CALTRANS CLIMATE CHANGE

VULNERABILITY ASSESSMENT SUMMARY REPORT

DISTRICT 11

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

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

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

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

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

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OVERVIEW OF METHODOLOGY

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

The IPCC represents future emissions conditions through a set of representative concentration pathways (RCPs) that reflect four scenarios for greenhouse gas (GHG) emission concentrations under varying global economic forces and government policies. The four scenarios are RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5. This analysis considered RCP 4.5, which assumes that carbon emissions will peak by mid-century, and RCP 8.5, which assumes a continuation of current emission trends until end of century. This Summary Report presents only results from the RCP 8.5 analysis—the RCP 4.5 analysis is summarized in the associated Technical Report, and the full dataset is compiled in a GIS 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. The information presented in this report is the latest phase of this effort. It identifies portions of the State Highway System that could be vulnerable to different climate stressors and Caltrans processes that may need to change as a result.

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

The information in this Summary Report outlines the potential vulnerabilities to Caltrans' District 11 portion of the State Highway System. It illustrates the types of climate stressors that may affect how highways are planned, designed, built, operated, and maintained. This study is needed to add clarity regarding climate change effects and responses in the region served by District 11 and to begin to define a subset of assets on the State Highway System on which to focus future studies and adaptation efforts. This report does not identify projects to be implemented, nor does it present the cost associated with such projects. These items will be addressed in future work performed by Caltrans.

THE MOBILITY PROVIDED BY A RESILIENT STATE HIGHWAY SYSTEM ENABLES THE ECONOMIC AND SOCIAL WELL-BEING OF DISTRICT 11 COMMUNITIES AND RESIDENTS

DISTRICT 11 CHARACTERISTICS

Caltrans District 11 is located in the southern region of California. It stretches from the Pacific Ocean to Arizona and borders Mexico to the south, with headquarters in San Diego. District 11 consists of two very different counties: urbanized San Diego County bordering the Pacific Ocean, and rural Imperial County bordering Arizona. As noted in the District's System Management Plan, District 11 is "one of the most geographically and culturally diverse areas in the country with a wide range of climates and terrain—from the temperate coastal region to chilly mountain peaks and blazing desert sands. Heading east from the San Diego coastline, the landscape of canyons and mesas climbs into mountains reaching more than 6,000 feet and then drops down to 230 feet below sea level in the low desert of Imperial County."[3] San Diego County has 70 miles (110 km) of coastline.

KEY STATE POLICIES ON CLIMATE CHANGE

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

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

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

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

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3 - California Department of Transportation, "District 11 System Management Plan," 2016, http://www.dot.ca.gov/dist11/departments/planning/planningpages/dsmp.htm
4 - California Governor's Office of Planning and Research, "Planning and Investing for a Resilient California," March 13, 2018, http://opr.ca.gov/planning/icarp/resilient-ca.html
5 - "Assembly Bill No. 1482," California Legislative Information, October 8, 2015, https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201520160AB1482
6 - "Assembly Bill No. 2800," California Legislative Information, September 24, 2016, http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160AB2800
7 - Climate-Safe Infrastructure Working Group, Paying it Forward: The Path Toward Climate-Safe Infrastructure in California, September 2018, http://resources.ca.gov/climate/climate-safe-infrastructure-working-group/

RECENT EXTREME EVENTS IN DISTRICT 11

Given the diverse climatic conditions currently experienced in District 11, the range of extreme weather impacts in the district is very broad. Extreme heat in Imperial County at one end of the district to sea level rise and flooding in the western portions of the district make District 11 one of most potentially impacted districts to changes in climate.

- **Temperature** – San Diego County has a Mediterranean climate with relatively mild summers and winters. In recent years, the summers in District 11 have been hotter and longer and the winters have been drier—the San Diego area in the summer of 2017 experienced heat waves with periods of triple-digit temperatures lasting over a week.[8] Imperial County saw similar trends toward hotter temperatures. Death Valley National Park broke its 100-year-old record for the hottest month ever in July 2017 when the average temperature was 107.4 degrees. It was the hottest month ever recorded in the US. The hottest day of the month reached 127 degrees.[9]
- **Precipitation** – Climate change may influence fluctuations in precipitation, with dry years becoming drier and wet years wetter. The water years 2012 to 2014 were the three driest consecutive years in California's history and this period marks the second time a statewide emergency proclamation has been issued for drought.[10]

  Lower precipitation levels can have many negative effects in District 11 communities, perhaps the most significant being drought. In January 2014, Governor Jerry Brown declared a drought State of Emergency that lasted in most of California until April 2017. Imperial County was declared a National Disaster Area by the US Department of Agriculture in 2017 due to drought-related agricultural losses and damages—this was despite the county's access to irrigation water from the Colorado River.
- **Wildfire** – District 11 has been significantly affected by massive wildfires in recent years. In 2007, the Witch Creek Fire burned areas in north and northeast San Diego County and caused the evacuation of approximately 500,000 people from 346,000 homes. Many major roads were closed as a result of fires and smoke, including I-15 and I-5, and Amtrak service was also suspended. The May 2014 San Diego County wildfires were a combination of 20 wildfires that were strengthened by severe Santa Ana Wind conditions, historic drought conditions, and a heat wave. Approximately 26,000 acres burned and 65 structures were destroyed.
- **Sea Level Rise** – Sea level rise is a long-term threat in coastal areas. The effects of thermal expansion of ocean water and melting glacial and ice sheet result in higher sea levels worldwide. Higher sea levels will influence coastal infrastructure and could inundate low-lying areas, damage substructure, and increase shoreline erosion. They can also impact infrastructure designed for historical sea levels—and therefore incapable of withstanding higher water levels. By the end of the century, the San Diego sea levels are projected to be anywhere from 1.1 to 7 feet above current levels, with an extreme high of 10.2 feet.
- **Storm Surge** – Increasing sea levels combined with storm patterns are expected to alter and increase the effects of storm surge in coastal areas, potentially causing extensive damage to infrastructure. Storm surge is currently considered in transportation system design, but bigger and more powerful surges were unaccounted for in past designs. Coastal infrastructure will be exposed to higher forces during storms, and infrastructure originally assumed to be not at risk, may be. Storm surge is also expected to increase coastal erosion, shoreline retreat, landslides, and flooding.

8 - Gary Robbins, "Temperature Records Tumble across San Diego County as Heat Wave Peaks", The San Diego Union Tribune, October 24, 2017, http://www.sandiegouniontribune.com/weather/sd-me-tuesday-heat-20171024-story.html.

9 - Joseph Serna, "Death Valley Breaks 100-year-old Record for Hottest Month Ever in July," Los Angeles Times, August 3, 2017, http://www.latimes.com/local/lanow/la-me-ln-death-valley-heat-record-20170803-story.html

10 - California Department of Water Resources, "California's Most Significant Droughts: Comparing Historical and Recent Conditions," February 2015, https://water.ca.gov/LegacyFiles/waterconditions/docs/California_Signficant_Droughts_2015_small.pdf

TWIN PIPES WASH COVERED WITH SAND

CARLSBAD FIRE

SR 78 | STORM DAMAGE

SR 78 | STORM DAMAGE

VULNERABILITY AND THE STATE HIGHWAY SYSTEM

CALTRANS EFFORTS

Caltrans has been addressing concerns associated with climate change over the last decade, since the establishment of its Climate Change Branch. Caltrans has since developed guidance on how climate change considerations can be incorporated into project design and other functional Caltrans responsibilities. Activities to respond to climate change and develop guidance documents include:

- The release of Guidance on Incorporating Sea Level Rise (2011) to inform effective design and programmatic considerations that incorporate projections of sea level rise.
- 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 in 2016 to ensure effective collaboration between agencies, including in planning for sea level rise impacts.[11]
- The report out of adaptation goals and progress to OPR through the State Sustainability Roadmaps, Adaptation Chapters, the last of which was submitted in October, 2018.[12]

Caltrans' ongoing efforts include developing a more detailed understanding of the risks to the state's transportation system through this study. Next Caltrans is exploring the actions that need to be taken internally to ensure the resiliency of the State Highway System long into the future.

ADDRESSING CONCERNS IN DISTRICT 11

Caltrans District 11's portion of the State Highway System serves critical functions for local communities and the national commerce. Given the importance of this 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 weather and climate-related hazards. Caltrans' approach focuses on the vulnerability of the transportation system to climate change impacts such as temperature rise and extreme weather impacts, like increased heavy precipitation events.

The approach outlined on this page and the next describes an assessment process consistent with Caltrans practices and is focused on the assessment of likely impacts of climate change-related stressors on the State Highway System. The approach focuses on three issues:

- **Exposure** – identifying Caltrans assets that could be affected by expected future weather and climate-related climate hazards.
- **Consequence** – determining what damage might occur to system assets – in terms of loss of use, costs of repair, and increased maintenance needs.
- **Prioritization** – determining which assets to prioritize for more detailed assessment and capital investments to address identified risks.

Implementing this approach requires the participation of a wide range of Caltrans professionals from planning, asset management, operations/maintenance, design, emergency response, and project accounting, and will require coordination with environmental and social resource agencies. It will take an agency-wide effort to implement successfully.

ENSURING SYSTEM RESILIENCY

Once system vulnerabilities are identified, Caltrans will begin considering enhanced system resiliency when choosing projects and project designs. In District 11, this will require implementing projects that help to address the wildfire, precipitation, and increased temperature effects that are expected to occur. These strategies may include:

- Expanding the capacity of drainage structures to accommodate sporadic, heavy rain events.
- Using responsible vegetation management to mitigate risk to the State Highway System in higher wildfire concern areas.
- Raising the elevation of coastal highways that may be inundated by sea level rise.

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

11 - 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

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

HWY 86 | TWIN PIPES FOUND

EAST HWY 78

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

THE APPROACH INCLUDES THE FOLLOWING KEY ELEMENTS:

CONDUCT A VULNERABILITY ASSESSMENT OF ALL CALTRANS ASSETS

INCLUDING EXPECTED TIMING OF IMPACTS

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

DETERMINE THE CONSEQUENCE OF IMPACTS ON CALTRANS ASSETS

DAMAGE/LOSS
DURATION

PRIORITIZE ACTIONS

BASED ON TIMING AND CONSEQUENCE OF IMPACTS

CURRENT STAGE

EXPOSURE

Define the components and locations of the highway system (roads, bridges, culverts, etc.) that may be exposed to changing conditions caused by the effects of climate change such as sea level rise, storm surge, wildfire, landslides, and more. Key indicators for this measure include the potential timing of expected changes – e.g., what year could you expect these conditions to occur.

CONSEQUENCE

Identify the implications of extreme weather or climate change on Caltrans assets. Key variables include estimates of cost of damage and 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, and landslide events, and limited visibility from poor air quality.

PRIORITIZATION

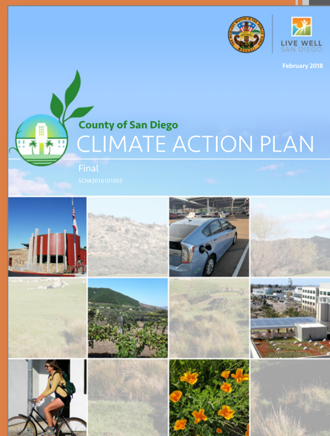
Develop a method to support investment decision-making from among multiple options related to future climate risk, with elements including:

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

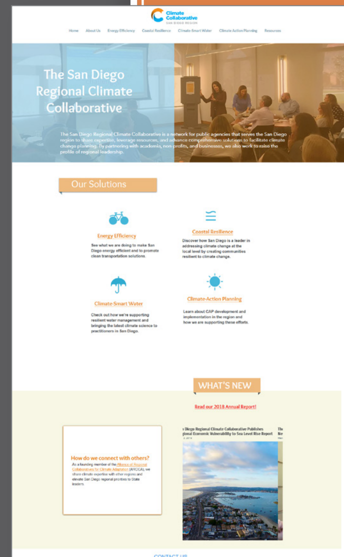
BY USING THIS APPROACH, CALTRANS CAN CAPITALIZE ON ITS INTERNAL CAPABILITIES TO IDENTIFY PROJECTS THAT INCREASE STATE HIGHWAY SYSTEM RESILIENCY.

