CALTRANS CLIMATE CHANGE VULNERABILITY ASSESSMENTS

2019

District 1

Technical Report

CONTENTS

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FIGURES

ACRONYMS AND ABBREVIATIONS

ADAP	Adaptation Decision-Making Assessment Process
CalFire	California Department of Forestry and Fire Protection
Caltrans	California Department of Transportation
CCC	California Coastal Commission
CEC	California Energy Commission
CMIP	Coupled Model Intercomparison Project
DWR	California Department of Water Resources
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
GCM	Global Climate Model
GHG	Greenhouse Gas
GIS	Geographic Information System
IPCC	Intergovernmental Panel on Climate Change
LOCA	Localized Constructed Analogues
MACA	Multivariate Adaptive Constructed Analogs
NOAA	National Oceanic and Atmospheric Administration
NRA	Natural Resources Agency
RCP	Representative Concentration Pathway
SHS	State Highway System
SR	State Route
USGS	US Geological Survey

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1. INTRODUCTION

The following report, developed for the California Department of Transportation (Caltrans), summarizes a vulnerability assessment conducted for that portion of the State Highway System (SHS) located in Caltrans District 1.[1] Although the SHS can be vulnerable to many different types of disruptions, this assessment specifically examined SHS vulnerabilities from climate change.

Climate change and extreme weather events have received increasing attention worldwide as one of the greatest challenges facing modern society. Many state agencies—such as the California Coastal Commission (CCC), the California Energy Commission (CEC), and the California Department of Water Resources (DWR)—have developed approaches for understanding and assessing the potential impacts of a changing climate on California's natural resources and built environment. State agencies are invested in defining the implications of climate change and many of California's academic institutions are engaged in developing resources for decision-makers. Caltrans initiated the current study to better understand the vulnerability of California's SHS and other Caltrans assets to future changes in climate. The vulnerability study had three objectives:

- Understand the types of weather-related and longer-term climate change events that will likely occur with greater frequency and intensity in future years,
- Conduct a vulnerability assessment to determine those Caltrans assets vulnerable to various climate-influenced natural hazards, and
- Develop a method to prioritize candidate projects for actions that are responsive to climate change concerns, when financial resources become available.

The current study focuses on the 12 Caltrans districts, each facing its own set of challenges regarding future climate conditions and potential weather-related disruptions. The District 1 report is one of the district reports that are in various stages of development.

1.1. Purpose of Report

The *District 1 Technical Report* is one of two documents developed to describe the work completed for the District 1 vulnerability assessment, the other being the *District 1 Summary Report*. The *Summary Report* provides a high-level overview on methodology, the potential implications of climate change to Caltrans assets, and how climate data can be applied in decision making. It is intended to orient non-technical readers on how climate change may affect the SHS in District 1.

This *Technical Report* is intended to provide a more in-depth discussion, primarily for District 1 staff. It provides background on the methodology used to develop material for both reports and general information on how to replicate those methods, if desired. The report is divided into sections by climate stressor (e.g., wildfire, temperature, precipitation) and each section presents:

- How that climate stressor is changing
- The data used to assess SHS vulnerabilities from that stressor
- The methodology for how the data were developed

[1] This assessment was conducted for the SHS in District 1 and does not include other Caltrans assets or state/local roads.

- Maps of the portion of district SHS exposed to that stressor, and
- Mileage of exposed SHS.

Finally, this *Technical Report* outlines a recommended framework for prioritizing a list of projects that might be considered by Caltrans in the future, as Caltrans plans adaptive responses. This framework was developed based on an examination of other prioritization frameworks used by transportation agencies and of alternative frameworks developed to guide decision making given climate change.

All data used in the District 1 Technical and Summary Reports were collected into a single database and provided to Caltrans. Caltrans will be able to use this data in its own mapping efforts and technical analyses. This database is expected to be a valuable resource for ongoing resiliency planning efforts. The contents of the District 1 database will also be available to the public in an online, interactive mapping tool.[2]

1.2. District 1 Characteristics

Caltrans District 1 is headquartered in Eureka, California. It consists of 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, home to a large variety of species. Some of the district's most important roadways follow the California Coastal Zone. The natural beauty along the coast, within Redwood National and State Parks, and throughout the district, attracts visitors from around the world.

23 state highways are wholly or partially located within District 1, with a combined length of 945 centerline miles. There are no significant air cargo or rail services and thus the district economy, especially the agriculture industry, is heavily dependent on the SHS in District 1. In addition, the SHS provides the primary access for outlying communities to receive emergency services, and in most communities, the state highway serves as the "main street."

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 corridors of State Routes (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

[2] Caltrans. "Caltrans Climate Change Vulnerability Assessment Map." 2017. Last accessed June 23, 2019, http://caltrans.maps.arcgis.com/apps/webappviewer/index.html?id=517eecf1b5a542e5b0e25f337f87f5bb

accommodations. SRs 101 and 299 also are part of the Strategic Highway Network (STRAHNET), which serves military bases.

According to the District System Management Plan, "coastal areas of the District experience mild, dry, and frequently foggy summers, and wet, cool winters. Inland, summers are dry and substantially warmer, while winters are wet and cool, with snowfall common at elevations over 3,000 feet."[3] District 1 has acknowledged that portions of the coastal transportation infrastructure are vulnerable to the impacts of sea level rise. "Several segments of the District's highways and other facilities are currently impacted by major flood events, especially in conjunction with high tides, high winds and storm surges. Rises in sea level would aggravate flooding and potentially increase damage."[4] The Plan also noted that (as of 2009) with the projected rise in sea level, an estimated 11,000 residents of District 1 would be vulnerable to sea level rise. More generally the district noted in its SR 1 Transportation Concept Report that "California coast climate change will exacerbate existing coastal hazards such as coastal bluff erosion, dune erosion, 1-percent flood events, landslide frequency, and wildfire severity. In addition to existing coastal hazards, sea level rise has the potential to inundate low lying coastal areas".[5]

District 1 staff interact with many different organizations and agencies, including four regional transportation planning agencies, local governments, Native American Tribes, non-profit organizations, political representatives, bicycle and pedestrian advocacy groups, and other stakeholder organizations. Given the natural beauty and environmental sensitivity in the region, many groups have been created to protect the natural environment.

[3] Caltans District 1. 2012. "District 1 System Management Plan." Last accessed June, 2019, http://www.dot.ca.gov/dist1/planning/regional-system/dsmp.pdf

[4] Ibid.

