CALTRANS CLIMATE CHANGE

VULNERABILITY ASSESSMENT SUMMARY REPORT

DISTRICT 1

2019

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

This Summary Report and its associated Technical Report describe climate change effects in District 1. This document provides a high-level review of potential climate impacts to the district's portion of the State Highway System (SHS), while the Technical Report presents detail on the technical processes used to identify these impacts. Similar reports are 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 SHS and other Caltrans assets, and inform future decision-making.

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

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

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

2 - "Global Warming in the Western United States," Union of Concerned Scientists, http://www.ucsusa.org/global_warming/regional_information/ca-and-western-states.html#.WMwOFm_yvIU

TABLE OF CONTENTS

SLIDE ACTIVITY | SR 1 NEAR LEGGETT

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, 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 (50th percentile result) is reported in this Summary Report (and the associated Technical Report) due to space limitations.

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

This assessment uses or references:

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

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

EVACUATION PLANNING

Among the things that Caltrans must consider when planning for climate change is the role of the SHS when disaster strikes. The SHS is the backbone of most county-level evacuation plans and often provides the only high-capacity evacuation routes from rural communities. In addition, state highways also serve as the main access routes for emergency responders, and may serve as a physical line of defense (a firebreak, an embankment against floodwaters, etc.). As climate-related disasters become more frequent and more severe, this aspect of SHS usage will assume a greater importance that may need to be reflected in design. The upcoming studies of climate change adaptation measures will take these factors into account when identifying measures appropriate to each situation.

BACKGROUND AND APPROACH

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

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

This Summary Report summarizes the potential vulnerabilities to Caltrans District 1's portion of the SHS. It explains various climate stressors that may affect how highways are planned, designed, built, operated, and maintained. It does not identify projects to be implemented, however, nor does it present the associated costs of such projects—these will be addressed in future studies. This study's intent is to help explain potential climate change impacts in the District 1 region (which is a subject with many unknowns) and begin to identify a subset of assets on the SHS on which to focus future efforts.

FLOODING | FERNBRIDGE

DISTRICT 1 IS MADE UP OF DEL NORTE, HUMBOLDT, LAKE, AND MENDOCINO COUNTIES, AND COVERS ROCKY COASTLINE, REDWOOD FORESTS, AND LOW-LYING MARSHLANDS. ITS NATURAL BEAUTY ATTRACTS VISITORS FROM AROUND THE WORLD.

DISTRICT 1 CHARACTERISTICS

Caltrans District 1 is headquartered in Eureka, California. It has a total area of just over 10,500 square miles, most of which is rural. The district is responsible for the portion of the SHS in Del Norte, Humboldt, Lake, and Mendocino Counties. Humboldt County has the largest population with close to 137,000 residents. Within the district's boundaries are some of California's most sensitive coastal resources and natural habitats and a large variety of biological species. Some of the district's most important roadways follow the California Coastal Zone, and the natural beauty there, at Redwood National and State Parks, and throughout the district attracts visitors from around the world.

Much of District 1's land is under the jurisdiction of governmental agencies and tribal nations. Population centers range from small, rural unincorporated areas to over 27,000 residents in Eureka. The district's state highways provide access to many popular recreational areas and primarily serve seasonal tourist traffic. There are no interstate highways in District 1, so the major state roads are the designated principal arterials—US 101, US 199, and the principal arterial corridor of SR 20, 29, and 53 in Lake County are the most-trafficked major state highways. The iconic SR 1 corridor is the primary north-south route in the coastal parts of the district, and it features abundant trails and pedestrian accommodations. SR 101 and 299 also are part of the Strategic Highway Network (STRAHNET), which serves military bases.

KEY STATE POLICIES ON CLIMATE CHANGE

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

Executive Order (EO) B-30-15 – requires the consideration of climate change in all state investment decisions through the use of full life cycle cost accounting, the prioritization of adaptation actions which also mitigate GHGs, the consideration of the state's most vulnerable populations, the prioritization of natural infrastructure solutions, and the use of flexible approaches where possible. The Governor's Office of Planning and Research (OPR) have since released guidance for implementing EO B-30-15 titled Planning and Investing for a Resilient California. The document provides high level guidance on how state agencies should consider and plan for future conditions. Caltrans supported the development of this guidance by serving on a Technical Advisory Group convened by OPR.[3]

Assembly Bill 1482 – requires all state agencies and departments to prepare for climate change impacts with efforts including: continued collection of climate data, considering climate in state investments, and the promotion of reliable transportation strategies.[4]

Assembly Bill 2800 – requires state agencies to take into account potential climate impacts during planning, design, building, operations, maintenance, and investments in infrastructure. It also requires the formation of a Climate-Safe Infrastructure Working Group consisting of engineers with relevant experience from multiple state agencies, including Caltrans.[5] The Working Group has since completed Paying it Forward: The Path Toward Climate-Safe Infrastructure in California, which recommends strategies for legislators, engineers, architects, scientists, consultants, and other key stakeholders to develop climate ready, resilient infrastructure for California.[6]

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3 - California Governor's Office of Planning and Research, "Planning and Investing for a Resilient California," March 13, 2018, http://opr.ca.gov/planning/icarp/resilient-ca.html
4 - "Assembly Bill No. 1482," California Legislative Information, October 8, 2015, https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201520160AB1482
5 - "Assembly Bill No. 2800," California Legislative Information, September 24, 2016, https://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/

EXTREME EVENTS IN DISTRICT 1

In recent years, extreme weather and landslides have damaged the District 1 SHS and provided a glimpse into what the district could increasingly face in the future as California's climate changes. Below is a summary of recent challenges in District 1—this vulnerability assessment includes analyses of their potential future impacts:

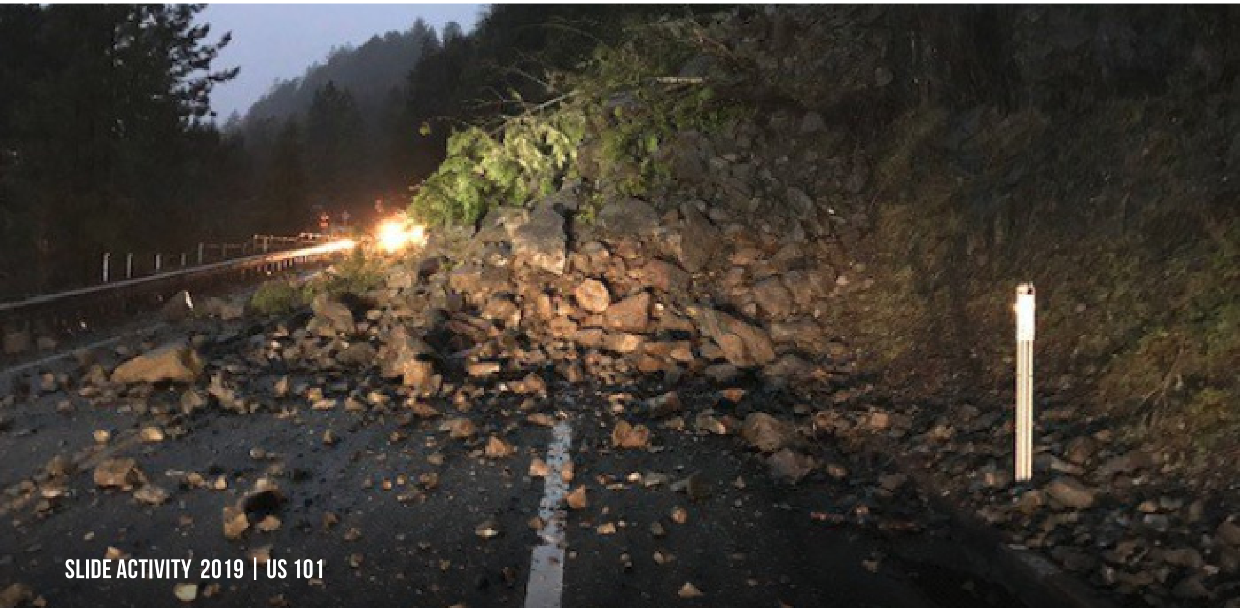
- **Temperature** – District 1 has a diverse geography with mountainous areas to the east and coastal plains to the west. Its proximity to the Pacific Ocean has a cooling effect along the coast, and days above 90 degrees Fahrenheit are very unusual—Humboldt Bay, for example, is surrounded by hills that trap cool marine air, which results in cool and often foggy weather. The district's terrain and wind patterns can cause large temperature variations. For example, the average July high temperature in Willow Creek is 95°F, whereas in Arcata, just 40 miles east, the average July high is 63°F.[7] Average and extreme temperatures are expected to rise at higher elevations, which could cause higher tree mortality due to heat and changing snowmelt patterns.
- **Precipitation** – Humboldt County is well-known for the wet and rainy conditions that make it ideal for coastal redwoods, but these events also cause problems for roadways. Total rainfall can average 40 inches in the driest parts of Humboldt County and over 100 in the wettest.[8] Across District 1, flooding, landslides, and mudslides caused by heavy precipitation result in delays and road closures. Sudden and extreme rain events sometimes exceed the capacity of highway culverts and inundate roadways. In 2017, a major inundation west of Fernbridge closed Route 211 in Humboldt County—floodwaters crested at 24 feet 8 inches—putting it just below the level of a "major flood."
- **Wildfire** – Following the 2011 to 2017 drought, there were many severe wildfires throughout California, and District 1 experienced some of the worst. The Mendocino Complex Fire (comprised of the River and Ranch Fires) started in July 2018 and burned until September 2018 in Mendocino, Lake, Colusa, and Glenn Counties.[9] The Complex caused the closure of SR 20, SR 175, and SR 29, caused resident evacuations, burned 459,000 acres, destroyed 280 structures, and killed one person.[10] Triple-digit temperatures and high winds preceded the fires.
- **Sea Level Rise and Storm Surge** – Sea level rise and storm surge are long-term threats in coastal areas. Ocean water expansion due to temperature rise, combined with glacial and ice sheet melt, are raising sea levels around the world. In Humboldt County, regional studies have helped explain the impacts of sea level rise and storm surge on Humboldt Bay and surrounding communities. The City of Arcata independently conducted a sea level rise vulnerability assessment and started a community-wide effort to document flooding from King Tides[11] (the highest high tides measured annually). For that effort, the city encourages community members to photograph King Tide flooding around the city and in specific locations. The city collects, documents, and analyses the photos and deploys them to an interactive online map. The effort will help city officials and residents better understand flood impacts on their community and develop effective responses as sea levels rise and conditions worsen.
- **Cliff Retreat** – Large waves and elevated tides result in flooding and coastal erosion along the expansive District 1 coastline—particularly in locations where the coast's shape funnels waves into narrow constraints, such as at Shelter Cove and Big Lagoon. The Federal Emergency Management Agency (FEMA) conducted a detailed study on coastal hazards that indicated a 100-year storm event could overtop structures, bluffs, and dunes at five of the forty-four examined locations along the Humboldt County coast.[12] Cliff instability is already an issue in Humboldt County and District 1 as a whole—most notably in Last Chance Grade, where US 101 traverses three miles of geologically active coastline in Del Norte County.[13]

HORSESHOE SLIDE

7 National Centers for Environmental Information," National Oceanic and Atmospheric Administration, last accessed October 11, 2019 from https://www.ncdc.noaa.gov/
8 Climate," Humboldt County, last accessed October 11, 2019 from https://humboldtgov.org/1217/Climate
9 Mendocino Complex," InciWeb - Incident Information System, June 18, 2019, https://inciweb.nwcg.gov/incident/6073/
10 CalFire, "Top 20 Largest California Wildfires," August 8, 2019, https://www.fire.ca.gov/media/5510/top20_acres.pdf
11 "King Tides and Sea Level Rise," City of Arcata, last accessed September 4, 2019, https://www.cityofarcata.org/759/Sea-Level-Rise
12 FEMA Region IX. California Coastal Analysis and Mapping Project / Open Pacific Coast Study, Intermediate Data Submittal #3: Nearshore Hydraulics, Humboldt County, California, 2014, last accessed August 29, 2019, https://humboldtgov.org/DocumentCenter/View/70093/FEMA-Open-Pacific-Coast-Study---Nearshore-Hydraulics?bidId=
13 "Last Chance Grade," Caltrans, last accessed September 4, 2019, https://lastchancegrade.com/

VALLEY WILDFIRE | MIDDLETOWN, LAKE COUNTY

THE KING TIDE AT TULUWAT | PHOTO BY JACK MURPHY



SLIDE ACTIVITY 2019 | US 101

SLIPOUT | SR101 NORTH OF LEGGETT 2019

VULNERABILITY AND THE STATE HIGHWAY SYSTEM

CALTRANS EFFORTS

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

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

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

ADDRESSING CONCERNS IN DISTRICT 1

Caltrans District 1's portion of the SHS serves critical functions for commerce, communities, and more. The system's importance makes understanding the potential impacts of climate change and extreme weather on its performance a key part of creating a resilient highway system.

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

The approach outlined on the following page describes an assessment process consistent with Caltrans practices, and it focuses on:

- **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.
- **Prioritization** – determining how to make effective capital programming decisions to address risks (including the consideration of system use and timing of expected exposure).
- **Consequence** – determining the level of loss-of-use and costs-of-repair that may affect system assets.

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

ENSURING SYSTEM RESILIENCY

After identifying system vulnerabilities, Caltrans will begin the next phase of this assessment which will include prioritizing the district's most vulnerable assets for facility-level assessment and developing adaptation responses as necessary. Protecting the highway network's most critical and vulnerable assets will enhance overall system resiliency. Some potential adaptation strategies for District 1 include:

- Realigning or raising roadways that may be susceptible to flooding.
- Siting new roadways in locations outside of hazard areas.
- Reviewing asset conditions to identify those in poor condition or in need of rehabilitation or replacement (such assets may be the most vulnerable). During asset rehabilitation or replacement, there is an opportunity to improve the asset's future resiliency by updating its design.
- Managing the retreat of portions of the SHS that are vulnerable to sea level rise and coastal erosion.
- Identifying SHS areas where there are wildfire concerns. Clearing dead or dying vegetation, and adjusting landscaping and vegetation management in those areas to reduce wildfire risk.
- Identifying natural infrastructure strategies where appropriate.
- Exploring strategies for beneficial reuse of sediment from flood basins, landslides, projects, and other activities. This may include beach replenishment and could be coordinated with stakeholders like the California Coastal Sediment Management Workgroup.