OTHER EFFORTS IN DISTRICT 11 TO ADDRESS CLIMATE CHANGE

CLIMATE ACTION PLANS

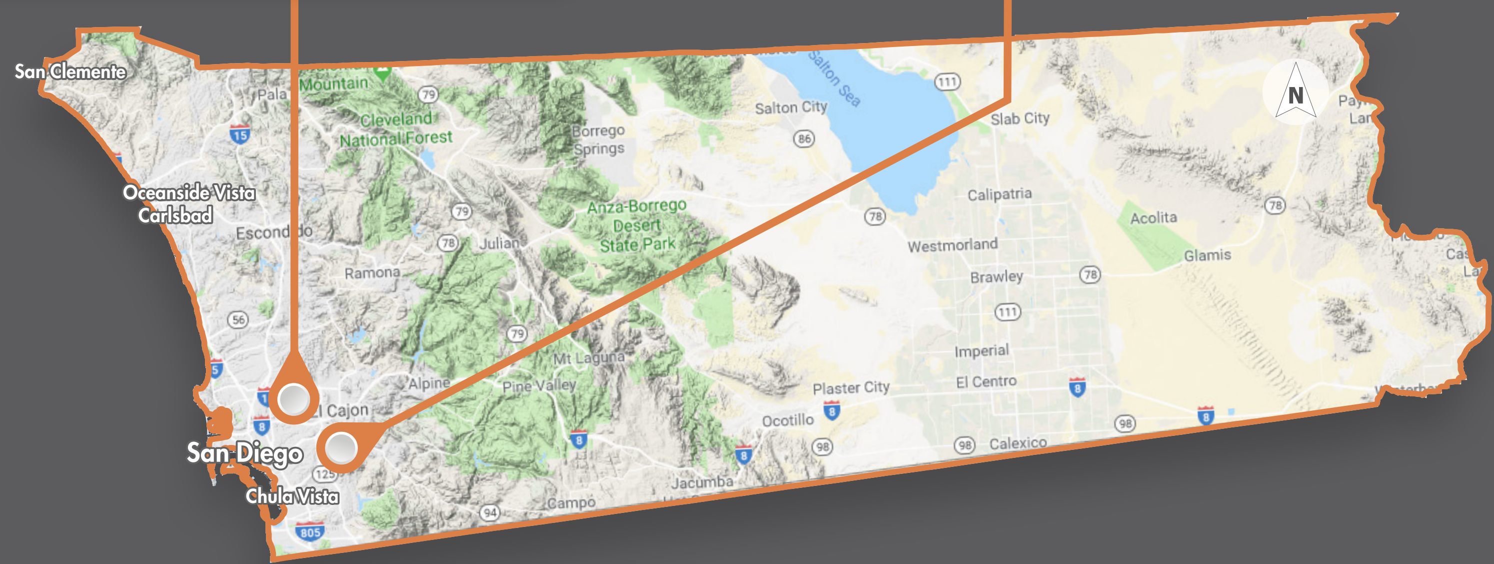


Many communities and county agencies in District 11 have either adopted Climate Action Plans (CAPs) designed to mitigate greenhouse gas emissions and reduce the impacts of climate change in their communities, or have included them in their comprehensive plan. The City and County of San Diego, and the cities of Calexico, Carlsbad, Chula Vista, Del Mar, Encinitas, Escondido, Imperial Beach, Oceanside, and Vista have all adopted CAPs. Both Metropolitan Planning Organizations (MPOs) in District 11—the Southern California Association of Governments (SCAG), representing Imperial County, and the San Diego Association of Governments (SANDAG) - have conducted their own climate change studies as well.



SAN DIEGO REGIONAL CLIMATE COLLABORATIVE

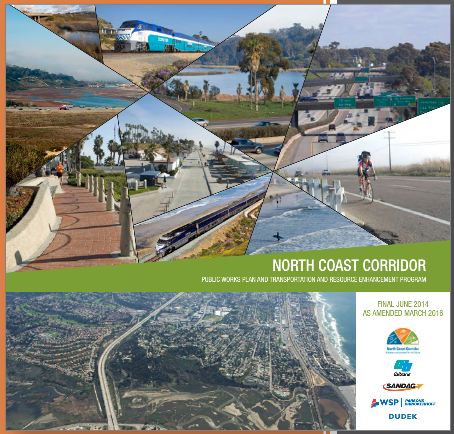
The San Diego Regional Climate Collaborative is a regional collaborative focused on promoting climate adaptation and mitigation strategies across the San Diego region. The collaborative is one of seven across the state that make up the Alliance for Regional Collaboratives for Climate Adaptation (ARCCA). Members include the cities of Chula Vista, Del Mar, Encinitas, National City, Oceanside and San Diego, the county of San Diego, Port of San Diego, San Diego Airport Authority, San Diego Association of Governments, Cleantech San Diego, San Diego Climate Science Alliance, The San Diego Foundation, San Diego Gas & Electric, San Diego State University, UC San Diego, and University of San Diego.



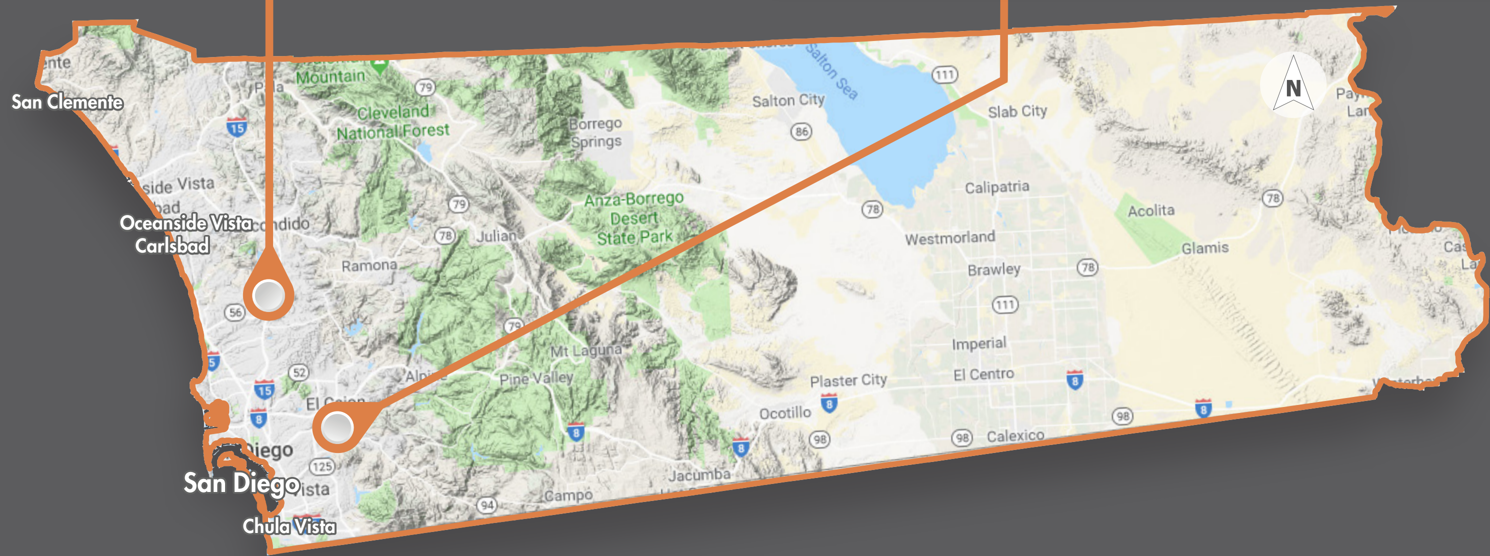
SOUTHERN CALIFORNIA ASSOCIATION OF GOVERNMENTS (SCAG)

The Southern California Association of Governments (SCAG) is a Joint Powers Authority, MPO, Regional Tranpsortation Planning Agency and Council of Governments representing Imperial, Los Angeles, Orange, Riverside, San Bernardio, and Ventura Counties. SCAG has conducted studies of climate change projections and impacts for Southern California and the regions it represents, which are available on their sustainability program portal. One of SCAG's most important reports on the topic is Climate Change and the Future of Southern California,[13] which examines future trends in Southern California and the strategies counties and communities can adopt to mitigate and adapt to changing climatic and extreme weather conditions.

SAN DIEGO ASSOCIATION OF GOVERNMENTS



San Diego Association of Governments (SANDAG) has adopted a Climate Action Strategy that recommends considering climate change factors when designing transportation facilities. A joint SANDAG/ Caltrans study of the North Coast Corridor which incorporated a SANDAG sea level rise analysis into project recommendations is an example of how the plan has been implemented. The corridor planning document used design water level guidance developed by SANDAG that included recommended values and approaches for vertical datums, ocean water level, astronomical tides, storm surge, wave setup, cyclic climatic patterns, tsunamis, local sea level rise, extreme ocean water level, fluvial water level, numerical model selection, downstream boundary conditions, water levels at bridge crossings, combined water levels, and bridge freeboards.[14]



13 – Southern California Association of Governments, "Climate Change and the Future of Southern California," July 2009, http://scag.ca.gov/Documents/ClimateChange_Full_lores.pdf

14 – SANDAG and Caltrans, "North Coast Corridor Public Works Plan/Transportation and Resource Enhancement Program, June 2014, http://www.dot.ca.gov/dist11/Env_docs/I-5PWP/2016/march/nccpwptrepfull.pdf

PHASES FOR ACHIEVING RESILIENCY

California has been a national leader in responding to extreme climatic conditions, particularly in regards 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 this study fits within that framework.

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 affect state highway maintenance and their risk due to wildfires. Understanding these potential impacts provides an impetus to study ways to enhance the resiliency of the State Highway System.

SCOPE OF THIS STUDY

COORDINATE WITH FEDERAL/STATE RESOURCE AGENCIES ON APPLICABLE CLIMATE DATA:

Many state agencies have been actively engaged in projecting specific future climate conditions for purposes such as water supply, energy impacts, and environmental impacts. Federal agencies have also been studying change for other purposes such as anticipating coastal erosion and wildfires.

INITIATE VULNERABILITY ASSESSMENT:

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

IDENTIFY EXPOSURE OF CALTRANS HIGHWAYS TO POSSIBLE CLIMATE CHANGE DISRUPTIONS:

Identifying locations where Caltrans' assets might be exposed to extreme weather-related disruptions provides an important foundation for decisions 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 & 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, the estimated benefits to the State of California related to these steps, a timeline and staff responsibility.

INCORPORATE RESILIENCY PRACTICES THROUGHOUT CALTRANS:

Each Caltrans functional area will be responsible for incorporating those actions that are outlined in their Action Plan, while reporting progress regularly 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 and how the experience can guide project implementation, and actions similar to those in the pilot studies.

PRIORITIZE A SET OF PROJECTS/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 those projects with primary benefits related to system resiliency, or on other projects with benefits that could go beyond resiliency.

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 it 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 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

Temperatures across California have been steadily rising over the last century. On average, present day (1986 to 2016) temperatures in California have warmed above those recorded during 1901 to 1960 by 1 to 2.9 °F, depending upon location.[15] There is very high confidence that this trend of increasing temperature will continue, leading to higher high temperatures, longer heat waves, and potentially more severe drought events.

The figure on the following page shows the change in the average maximum temperature over seven consecutive days (which is an important element in determining the right pavement mix for long-term performance) for three time periods compared to a historical period from 1975 to 2004. In general, other studies in the US have found that increasing temperatures could impact the transportation system by affecting:

DESIGN

- Ground conditions and water saturation levels can affect foundations and retaining walls.
- Materials exposed to high temperatures over long periods of time can crack, heave, or otherwise become deformed (e.g. pavement heave or track buckling). High temperatures are considered in the design of pavements in particular to mitigate future deterioration.

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 transit facilities along roadways.
- Higher temperatures could deteriorate bridge joint seals due to expansion, which could accelerate replacement schedules and even affect bridge superstructure.

TEMPERATURE CHANGE IN DISTRICT 11

Ensuring long-term pavement quality on Caltrans roadways requires consideration of high and low temperatures in the study area. As shown in Figure 1, District 11 temperatures are expected to warm considerably by the year 2085, requiring a review of pavement design parameters. District-wide, maximum seven-day high temperatures are expected to increase by an estimated 0–3.9 degrees by 2025, 2–7.9 degrees by 2055, and 6–11.9 degrees by 2085. Maximum seven-day high temperatures are expected to increase mostly uniformly across the district.