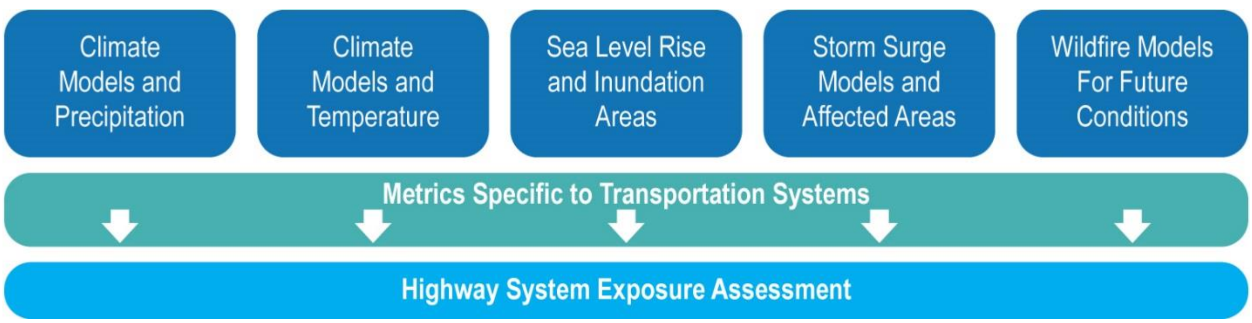
[5] Caltrans District 1, 2016. Transportation Concept Report State Route 1, District 01, March. Last accessed June 29, 2019, http://www.dot.ca.gov/dist1/planning/regional-system/tcr/tcr_1.pdf

2. POTENTIAL EFFECTS FROM CLIMATE CHANGE ON THE STATE HIGHWAY SYSTEM IN DISTRICT 1

Climate and extreme weather conditions in District 1 are changing as global greenhouse gas (GHG) emissions lead to higher temperatures and changes in precipitation patterns. These changing conditions are anticipated to affect the SHS in District 1 as well as other Caltrans assets. These impacts may appear in a variety of ways and may increase District 1's infrastructure's exposure to environmental factors that exceed the original design considerations. The project study team, made up of consultant staff and subject matter experts, considered a range of climate stressors and how they align with Caltrans design criteria/other metrics specific to transportation systems.

Figure 2-1 illustrates the general process for deciding which metrics should be included in the overall SHS vulnerability assessment. First, Caltrans and the project study team considered which climate stressors affect transportation systems. Then, Caltrans and the project study team decided on a relevant metric that the climate stressor data could inform. For example, precipitation data were formatted to show the 100-year storm depth given that the 100-year storm is a criterion used in the design of Caltrans assets.[6]

FIGURE 2-1: CONSIDERATIONS FOR THE STATE HIGHWAY ASSESSMENT



Extreme weather events already disrupt and damage District 1 infrastructure. The following examples include weather-related issues and events that Caltrans District 1 has addressed in the past, which may become more prevalent as climate changes:

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.

[6] A 100-year storm has a one percent chance of occurrence every year.
[7] "National Centers for Environmental Information," National Oceanic and Atmospheric Administration, last accessed October 11, 2019 from https://www.ncdc.noaa.gov/

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 flood west of Fernbridge closed SR 211 in Humboldt County—floodwaters crested at around 24 feet—putting it just below the level of a "major flood."

FIGURE 2-2: SRS 96 AFTER WINTER STORM

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 for 160 days in Mendocino, Lake, Colusa, and Glenn Counties. It was the largest wildfire complex in California history and caused the closure of SR 20, SR 175, and SR 29,[9] caused resident evacuations, burned 459,000 acres, destroyed 280 structures, and killed one person.[10] Triple-digit temperatures and high winds preceded the fires.

[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," Last accessed August 8, 2019, https://www.fire.ca.gov/media/5510/top20_acres.pdf

Sea Level Rise – Sea level rise is a long-term threat in coastal areas. The effects of thermal expansion of ocean water combined with contributions from glacial and ice sheet melting will result in higher sea levels around the world. Higher sea levels will impact coastal infrastructure, potentially inundate low-lying sections, damage substructures, and cause erosion at the shoreline. In Humboldt County, regional studies have helped explain the projected impacts of sea level rise on Humboldt Bay and surrounding communities. The City of Arcata independently conducted a sea level rise 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.

Storm Surge – Increasing sea levels combined with new climatological changes to storm patterns are expected to alter and increase the effects of storm surge in coastal areas. Storm surge can have a powerful impact on coastal infrastructure and can cause extensive damage. Coastal infrastructure in many locations will be exposed to higher forces during storms than they were originally designed to withstand. Others, which originally were assumed to be outside of the surge zone, may now be exposed to the effects of storm surge. Storm surge is also expected to increase coastal erosion and landslides, causing shoreline retreat and exposing roadways to increased impacts from flooding.

Cliff Retreat – Large waves and elevated tides result in flooding and coastal erosion along District 1's 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 44 open coast locations along the Humboldt County coast.[12] Cliff instability along District 1's coastline is already an issue—most notably in Last Chance Grade, where US 101 traverses three miles of geologically active coastline in Del Norte County.[13]

Combined Effects – When extreme weather events follow one another, the impacts can become even more severe. For example, a wildfire following a drought can be more severe and widespread than if it happened during a normal year. These types of combined effects can sometimes be predicted and prepared for. If a wildfire burns a slope, Caltrans maintenance staff can take steps to stabilize that slope in preparation for the rainy season and mitigate risk of landslides. If these events cannot be prevented, Caltrans must focus their efforts on their response.

[11] City of Arcata. "King Tides and Sea Level Rise," Last accessed September 4, 2019, https://www.cityofarcata.org/759/Sea-Level-Rise

[12] FEMA Region IX, 2014. California Coastal Analysis and Mapping Project / Open Pacific Coast Study, Intermediate Data Submittal #3: Nearshore Hydraulics, Humboldt County, California. Last accessed August 29, 2019, https://humboldtgov.org/DocumentCenter/View/70093/FEMA-Open-Pacific-Coast-Study---Nearshore-Hydraulics?bidId=

[13] Caltrans. "Last Chance Grade," Last accessed September 4, 2019, https://lastchancegrade.com/

FIGURE 2-3: LAST CHANCE GRADE SLIDE

3. ASSESSMENT APPROACH

3.1. State of the Practice in California

California has been on the forefront of climate change policy, planning, and research across the nation. State officials have been instrumental in developing and implementing policies that foster effective GHG mitigation strategies and the consideration of climate change in State decision-making. California agencies have also been pivotal in creating climate change datasets that can be used to consider regional impacts across the state. At a more local level, efforts to plan for and adapt to climate change are underway in communities across the state. These practices are key to the development of climate change vulnerability assessments in California and were found to be very helpful in the development of the District 1 report. The sections below provide some background on the current state-of-the-practice in adaptation planning and how specific analysis methods were considered/applied in the District 1 vulnerability assessment.

