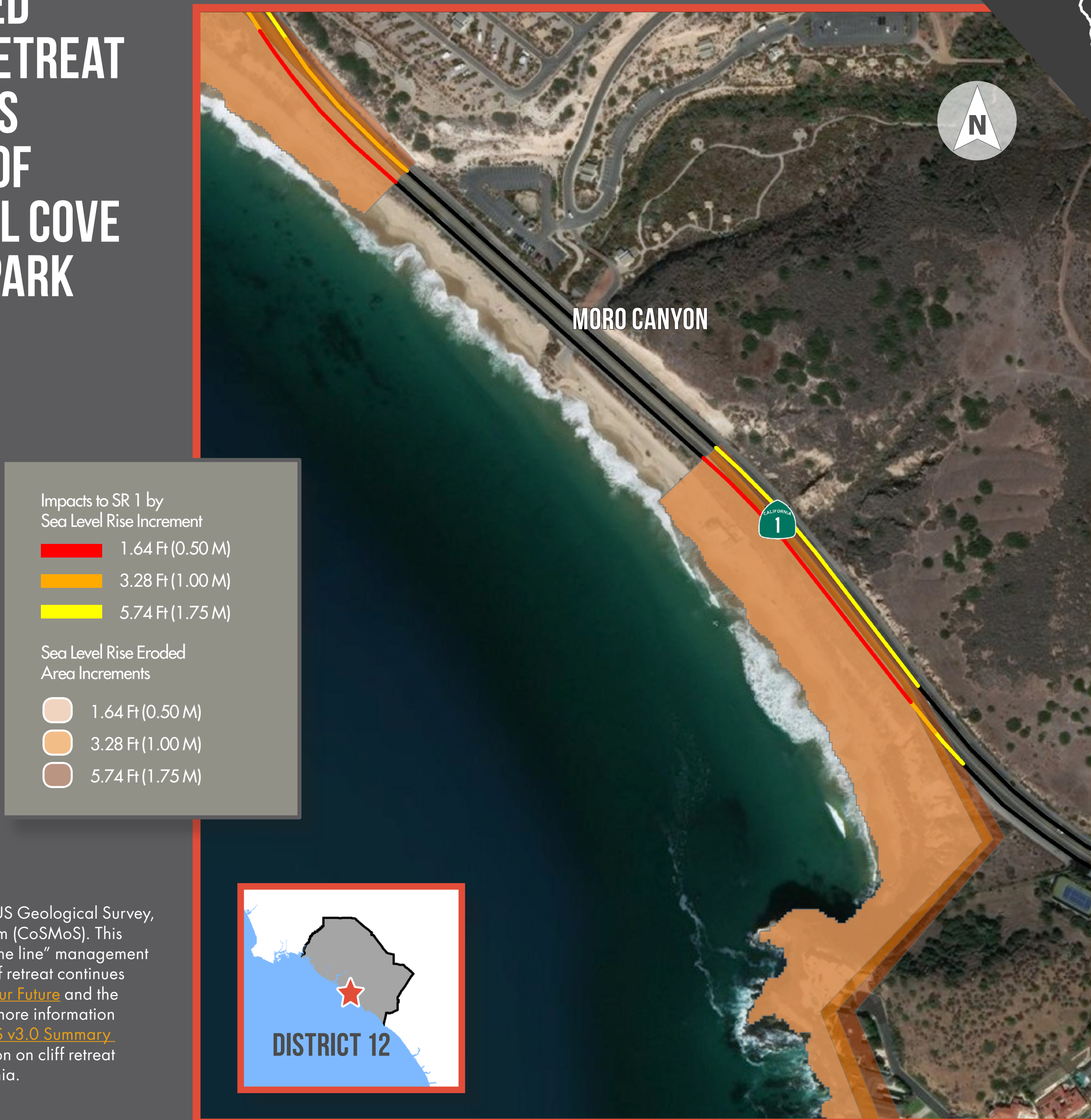
26 - UC San Diego, "Study Identifies California Cliffs at Risk of Collapse," 2017, https://phys.org/news/2017-12-california-cliffs-collapse.html.