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

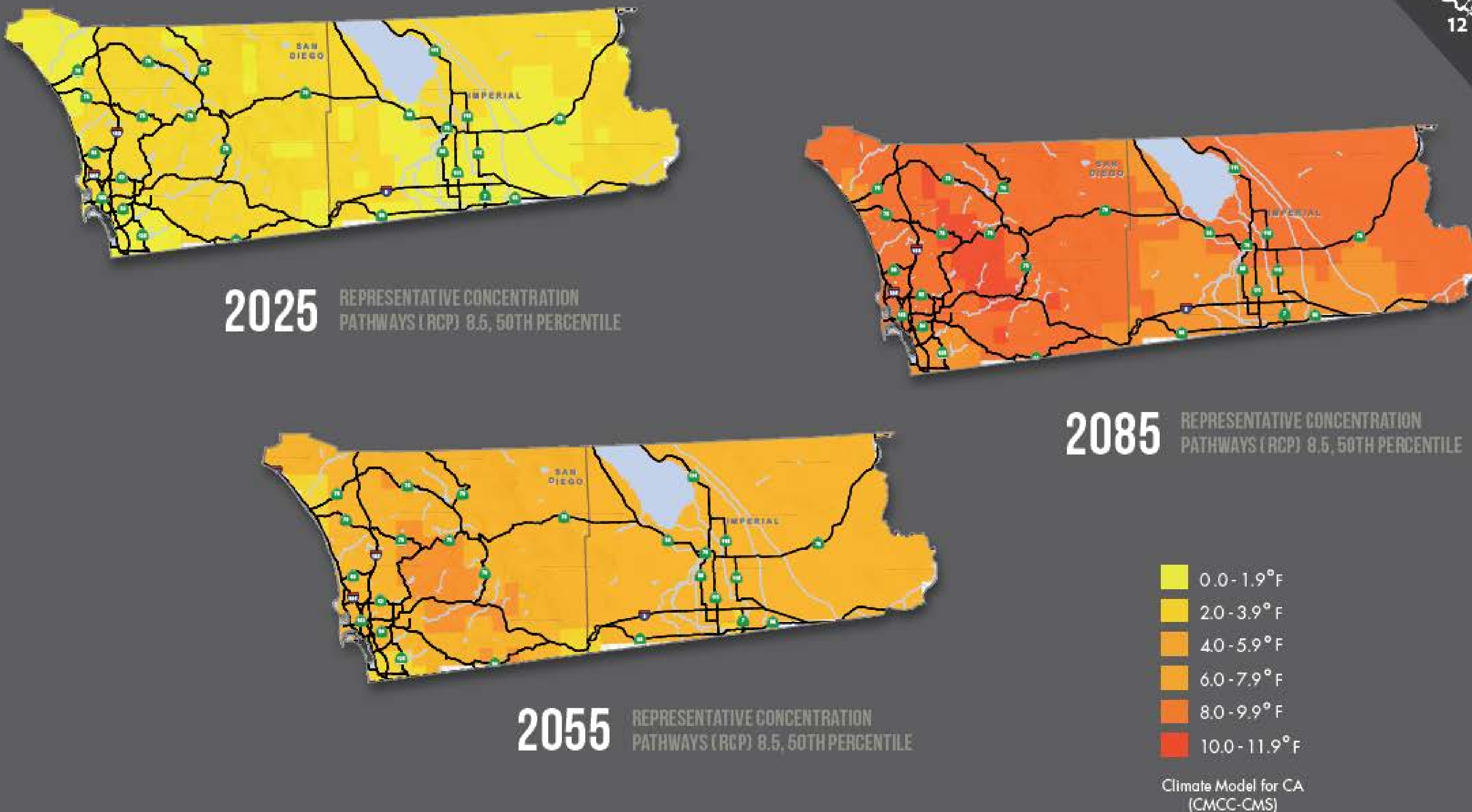
ROADSIDE LANDSCAPING WILL NEED TO SURVIVE LONGER PERIODS OF HIGH TEMPERATURES

LANDSCAPE | I-8 ONRAMP AT TAYLOR STREET

Fig. 1

CHANGE IN THE AVERAGE MAXIMUM TEMPERATURE OVER SEVEN CONSECUTIVE DAYS

A REQUIRED MEASURE FOR PAVEMENT DESIGN



Future change in the Maximum Average Temperature Over Seven Consecutive Days within District 11, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 11. 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

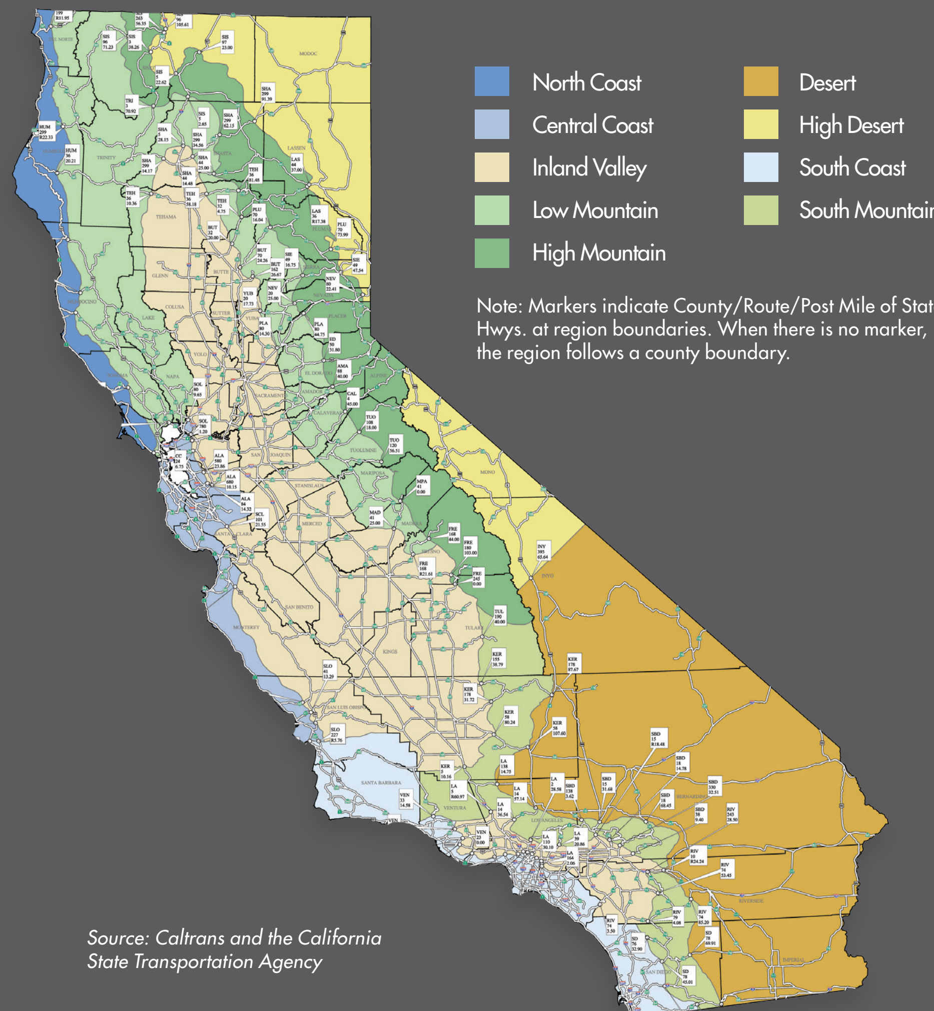
Pavement condition is related to how pavement is designed and is an important component of Caltrans' highway asset management strategy. Ensuring that highway pavements remain durable and maintain good ride quality when exposed to various conditions is an important responsibility of every state transportation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

Many of Caltrans' assets, including roadways, bridges, and culverts, will likely be in place for a long time. Decisions made today for these assets need to incorporate a longer-term view, so the asset is effective through its design life. This is not the case for asphalt pavement, which is replaced approximately every 20-40 years depending on the pavement's purpose. For example, the Caltrans Highway Design Manual notes that pavement design life for new construction and reconstruction shall be no less than 40 hears, but roadside facilities, such as parking lots and rest areas, can be designed for 20-year pavement life Given the relatively short life of pavements, decisions on pavement mix and binder grade may only consider nearer term projections of temperature rise.

Caltrans has divided the state into nine pavement climate regions (as shown in Figure 2) which helps determine the types of pavement mixes recommended 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.

Fig. 2

CALTRANS PAVEMENT REGIONS



Source: Caltrans and the California State Transportation Agency

TIMEFRAMES AND ASSET DECISION-MAKING

Decision-making for transportation assets requires consideration of many factors, including how long an asset will be in place. This is often referred to as the design life, or useful life, of an asset. Some assets managed by Caltrans, like asphalt pavement, are replaced around every 20-40 years while others, like bridges, are built with the expectation of a useful life of 50 years or longer. A road alignment may be in place for a century or longer—a reality highlighted by the fact that alignment of the first national highway (as it was defined then), built to connect settlers to the Ohio Valley and the west, is still in existence today.

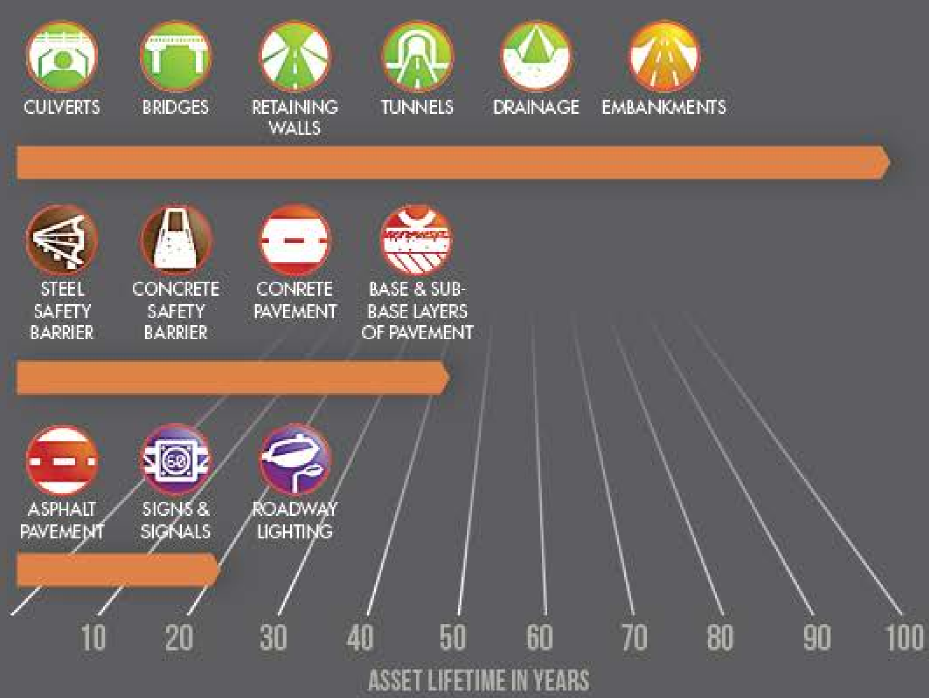
The two graphics included on this page highlight how design life considerations are a critical part of planning for transportation investment. Figure 3 below shows how future temperature scenarios vary widely depending on emission levels and global response. One thing to note is that the conditions are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

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.

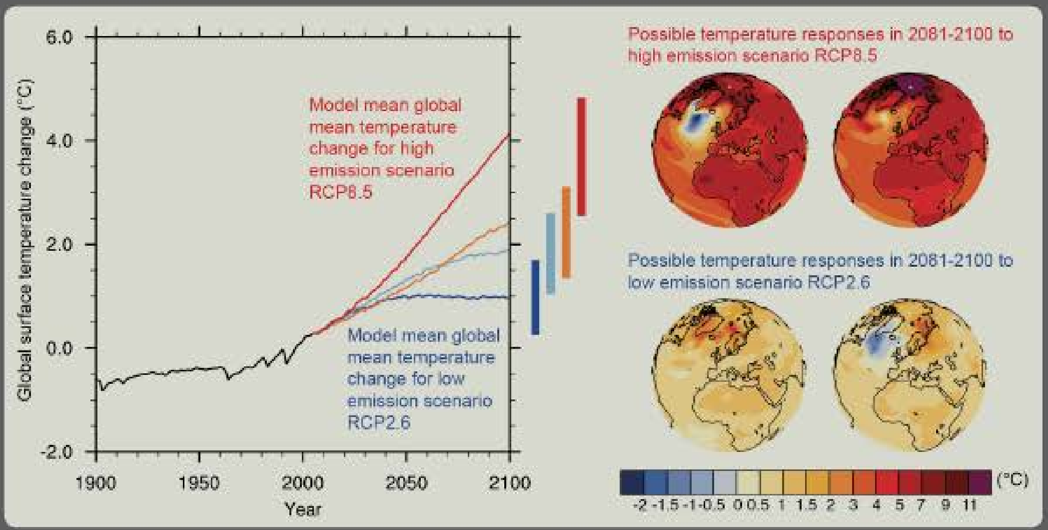
Fig. 4 **TRANSPORTATION INFRASTRUCTURE ASSETS**



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

Increasing temperatures are expected to cause changing precipitation events, due to an increase in energy and moisture in the atmosphere. The Scripps Institution of Oceanography at the University of California, San Diego has generated projected future rainfall data to the year 2100 using two different RCPs and a variety of models. One useful way to examine this data is to assess changes to the 100-year storm event over time. The 100-year storm event has a likelihood of occurring once every 100 years—in other words, it has a 1% chance of happening in any given year. A storm of this magnitude could cause significant damage and is therefore a design standard for infrastructure projects.

More intense storm events of this size, 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, including flooding, landslides, washouts, erosion, and structural damage from heavy rainfall. The primary concern regarding transportation assets is not the overall volume of rainfall over an extended period, but rather more frequent and larger storm events and their potential for damaging the State Highway System.