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

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

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

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

THE APPROACH INCLUDES THE FOLLOWING KEY ELEMENTS:

CONDUCT A VULNERABILITY ASSESSMENT OF ALL CALTRANS ASSETS INCLUDING EXPECTED TIMING OF IMPACTS

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

DETERMINE THE CONSEQUENCE OF IMPACTS ON CALTRANS ASSETS

DAMAGE/LOSS
DURATION

PRIORITIZE ACTIONS

BASED ON TIMING AND CONSEQUENCE OF IMPACTS

CURRENT STAGE

EXPOSURE

Define the components and locations of the highway system (roads, bridges, culverts, etc.) that may be exposed to changing conditions caused by the effects of climate change such as sea level rise, storm surge, wildfire, landslides, and more. One key indicator for this measure is the potential timing of impact (e.g. the year or time frame a potential condition is expected to occur).

CONSEQUENCE

Identify the implications of extreme weather or climate change on Caltrans assets. Key variables include estimates of damage costs, the length of closure to repair or replace the asset, and measures of environmental or social impacts. The consequence of failure from climate change include (among others):

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

PRIORITIZATION

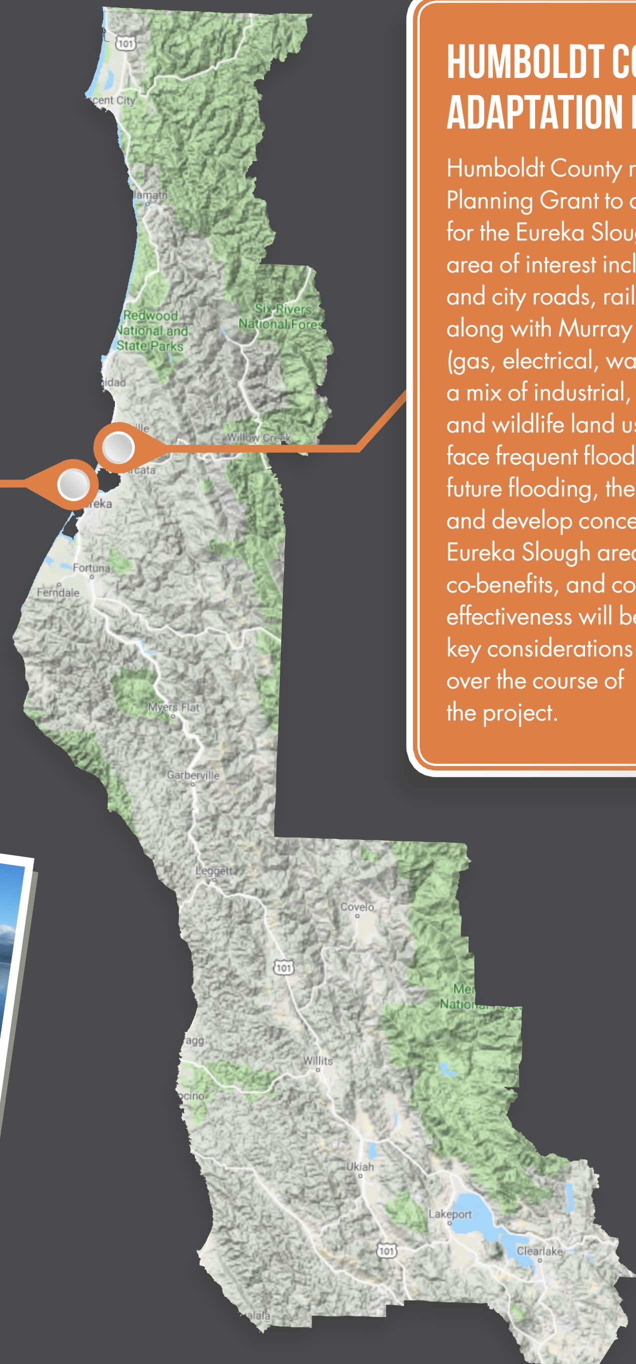
Develop a method to support investment decision-making from multiple options related to future climate risk, with elements including:

- Impacts – what are the projected costs to repair or replace? What are the likely impacts on travel/goods movement? Who will be directly or indirectly affected?
- Likelihood - what is the probability of impact?
- Timing – how soon can the impacts be expected?

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

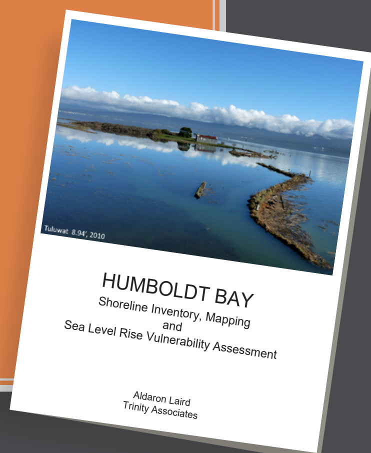
EFFORTS IN DISTRICT 1 TO ADDRESS CLIMATE CHANGE

Caltrans recognizes that other regional efforts to mitigate the effects of climate change are underway in District 1. Ongoing coordination with local governments and stakeholders will be critical to ensuring that methodologies and adaptation strategies are not redundant with other efforts—this is especially important for combating the kinds of stressors that will affect large numbers of people and require a collective response, such as rising seas.



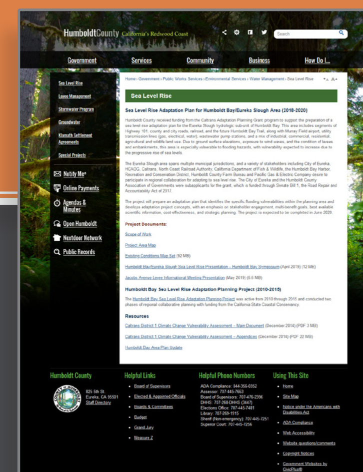
HUMBOLDT BAY SEA LEVEL RISE ADAPTATION PLANNING PROJECT

This project is a regional collaboration funded by the California State Coastal Conservancy to "inform the public and local agencies of the risk that sea level rise poses to the communities and environment on Humboldt Bay and identify adaptation strategies and options to protect critical regional assets."[16] Project components include, 1) gathering baseline data on shoreline vulnerability, 2) modeling vulnerable locations along the coast, 3) creating a working group to advise the study, and 4) developing an adaptation plan for Humboldt Bay. The adaptation plan included a detailed analysis of the threats to transportation for the US 101 corridor.



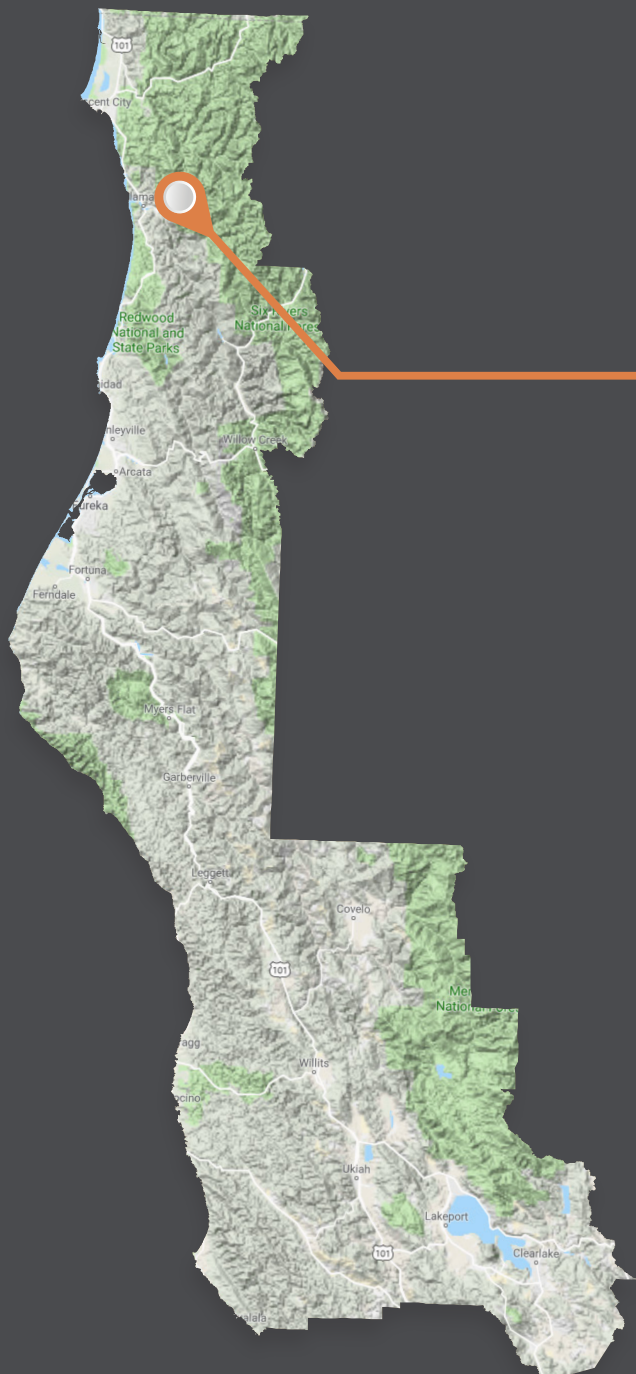
HUMBOLDT COUNTY SEA LEVEL RISE ADAPTATION PLAN

Humboldt County recently received a Caltrans Adaptation Planning Grant to complete a sea level rise adaptation plan for the Eureka Slough, which feeds into Humboldt Bay. The area of interest includes "segments of Highway 101, county and city roads, railroad, and the future Humboldt Bay Trail, along with Murray Field airport, utility transmission lines (gas, electrical, water), wastewater pump stations, and a mix of industrial, commercial, residential, agricultural and wildlife land use."[17] These community assets could face frequent flooding as sea levels rise. Given the risk of future flooding, the plan will identify critical vulnerabilities and develop conceptual adaptation strategies for the Eureka Slough area. Community engagement, adaptation co-benefits, and cost-effectiveness will be key considerations over the course of the project.



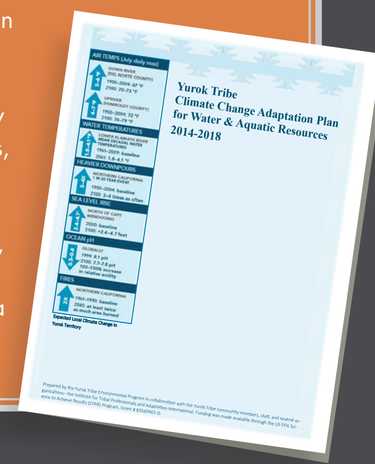
16 - Humboldt Bay Sea Level Rise Adaptation Planning Project. 2018. Last accessed August 29, 2019, http://humboldtbay.org/humboldt-bay-sea-level-rise-adaptation-planning-project

17 - Sea Level Rise Adaptation Plan for Humboldt Bay/Eureka Slough Area (2018-2020)," Humboldt County, last accessed October 11, 2019 from https://humboldtgov.org/2487/Sea-Level-Rise



YUROK TRIBE CLIMATE CHANGE ADAPTATION PLAN

This plan is one of the only tribal adaptation plans in the US. Its goal is to "assess the vulnerabilities and resiliencies of Yurok waters, aquatic species, and people in the face of climate change and to identify actions and strategies that will allow Yurok lifeways, culture, and health to grow despite the changing climate."[18] The plan focuses primarily on water resources and community impacts in Yurok territory, provides over 400 adaptation strategies collected from Yurok tribal members and staff, and includes a comprehensive literature review.



DISTRICT 1 CLIMATE CHANGE VULNERABILITY ASSESSMENT AND PILOT STUDIES: FHWA CLIMATE RESILIENCE PILOT FINAL REPORT[19]

This study was one of the climate adaptation pilot studies funded by the Federal Highway Administration (FHWA) in 2014. Its purpose was to identify and classify the threats that climate change may pose to state-owned transportation assets and evaluate the efficacy of adaptation options at four prototype locations. The approach followed FHWA's vulnerability assessment guidelines, including establishing each asset's criticality and vulnerability to climate change-related stressors and identifying adaptation strategies. Historical maintenance records and climate-model exposure data helped identify potential impacts. The study concluded that sea level rise and increased coastal erosion will be the primary climate change impacts in District 1. The study recommended that Caltrans work with FHWA and other agencies to update design standards for better climate change adaptability.

18 - Yurok Tribe, "Yurok Tribe Climate Change Adaptation Plan for Water & Aquatic Resources 2014-2018," 2013, Last accessed August 29, 2019, http://www.yuroktribe.org/departments/ytep/documents/Yurok_Climate_Plan_WEB.pdf

19 - Caltrans District 1 and FHWA, "District 1 Climate Change Vulnerability Assessment and Pilot Studies: FHWA Climate Resilience Pilot Final Report, December 2014, https://www.fhwa.dot.gov/environment/sustainability/resilience/pilots/2013-2015_pilots/california/final_report/index.cfm

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 SHS.

SCOPE OF THIS STUDY

COORDINATE WITH FEDERAL/STATE RESOURCE AGENCIES ON APPLICABLE CLIMATE DATA:
Many state agencies have been actively engaged in projecting specific future climate conditions to plan for water supply, energy impacts, and environmental impacts. Federal agencies have also been studying climate change for other purposes such as anticipating coastal erosion and wildfires.

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

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

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

According to the US National Climate Assessment, 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."[20] California's size and its many highly varied climate zones will likely lead to temperatures rising in varying degrees across the state.