3.1.1. Policies

Various policies implemented at the state level have directly addressed not only GHG mitigation, but climate adaptation planning. These policies require State agencies to consider the effects of climate in their investment and design decisions, among other considerations. State adaptation policies that are relevant to Caltrans include:

- **Assembly Bill 32** (2006) or the "California Global Warming Solution Act" was marked as being the first California law to require a reduction in emitted GHGs. The law was the first of its kind in the country and set the stage for further policy in the future.[14]
- **Executive Order S-13-08** (2008) directs state agencies to plan for sea level rise and climate impacts through the coordination of the state Climate Adaptation Strategy.[15]
- **Executive Order B-30-15** (2015) requires the consideration of climate change in all state investment decisions through full life cycle cost accounting, the prioritization of adaptation actions that 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.[16]
- **Assembly Bill 1482** (2015) requires all state agencies and departments to prepare for climate change impacts through (among others) continued collection of climate data, considerations of climate in state investments, and the promotion of reliable transportation strategies.[17]

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[14] California Air Resources Board, "Assembly Bill 32 Overview," modified. Last accessed August 5, 2014, https://www.arb.ca.gov/cc/ab32/ab32.htm

[15] California Legislative Information, "California Executive Order S-13-08 Requiring State Adaptation Strategy," Adaptation Clearinghouse, Last accessed August 29, 2019, https://www.adaptationclearinghouse.org/resources/california-executive-order-s-13-08-requiring-state-adaptation-strategy.html

[16] Office of Governor Edmund Brown, "Governor Brown Establishes Most Ambitious Greenhouse Gas Reduction Target in North America," modified April 29, 2015, Last accessed August 29, 2019, https://www.ca.gov/archive/gov39/2015/04/29/news18938/

[17] California Legislative Information, "Assembly Bill No. 1482," October 8, 2015, Last accessed August 29, 2019, https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201520160AB1482

- **Senate Bill 246** (2015) establishes the Integrated Climate Adaptation and Resiliency Program to coordinate with regional and local efforts with state adaptation strategies.[18]
- **Assembly Bill 2800** (2016) requires that state agencies account for climate impacts during planning, design, building, operations, maintenance, and investments in infrastructure. It also requires the formation of a Climate-Safe Infrastructure Working Group represented by engineers with relevant experience from multiple state agencies, including the Department of Transportation.[19]

These policies are among the factors state agencies consider when addressing climate change. Conducting an assessment such as this one for District 1 is a key step towards preserving Caltrans infrastructure against future extreme weather conditions and addressing the requirements of the relevant state policies above, such as Executive Order B-30-15, Assembly Bill 1482, and Assembly Bill 2800. Other policies, such as Executive Order S-13-08, stimulate the creation of climate data that can be used by state agencies in their own adaptation planning efforts. It is important for Caltrans staff to be aware of the policy requirements defining climate change response and how this assessment may be used to indicate compliance, where applicable.

One of the most important climate adaptation policies out of those listed above is Executive Order B-30-15. Guidance specific to the Executive Order and how state agencies can begin to implement was released in 2017, titled *Planning and Investing for a Resilient California*. This guidance will help state agencies develop methodologies in completing vulnerability assessments specific to their focus areas and in making adaptive planning decisions. *Planning and Investing for a Resilient California* created a framework to be followed by other state agencies, which is important in communicating the effects of climate change consistently across agencies.

3.1.2. Research

California has been on the forefront of climate change research nationally and internationally. For example, Executive Order S-03-05, directs that State agencies develop and regularly update guidance on climate change. These research efforts are titled the California Climate Change Assessments, the fourth edition of which was completed in 2018 (California's Fourth Climate Change Assessment). To understand the research and datasets coming out of the California's Fourth Climate Change Assessment, which are utilized in this District 1 vulnerability assessment, some background is needed on Global Climate Models (GCMs) and emissions scenarios.

Global Climate Models

GCMs have been developed worldwide by many academic or research institutions to represent the physical processes that interact to cause climate change, and to project future changes to GHG emission levels.[20] These models are run to reflect the different estimates of GHG emissions or atmospheric concentrations of these gases, which are summarized for use by the Intergovernmental Panel on Climate Change (IPCC).

[18] California Legislative Information, "Senate Bill No.246," October 8, 2015, Last accessed August 29, 2019, https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB246

[19] California Legislative Information, "Assembly Bill No. 2800," September 24. 2016, Last accessed August 29, 2019, http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160AB2800

[20] Intergovernmental Panel on Climate Change (IPCC), "What is a GCM?", Last accessed August 29, 2019, http://www.ipcc-data.org/guidelines/pages/gcm_guide.html

The IPCC is the leading international body recognized for its work in quantifying the potential effects of climate change and its membership is made up of thousands of scientists from 195 countries. The IPCC periodically releases Assessment Reports (currently in its 5th iteration), which summarize the latest research on a broad range of topics relating to climate change. The IPCC updates research on GHG emissions, identifies scenarios that reflect research on emissions generation, and estimates how those emissions may change given international policies. The IPCC also summarizes scenarios of atmospheric concentrations of GHG emissions to the end of the century.

There are dozens of climate models worldwide, but there are a set of GCMs that have been identified for use in California, as outlined in California's Fourth Climate Change Assessment section.

Emissions Scenarios/Pathways

There are two commonly cited sets of emissions data that are used by the IPCC:

1. The Special Report Emissions Scenarios (SRES)
2. The Representative Concentration Pathways (RCPs)

RCPs represent the most recent generation of GHG scenarios produced by the IPCC and are used in this report. These scenarios use three main metrics: radiative forcing, emission rates, and emission concentrations.[21] Four RCPs were developed to reflect assumptions for emissions growth, and the resulting concentrations of GHG in the atmosphere. The RCPs developed are applied in GCMs to identify projected future conditions and enable a comparison of one against another. Generally, the RCPs are based on assumptions for GHG emissions growth and an identified point at which they would be expected to begin declining (assuming varying reduction policies or socioeconomic conditions). The RCPs developed for this purpose include the following:

- RCP 2.6 assumes that global annual GHG emissions will peak in the next few years and then begin to decline substantially.
- RCP4.5 assumes that global annual GHG emissions will peak around 2040 and then begin to decline.
- RCP 6.0 assumes that emissions will peak near the year 2080 and then start to decline.
- RCP 8.5 assumes that high GHG emissions will continue to the end of the century.[22]

California's Fourth Climate Change Assessment

The California Climate Change Assessments are inter-agency research and "model downscaling" efforts for multiple climate stressors. California's Fourth Climate Change Assessment was led by the California Energy Commission (CEC) with other contributors including agencies such as the Department of Water Resources (DWR) and the Natural Resources Agency, as well as academic institutions such as the Scripps Institution of Oceanography (Scripps) and the University of California, Merced.