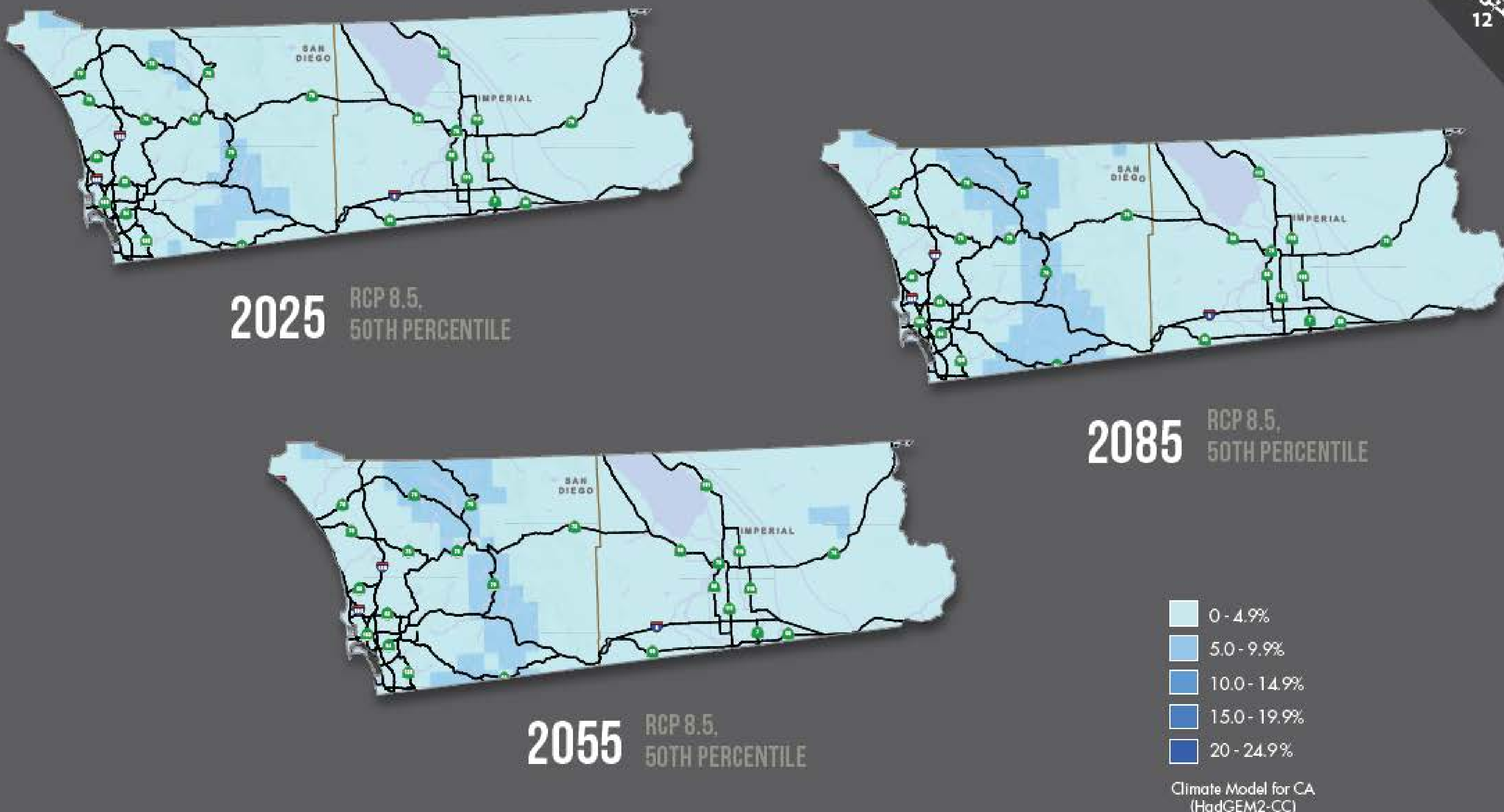
PRECIPITATION CHANGE IN DISTRICT 11

As seen in the Figure 5, District 11 will likely experience anywhere from a 0–24.9% increase in precipitation depth from a 100-year storm, where the greatest potential increase occurs during mid-century. The data also shows that central San Diego County will have the greatest change in 100-year storm precipitation depth. This information is useful for planning-level studies, but the district will still need to conduct hydrologic analyses to finalize design of bridges, culverts, and other assets affected by runoff and river flows. These analyses should consider future precipitation projections to ensure that assets are designed correctly for future conditions.

FLOODING IS EXPECTED TO INCREASE IN LOW-LYING AREAS

Fig. 5

PERCENT CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH



Future Percent Change in 100-year Storm Precipitation Depth within District 11, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 11. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown were generated by downscaling global climate outputs using the LOCA technique.

WILDFIRE

Higher temperatures decrease the moisture in soils and vegetation, leading to increased wildfire risk. Wildfires can contribute to landslide and flooding exposure by burning off protective land cover and reducing the capacity of the soils to absorb rainfall. California is already prone to serious wildfires, and the results of future climate forecasts suggests that the vulnerability will only get worse. The need to address these concerns led Governor Jerry Brown to announce (May 2018) a new fund to help forest management and reduce wildfire risk.

The areas shaded in red in Figure 6 indicate increased likelihood of wildfires based upon 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 for RCP 4.5 and 8.5 (Figure 6 shows these projections for RCP 8.5). 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 11

Wildfires are an important concern in District 11, and this is particularly true for the portion of state highways in San Diego County. This risk extends primarily over the forested areas of San Diego County ranging from Cleveland National Forest in the north to Cuyamaca Rancho State Park and Otay County Open Space Preserve in the south. In Imperial County, the main risk is south of the Salton Sea and along the Arizona border where the Colorado River runs south to Mexico. The models used show low wildfire risk in most of Imperial County due to its desert environment.

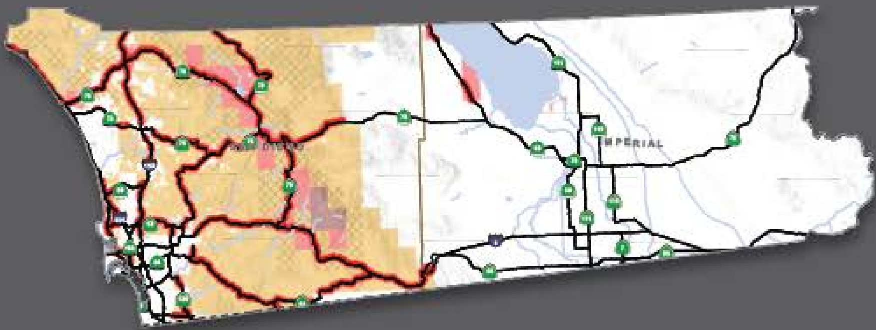
Table 1: Miles of Roadways in Moderate to Very High Wildfire Exposure Areas for the RCP 8.5 Scenario

County	Miles		
	2025	2055	2085
Imperial	16.3	21.3	44.9
San Diego	374.1	375.9	398.5

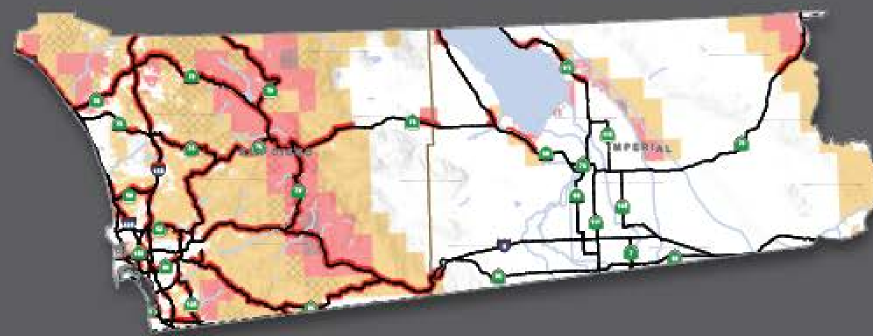
CARLSBAD FIRE

Fig. 6

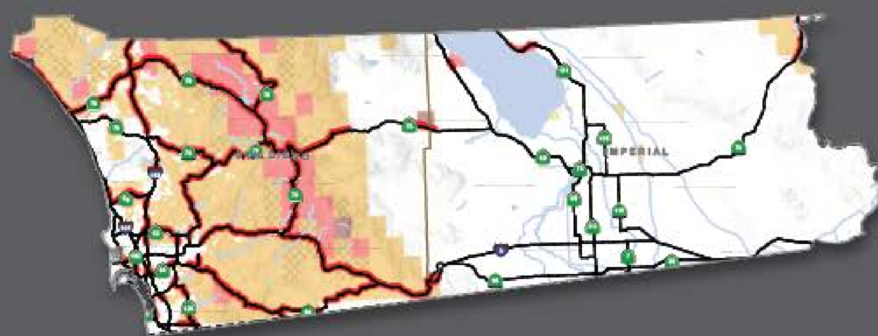
LEVEL OF WILDFIRE CONCERN



2025 RCP 8.5, MULTI-MODEL MAXIMUM



2085 RCP 8.5, MULTI-MODEL MAXIMUM



2055 RCP 8.5, MULTI-MODEL MAXIMUM

Levels of Concern

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

Future Level of Wildfire Concern for the Caltrans State Highway System within District 11, Based on the RCP 8.5 Emissions Scenario.

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

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

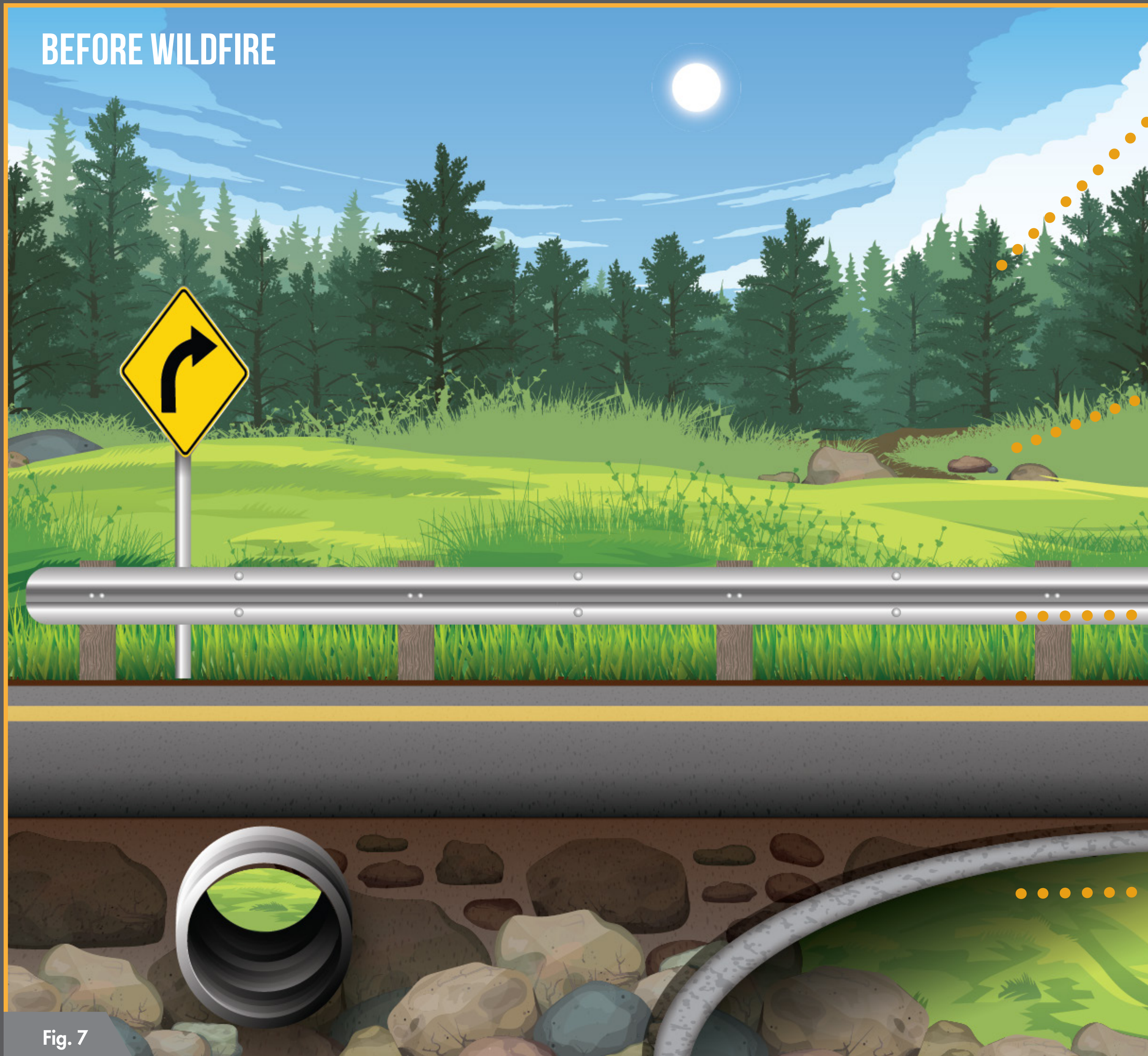


Fig. 7

FOREST/TREE COVER MODERATES RAINFALL EFFECTS ON THE GROUND, LIMITING EROSION OF THE SOILS

GROUNDCOVER OF TREES, SHRUBS AND GRASSES STABILIZE AND SLOW SURFACE FLOWS AND FACILITATE RAINFALL INFILTRATION INTO THE SOIL

INSTALLED SIGNS AND GUARDRAILS IMPROVE SAFETY FOR ROADWAY USERS

CLEAR CULVERTS ALLOW WATER TO PASS UNDER THE ROADWAY AND PROVIDE WILDLIFE CROSSINGS

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

LOSS OF FOREST COVER RESULTS IN MORE EROSION OF SOILS

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

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

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

DESTROYED SIGNS AND GUARDRAILS REDUCE DRIVER SAFETY

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

Fig. 8

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

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 11 includes an extensive coastline and Caltrans facilities provide access to bayshore and coastal areas. Sea level rise will exacerbate the flooding and inundation that could occur in these areas during regular tidal or storm events. For Caltrans, this means that many of its coastal roads, bridges, and supporting facilities face risk of inundation or damage in the future.