27 - Molly Loughney Melius and Margaret R. Caldwell, California Coastal Armoring Report: Managing Coastal Armoring and Climate Change Adaptation in the 21st Century, Environment and Natural Resources Law & Policy Program Working Paper, 2015. https://law.stanford.edu/wp-content/uploads/2015/07/CalCoastArmor-FULL-REPORT-6.17.15.pdf

28 - California Coastal Commission Sea Level Rise Policy Guidance: Interpretive Guidelines for Addressing Sea Level Rise in Local Coastal Programs and Coastal Development Permits, California Coastal Commission, July 2018, https://documents.coastal.ca.gov/assets/climate/2018ScienceUpdate_website_7.20.18.pdf

Fig. 15

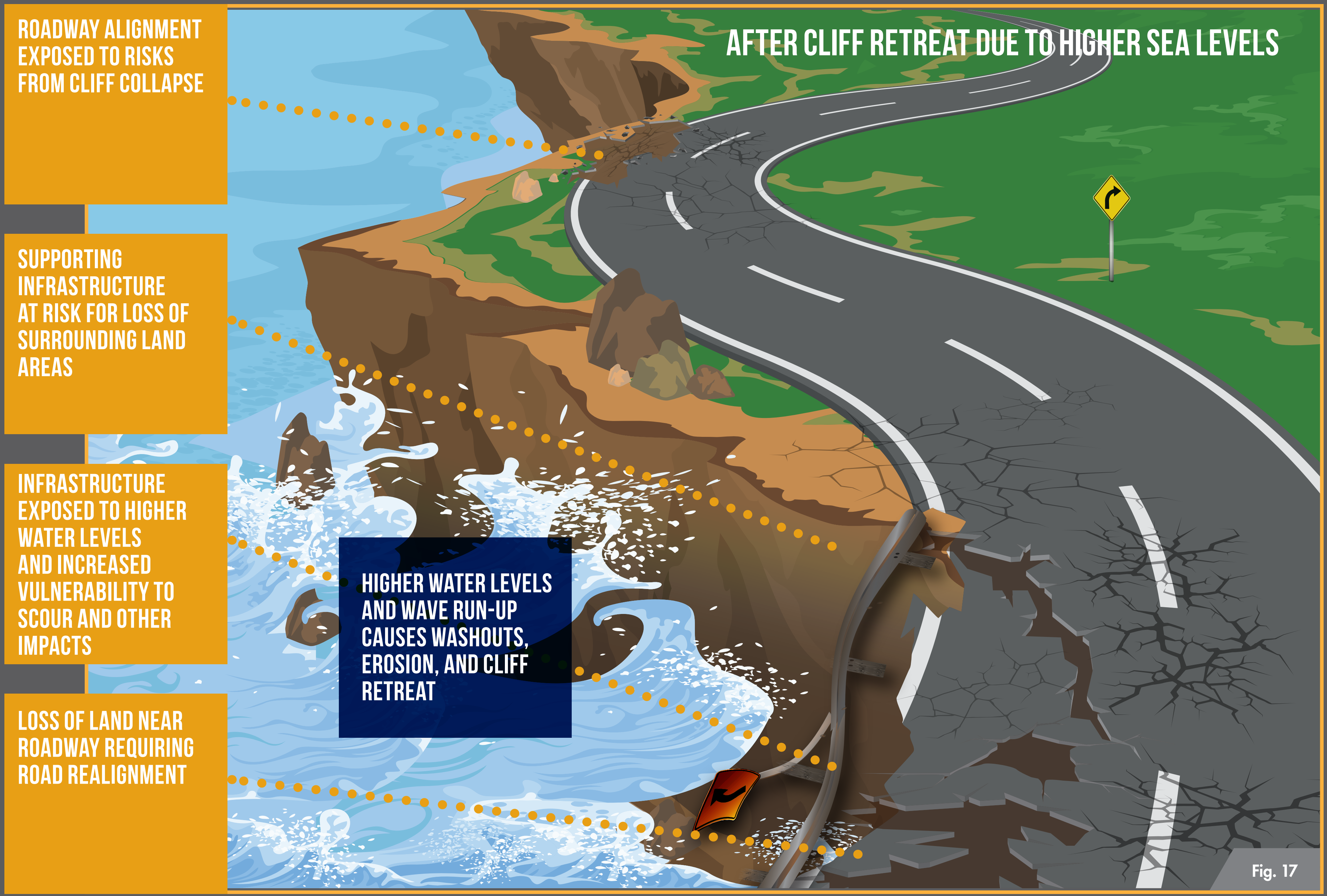
MODELED CLIFF RETREAT IMPACTS SOUTH OF CRYSTAL COVE STATE PARK



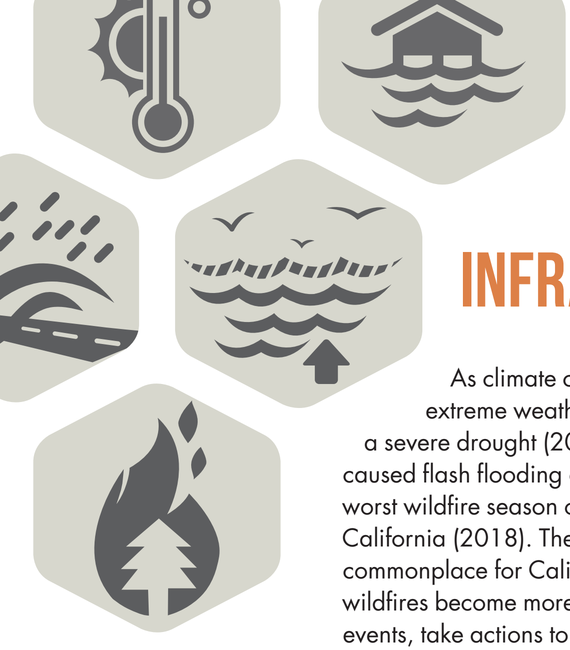
Cliff retreat data are from the US Geological Survey, Coastal Storm Modeling System (CoSMoS). This data applies the "do not hold the line" management option, which assumes that cliff retreat continues unimpeded. See Our Coast, Our Future and the USGS CoSMoS webpage for more information on the model.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



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



INFRASTRUCTURE IMPACT EXAMPLE

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 an example of a weather-related event at the district level and the district response.

EMERGENCY REPAIRS ON STATE ROUTES 241 AND 91

In accordance with Governor Brown's disaster proclamation on October 9th, 2017, Caltrans performed emergency work in Orange County on wildfire-damaged areas of SR 241 and SR 91 in the Cities of Anaheim, Tustin, and Orange. The projects included replacing damaged guard railings, signs, lighting and electrical elements, culverts, traffic control devices, delineators, reflective markers, wildlife protection fencing, access control fencing, and erosion control features. Other actions included clearing drainages of fire-related debris, reconstruction of the debris-catchment wall at the Coal Canyon Basin, and the construction of emergency erosion control and debris-catchment elements on SR 241 and SR 91. The primary intent of these projects was to repair the damaged roadways to enhance safety and stabilize the project sites for winter.

SR 91 was previously affected by rock and landslides following heavy rain in 2014, which closed the roadway and required extensive clean up by District 12 (see page 34). Given previous rock slide issues on the corridor, district staff were especially responsive to the 2017 SR 91 wildfire events and took action to minimize slide risk.

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)[29] process.