[21] G.P. Wayne. "A Guide to the IPCC's New RCP Emissions Pathways." From IPCC Expert Meeting Report, Towards New Scenarios for Analysis of Emissions, Climate Change, Impacts, and Response Strategies, IPCC 2007, August 30, 2013. Last accessed August 29, 2019, https://skepticalscience.com/rcp.php

[22] Malte Meinshausen, S.J. Smith, J.S. Daniel, et al. "The RCP Greenhouse Gas Concentrations and Their Extensions From 1765 To 2300 (Open Access)," *Climatic Change*, (2011) 109:213, Last accessed August 29, 2019, https://doi.org/10.1007/s10584-011-0156-z

Model downscaling is a statistical technique that refines the results of GCMs to a regional level. The model downscaling used in the Fourth Assessment is a technique called Localized Constructed Analogs (LOCA), which "uses past history to add improved fine scale detail to GCMs."[23] This effort was undertaken by Scripps and provides a finer grid system than is found in other techniques, enabling the assessment of changes in a more localized way than was previously available, since past models summarized changes with lower resolution.[24] Out of the 32 LOCA downscaled GCMs for California, 10 models were chosen by state agencies as being most relevant for California. This effort was led by DWR and its intent was to understand which models to use in state agency assessments and planning decisions.[25] The 10 representative GCMs for California are:

- ACCESS 1-0
- CanESM2
- CCSM4
- CESM1-BGC
- CMCC-CMS
- CNRM-CM5
- GFDL-CM3
- HadGEM2-CC
- HadGEM2-ES
- MIROC5

Data from these models are available on Cal-Adapt, California's Climate Change Research Center.[26] The Cal-Adapt data are some of the best available data in California on climate change and, for this reason, selections of data from Cal-Adapt and the GCMs above were utilized in this study.

3.2. Other District 1 Efforts to Address Climate Change

In addition to the work done by Caltrans, there are regional efforts underway in District 1 relating to climate change planning and preparedness. Some examples of these efforts in District 1 include:

- **District 1 Climate Change Vulnerability Assessment and Pilot Studies FHWA Climate Resilience Pilot Final Report (2014)[27]** – 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

[23] Cal-Adapt. "LOCA Downscaled Climate Projections," Last accessed August 29, 2019, http://cal-adapt.org/

[24] David W. Pierce, Dan Cayan, and Bridget Thrasher, "Statistical Downscaling Using Localized Constructed Analogs," April 16, 2014, Last accessed August 29, 2019, http://journals.ametsoc.org/doi/abs/10.1175/JHM-D-14-0082.1

[25] California Department of Water Resources, "Perspectives and Guidance for Climate Change Analysis," Climate Change Technical Advisory Group, August 2015, Last accessed August 29, 2019, https://water.ca.gov/LegacyFiles/climatechange/docs/2015/1_14_16_PerspectivesAndGuidanceForClimateChangeAnalysis_MasterFile_FINAL_08_14_2015_LRW.pdf

[26] For more information, visit http://cal-adapt.org/

[27] http://www.dot.ca.gov/dist1/planning/regional-system/ccps/final_report-main_document.pdf

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.

- **Climate Change and Health Profile Reports for Del Norte, Humboldt, Lake and Mendocino Counties (2017) –**The four District 1 counties in cooperation with the California Department of Public Health produced reports about climate change and future health impacts to county residents. The reports include regional climate projections for temperature, heat waves, fire, precipitation, and snow pack, and describe how changes in climate could impact public health (the counties are in the North Coast climate impact area). Climatic changes can cause a range of impacts to water and air quality, weather, and the local environment that can subsequently lead to disease, injuries, malnutrition, and mental health effects in humans. These impacts may be disproportionately felt by vulnerable populations such as the very young or elderly, disabled, low income, or those with other health conditions. To identify the size of these population groups who are at the highest risk, both county reports provide local population demographic profiles. Some of these statistics are summarized below for Mendocino County:
    - In 2010, approximately 44% (38,802 residents) of the county's population lived in fire hazard zones of medium to very high severity. From 1980 to 1989, 25 wildfires at least 490 acres in size consumed a total of 226,786 acres in the North Coast Region.
    - In 2010, the age-adjusted death rate in Mendocino County was higher than the state average. Disparities in death rates among race/ethnicity groups highlight how certain populations disproportionately experience health impacts. Within the county, the highest death rate occurred among American Indians and the lowest death rate occurred among Hispanics/Latinos.
    - In 2012, nearly 46% of adults (59,511; pooled for Lake and Mendocino counties) reported one or more chronic health conditions including heart disease, diabetes, asthma, severe mental stress or high blood pressure.
    - Among climate-vulnerable groups in 2010 were 5,347 children under the age of 5 years and 13,493 adults aged 65 years and older.
    - In 2010, Mendocino County had approximately 5,010 outdoor workers whose occupation increased their risk of heat illness. In 2010, roughly six percent of households did not own a vehicle that could be used for evacuation (statewide average was eight percent).
    - In 2009, approximately 59% of households were estimated to lack air conditioning, which may be needed in future years given temperature rise in the county (statewide average was 36%).[28]

[28] California Department of Public Health. 2017. "Climate Change and Health Profile Report Mendocino County," Last accessed August 29, 2019, https://www.cdph.ca.gov/Programs/OHE/CDPH%20Document%20Library/CHPRs/CHPR045Mendocino_County2-23-17.pdf

Each report suggested ways that the counties can act to protect these people and the rest of the public against projected climate-related health impacts. Some of these suggestions can be enacted in the near-term, like starting a public outreach campaign, improving heat warning systems, and further research on the nexus between climate change and health. Other suggestions are long-term goals, such as developing resiliency funding opportunities, reducing urban heat islands, and promoting access to health care.[29]

- **The Pacific Institute (2009)** – A 2009 study by the Pacific Institute, entitled *The Impacts of Sea Level Rise on the California Coast,* along with projections from the 2012 National Research Council (NRC) report: *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future,* have been used in the district to warn about future threats relating to sea level rise and coastal erosion. This base data was used in the Transportation Concept Report for SR 1 to identify the following key issues along the corridor.
    - "Bluff Erosion: SR 1 is potentially exposed to damage from various slides and slips. Often when the highway is located on a seaside cliff or bluff few alternative routes are feasible. In these circumstances, protection strategies may be the only viable strategy.
    - Dune Erosion: while dune erosion may not directly impact roadway integrity, dunes, beaches, and wetlands afford SR 1 protection from storm surge, and flooding. Adaptation strategies to protect or elevate the roadway may be necessary near dune erosion sights, and proactive protection strategies for natural armoring should be considered when feasible.
    - 1-Percent Annual Chance Flood: the combination of increased sea levels and climate change induced variations in storm severity has the potential to increase flood related closures of SR 1. Adaptation strategies for flooding generally include accommodating by elevating the roadway or retreating from flood zones.
    - Salt Water Inundation: SR 1 is expected to experience minimal salt water inundation by 2100. SR 1's resilience to sea level rise can be attributed to elevation, and natural armoring. Although no major inundation is expected along SR 1, areas crossed by bridges may become inundated requiring minor protection strategies be considered. Furthermore, saltwater inundation, dune erosion, and bluff erosion may bring sections of SR 1".[30]
- **Humboldt Bay Sea Level Rise Adaptation Planning Project (2018) -** 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."[31] 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)

[29] California Department of Public Health. 2017. Op cit.
[30] Caltrans District 1, 2016. op cit.
[31] 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

developing an adaptation plan for Humboldt Bay. The adaptation plan included a detailed analysis of the threats to transportation for the US 101 corridor.