On the following page, a figure compares the change in the average maximum temperature over the course of seven consecutive days (which is important for determining the best pavement mix for long-term performance) for three time periods, compared to data from 1975 to 2004. US studies generally show that rising temperatures could impact the transportation system in several ways, including:

DESIGN

- Ground conditions and water saturation levels can affect retaining walls and foundations.
- Materials with long exposure to high temperatures can deform (including track buckling or pavement heave). Pavement design must consider elevated temperatures to mitigate future deterioration.

OPERATIONS AND MAINTENANCE

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

EFFECTS OF TEMPERATURE CHANGE IN DISTRICT 1

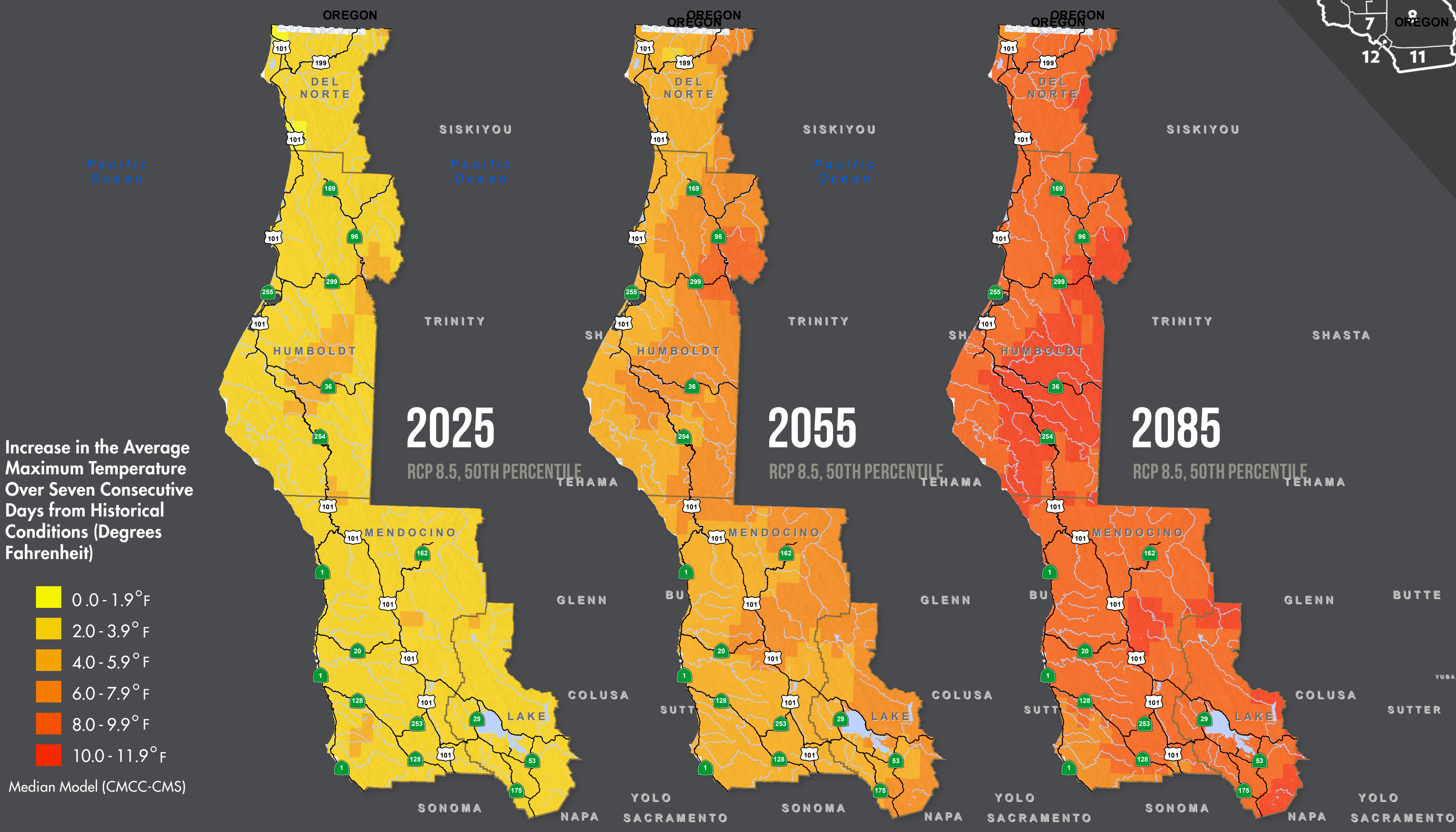
Figure 1 shows rising average maximum temperatures over seven consecutive days across District 1 compared to historical averages. By 2025 (which represents 2010 to 2039), temperatures are expected to rise by anywhere from 0 to 5.9 degrees Fahrenheit. By 2055 (representing 2040 to 2069), the projected rise is 2 to 9.9 degrees Fahrenheit. Finally, by 2085 (representing 2070 to 2099), the expected temperature rise is 6 to 11.9 degrees Fahrenheit. These values are the added temperature rise above the current average maximum temperatures, meaning that the hottest hot days in District 1 could be up to 11.9 degrees warmer—this has implications for the natural environment of District 1 as it will dry out vegetation and affect the health of the coastal redwoods. It also has implications for the SHS's design, because high temperatures can affect material quality and lifespan.

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

Fig. 1

INCREASE IN THE AVERAGE MAXIMUM TEMPERATURE OVER SEVEN CONSECUTIVE DAYS

A REQUIRED MEASURE FOR PAVEMENT DESIGN



Future Change in the Average Maximum Temperature over Seven Consecutive Days within District 1, Based on RCP 8.5.

Caltrans Transportation Asset Vulnerability Study [illegible] Climate data provided by the Scripps Institution of Oceanography [illegible] were generated by downscaling global climate model outputs using [illegible]

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.

DRAFT DRAFT DRAFT

PAVEMENT DESIGN

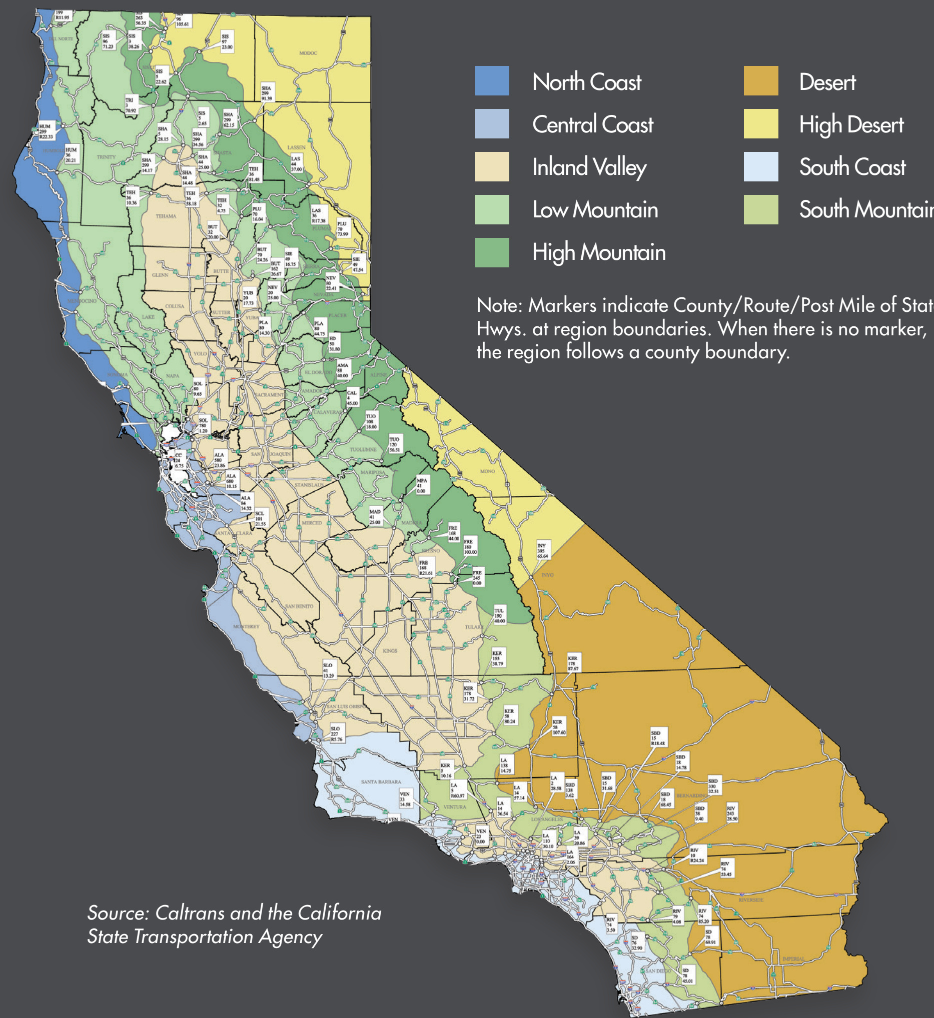
Ensuring the durability and good ride quality of highway pavements under various conditions is an important responsibility of every state transportation agency. Pavement durability is an important component of Caltrans' highway asset management strategy, and it is affected by how the pavement was designed. Several factors help determine if highway pavement should be a concrete or an asphalt mix. For asphalt mixes, using the best pavement binder is important, and that decision is based in part on the project area's temperature conditions.

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

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

Fig. 2

CALTRANS PAVEMENT REGIONS



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

Source: Caltrans and the California State Transportation Agency

TIMEFRAMES AND ASSET DECISION-MAKING

Many factors must be considered in transportation asset decision-making, including the asset's design life (or useful life), which is how long the asset will be in place. For example, asphalt pavement is usually replaced around every 20-40 years, while bridges can last 50 years or longer.

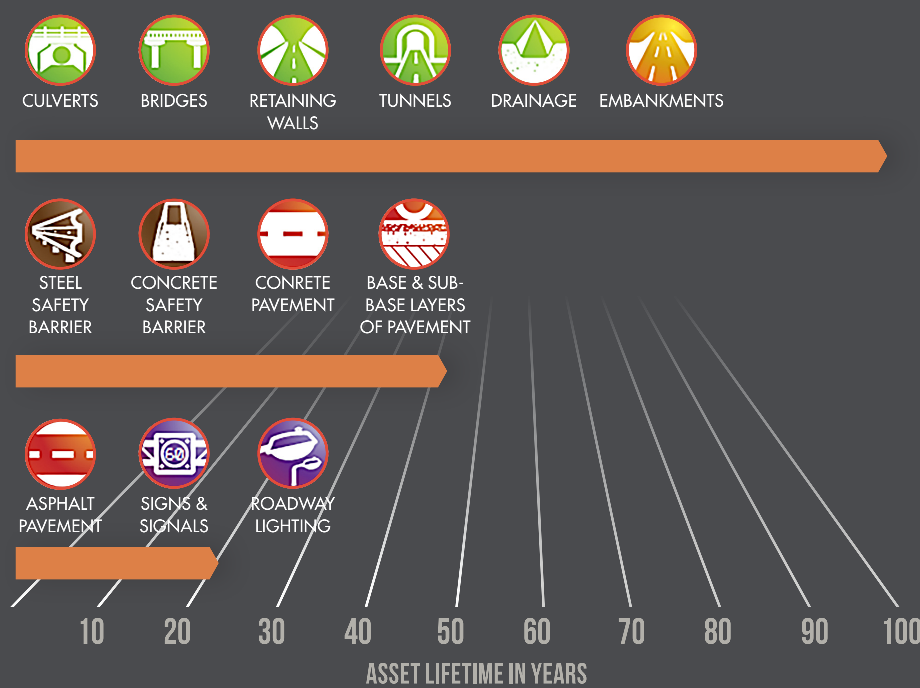
The following graphics highlight how design-life considerations are critical in transportation investment planning. Figure 3 shows how emission levels and global response can significantly affect future temperature scenarios. Temperature conditions are fairly consistent through around 2050, but then begin to diverge more significantly—therefore, decisions made on investments near the end of the century must include a much wider range of future temperature uncertainty.

Fig. 4 TRANSPORTATION INFRASTRUCTURE ASSETS

ASSETS LIKE BRIDGES ARE BUILT WITH A USEFUL LIFE OF 50 YEARS OR LONGER.

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

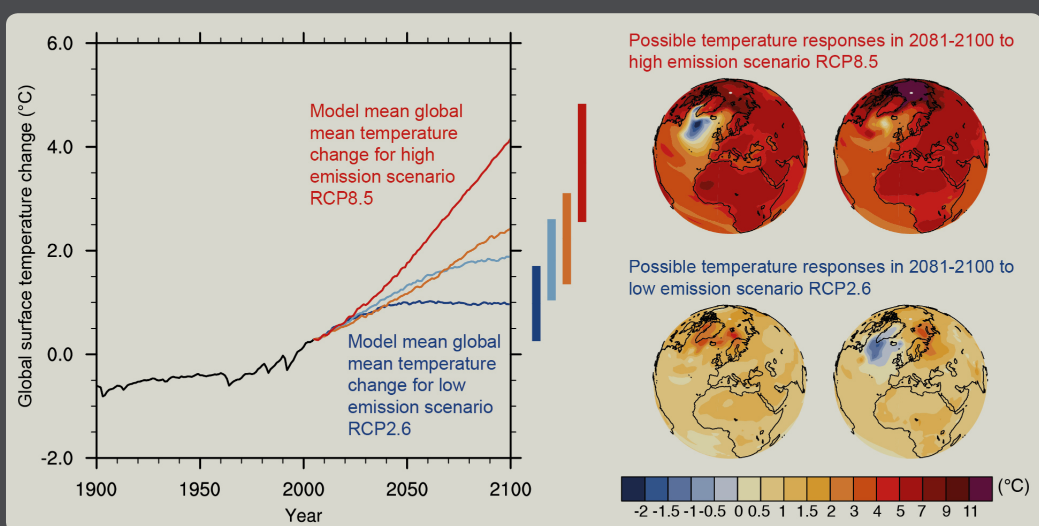
ASSETS WITH SHORTER LIFETIMES, LIKE ASPHALT PAVEMENT, REQUIRE CONSIDERATION OF NEARER TERM FUTURE CONDITIONS.