Like other forecasted changes in climate, future projections of sea level rise vary, depending in part on the assumptions made regarding future concentrations of GHGs and how the Earth's systems will respond. The State of California Sea Level Rise Guidance: 2018 Update provides the most recently developed sea level rise scenarios for locations across the California coastline.[16] This guidance document also provides direction on how to use these new projections in project planning and decision-making. A selection of these scenarios and how to use them is shown and explained further in Figure 10.

These projections were used and paired with sea level rise heights modeled by the Coastal Storm Modeling System (CoSMoS). 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 (5.00 meters). These data were developed to model sea level rise and storm surge above the average daily high tide for most of the California coast and within San Francisco Bay. The District 11 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 flagging bridges where sea level is rising, even though they may not be overtopped. This is because bridges don't necessarily need to be flooded to be affected by sea level rise. Figure 11 is provided to illustrate some of the risks posed to bridges due to sea level rise.

SEA LEVEL RISE EFFECTS IN DISTRICT 11

Increasing sea level rise will exacerbate tidal flooding 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 Pacific shoreline. Table 2 shows the center line miles of District 11 State Highway exposed to sea level rise for three modeled CoSMoS increments: 1.64, 3.28, and 5.74 feet. Compared to other coastal districts, District 11 does not have as many road segments exposed to potential sea level rise. The main area of concern in District 11 is State Route 75 along Coronado, where the highway dips back down after crossing the Coronado Bridge. Flooding of coastal highways will become more commonplace as sea levels rise. Caltrans can develop a number of strategies to address long-term inundation, such as the use of natural buffers, pumping water out of inundated areas, elevating roadways, and retreat.

16 - 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

Table 2: Miles of District 11 State Highway System Exposed to Sea Level Rise Inundation

County	Miles		
	1.64 ft (.5 m)	3.28 ft (1m)	5.74 ft (1.75 m)
Imperial	0	0	0
San Diego	1.98	3.60	6.21

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)

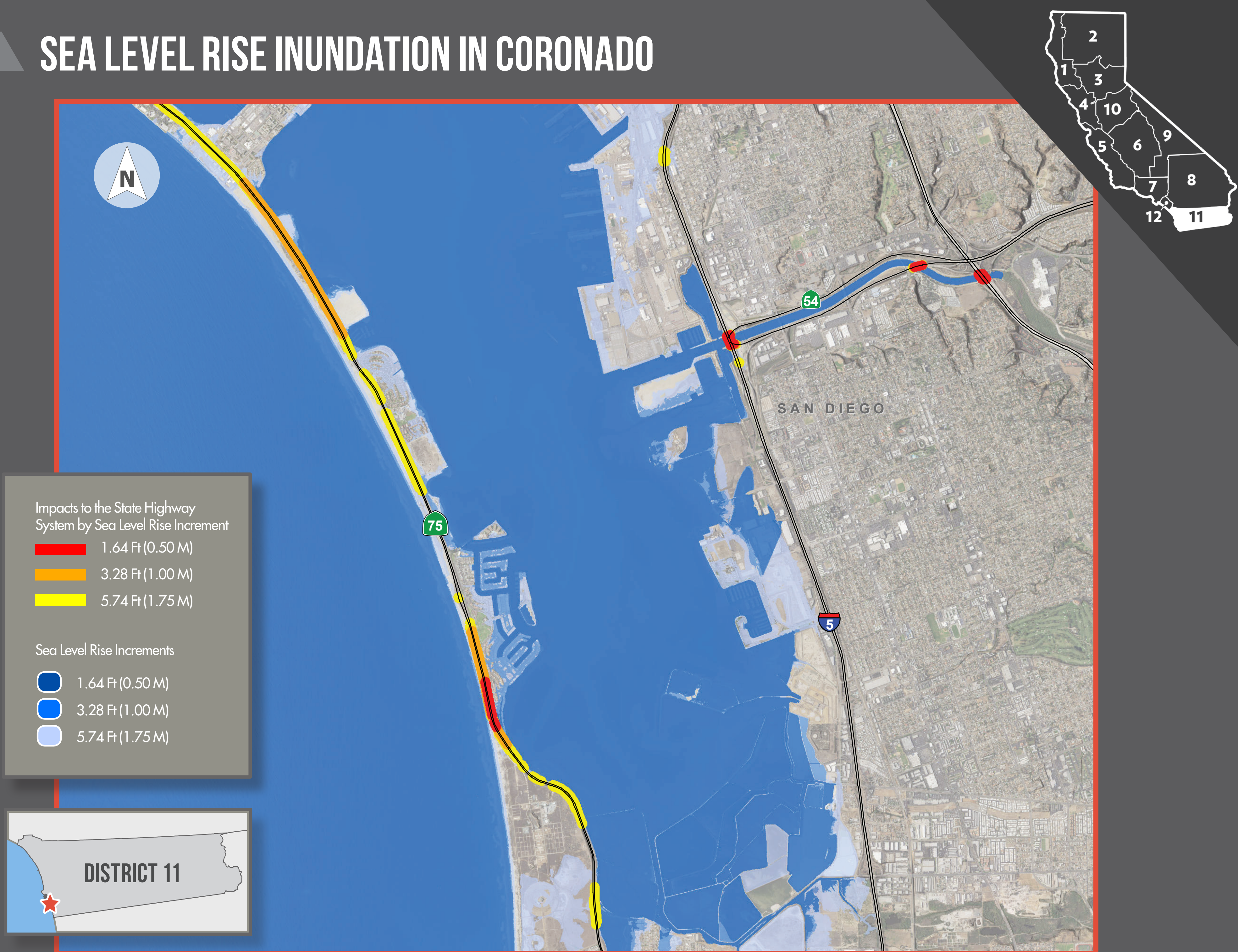
APPROXIMATELY SIX MILES OF DISTRICT 11 ROADS AND BRIDGES MAY BE INUNDATED UNDER 5.74 FT (1.75 M) OF SEA LEVEL RISE

BEACH EROSION ALONG THE PASEO DEL MAR, AT THE CORONADO SHORES CONDOMINIUMS

source: Trisha Trowbridge

Fig. 9

SEA LEVEL RISE INUNDATION IN CORONADO



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.

Fig. 10

SEA LEVEL RISE ESTIMATED FOR DISTRICT 11

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 San Diego 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).[17] 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.

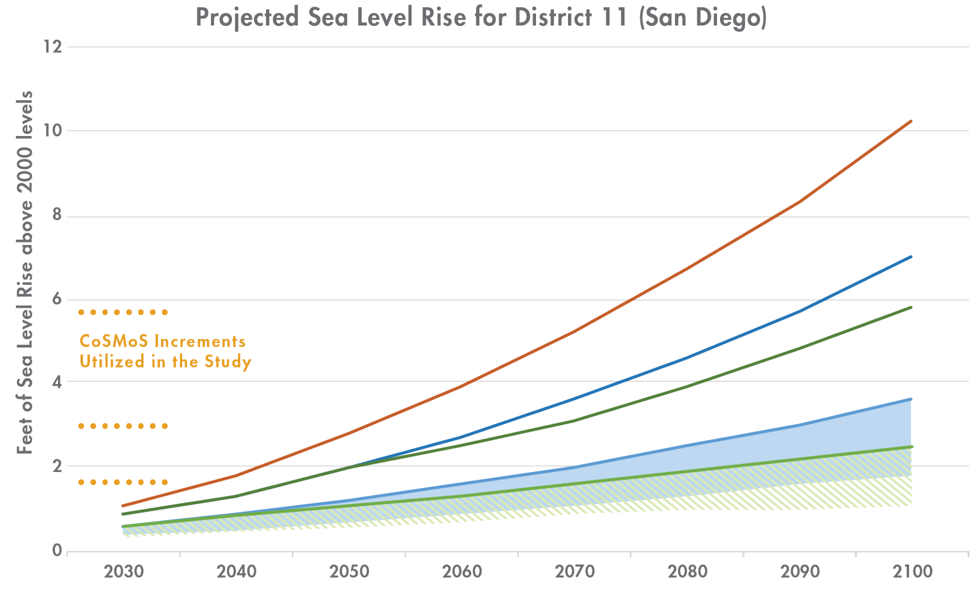
Sea level rise scenarios presented in the OPC guidance identify several values or ranges, including:

- 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.



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.

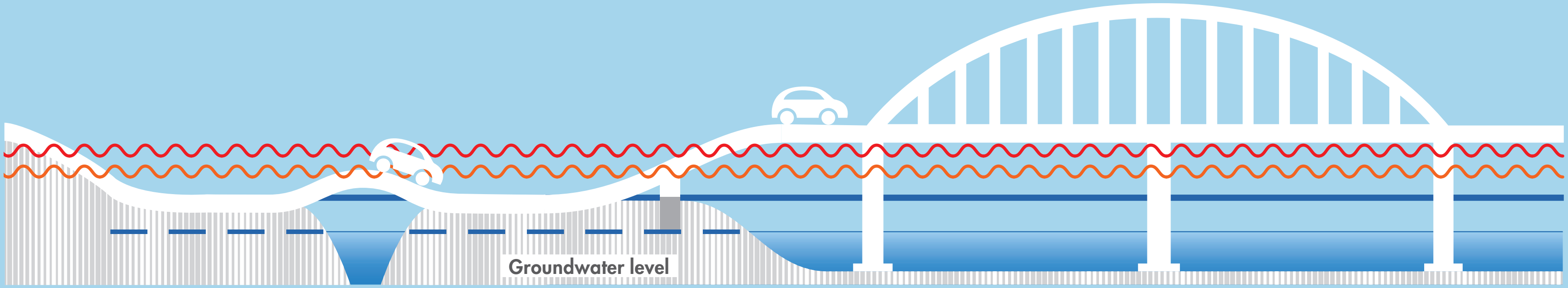
OPC Estimates for Sea Level Rise

- 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

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

Fig. 11

BRIDGES IN COASTAL AREAS AND CLIMATE CHANGE



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.

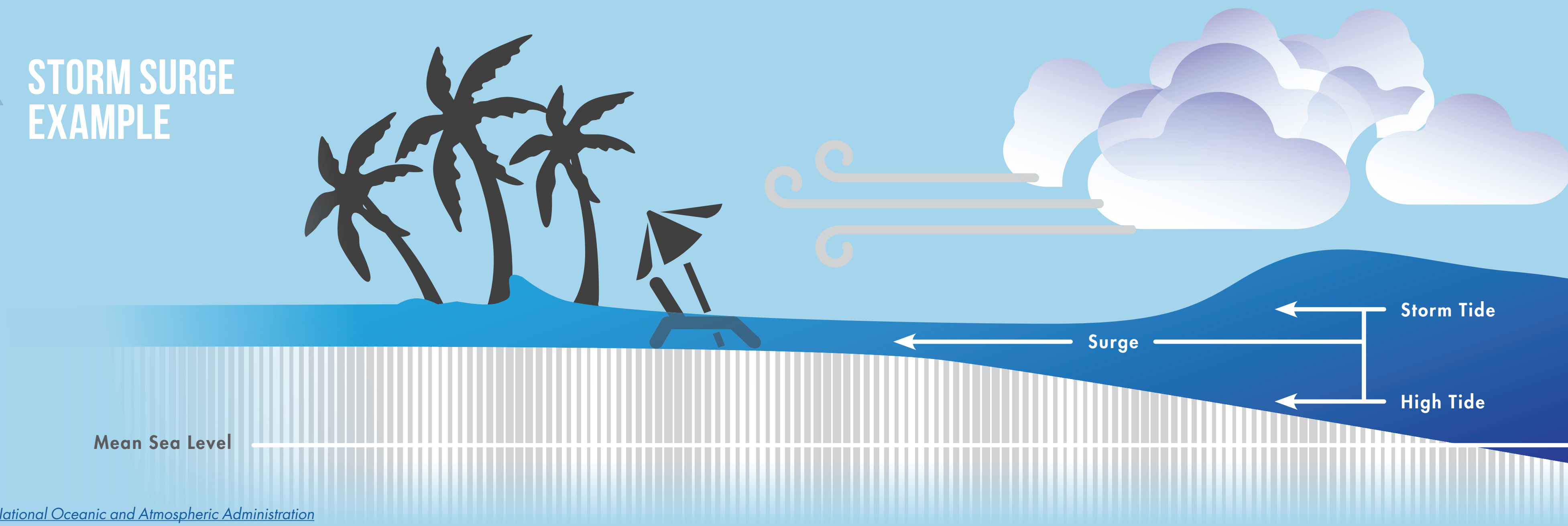
Some bridge vulnerabilities include:

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. 12

STORM SURGE EXAMPLE



Source: National Oceanic and Atmospheric Administration

STORM SURGE

The inundation of coastal areas becomes even worse when combined with storm surge, and it is expected that the frequency and intensity of storm events will increase over time. 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 that can increase damage and reduce useful life. Storm surge is expected to increase coastal erosion and landslides, causing shoreline retreat and exposing roadways to increased flooding (see Figure 13 on following page).