- **Yurok Tribe Climate Change Adaptation Plan (2013)** – 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."[32] 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.

- **Humboldt Bay Shoreline Inventory, Mapping and Sea Level Rise Vulnerability Assessment (2013)** - The purpose of this project was to, 1) inventory and map existing shoreline conditions on Humboldt Bay, 2) assess existing shoreline vulnerability to breaching or overtopping, under current tidal and climatic conditions, 3) assess existing shoreline vulnerability to sea level rise, and 4) identify land uses and infrastructure. One of the major products of the study was the creation of a GIS database containing geospatial data of Humboldt Bay's shoreline. The study observed,

  > "Based upon existing conditions, a sea level rise of 1 foot plus extreme high tide (EHT) would expose approximately 11 miles of dikes (28%) to overtopping in all six hydrologic units of Humboldt Bay. A conservative estimate for California is that we could see 1 foot of sea level rise by 2050. Unfortunately, based upon the North Spit tide record, Humboldt Bay is also subsiding, resulting in the highest rate of sea level rise in California. Because of the effect of subsidence, Humboldt Bay could realize a relative sea level rise of 1 foot sooner than 2050."

  As noted in the conclusions, there is time to plan and adapt to sea level rise, but the more time jurisdictions wait, the more likely that extensive emergency flooding will be a problem.

- **Humboldt Bay: Sea Level Rise, Hydrodynamic Modeling, and Inundation Vulnerability Mapping (2015)** - Sea level rise is an important concern for those who live and work near Humboldt Bay. The Coastal Ecosystems Institute of Northern California (CEINC) sponsored a study that identified sea level rise vulnerabilities in Humboldt Bay through a detailed technical study. The study was co-sponsored by the Humboldt County Public Works (County) and Humboldt Bay Harbor, Recreation, and Conservation District (District). Five sea level rise scenarios were assessed in this study. Tidal inundation maps indicated areas surrounding Humboldt Bay landward of mean high water (MHW) are vulnerable to existing and future sea levels that are currently protected from inundation due to the natural shoreline, levees, railroad and/or road grades, or other such barriers. The study also concluded that sea level rise rates observed in Humboldt Bay are faster than other parts of the west coast, and the southern end of the Bay will be affected sooner than the north. Sea level rise will increase the threat of levee failure, and increase the frequency of extreme events overtopping the levees and road and railroad grades, which protect the Bay's vulnerable areas.

- **Coastal Storm Modeling System (CoSMoS)** – The Caltrans Vulnerability Assessments for other districts have used CoSMoS, from the US Geological Survey (USGS), to assess sea level rise,

[32] 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

storm surge, and cliff retreat impacts to the SHS. This model makes detailed predictions of storm-induced coastal flooding, erosion, and cliff failures over large geographic scales. Coastal data are only available for the California north-central coast (Half Moon Bay to Pt. Arena), San Francisco Bay, Southern California, and Central California. However, data will soon be available for the rest of the Northern California coast, so that future District 1 studies will be able to use this model. The model was funded by stakeholders interested in understanding the associated impacts of various storm events combined with future sea level rise along the California coast and within San Francisco Bay. The CoSMoS model is robust in the variables considered and is conservative in its estimates by always assuming a maximum water level scenario for simulated storm events.

- **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." 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.

3.3. General Methodology

The adaptation planning methodology varies from stressor to stressor, given that each uses a different set of models, emissions scenarios, and assumptions, leading to data and information on which to develop an understanding of potential future climate conditions. The specific methods employed are further defined in each stressor section; however, there are some general practices that apply across all analysis approaches.

3.3.1. Time Periods

It is helpful to present climate projections in a way that allows for consistent comparison between analysis periods for different stressors. For this study, those analysis periods have been defined as the beginning, middle, and end of century, represented by the out-years 2025, 2055, and 2085, respectively. These years are chosen because some statistically derived climate metrics used in this report (e.g. the 100-year precipitation event) are typically calculated over 30-year time periods centered on the year of interest. Because currently available climate projections are only available through the end of the century, the most distant 30-year window runs from 2070 to 2099. 2085 is the center point of this time range and the last year in which statistically derived projections can defensibly be made. The 2025 and 2055 out-years follow the same logic but applied to each of the prior 30-year periods (2010 to 2039 and 2040 to 2069, respectively).

3.3.2. Geographic Information Systems (GIS) and Geospatial Data

Developing an understanding of Caltrans assets exposed to sea level rise, storm surge, and projected changes in temperature, precipitation, and wildfire required complex geospatial analyses. The geospatial analyses were performed using ESRI geographic information systems (GIS) software. 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/or value of a given hazard at various future time periods, under different climate scenarios. For example, extreme temperature maps were created for temperature metrics important to pavement binder grade specifications; maps of extreme (100-year) precipitation depths were developed to show changes in rainfall; burn counts were compiled to produce maps indicating future wildfire frequency; and sea level rise, storm surge, and cliff retreat maps were made to understand the impacts of future tidal flooding and erosion.

Determine critical stressor thresholds: Some stressors, namely temperature, precipitation and wildfire, vary in intensity across the landscape. In many locations, the future change in these stressors is not projected to be high enough to warrant special concern, whereas other areas may see a large increase in hazard risk. To highlight the areas most affected by climate change, the geospatial analyses for these stressors defined the critical thresholds for which the value of (or the change in value of) a stressor would be a concern to Caltrans. For example, the wildfire geospatial analysis involved several steps to indicate which areas are considered to have a medium, high, and very high fire exposure based on the projected frequency of wildfire.

Overlay the stressor layers with Caltrans SHS to determine exposure: Once high stressor areas had been mapped, the next general step in the geospatial analyses was to overlay the Caltrans SHS centerlines with the stressor data to identify the segments of roadway most exposed to each stressor.

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. This step was performed by Caltrans and provides an output GIS file indicating the centerline miles of roadway affected by a given stressor. Using GIS, this data can then be summarized in many ways (e.g. by district, county, municipality, route number, or some combination thereof) to provide useful statistics to Caltrans planners.

Upon completion of the geospatial analyses, GIS data for each step were saved to a database that was supplied to Caltrans after the study was completed. Limited metadata on each dataset was also provided in the form of an Excel table that described each dataset and its characteristics. This GIS data will be useful to Caltrans for future climate adaptation planning activities.