At its core, the ADAP process is a risk-based, scenario-driven design process. It incorporates broader economic and social costs, as well as projected future climate conditions, into design decision-making. It can be considered a type of sensitivity test for Caltrans assets and it incorporates an understanding of the implications of failure on Caltrans system users, and the agency's repair costs. The ADAP flowchart shows the basic elements of climate change assessment in District 12 for existing and future roadways.

The example below highlights a district effort that demonstrates a response to extreme weather. The effort provides an example of how Caltrans districts can prepare for, and respond to, future climate change and extreme weather events.

STATE ROUTE 74 CULVERT REPLACEMENT

As a result of damage caused by 2017 winter storms, Caltrans removed and replaced a 24-inch diameter culvert drainage pipe, dewatered, and rebuilt a section of asphalt concrete roadway along SR 74 (Ortega Highway) in unincorporated Orange County. The redesign proactively considered the risks associated with future winter storms.

29 - 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

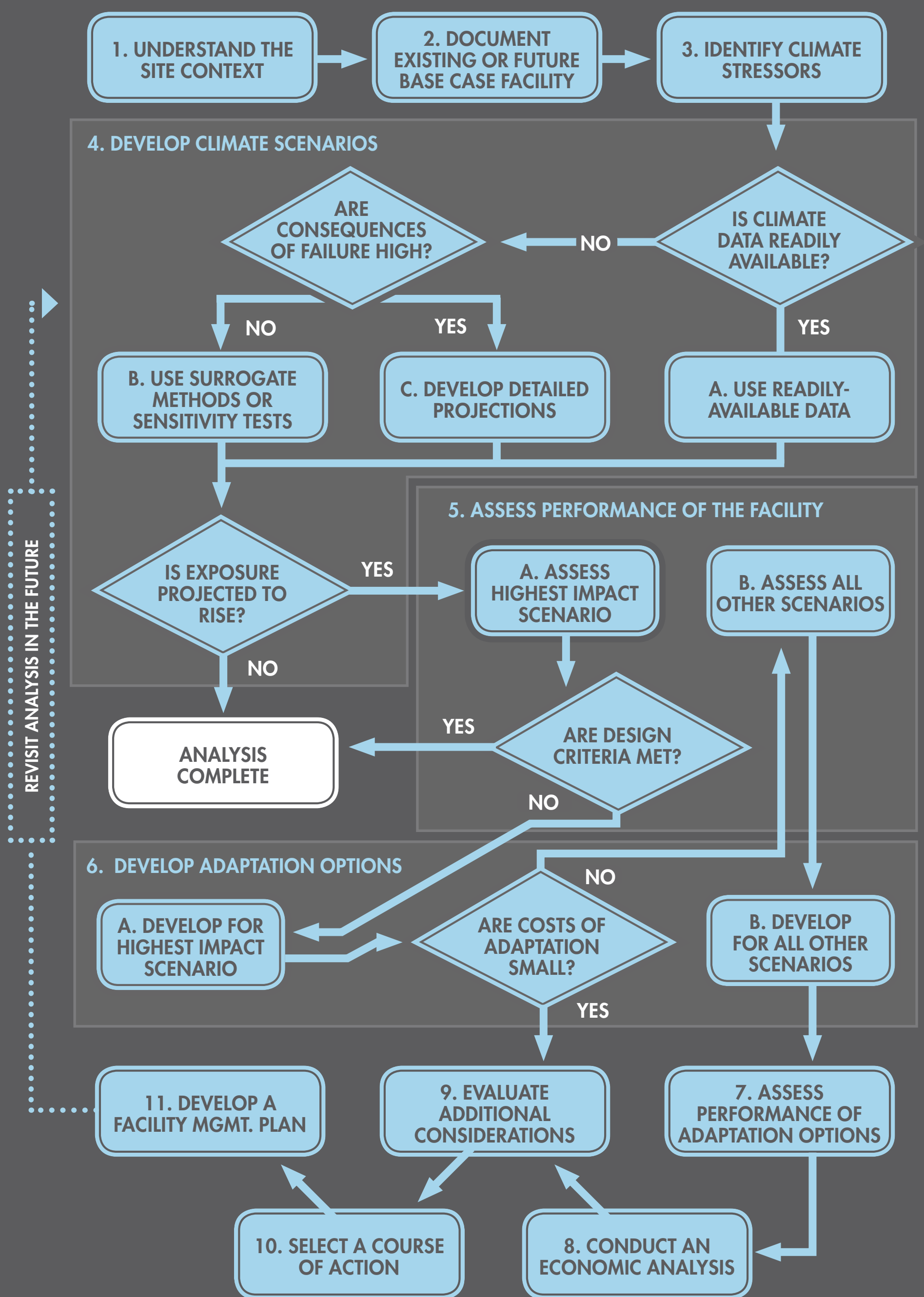
BEFORE

AFTER

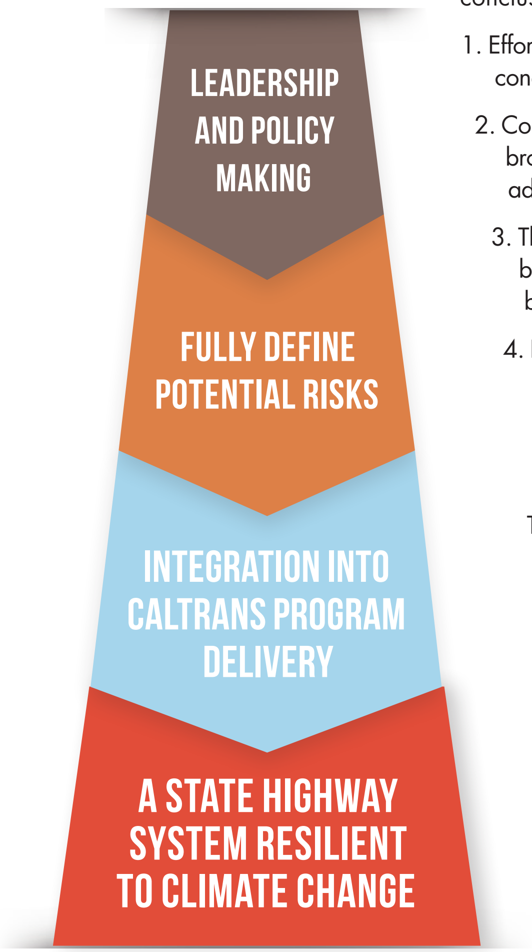
SR 74 | DISTURBED AREA FOLLOWING CULVERT REPLACEMENT

Fig. 18

FHWA'S ADAP DESIGN PROCESS



WHAT DOES THIS MEAN TO CALTRANS?



GENERAL CONCLUSIONS

Recent extreme weather events in District 12 provide an opportunity to address many of the potential climate change impacts outlined in this report. Caltrans can draw the following conclusions:

1. Efforts to build or repair District 12 facilities should consider future conditions as opposed to relying on historical conditions
2. Consequence costs should be a factor in redesign to assess broader economic measures and the potential cost savings from adaptation
3. The development of updated design approaches, which includes best available climate data from state resource agencies, should be a part of event response
4. FHWA's ADAP process should be applied when planning or designing facilities and assets. This will help account for uncertainties in climate data and provide a benefit-cost assessment methodology that considers long-term costs to guide decisions