The graphic above 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



Source: IPCC, see FAQ 12.1

PRECIPITATION

Atmospheric moisture and energy increases caused by rising temperatures are expected to change the nature of precipitation events in California. More intense storms, combined with other changes in land cover and land use, can raise the risk of damage or loss from flooding. Precipitation can cause landslides, flooding, washouts, erosion, and structural damage—all of which affect California's transportation assets. The main threat to transportation assets comes not from higher overall rainfall volumes over an extended period, but from larger and more frequent storm events and their resulting damage to the SHS. These large storm events are becoming more frequent with the changing climate.

The Scripps Institution of Oceanography at the University of California, San Diego has projected future rainfall data to the year 2100 using RCP 4.5, RCP 8.5, and a variety of models. A storm with a likelihood of occurring once every 100 years (or a one percent chance of occurring in any given year) is known as a "100-year storm event," and it is one good way to examine this data. A storm of this magnitude could cause major damage, so it is a good design standard for infrastructure projects. Understanding how the 100-year storm may change in the future can help Caltrans to build more resilient infrastructure that can accommodate heavier storm events. The percentage increase in the 100-year storm depth was processed for District 1 using 10 different models. The median model for precipitation change (HadGEM2-CC) is shown in the figure on the following page.

PRECIPITATION CHANGE EFFECTS IN DISTRICT 1

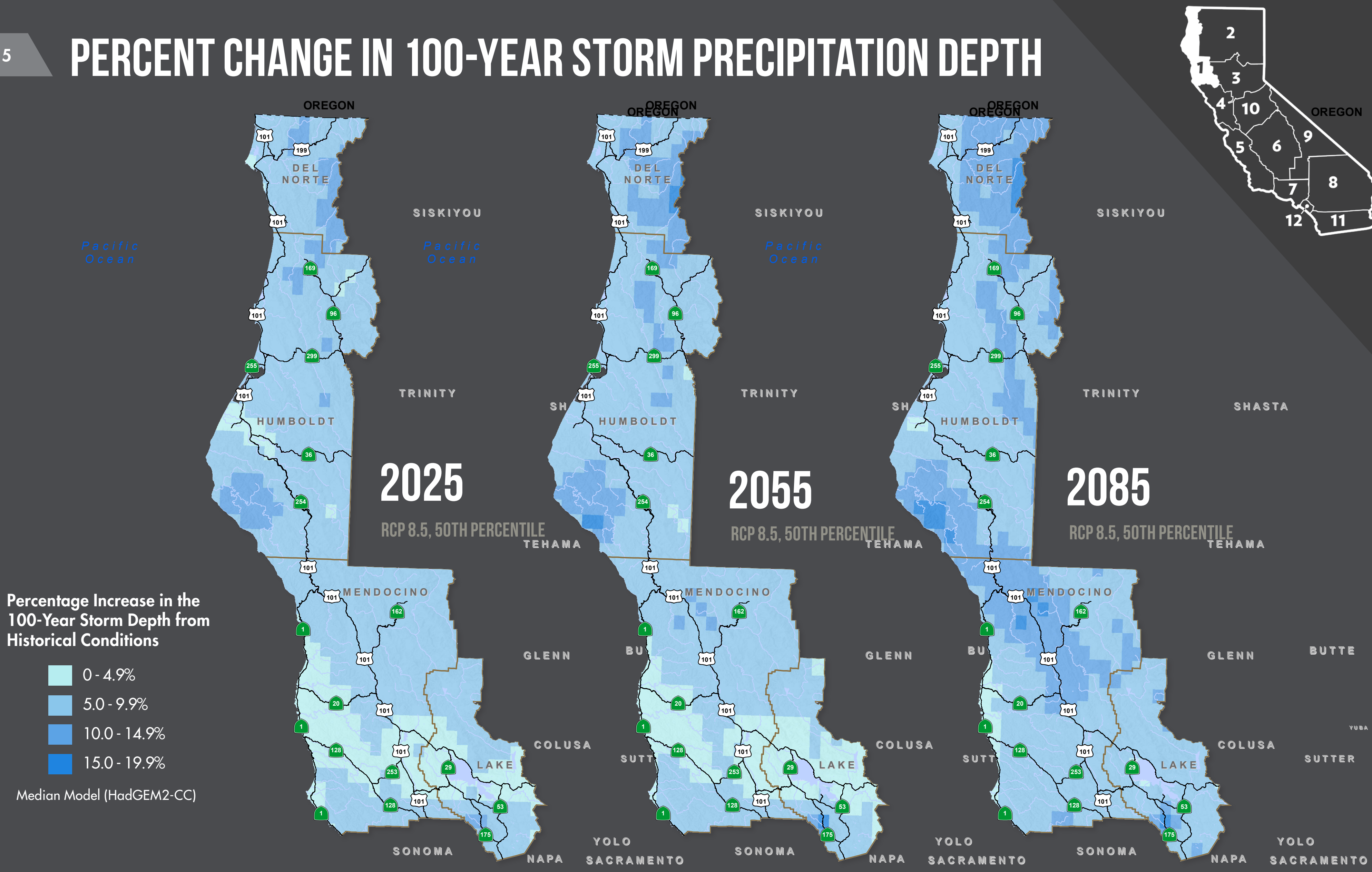
As seen in Figure 5, the 100-year storm depth is expected to increase by anywhere from 0 to 19.9% over the coming century in District 1. The greatest increases are projected for the years 2055 (representing 2040 to 2069) and 2085 (representing 2070 to 2099). There are some regional differences in the precipitation projections—for example central/eastern Del Norte County, the southwestern coast of Humboldt County, northwestern Mendocino County, and southern Lake County show the greatest overall increases in precipitation (this analysis does not consider the effects of changing floodplains, which will also affect the SHS). This information is useful for planning-level studies, but the district will still need to conduct hydrologic analyses to better understand risks to bridges, culverts, and other assets affected by runoff and river flows—the analyses should consider future precipitation projections to ensure effective asset design for future conditions.

SR 128 | FLOODS ALMOST ANNUALLY AT THE NAVARRO RIVER | 2017

US 101 | FLOODING | 2005

Fig. 5

PERCENT CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH



Future Percent Change in 100-year Storm Precipitation Depth within District 1, Based on RCP 8.5

Caltrans Transportation Asset Vulnerability [illegible] Climate data [illegible] were generated by downscaling global climate outputs using [illegible] Constructed Analogs (LOCA) technique.

Results represent the 50th percentile of downscaled climate model outputs under RCP 8.5 for the metric shown, as calculated across the state using the area weighted mean. There are several methodological challenges with using downscaled global climate model projections to derive estimations of future extreme precipitation events, addressable through vetted and available methods. Results should be compared across multiple models to conduct a robust assessment of how changing precipitation conditions may impact the highway system, and to make informed decisions.

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

WILDFIRE

Changing precipitation patterns and higher temperatures are expected to affect both the intensity and scale of wildfires. Higher temperatures decrease the moisture in vegetation and soils, which leads to a higher risk of wildfire. Wildfires can contribute to flooding and landslides by burning off protective land cover and reducing the ability of the underlying soil to absorb rainfall. California is already prone to serious wildfires, and future climate forecasts suggest that this vulnerability will get worse. In response to these concerns, Governor Jerry Brown announced (in May 2018) a new fund to support forest management and reduce wildfire risk. Governor Newsom later issued Executive Order N-05-19 to create a task force to develop a community resilience and education campaign and provide the Governor with immediate, mid-, and long-term suggestions to prevent deadly and destructive wildfires.

The areas shaded in red in Figure 7 represent an increased likelihood of wildfires based on projected percentages of area burned over time. These projections used data generated by the MC2 – EPA (from the United States Forest Service), MC2 – Applied Climate Science Lab (University of Idaho), and the Cal-Adapt 2.0 (UC Merced) wildfire models. Each model was paired with three downscaled GCMs to produce nine future scenarios. Incorporating three different wildfire models was a conservative approach because final data shows the highest wildfire risk categorization of all model results. The results for RCP 8.5 (the high-emissions scenario) are provided in Figure 6 and Table 1. The associated Technical Report includes the RCP 4.5 results.

WILDFIRE EFFECTS IN DISTRICT 1

Compared to other districts, wildfire concern is relatively low in District 1 until the end of the century. Figure 6 shows that by 2025 (which represents the years 2010 to 2039) much of the SHS will lie in areas of medium wildfire concern, but some portions of the highway network, such as US 101 along the coastline, lie outside these areas of concern. High-concern areas appear along the SHS in southern Mendocino and Lake counties. By mid-century, much of the medium-concern areas become high- or very-high concern and the low-concern areas along US 101 become medium concern. By end of century, there are very few areas along the SHS with no wildfire concern. The hatch marks on each map show where the models agree—this means that there is a higher level of confidence for the projections for those locations. Areas without hatch marks show the highest projected wildfire concern that the models identified. Table 1 shows the SHS centerline mileage that passes through the medium- to very-high concern areas. See the associated District 1 Technical Report for a more-detailed breakdown.

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

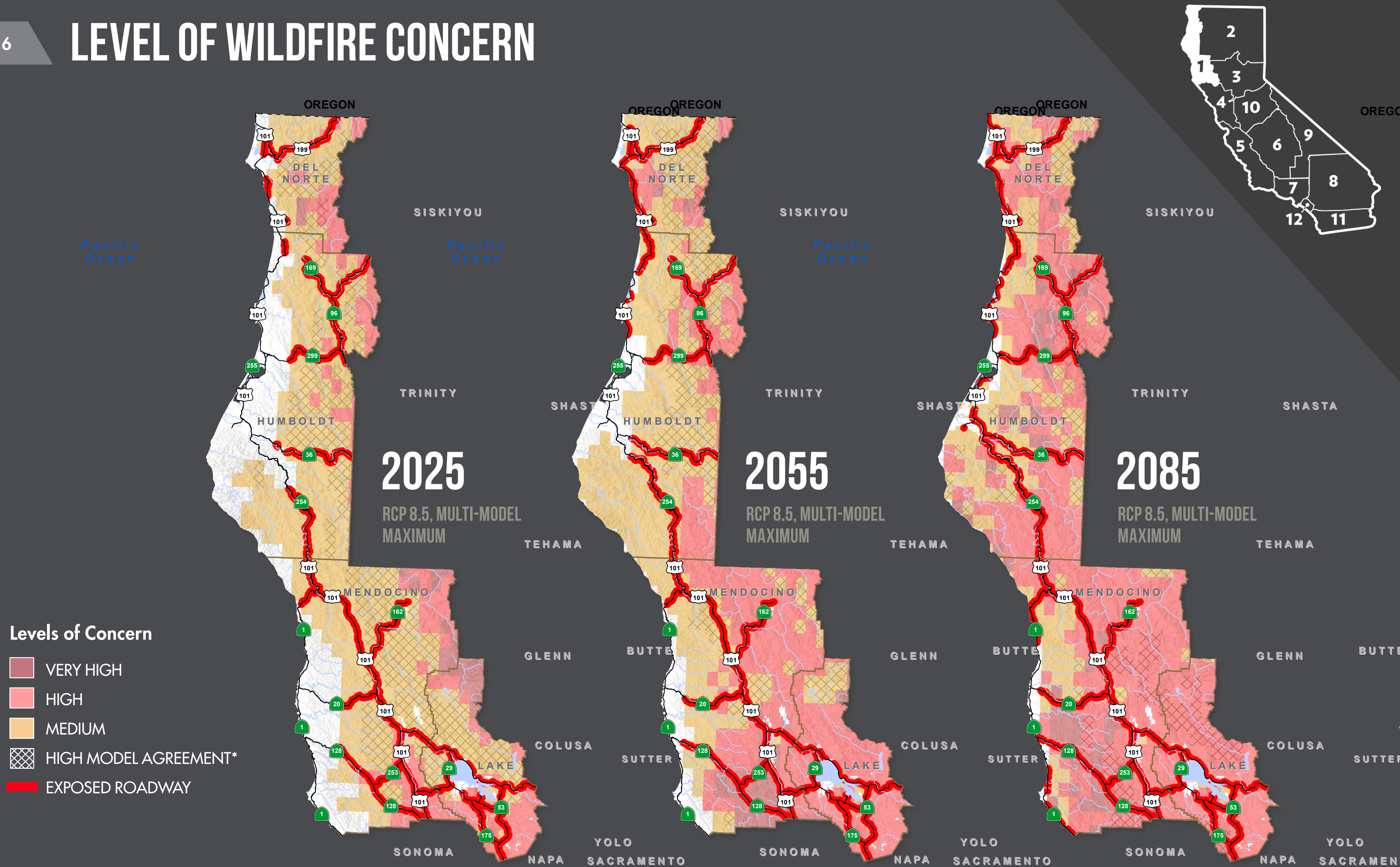
County	Year		
	2025	2055	2085
Del Norte	**47**	**83**	**87**
Humboldt	**180**	**242**	**281**
Lake	**115**	**119**	**122**
Mendocino	**242**	**259**	**294**


MENDOCINO COMPLEX FIRE | 2018

VALLEY WILDFIRE | MIDDLETOWN, LAKE COUNTY

Fig. 6

LEVEL OF WILDFIRE CONCERN



Future Level of Wildfire Concern for the Cal[illegible] SHS within D[illegible] RCP 8.[illegible]

The fire model composite summaries shown are based [illegible] from three models: (1) [illegible] Climate [illegible] Risk Assessment, developed by [illegible] USFS [illegible] Applied Climate Science Lab at the University of Idaho, developed [illegible] University of [illegible] University of California, Merced [illegible] University of California, Merced. For each of these wildfire models, climate inputs were used from [illegible]: (1) CAN ESM2; (2) HADGEM [illegible] maps show the multi-model [illegible] across the nine combinations of the three fire models and the three GCMs.

Areas in white do not necessarily mean there is no wildfire risk, only that the risk classification is below medium. More information on models used and the classifications for levels of concern can be found in the associated Technical Report.