4. TEMPERATURE

The US National Climate Assessment states that the "number of extremely hot days is projected to continue to increase over much of the United States, especially by late century. Summer temperatures are projected to continue rising, and a reduction of soil moisture, which exacerbates heat waves, is projected for much of the western and central US in summer."[33] Because of California's size and its many highly varied climate zones, temperatures will likely rise in varying degrees across the state. US studies generally show that rising temperatures could impact the transportation system in several ways, including:

4.1. Design

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

4.2. Operations and Maintenance

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

Resources available for this study did not allow for a detailed assessment of all the impacts temperature might have on Caltrans activities. Instead, it was decided to take a close look at one of the ways in which temperature will affect Caltrans: the selection of a pavement binder grade. Binder is essentially the "glue" that ties together the aggregate materials in asphalt. Selecting the appropriate and recommended pavement binder is reliant, in part, on the following:

- **Low temperature** – The mean of the absolute minimum air temperatures expected over a pavement's design life.
- **High temperature** – The mean of the average maximum temperatures over seven consecutive days.

[33] US National Climate Assessment, U.S. Global Change Research Program, 2014, Last accessed August 29, 2019, http://nca2014.globalchange.gov/report/our-changing-climate/extreme-weather

These climate metrics are critical to determining the extreme temperatures a roadway may experience over time. This is important to understand, because a binder must be selected that can maintain pavement integrity under both extreme cold conditions (which leads to contraction) and high heat (which leads to expansion).[34]

The work completed for this effort included assessing the expected low and high temperatures for pavement binder specification in three future 30-year periods centered on the years 2025, 2055, and 2085. Understanding the metrics for these periods will enable Caltrans to gain insight on how pavement design may need to shift over time. Asphalt pavements are typically put in place for a period of approximately 20 years, so their design lives closely match the 30-year analysis periods used in this report. Because of their relatively short design lives, asphalt overlays of different specifications can be used as climate conditions change.

The project study team used the LOCA climate data developed by Scripps for this analysis of temperature,[35] which have a spatial resolution of 1/16 of a degree or approximately three and a half to four miles.[36] This dataset was queried to determine the annual lowest temperature and the average seven-day consecutive high temperature. Temperature values were identified for each 30-year period. The values were derived separately for each of the 10 California appropriate GCMs, for both RCP scenarios, and for the three time periods noted.

4.3. Temperature Analysis Results in District 1

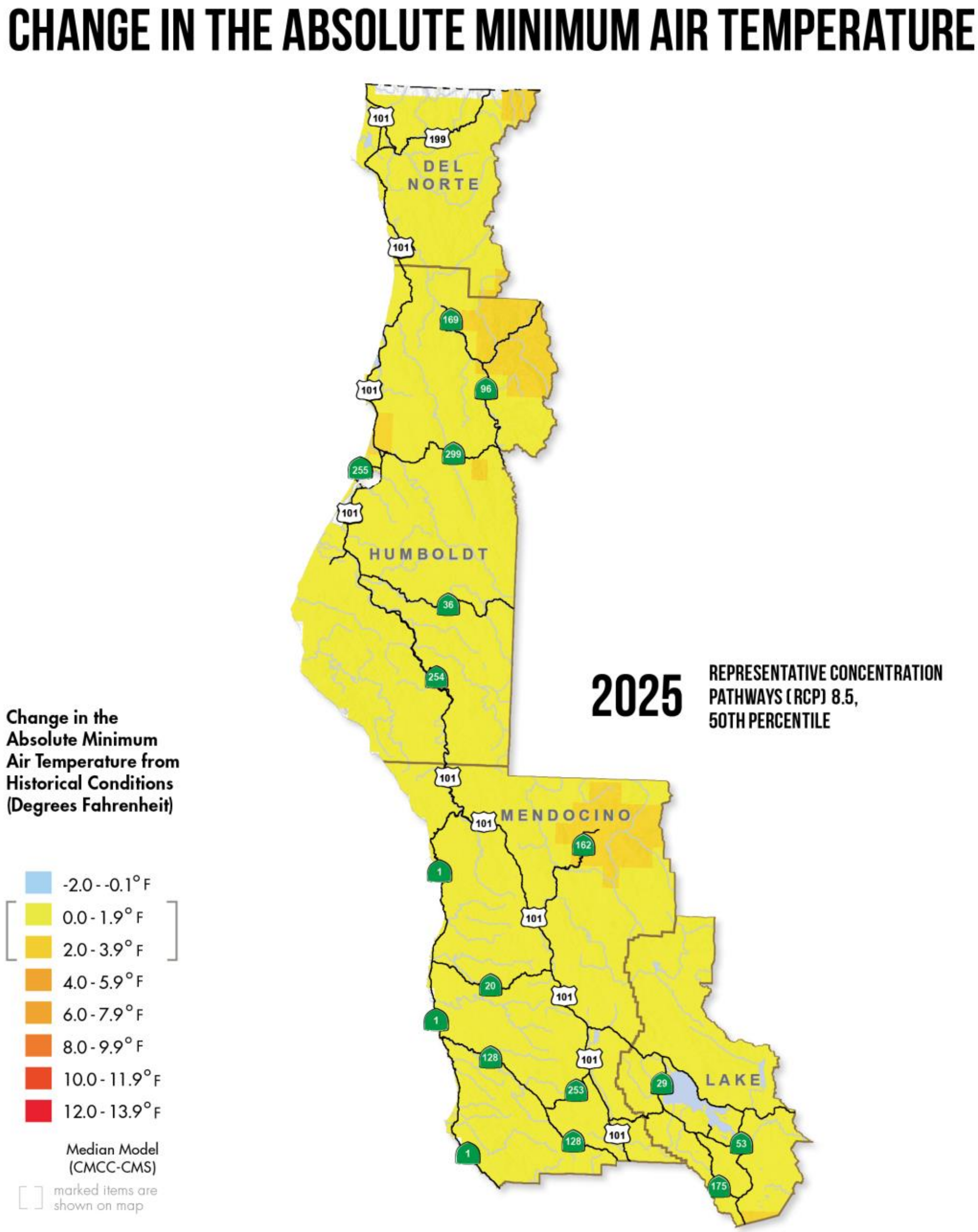
The figures on the following pages show the projected change in the two-temperature metrics explained above – the absolute minimum air temperature and the average maximum temperature over seven consecutive days, compared to historical averages (1975 to 2004). Temperatures are rising for both metrics across District 1. By 2025 (which represents 2010 to 2039), the minimum temperature is expected to rise by 0 to 3.9°F and the average maximum temperature is expected to rise by anywhere from 0 to 5.9 °F. By 2055 (representing 2040 to 2069), the projected rise for the minimum temperature is 2 to 5.9 °F and the average maximum is 2 to 9.9 °F. Finally, by 2085 (representing 2070 to 2099), the expected temperature rise is 4 to 9.9 °F for the minimum temperature and 6 to 11.9 °F for the maximum temperature metric. This has implications for SHS design and maintenance given that rising temperatures can affect pavement quality and lifespan.