The CoSMoS data was used to assess sea level rise and storm surge impacts to the State Highway System in District 11. The model provides outputs for a variety of storm events, including an annual storm, 20-year storm, 100-year storm, and a King Tide. The results from the 100-year storm analysis and three sea level rise heights are reported here.

Figure 13 shows the sections of the State Highway System in Coronado that are at high risk of future inundation due to sea level rise and storm surge from a 100-year storm. These state highways are critically important for the local communities and for intrastate travel and commerce.

As seas rise, more water is in motion during storm events. These higher water levels can cause increased inundation and more forceful storm surge conditions, which will increase long-term risks to infrastructure. Figure 12 identifies the basic elements of storm surge and how it is different from normal tidal conditions. The graphic, supplied by the National Oceanic and Atmospheric Administration (NOAA) and edited for this study, shows how water levels increase and reach farther inland during storm events and how that compares to a regular high tide.

STORM SURGE EFFECTS IN DISTRICT 11

Similar to the effects of sea level rise, State Route 75 is the most vulnerable portion of the State Highway System in District 11. SR 75 crosses the Coronado Bridge to the north, which is built tall enough to accommodate aircraft carriers going to the Naval Base. Inundation is not a concern for this portion of SR 75, but the low-lying portion that crosses Silver Strand State Beach could be exposed to future flooding from sea level rise and storm surge. See Table 3 for the total center line miles of District 11 State Highway System flooded under each sea level rise height and a 100-year storm.

Table 3: Miles of District 11 State Highway System Exposed to Surge During a 100-Year Storm

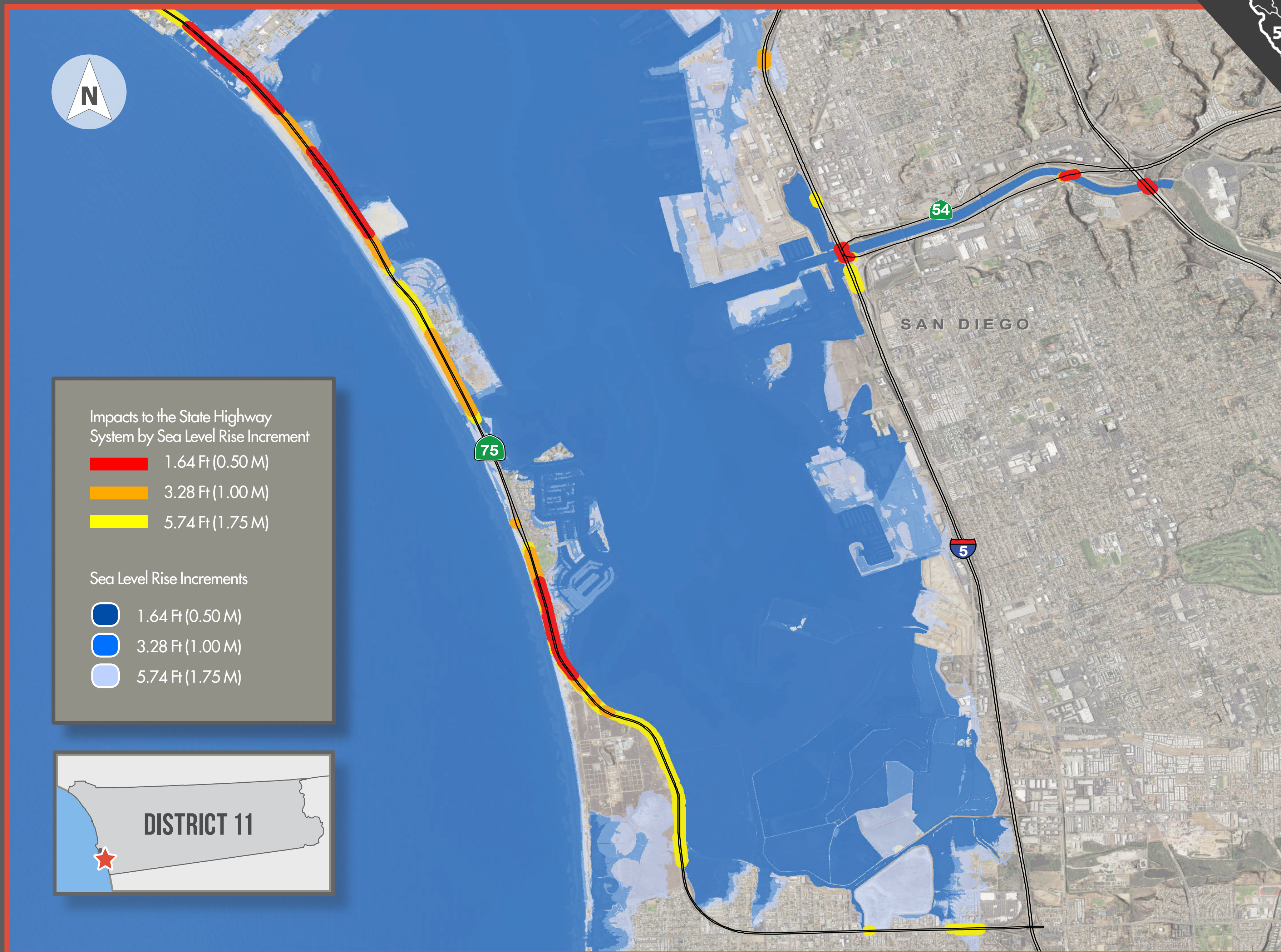
County	Miles		
	1.64 ft (.5 m)	3.28 ft (1m)	5.74 ft (1.75 m)
Imperial	0	0	0
San Diego	2.66	4.94	7.72

AROUND 8 MILES OF ROADWAYS AND BRIDGES IN DISTRICT 11 MAY BE FLOODED UNDER 5.74 FT (1.75 M) OF SEA LEVEL RISE AND A 100-YEAR STORM

STORM SURGE FLOODS | DISTRICT 11 OFFICE FALL 2017

Fig. 13

STORM SURGE FLOODING IN CORONADO



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.

CLIFF RETREAT

The sea level rise and storm surge concerns noted in this report outline how higher water levels will directly impact transportation infrastructure. Changing water levels in the oceans will also create different forces at the shoreline, eroding beaches and causing cliff retreat along the 1,100-mile California coastline. Cliff retreat occurs when waves impact the base of a cliff and hydraulic action carves out a portion of the cliff face. This loss of rock and soil increases over time and undermines support for the cliff itself, eventually resulting in the collapse of the cliff face. Over time the cliff recedes, or "retreats", from its original position. Examples this effect are seen throughout California, most notably (as described in a recent study of historic cliff retreat rates) in San Onofre, Portuguese Bend, Palos Verdes, Big Sur, Martins Beach, Daly City, Double Point, and Point Reyes.[18]

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

This conversation will benefit from work currently underway by the US Geological Survey and other researchers who are trying to better understand the potential for long-term coastal changes in California resulting from sea level rise and other climate change effects. This work includes:

- Conducting a detailed topographic survey of the shoreline
- Developing a coastal model that estimates inundation from future sea level rise and surge levels
- Applying research and erosion/retreat models of the shoreline to develop an estimate of changes to existing conditions — both with and without coastal protection strategies

County	Miles		
	1.64 ft (.5 m)	3.28 ft (1 m)	5.74 ft (1.75 m)
Imperial	0	0	0
San Diego	0.00	0.00	0.09

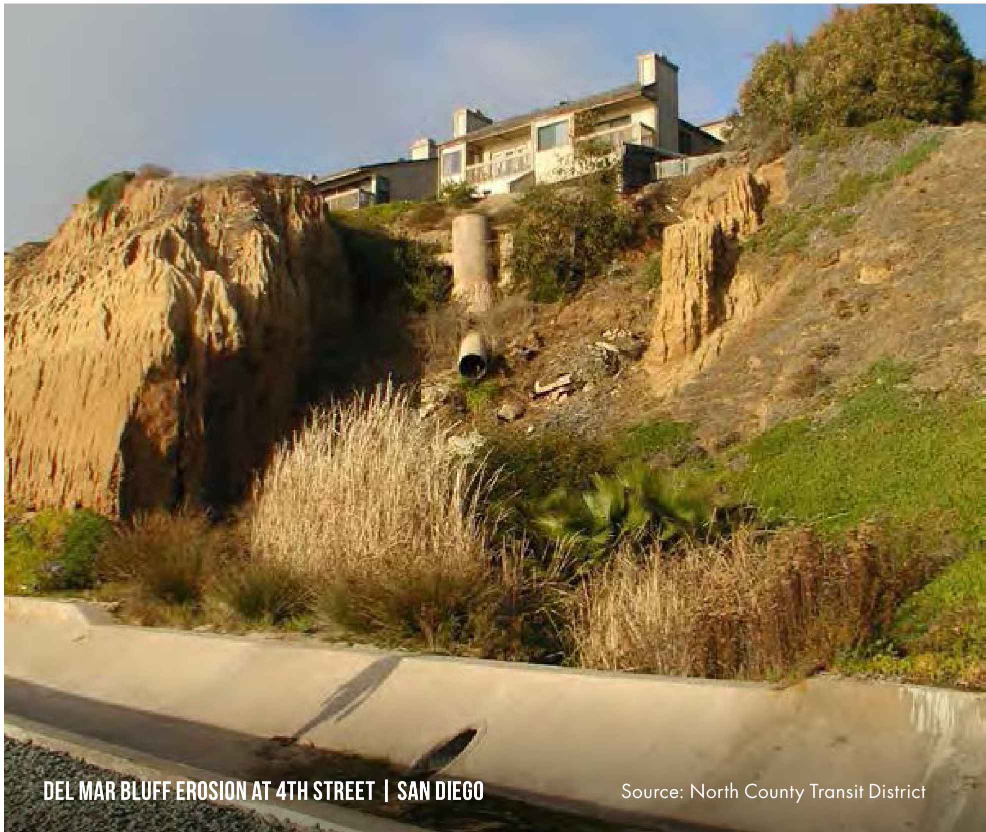
Table 4:
Miles of District 11 State Highway System Exposed to Cliff Retreat

The map to the right shows a detailed example of PCH cliff retreat impacts as the sea level rises. Note that this data estimates sea level rise 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 and erosion in decision-making for coastal infrastructure.

CLIFF RETREAT EFFECTS IN DISTRICT 11

Values used to determine the potential long-term effects of cliff retreat are the same increments of 1.64, 3.28, and 5.74 feet (0.5, 1, and 1.75 meters) of sea level rise. The figure on the following page indicates that cliff retreat is only projected to present an issue in one isolated location under these levels of sea level rise. The main area of concern from cliff retreat is on I-5 in northern San Diego County near the border with Orange County. The exposed area is minor compared to risk in other districts. Only 0.09 center line miles (or 475 feet) of I-5 is expected to be affected by cliff retreat under scenarios analyzed in this report. Higher sea level rise projections (greater than 5.74 feet) may present additional affected areas for the State Highway System in District 11.

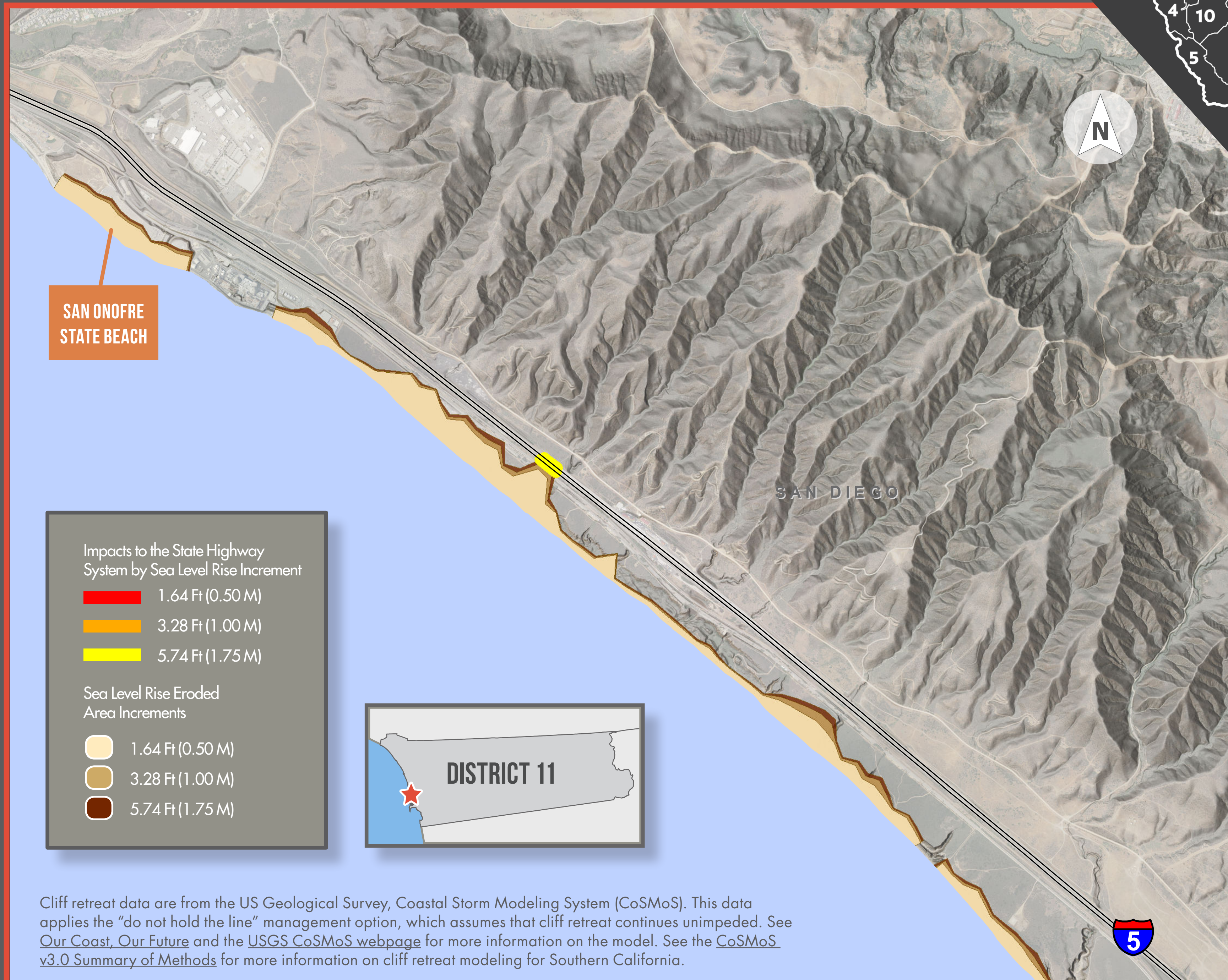
18 - UC San Diego, "Study Identifies California Cliffs at Risk of Collapse," 2017, https://phys.org/news/2017-12-california-cliffs-collapse.html