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

D1

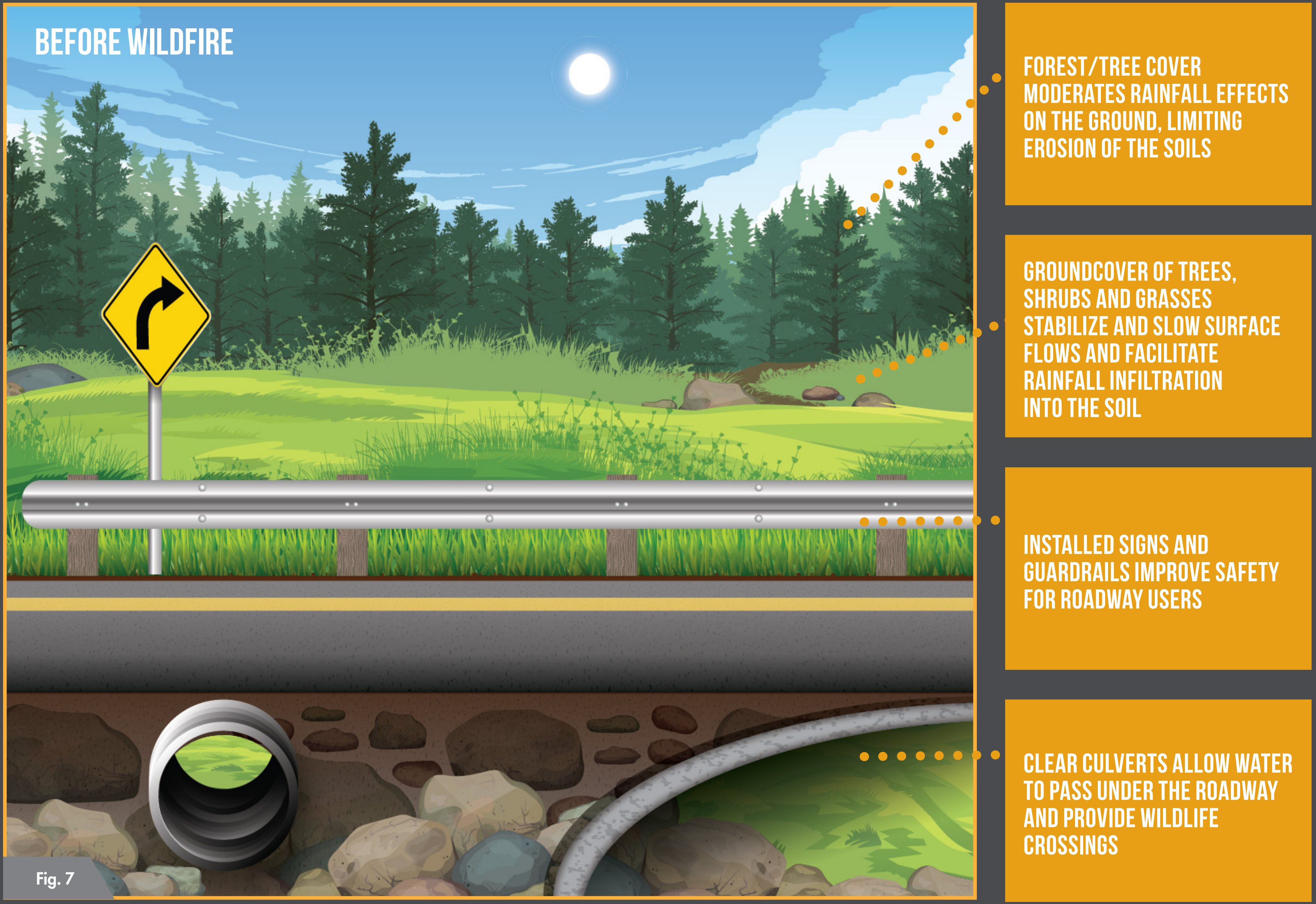


Fig. 7

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 1

Though many climate stressors could potentially impact District 1's SHS, rising sea levels are a primary concern for coastal communities. In addition to causing inconvenience, safety threats, and roadway deterioration and closures, rising seas at high tide can temporarily flood roadways. Historically, only major storm events would cause inland flooding, but higher coastal sea levels have made flooding more common. Eventually, rising seas will permanently inundate low-lying coastal areas. Higher wave run-up and more storm surge are also accelerating cliff retreat and coastal erosion, which threatens the coastal portions of the District 1 SHS.

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

The following sections provide a high-level overview of the District 1 assessments for sea level rise, storm surge, and cliff retreat. Each analysis encompasses the entire coastline—the District 1 Technical Report includes the full results. Modeling results showed notable SHS vulnerabilities around Humboldt Bay and along the Mendocino coastline—the following section highlights these areas. Figure 9 shows these locations and photos of recent coastal impacts in these areas. Zoomed-in maps highlight the modeling results in these locations. Mileage summaries are provided for the entire District 1 coastline in the following sections.

NORTH WESTPORT BLUFFS | FEBRUARY 2017

NORTH WESTPORT BLUFFS | AUGUST 2017

Fig. 9

RECENT COASTAL IMPACTS

THE EUREKA-ARCATA US 101 CORRIDOR

INDIANOLA CUTOFF FLOODING | US 101

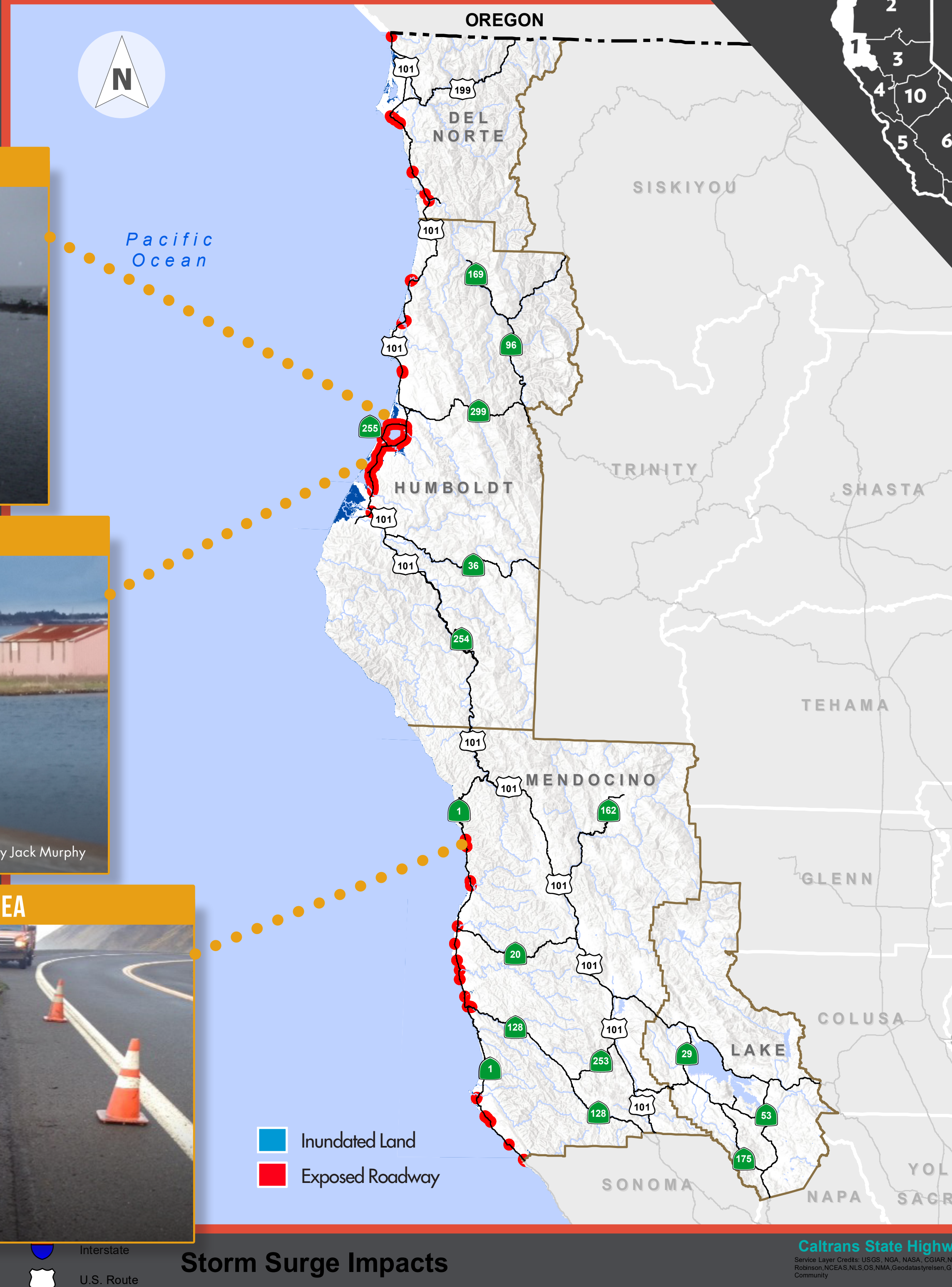
HUMBOLDT BAY

THE KING TIDE AT TULUWAT

Photo by Jack Murphy

WESTPORT, CA BLUFF AREA

NORTH WESTPORT BLUFFS



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 1 includes an extensive coastline and Caltrans facilities provide access to bayshore and coastal areas. Sea level rise will exacerbate the flooding and inundation that could occur in these areas during regular tidal or storm events. For Caltrans, this means that many of its coastal roads, bridges, and supporting facilities face risk of permanent inundation, meaning they could be consistently below the high tide line.

Like other forecasted changes in climate, future projections of sea level rise vary, depending in part on the assumptions made regarding future concentrations of GHGs and how the Earth's systems will respond. The State of California Sea Level Rise Guidance: 2018 Update provides the most recently developed sea level rise scenarios for locations across the California coastline.[21] This guidance document also provides direction on how to use these new projections in project planning and decision-making. A selection of these scenarios and how to use them is shown and explained further in Figure 11.

These projections were used and paired with sea level rise heights modeled by the National Oceanic and Atmospheric Administration (NOAA). NOAA developed their own sea level rise model to project potential inundation from sea level rise ranging from one to 10 feet (0.30 to 3.0 meters) above the average daily high tide.[22] NOAA produced results for both US coasts, including California's coast. All available sea level rise heights from NOAA were assessed, but due to space limitations maps were only created for 2, 3, and 6 feet (0.61, 0.91, and 1.83 meters) of sea level rise. The NOAA model analyzes sea level rise impacts based on the current shoreline and does not account for shoreline retreat. For this reason, some impacts may be missed in modeled results. Figure 10 shows a zoomed-in example of one location in the district that will be affected by sea level rise – district-scale figures are available in the District 1 Technical Report.

The assessments of sea level rise and surge on the following pages include flagging bridges where there may be impacts, even though they may not be overtopped by flooding. This is because bridges don't necessarily need to be flooded to be affected by sea level rise. Figure 12 is provided to illustrate some of the risks posed to bridges due to sea level rise.

SEA LEVEL RISE EFFECTS IN DISTRICT 1

Table 2 shows the centerline miles of District 1's SHS exposed to sea level rise based on modeled NOAA increments of 2, 3, and 6 feet. The most vulnerable sections include SR 255 and US 101 in the north, and portions of SR 1 in Mendocino County in the south. Figure 10 zooms in on the most vulnerable section (as indicated by the NOAA data) of the SHS in District 1, which is where SR 255 and US 101 surround and traverse Humboldt Bay. The model results, which are consistent with regional studies, show increasing flood risks to these important highways. It is also important to note that Humboldt Bay is experiencing subsidence, which is downward vertical land motion or sinking, at a rate between 3.56 mm/yr and 1.11 mm/yr. This rate of subsidence will exacerbate the risk of sea level rise to vulnerable infrastructure.[23]

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

23 - County of Humboldt, June 2018. "Humboldt Bay Trail South: Sea-Level Rise Vulnerability and Adaptation Report." https://humboldtgov.org/DocumentCenter/View/64364/Sea-Level-Rise-Vulnerability-and-Adaptation-Report-June-2018

Table 2: Centerline Miles of State Highways in District 1 Inundated by Sea Level Rise

County	Sea Level Rise Height		
	2 ft (.6 m)	3 ft (.91 m)	6 ft (1.83 m)
Del Norte	**0.2**	**0.2**	**0.9**
Humboldt	**2.7**	**5.3**	**13.2**
Mendocino	**0.4**	**0.5**	**0.7**

Note: There is no coastline in Lake County. Data does not include other state roads or local streets and roads.