[34] Note: The ideal low temperature range varies based on the type of binder being used and, in some cases, the placement temperature. Per the Caltrans Highway Design Manual, there are potentially several different types of binder being used in District 1 (dense-graded HMA, open-graded HMA, and rubberized asphalt). Thus, there is no single value that covers all binder application in the district; the value is different for each binder type.

[35] A more detailed description of the LOCA data set and downscaling techniques can be found at the start of this report.

[36] Cal-Adapt, "LOCA Downscaled Climate Projections," Last accessed August 29, 2019, https://cal-adapt.org/data/loca/

FIGURE 4-1: CHANGE IN THE ABSOLUTE MINIMUM AIR TEMPERATURE, 2025



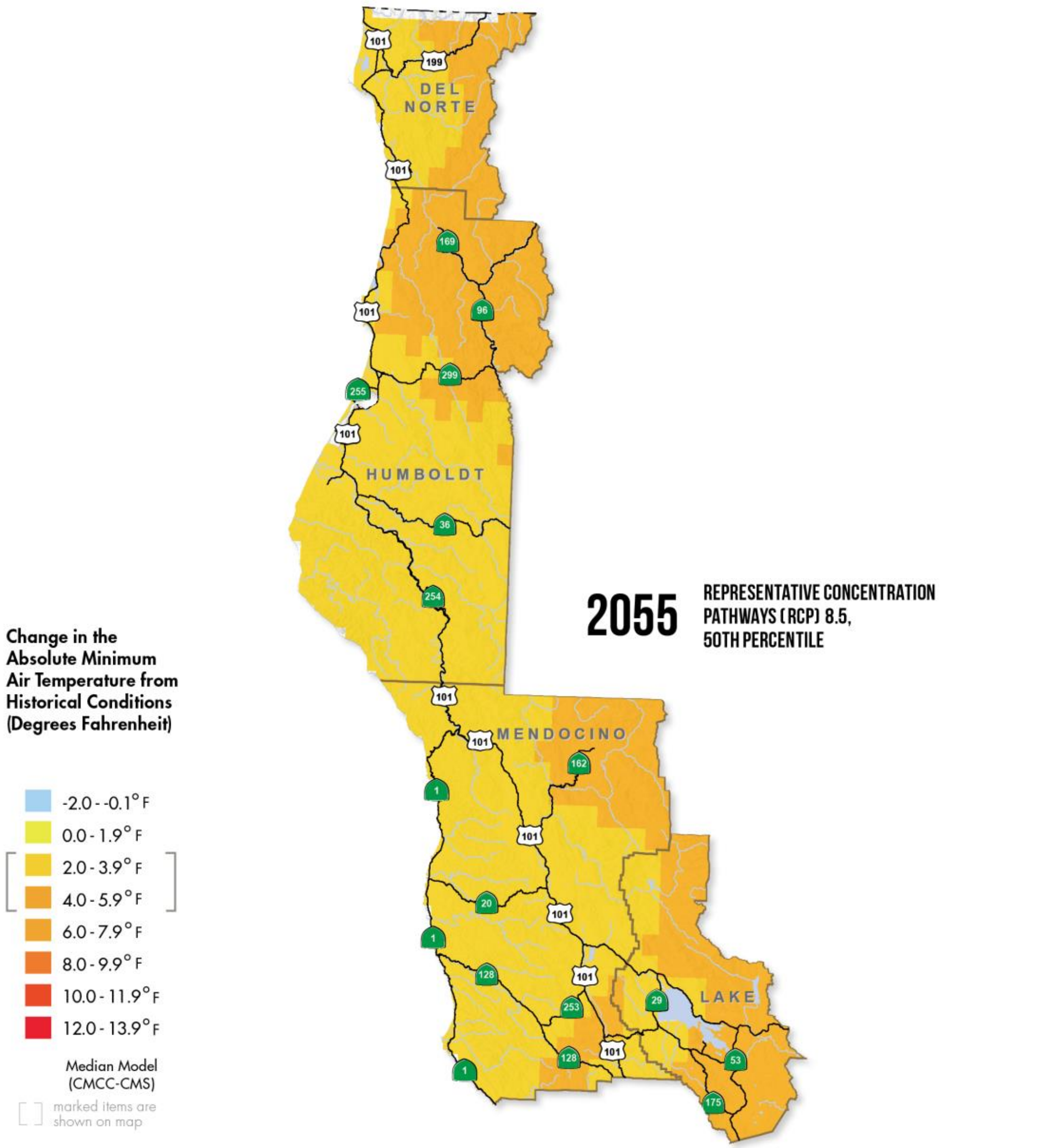
Future Change in the Absolute Minimum Air Temperature within District 1, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 1. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown was generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

Results represent the 50th percentile of downscaled climate model outputs under RCP 8.5 for the metric shown, as calculated across the state using the area weighted mean.