DEL MAR BLUFF EROSION AT 4TH STREET | SAN DIEGO
Source: North County Transit District

Fig. 14

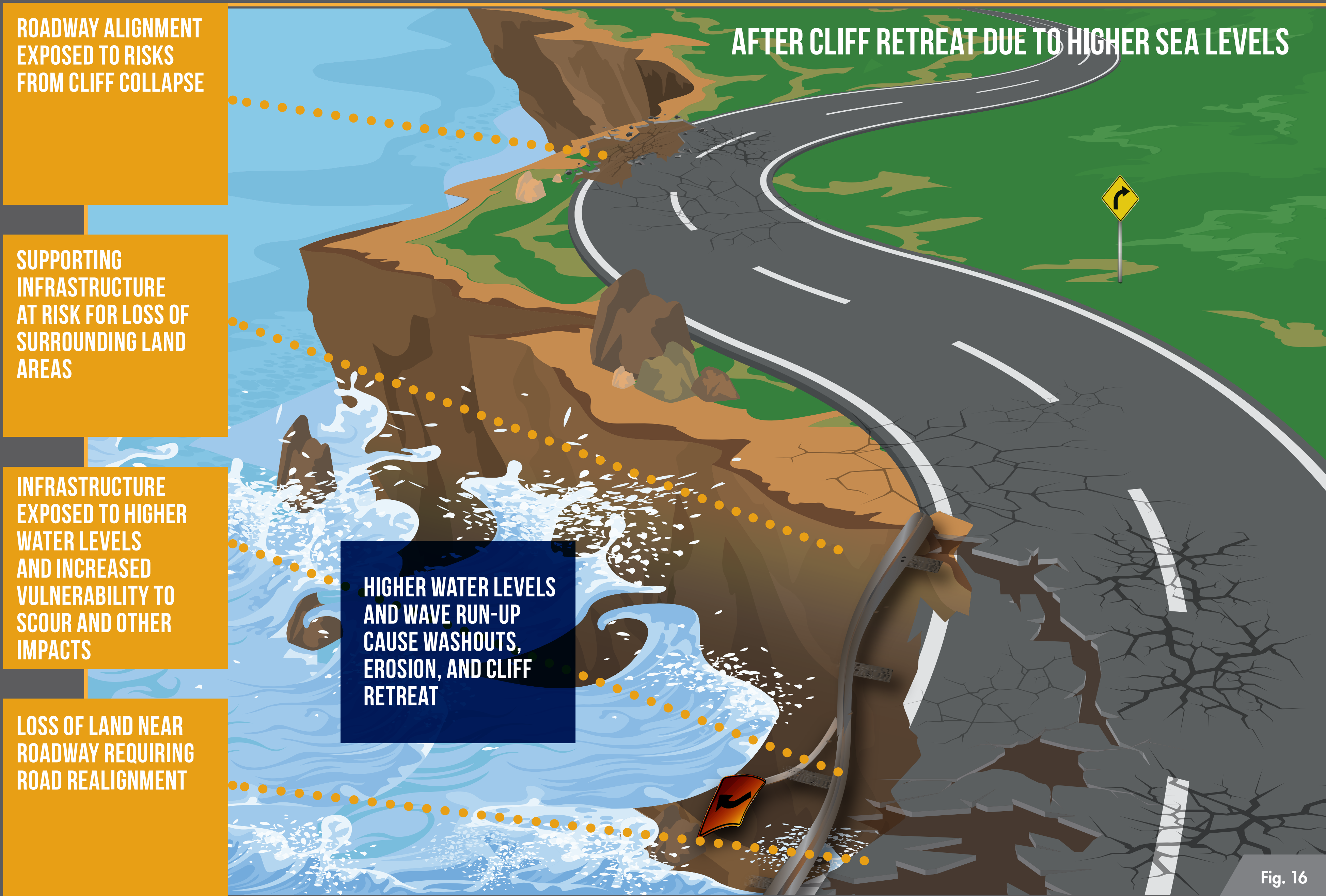
CLIFF RETREAT ON I-5



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. 15

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

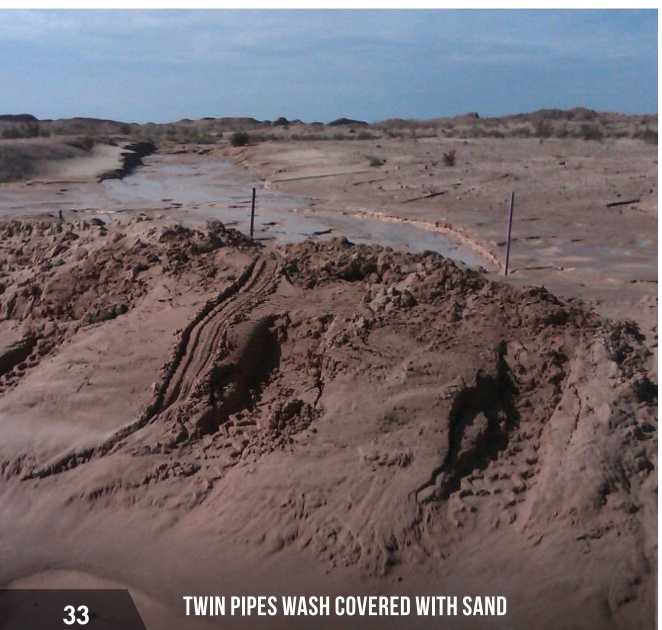
To highlight how climate change may affect facilities in District 11, examples from recent events on the district road network are highlighted below. These types of impacts will likely be more commonplace in the future as sea levels rise and weather becomes more volatile.

The I-5 corridor in District 11 is located mainly in the coastal zone and crosses several lagoons, rivers, creeks, and the 100-year floodplain. I-5 has already experienced storm surge erosion where it crosses coastal lagoons, which may worsen as sea levels rise. See Figure 17 for a map of Buena Vista Lagoon, one of the large coastal lagoons that I-5 crosses. Projections of future sea level rise combined with storm surge do not overtop or flood I-5 at this crossing, but storm events could cause increased erosion around the roadway.

Like the impacts on I-5, erosion from storm surge caused major water main breaks in the fall of 2017 in Mission Valley on I-8, the major east/west highway from the Pacific Coast to Arizona. In Imperial County, sections of I-8 are periodically inundated during heavy flooding events. While Imperial County is considered a desert region, it is subject to heavy rains that can cause both flash and normal flooding in many canals, washes, and drainage ditches. In San Diego County, I-8 is located within the floodplain (including 500-year flood zones) of the San Diego River from its westward start to just past I-15. Forester Creek borders a portion of the interstate in the City of El Cajon and is also within a 500-year flood zone.

Caltrans is implementing adaptive strategies for dealing with these concerns. For example, on I-8 in Imperial County, Caltrans will place continuously reinforced concrete pavement (CRCP) to provide a "long-life, superior roadway while at the same time reducing cost and improving safety for highway workers exposed to traffic by reducing maintenance time. The asphalt shoulders will also be replaced with CRCP reducing environmental impacts and increasing durability due to heavy truck traffic and excessive heat."[19]

19 - Caltrans, District 11, "Transportation Concept Report: Interstate 8," February 2016, http://www.dot.ca.gov/dist11/departments/planning/pdfs/tcr/2016-02-09-TCR-I-8.pdf.



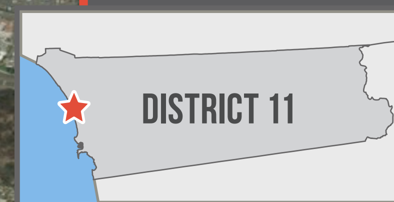
TWIN PIPES WASH COVERED WITH SAND

SR 78 | STORM DAMAGE

SR 78 | STORM DAMAGE

Fig. 17

I-5 HAS ALREADY EXPERIENCED STORM SURGE AND EROSION WHERE IT CROSSES COASTAL LAGOONS, WHICH MAY WORSEN AS SEA LEVELS RISE.



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 incorporate climate change: the Adaptation Decision-Making Assessment Process (ADAP).[20]

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 11 for existing and future roadways. The following section highlights a district effort that demonstrates a proactive response to mitigate flood risk. These efforts are examples of how Caltrans districts can prepare for, and respond to, future climate change and extreme weather events.

CULVERT INSPECTION PROGRAM

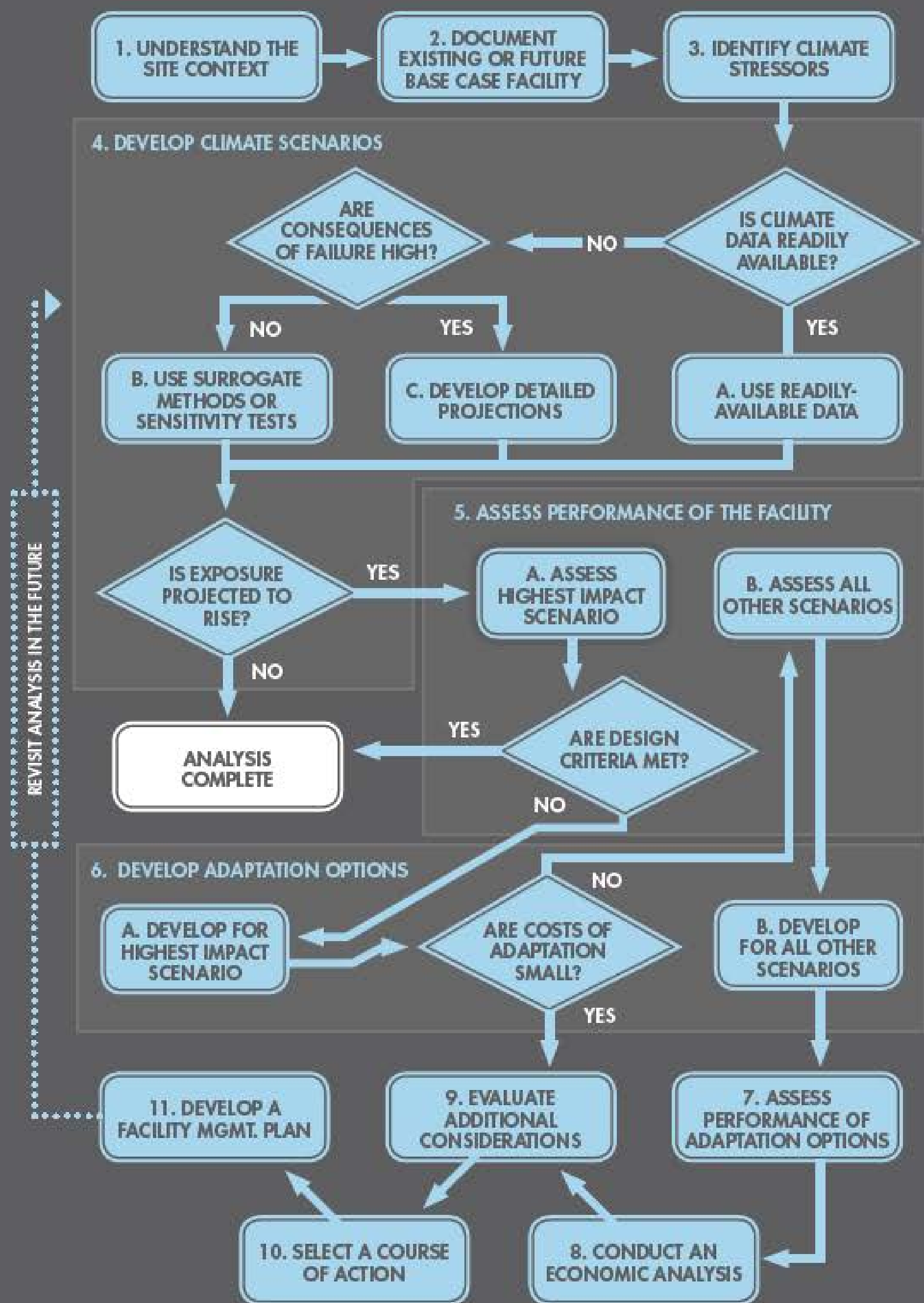
Examples from around the country show that culverts are one of the most important, but vulnerable, assets when dealing with heavy precipitation and flooding. A culvert collapse on I-8 shut down two eastbound travel lanes which were placed over 30 years ago (there are approximately 20,000 culverts in District 11). Forensic investigation showed that water infiltration and sedimentation caused the fill surrounding the culvert to fail, thus creating a sinkhole and collapsing the freeway shoulders. The reconstruction of this freeway segment took approximately nine months and cost $6 million. Tavern Road on I-8 had joints fail because of sedimentation, leading to a $7.5 million project to place another culvert.