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

FULLY DEFINE RISKS

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

INTEGRATION INTO CALTRANS PROGRAM DELIVERY

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

LEADERSHIP

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

COMMUNICATION AND COLLABORATION

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

A STATE HIGHWAY SYSTEM RESILIENT TO CLIMATE CHANGE

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

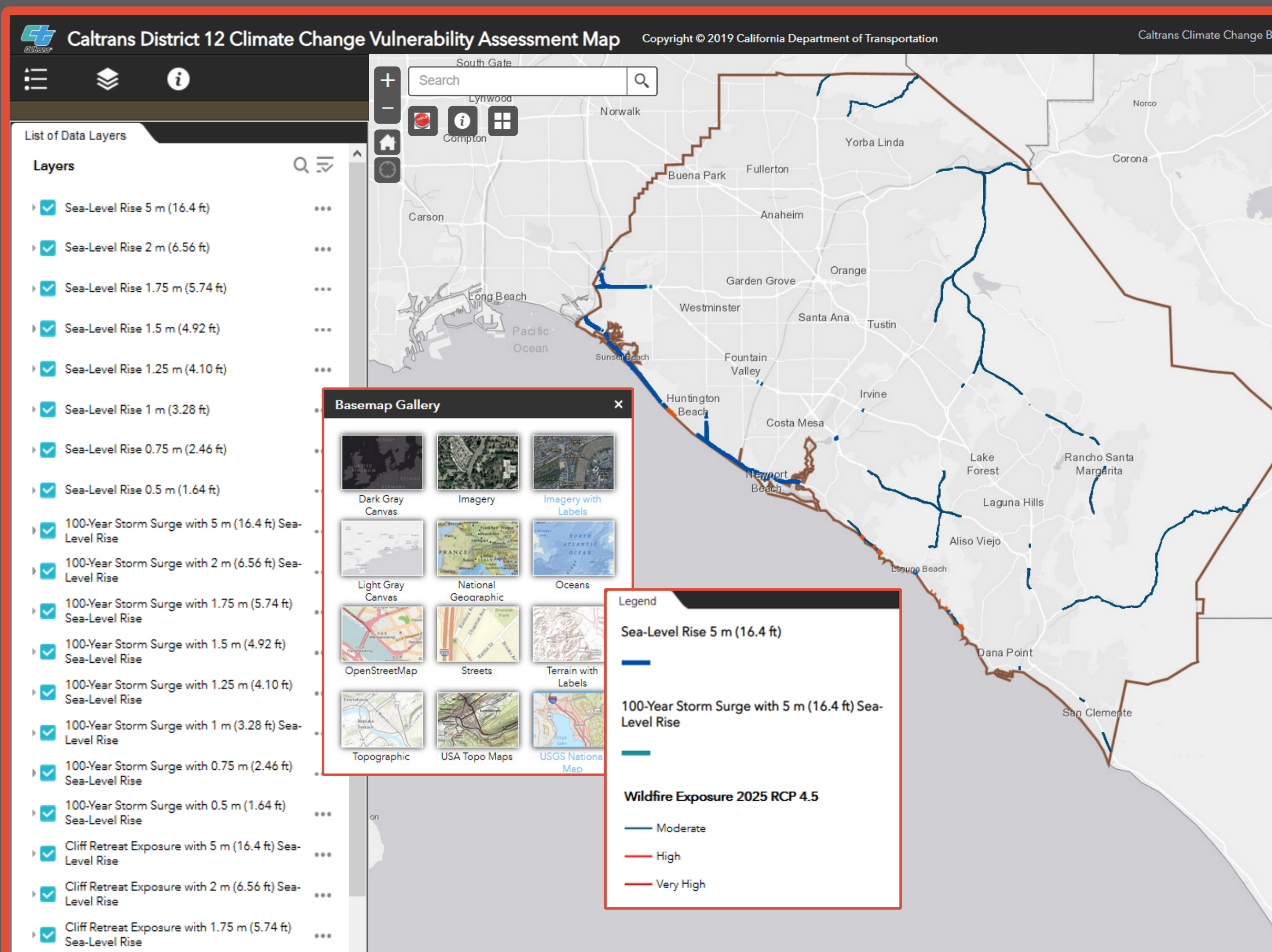
ON-LINE MAPPING TOOL FOR DECISION-MAKING

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.[30]

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

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

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



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

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

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