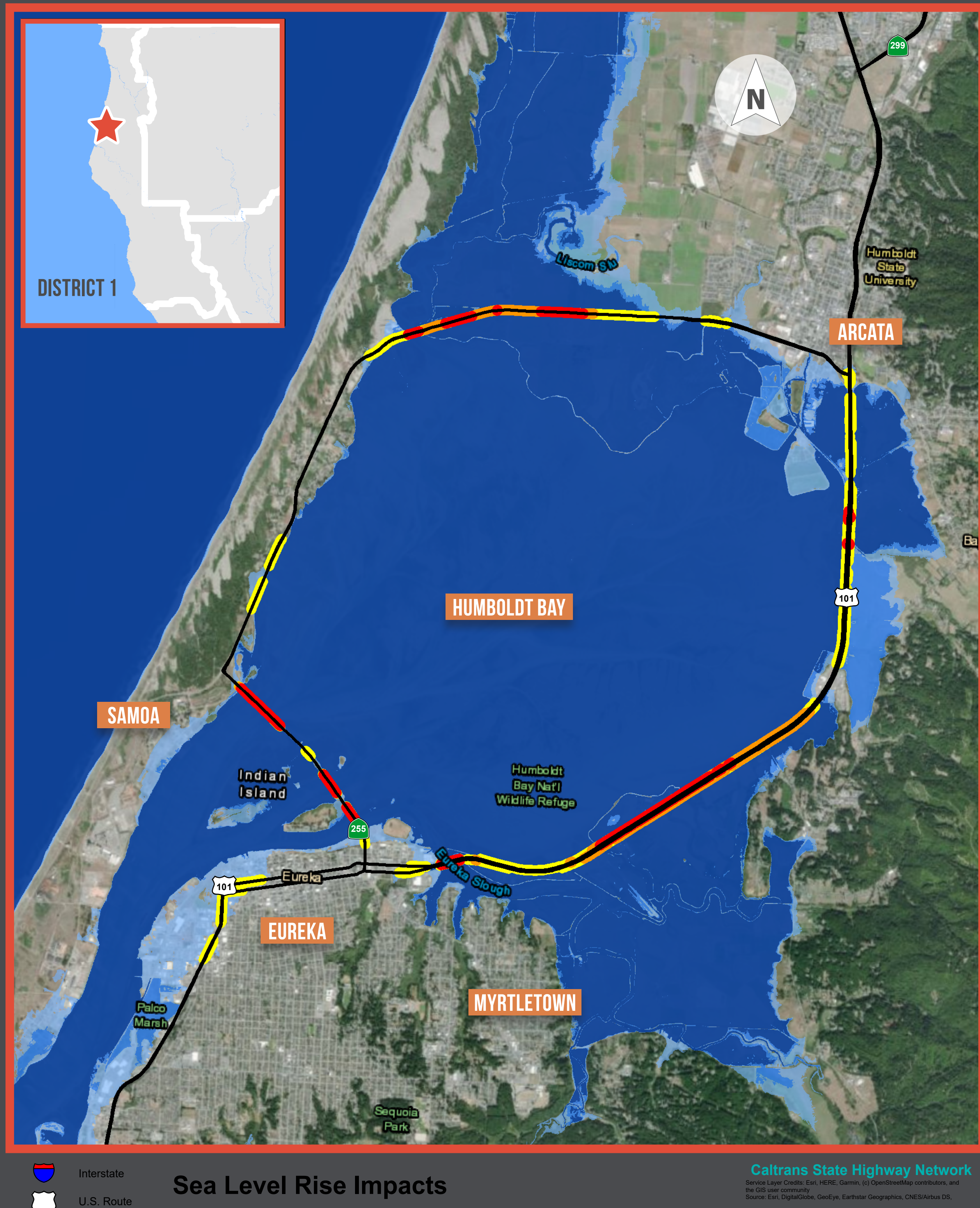
ANALYSIS FOR THIS REPORT WAS CONDUCTED ON THREE DISTINCT INCREMENTS OF SEA LEVEL RISE TO SHOW HOW CONDITIONS MAY CHANGE OVER TIME. THOSE INCREMENTS ARE 2 FEET (.6 METERS), 3 FEET (.91 METERS) AND 6 FEET (1.83 METERS)

APPROXIMATELY FIFTEEN MILES OF CALTRANS DISTRICT 1 HIGHWAYS AND BRIDGES MAY BE INUNDATED UNDER 6 FEET OF SEA LEVEL RISE.

FLOODING | US 101 NORTH OF KLAMATH

Fig. 10

MODELED SEA LEVEL RISE INUNDATION AROUND HUMBOLDT BAY



Impacts to State Highways by Sea Level Rise Increment

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

Sea Level Rise Increments

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

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

Fig. 11

SEA LEVEL RISE ESTIMATED FOR DISTRICT 1

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 the North Spit tide gauge by a scientific panel for the 2018 Update of the State of California Sea-Level Rise Guidance, an effort led by the Ocean Protection Council (OPC).[24] 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

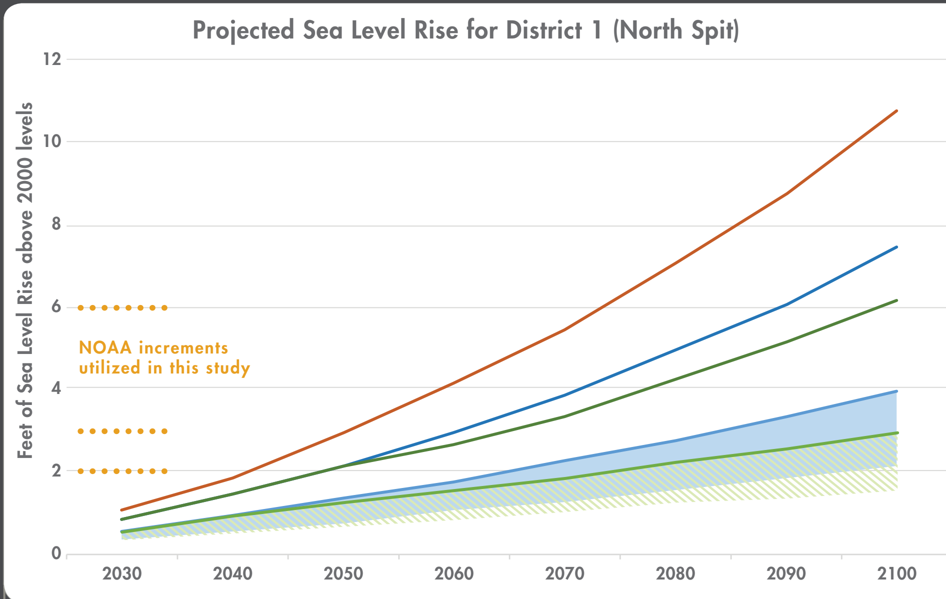
Each of these values are presented for low (RCP 2.6) and high (RCP 8.5) emissions scenarios to demonstrate a full range of potential projections over time. The OPC recommends using only RCP 8.5 for projects that have a lifespan to 2050, and using both scenarios for projects with longer lifespans. The 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. The low risk aversion scenario should be used for projects with limited consequences or a higher ability to adapt. This is not for critical infrastructure.
- **For medium to high risk aversion decisions,** the OPC recommends using the low (0.5%) probability scenario. This value is shown in dark green for RCP 2.6 and in dark blue for RCP 8.5 in the graphic to the right. The medium-high risk aversion scenario should be used for projects with greater consequences and/or a lower ability to adapt.
- **For high risk aversion decisions,** the OPC recommends considering the extreme (H++) scenario. This projection is shown in dark orange in the graphic to the right. The extreme risk aversion scenario should be used for projects that would be irreversibly destroyed or significantly costly to repair and/or would have considerable health, safety, and environmental consequences.

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

COASTAL COMMISSION SEA LEVEL RISE GUIDANCE

The *California Coastal Commission Sea Level Rise Policy Guidance* document was adopted in August of 2015 and has since been updated given the 2018 sea level rise guidance released by the OPC. The guidance provides a step-by-step process using the latest science to determine a range of sea level rise projections in the project area, identify potential impacts, develop adaptation options, and incorporate strategies into Local Coastal Programs. Similar guidance applies to addressing sea level rise in Coastal Development Permits. Caltrans references this guidance in their emergency and day-to-day work in coastal areas to ensure that they are meeting Coastal Commission permitting requirements and correctly applying the latest science.[25]



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

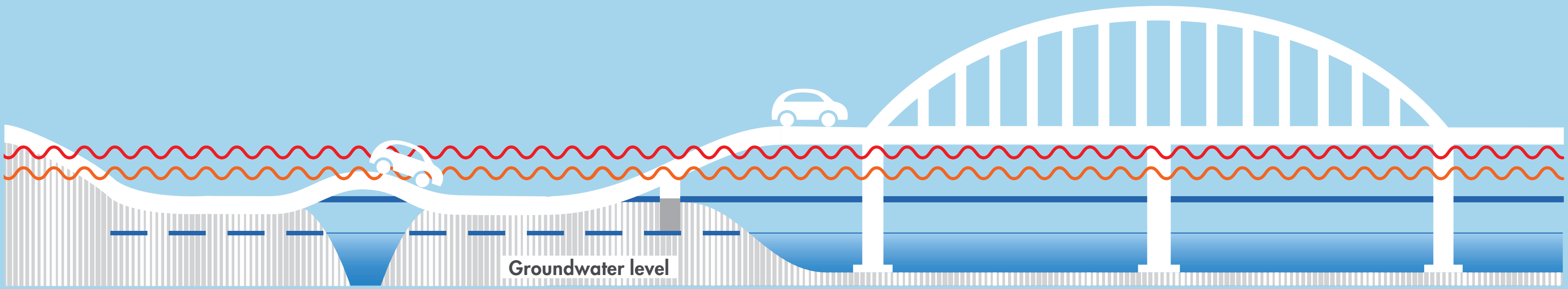
- Extreme Estimate of Sea Level Rise (H++ Scenario)
- **Low Probability** Estimate (0.5% Probability Scenario) for **High Emissions** Scenario
- **Low Probability** Estimate (0.5% Probability Scenario) for **Low Emissions** Scenario
- **High End of the Likely Range** (17% Probability Scenario) for **High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

24 - 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

25 - California Coastal Commission Sea Level Rise Policy Guidance: Interpretive Guidelines for Addressing Sea Level Rise in Local Coastal Programs and Coastal Development Permits," November 2018, https://documents.coastal.ca.gov/assets/slr/guidance/2018/0_Full_2018AdoptedSLRGuidanceUpdate.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.

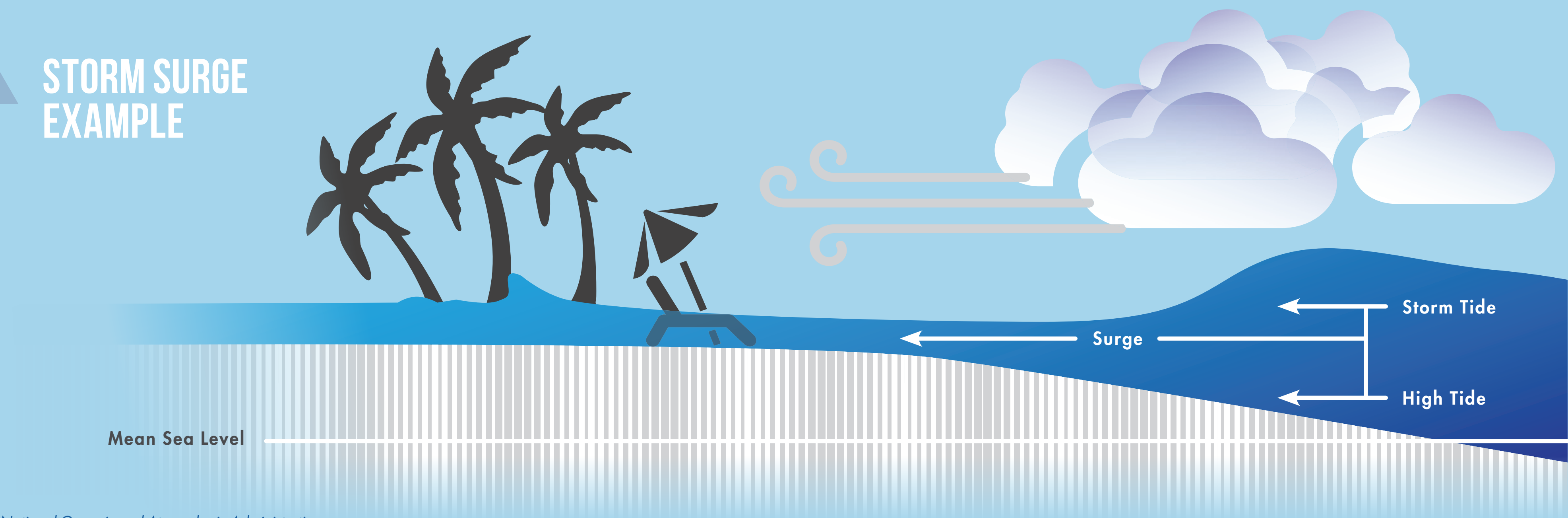
Some bridge vulnerabilities include:

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

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

Data from the CalFloD-3D (or "3Di") model was used to assess sea level rise and storm surge impacts to the SHS in District 1. The model was developed by researchers at UC Berkeley to understand the risks posed by sea level rise and a 100-year storm event to the California coast. The model applies real water level data from past, near 100-year storm events to better understand how storm surge occurs and flows inland.[26] The sea level rise heights provided by the model are: 1.64, 3.28, and 4.62 feet (0.50, 1.00, and 1.41 meters), combined with the surge associated with a 100-year storm.

These heights are the only ones available from the 3Di model and were applied in this assessment. The highest increment of 4.62 feet is considerably lower than the projections provided by the state (see Figure 11). The US Geological Survey (USGS) is completing additional sea level rise and surge modeling for the Northern Coast, which will include higher projections, and should be considered in future assessments of the district.

Figure 14 shows a zoomed-in portion of the SHS in District 1 that is at high risk of flooding due to sea level rise and surge from a 100-year storm. Full, district-scale maps of sea level rise and surge impacts are available in the District 1 Technical Report.

STORM SURGE EFFECTS IN DISTRICT 1

The areas of District 1 most vulnerable to flooding from sea level rise and storm surge mirror those identified by the NOAA data used in the sea level rise analysis, and include the district's northern portion along SR 255 and US 101. The 3Di model also suggests that there will be vulnerable portions of SR 1 in Mendocino County. Figure 14 zooms in on one of the most vulnerable locations in the district, the Eureka-Arcata US 101 corridor.

The California Coastal Commission recently approved an improvement project for the corridor, which will address safety concerns along this stretch of US 101. The corridor improvement project will also assess and respond to sea level rise through raising structures incrementally. Caltrans will maintain flexibility for future on-alignment adaptation projects.