Due to increased concern with culvert failure, District 11 began an inspection program for all State Highway System culverts, many of which were placed over 30 years ago. Much has changed since then, especially development expansion in urban areas which results in large amounts of impervious surfaces. Over a 15-year period, no internal inspection of culverts had been undertaken. Funds from Senate Bill No. 1 (SB-1) were used to triple the staff size to conduct these inspections, which rated each culvert as good, fair, or poor. Another change to existing Caltrans practice was to replace plastic pipes damaged by wildfires with more fire-resistant pipe materials.

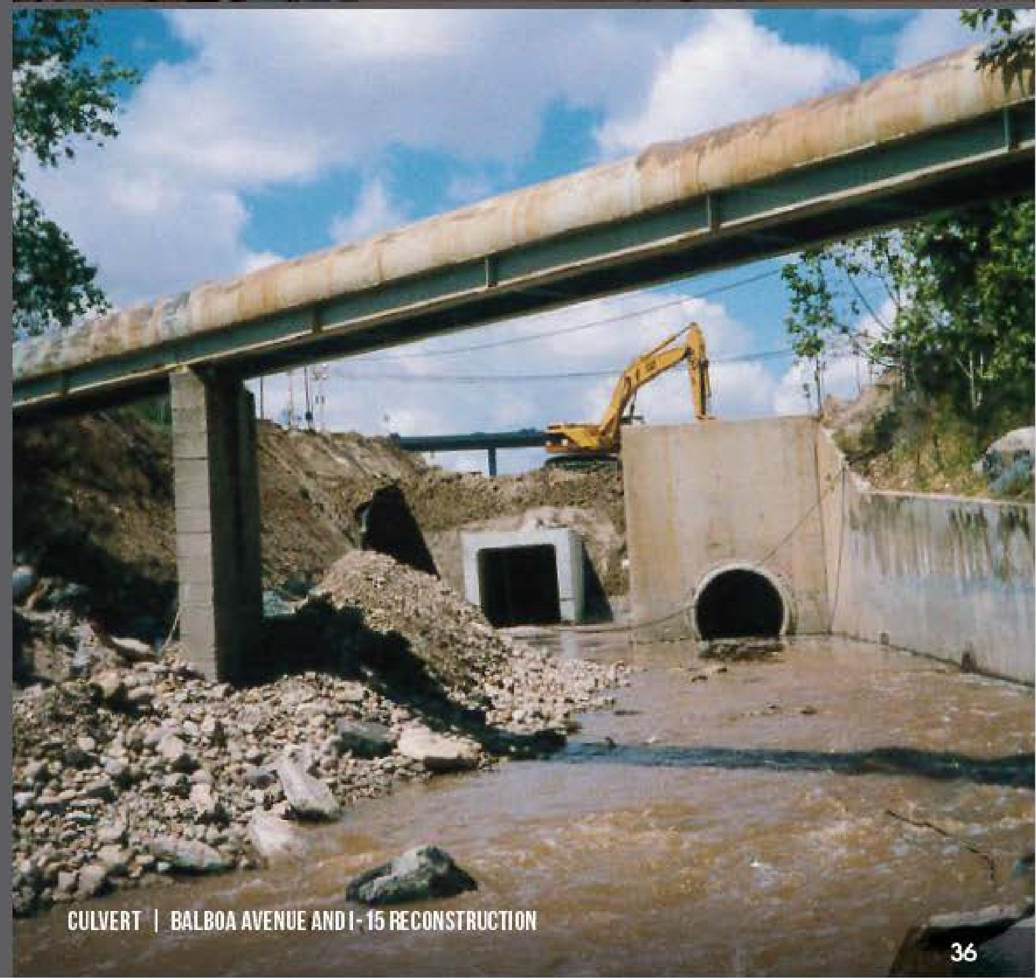
20 - "Adaptation Decision-Making Assessment Process," FHWA, last modified January 12, 2018, https://www.fhwa.dot.gov/environment/ sustainability/resilience/ongoing_and_current_research/teacr/adap/index.cfm

CALTRANS DISTRICT 11 – I-15 MANAGED LANE PROJECT AT SABRE SPRINGS

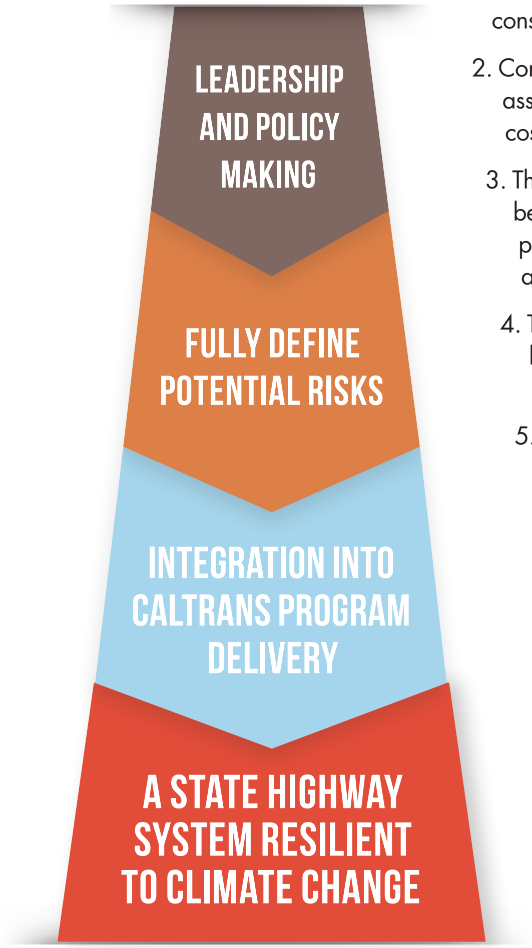
Fig. 18 FHWA'S ADAP DESIGN PROCESS




CONVEYOR


CULVERT | BALBOA AVENUE AND I-15 RECONSTRUCTION

WHAT DOES THIS MEAN TO CALTRANS?



GENERAL CONCLUSIONS

Recent extreme weather events in District 11 provide an opportunity to address future climate change conditions explained throughout this report. Caltrans has identified some key takeaways from this report, which are:

1. The repair of District 11 facilities should include the consideration of climate change (page 4 – state policies)
2. Consequence costs should be a determinant in redesign– assessing broader economic measures than facility damage costs (page 8 – vulnerability approach)
3. The development of updated design approaches using best available data from the State of California should be a part of the response to these events (page 11– phases for achieving resiliency)
4. The assessment of precipitation effects should include higher estimated rainfall totals derived from the climate data (page 17 – Precipitation section)
5. FHWA's ADAP process should be applied in any planning or design of a facility to incorporate uncertainties in climate data and utilize a benefit-cost assessment methodology that considers long-term costs to guide decisions (page 37 – Adaptive Design, Response, and Risk Management)

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 sustained effort on the part of Caltrans officials, because the methods for doing so are very different from those typically used by state Departments of Transportation (DOTs). Most importantly, these methods focus on examining the potential of future risks, rather than depending on historical data, to define the future.

Taking steps to address these climate concerns will require:

FULLY DEFINING 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. To fully assess and address risks, assets outside of normal DOT control, but which could affect state highway operation if they failed (e.g., dams and levees), should be evaluated.

LEADERSHIP

Leadership will be required at both the state government and transportation agency 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.

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.

COMMUNICATION AND COLLABORATION

Adapting to the challenges posed by climate change will require a proactive and collaborative approach. Caltrans recognizes that stakeholder input and coordination will be necessary to develop analyses and adaptation strategies that build upon and support the body of work underway by the state. Working with other state agencies and local communities on adaptation strategies can also lead to better decisions and a collective response, and prevents the possibility of working in silos.

This vulnerability assessment is the first step in assessing climate change in a systematic and comprehensive way. By following the steps noted above and continuing to assess risks to the State Highway System, Caltrans plans to prioritize its assets that are most at risk and in need of adaptive responses, to create a resilient State Highway System for California.

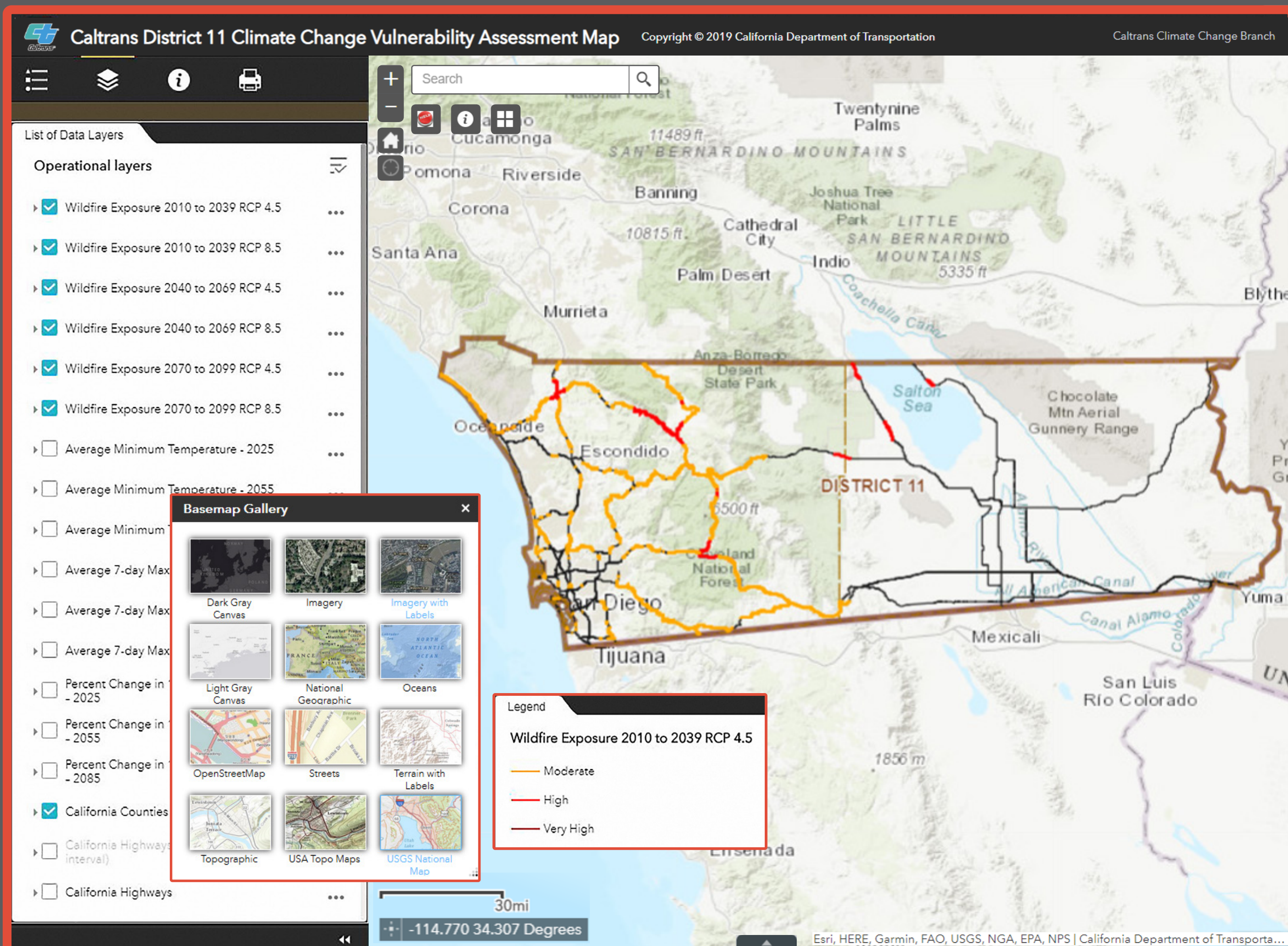
ON-LINE MAPPING TOOL FOR DECISION-MAKING

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.[21]

The tool enables Caltrans staff, along with California policy-makers and residents, to view climate projections used in this assessment and identify areas along the State Highway System that may be vulnerable.

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.

21 - 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.


Bridgepoint
Downtown
NEXT 2 EXITS
San Diego
Convention C
NEXT EXIT
1
2
3
4
5
6
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8
9
10
11
12