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

FERNBRIDGE | FEB 2019

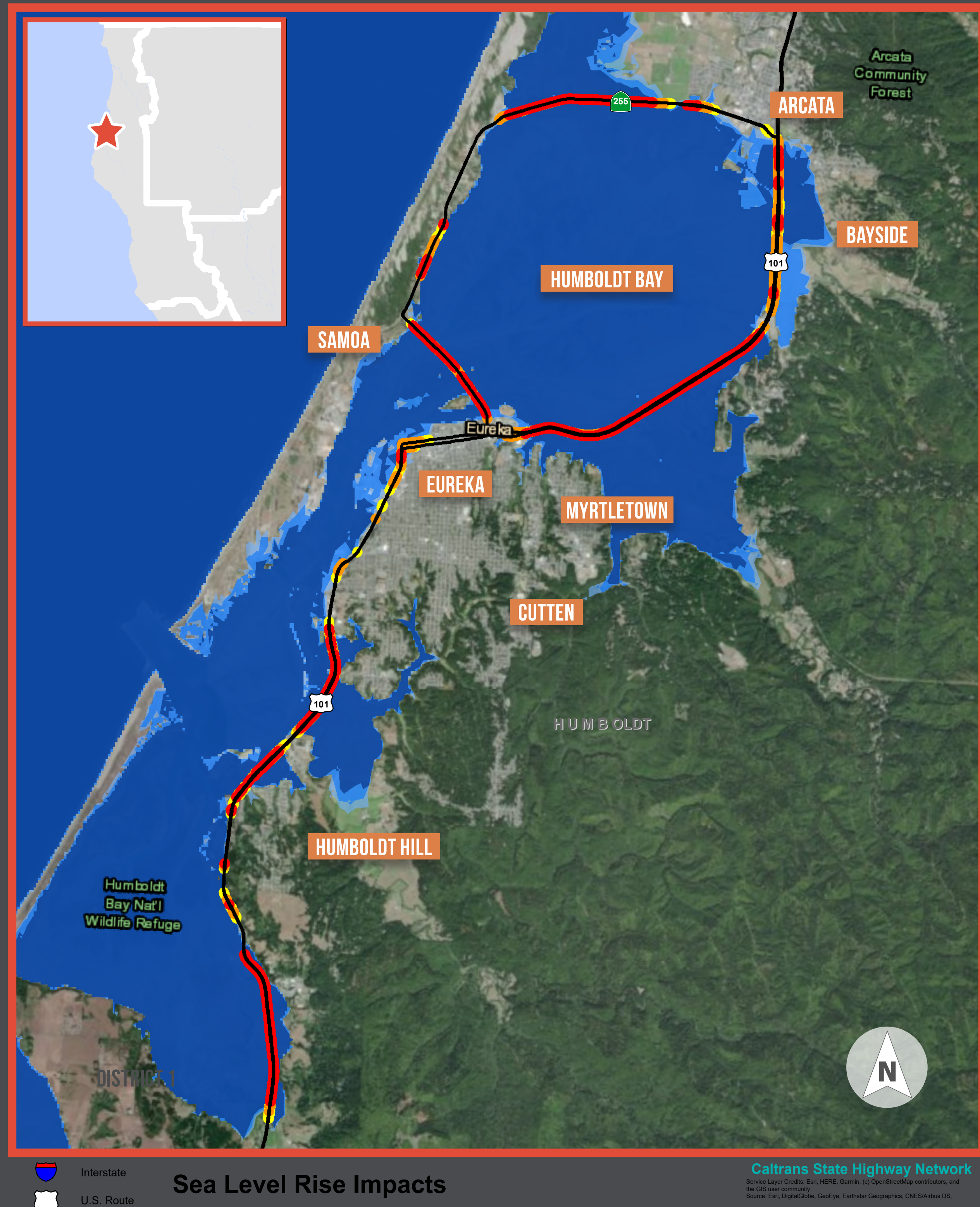
Table 3: Centerline Miles of State Highways in District 1 Flooded by Sea Level Rise and Surge During a 100-Year Storm

County	Sea Level Rise Height		
	1.64 ft (.5 m) + 100-Yr Storm	3.28 ft (1 m) + 100-Yr Storm	4.62 ft (1.41 m) + 100-Yr Storm
Del Norte	**0.3**	**1.0**	**1.9**
Humboldt	**10.4**	**14.9**	**16.9**
Mendocino	**0.9**	**1.1**	**1.7**

Note: There is no coastline in Lake County. Data does not include other state roads or local streets and roads.

Fig. 14

MODELED FLOODING FROM SEA LEVEL RISE AND STORM SURGE AROUND HUMBOLDT BAY



Impacts to State Highways by Sea Level Rise Increment

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

Sea Level Rise Increments

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

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

CLIFF RETREAT

The sea level rise and storm surge concerns noted in this report outline how higher water levels will directly impact transportation infrastructure. Changing water levels in the oceans will also create different forces at the shoreline, eroding beaches and causing cliff retreat along the 1,100-mile California coastline. Cliff retreat occurs when waves impact the base of a cliff and hydraulic action carves out a portion of the cliff face. This loss of rock and soil increases over time and undermines support for the cliff itself, eventually resulting in the collapse of the cliff face. Over time the cliff recedes, or "retreats", from its original position. Examples of 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.[27]

Rates of cliff retreat 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.

This District 1 assessment of cliff retreat used data developed by UC Berkeley for the sole purpose of this study. The data identify which sections of the District 1 coastline are at-risk from accelerated erosion and cliff retreat due to sea level rise. To develop this dataset, UC Berkeley researchers reviewed existing sea level rise and coastal erosion information developed by the Pacific Institute and US Geological Survey (USGS). Google Earth was used to identify areas along the District 1 coastline where there is active erosion today. NOAA elevation data was also used to understand existing conditions along the coastline. Information collected from these sources was used to conduct a new assessment of cliff retreat and erosion impacts to the SHS in District 1.

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

The data was simplified into a rating scheme that characterizes the level of concern for at-risk sites:

- **CRITICAL:** These areas show signs of ongoing distress to the road itself due to erosion or the encroachment of erosion requires immediate attention and on-site inspections.
- **MEDIUM:** These sections show signs of erosion and potential distress, and they should be reviewed and surveyed in detail to create a baseline of current conditions.
- **LOW:** These areas should be monitored with periodic surveys to track erosion.

Figure 15 on the following page provides a zoomed-in view of one location in the district where there are existing erosion concerns and projected "medium" and "critical" concern areas. The associated District 1 Technical Report includes district-wide maps of this data as well as more information how the data was created. Table 4 provides the centerline miles of highways in medium or critical concern areas across the district.

CLIFF RETREAT EFFECTS IN DISTRICT 1

Erosion and cliff retreat impacts are already a concern in District 1, where there are geologically active portions of the coastline that create ongoing issues for highway maintenance. Figure 15 focuses on one segment of the highway system where there are existing concerns: the bluffs near Westport in Mendocino County. The UC Berkeley study completed for District 1 identified multiple areas along SR 1 in this area that are at moderate and critical levels of concern. On-site evaluations of these areas will help District 1 understand current conditions, which can then be used to track changes over time. Depending upon the speed and severity of erosion and cliff retreat in this area, District 1 may consider re-routing SR 1 or protecting it through erosion control measures.

Table 4: Centerline Miles of State Highways in District 1 Vulnerable to Cliff Retreat Driven by Sea Level Rise

County	Medium	Critical
Del Norte	1.0	0.9
Humboldt	0.0	0.0
Mendocino	3.8	6.6
Total	**4.8**	**7.5**

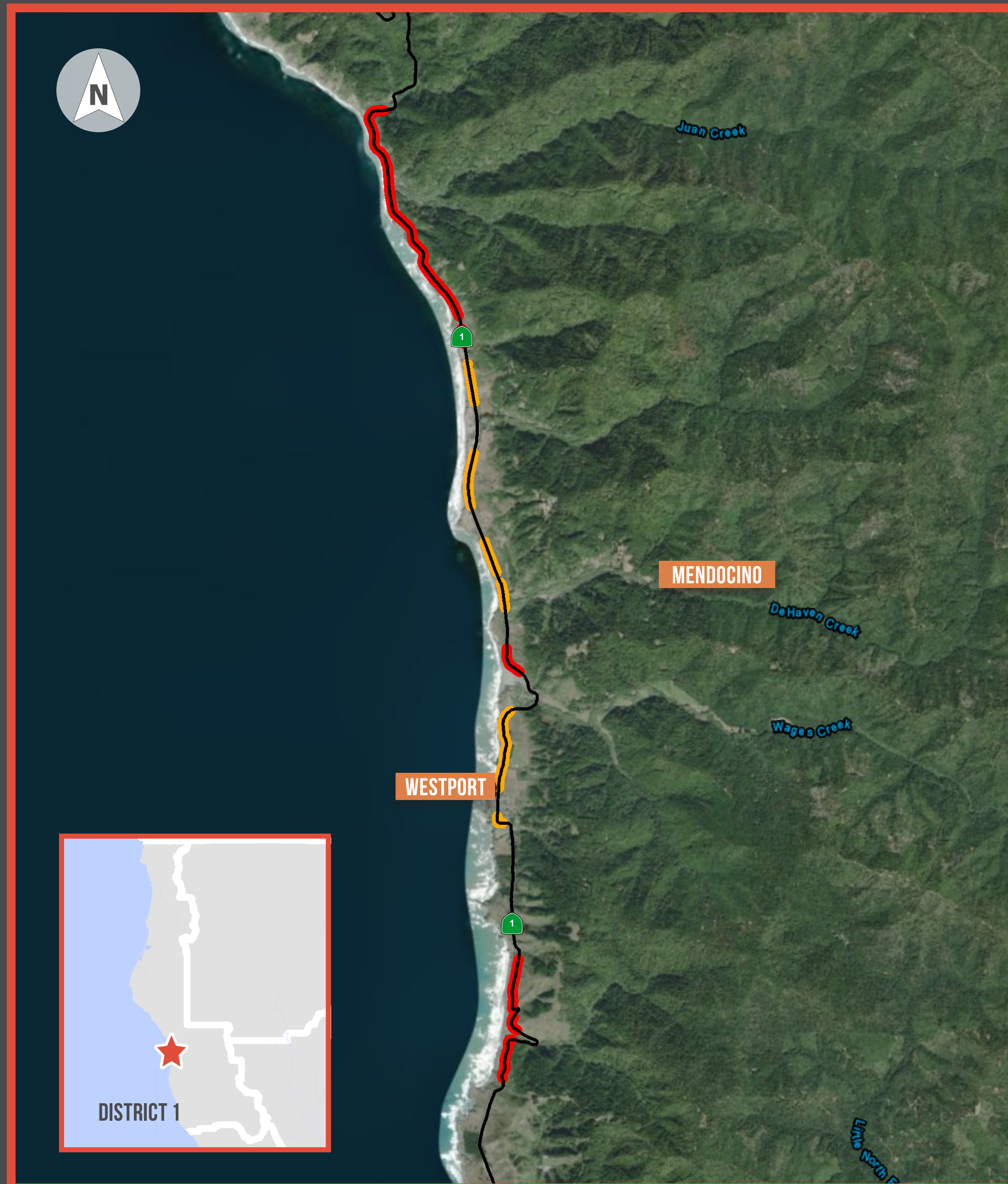
Note: There is no coastline in Lake County. Data does not include other state roads or local streets and roads.

Fig. 15

MODELED CLIFF RETREAT IMPACTS AROUND WESTPORT

Impacts to State Highways by Level of Cliff Retreat Concern

- Critical
- Medium



Interstate

U.S. Route

Cliff Retreat Hazard Level

Caltrans State Highway Network

Service Layer Credits: Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS,

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

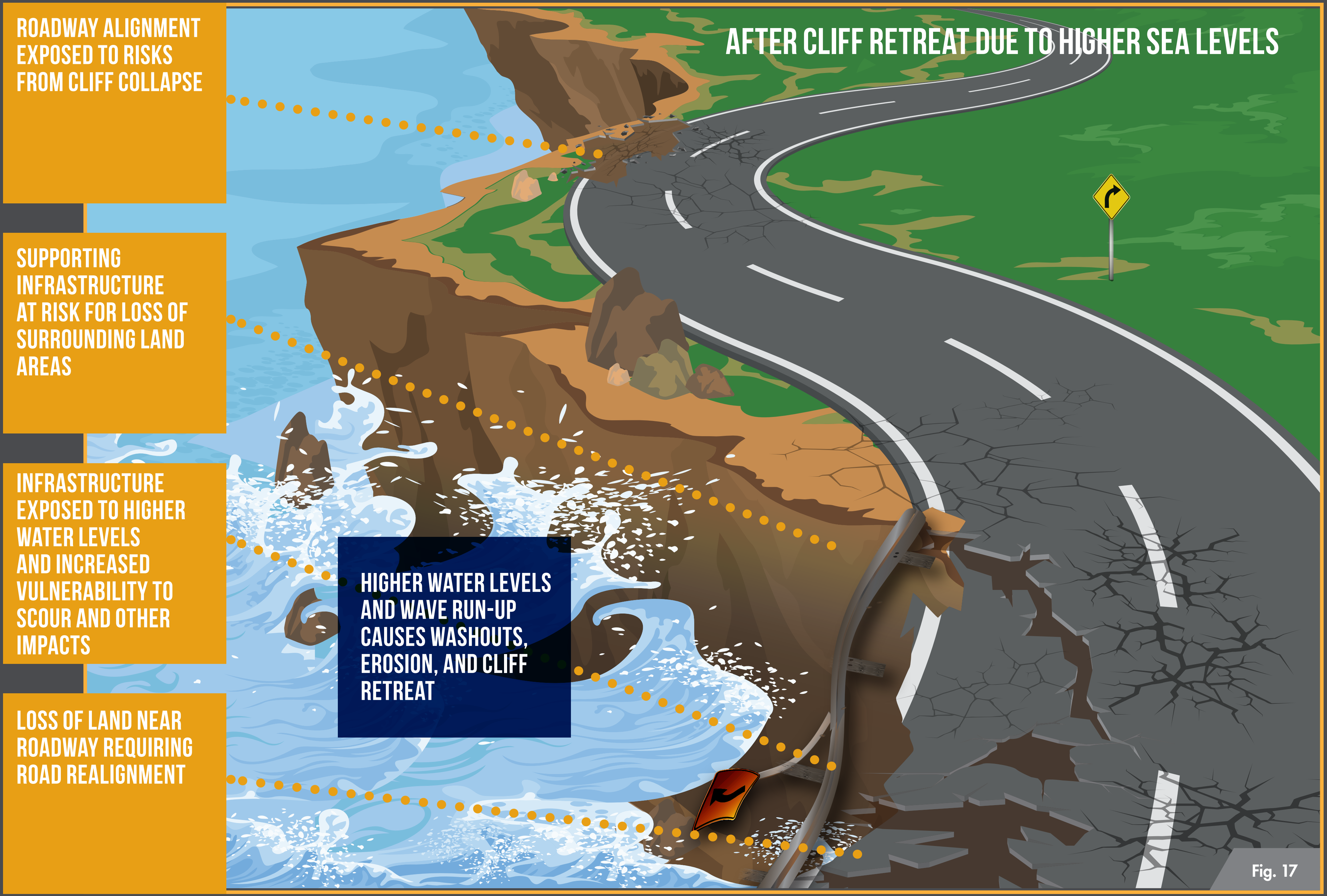


Fig. 17

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

INFRASTRUCTURE IMPACT 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.

CONFUSION HILL SLIDE | US 101

CONFUSION HILL SLIDE | US 101

CONFUSION HILL BRIDGES - US 101

US 101 was once positioned on an unstable hillside near the South Fork of the Eel River in Mendocino County. The hillside, known as the Confusion Hill Slide Area (named after a nearby roadside attraction), is an ancient, but still active, rockslide approximately 350 feet high and 3,000 feet wide. Heavy rain events would trigger landslides and debris flows onto US 101, causing traffic delays and expensive repairs—a full closure required a 250-mile detour and an estimated $7.1 million per month in travel delays.

For 17 years, US 101 experienced slip-outs, retaining wall failures, frequent debris flows, and road closures. District 1 documented that the closures were becoming more frequent and severe. In the winter of 2002 and 2003, roadway impacts caused such significant delays for community travel, goods movement, and local tourism that District 1 decided that US 101 had to be realigned to bypass the Confusion Hill Slide Area (see Figure 18).[28]

District 1 relocated approximately 1.9 miles of US 101, replacing the existing two-lane conventional highway with a relocated, two-lane conventional alignment that crossed the South Fork of the Eel River on two new bridges. The project started in 2008 and finished in 2009, and has since greatly reduced travel disruptions due to rock and landslides.

28 - Caltrans, "Confusion Hill Highway Realignment Project, Final Environmental Impact Report and Environmental Assessment," 2005, Last accessed August 29, 2019, https://web.archive.org/web/20100605054535/http://dot.ca.gov/dist1/d1projects/confusionhill/confhill_eir.pdf

Fig. 18

DIAGRAM OF CONFUSION HILL SLIDE AREA AND US 101 REALIGNMENT

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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].

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 1 for existing and future roadways. The following section highlights a district effort that demonstrates a proactive response to risks and prevent future impacts. While this effort did not specifically follow ADAP, it provides an example of how Caltrans districts can prepare their assets for future risks, such as extreme precipitation and increased river flows.

SR 20 AND SR 29 CULVERT REHABILITATION PROJECT

Many culverts along SR 20 and SR 29 in Lake County have reached the end of their useful life, and rehabilitation or replacement is necessary to prevent further damage to the culverts and surrounding roadbed. Drainage ditches with insufficient capacity also required rehabilitation. District 1 began a rehabilitation project for these routes to mitigate problems and provide capacity for future traffic flow. District 1 repaired or replaced thirty-two culverts and improved two ditches to provide additional capacity for heavy storm events. Future culvert replacements could follow ADAP to ensure that they are adequately sized for future precipitation.

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

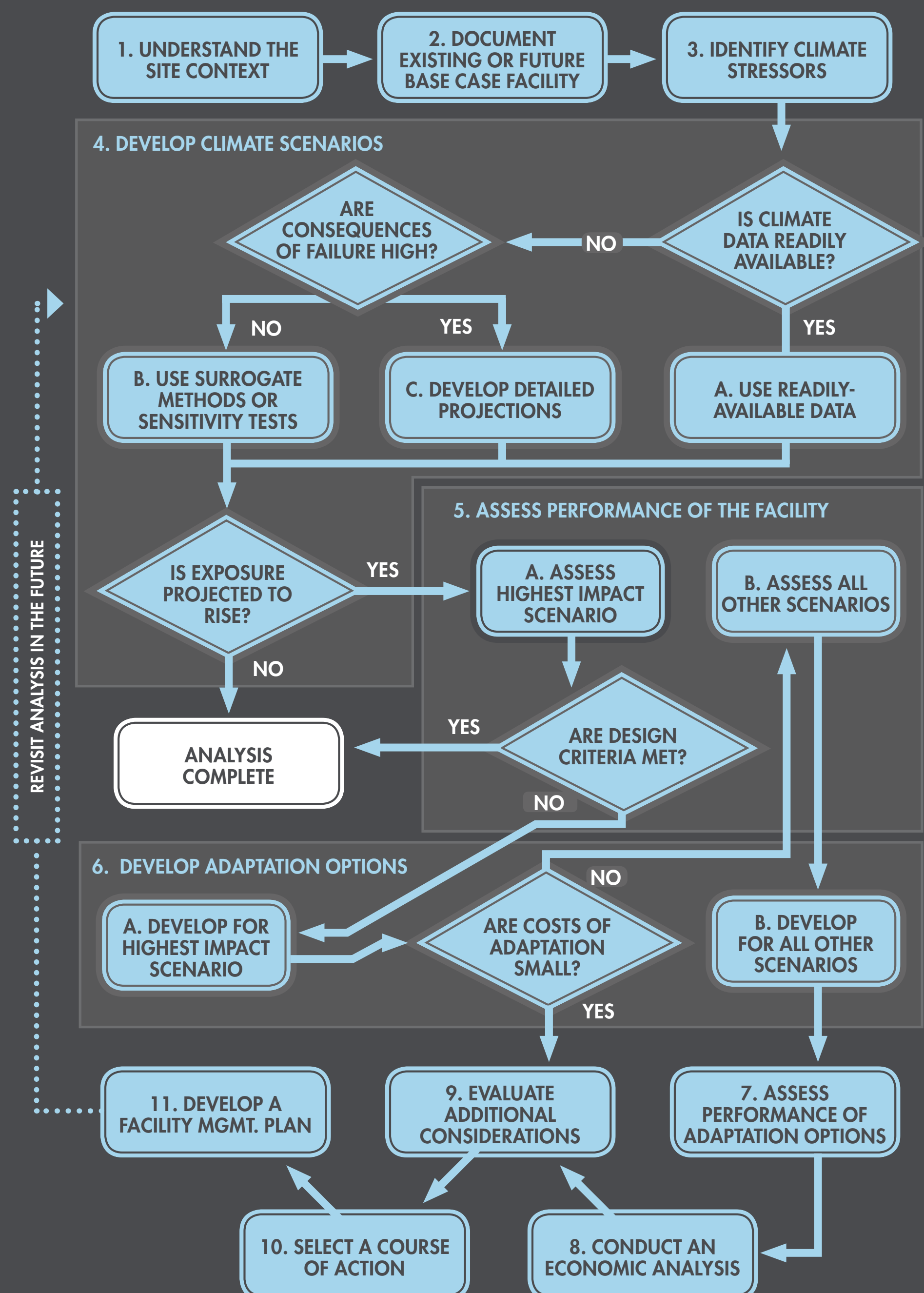
BEFORE

REPAIR

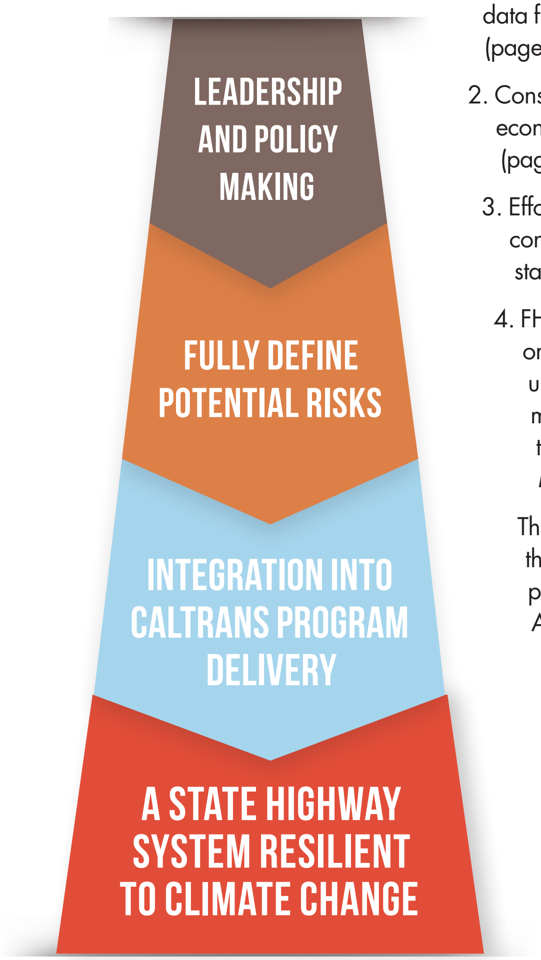
AFTER

Fig. 19

FHWA'S ADAP DESIGN PROCESS



WHAT DOES THIS MEAN TO CALTRANS?



GENERAL CONCLUSIONS

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

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

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

LEADERSHIP

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

Adapting to climate change challenges will require a proactive and collaborative approach. Caltrans recognizes that coordination with stakeholders is necessary for developing analyses and adaptation strategies that support and expand the state's current body of work. Working with local communities and other state agencies on adaptation strategies can improve decision-making and promote a collective response.

FULLY DEFINING RISKS

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

INTEGRATION INTO CALTRANS PROGRAM DELIVERY

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

A STATE HIGHWAY SYSTEM RESILIENT TO CLIMATE CHANGE

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

NEXT STEPS

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

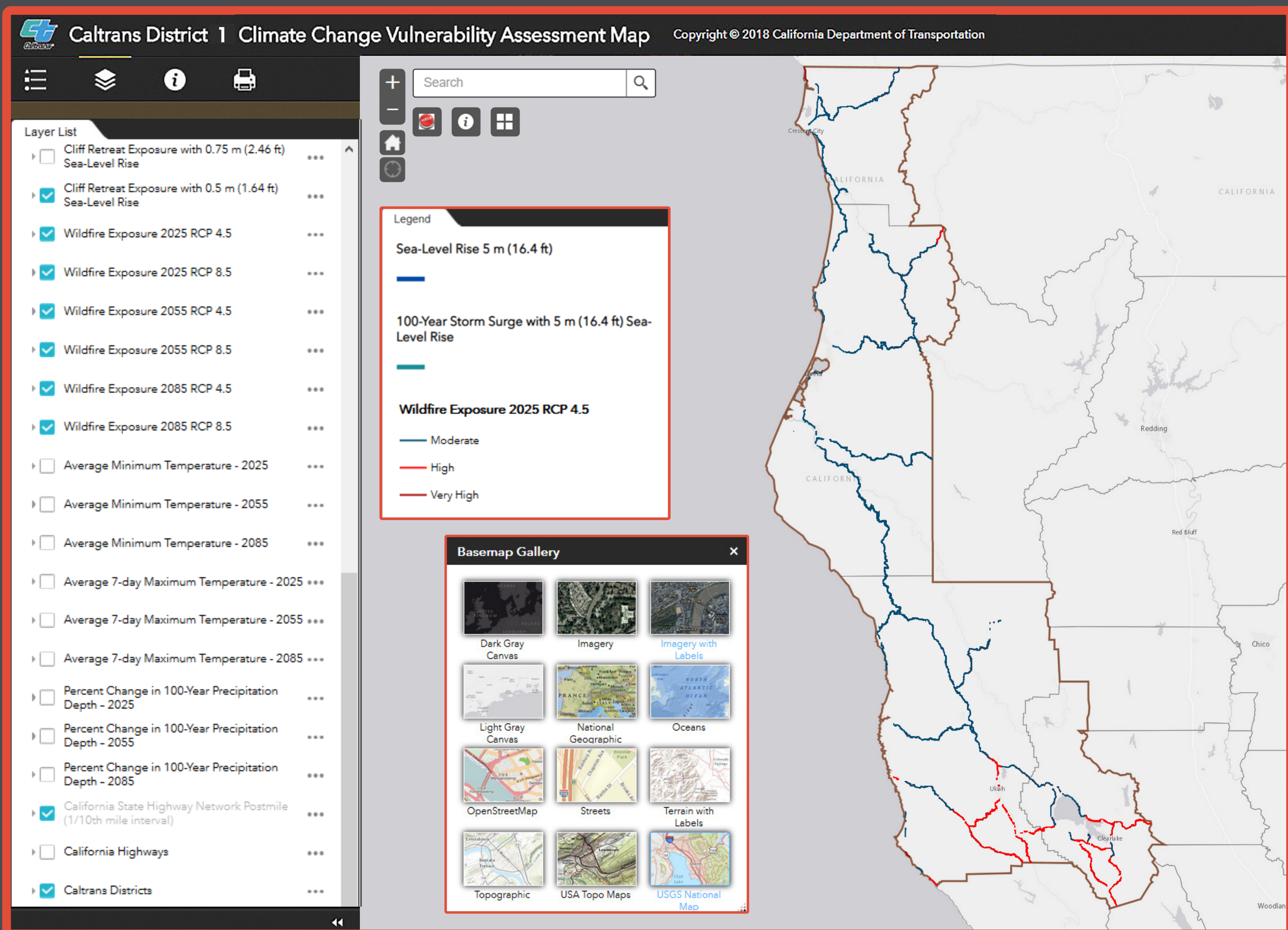
ON-LINE MAPPING TOOL FOR DECISION-MAKING

Caltrans has created an online mapping program to provide information for users across the state, using data assembled for this project. The Caltrans Climate Change Vulnerability Assessment Map can be accessed here.[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 SHS to determine exposure:** Once high hazard areas had been mapped, the next step was to overlay the Caltrans SHS centerlines with the data to identify the segments of roadway exposed.
- **Summarize the miles of roadway affected:** The final step in the geospatial analyses involved running the segments of roadway exposed to a stressor through Caltrans' linear referencing system, which provides an output GIS file indicating the centerline miles of roadway affected by a given hazard.

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