FIGURE 4-2: CHANGE IN THE ABSOLUTE MINIMUM AIR TEMPERATURE 2055

CHANGE IN THE ABSOLUTE MINIMUM AIR TEMPERATURE

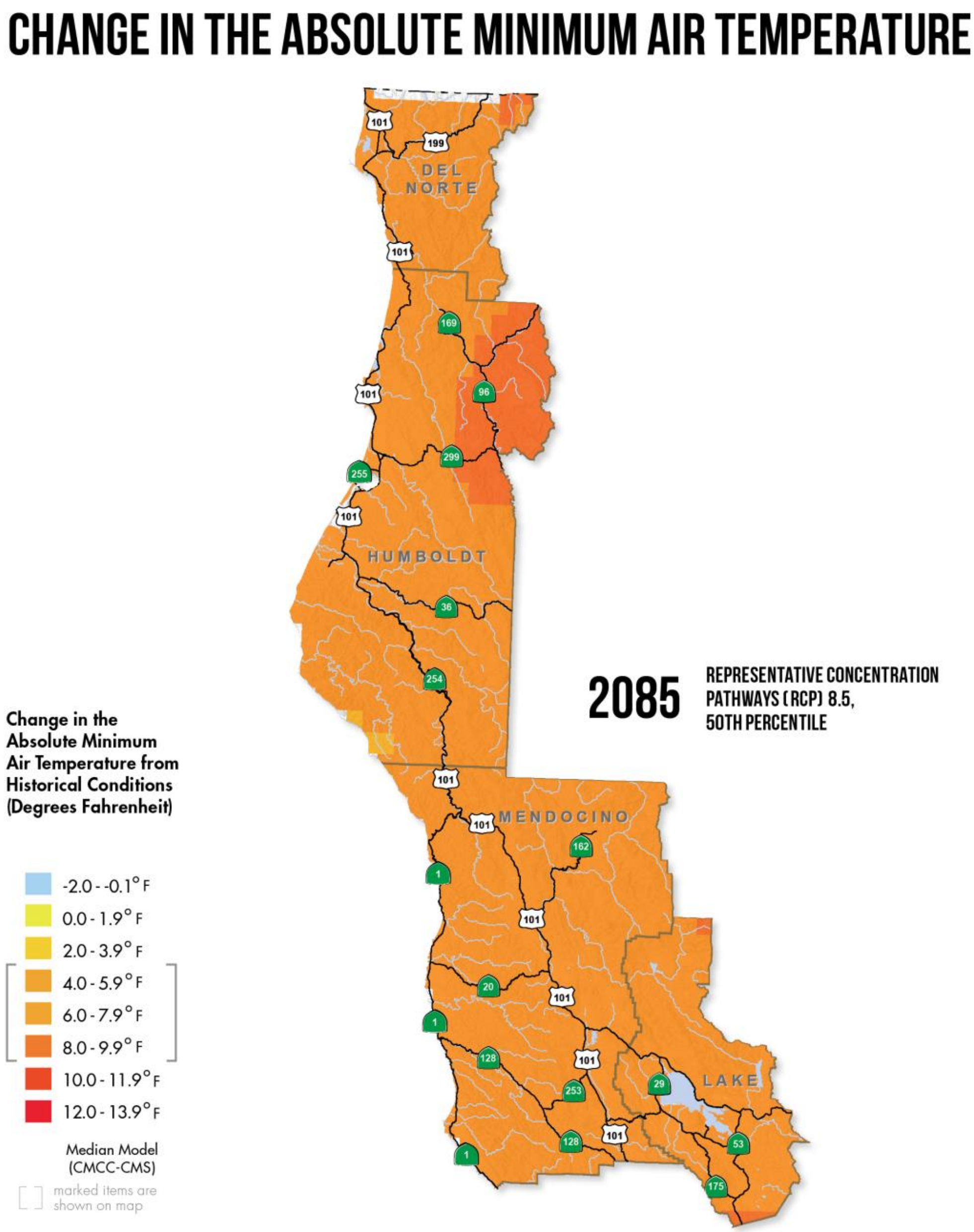


Future Change in the Absolute Minimum Air Temperature within District 1, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 1. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown was generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

Results represent the 50th percentile of downscaled climate model outputs under RCP 8.5 for the metric shown, as calculated across the state using the area weighted mean.

FIGURE 4-3: CHANGE IN THE ABSOLUTE MINIMUM AIR TEMPERATURE 2085

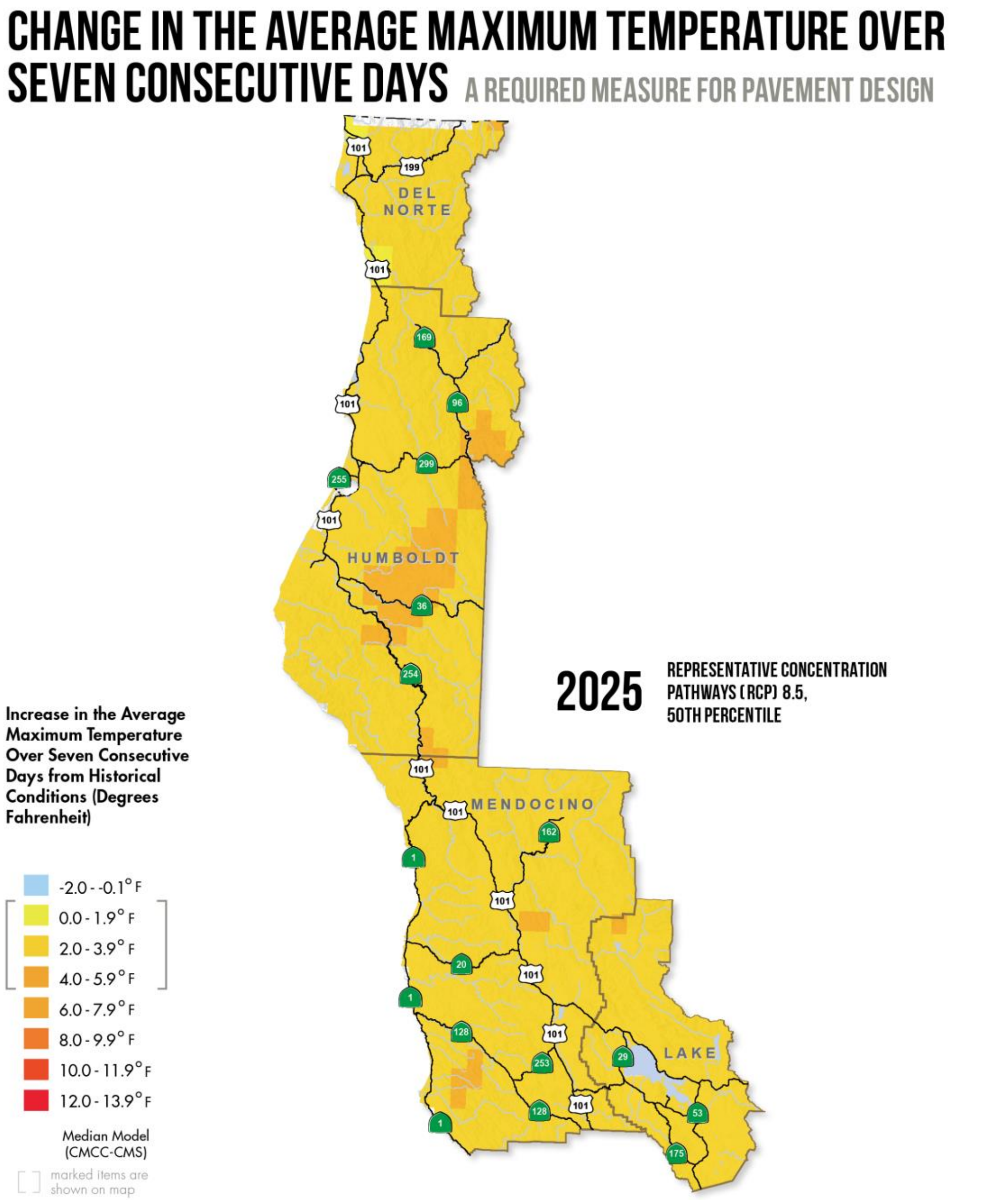


Future Change in the Absolute Minimum Air Temperature within District 1, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 1. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown was generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

Results represent the 50th percentile of downscaled climate model outputs under RCP 8.5 for the metric shown, as calculated across the state using the area weighted mean.

FIGURE 4-4: CHANGE IN THE AVERAGE MAXIMUM TEMPERATURE OVER SEVEN CONSECUTIVE DAYS 2025



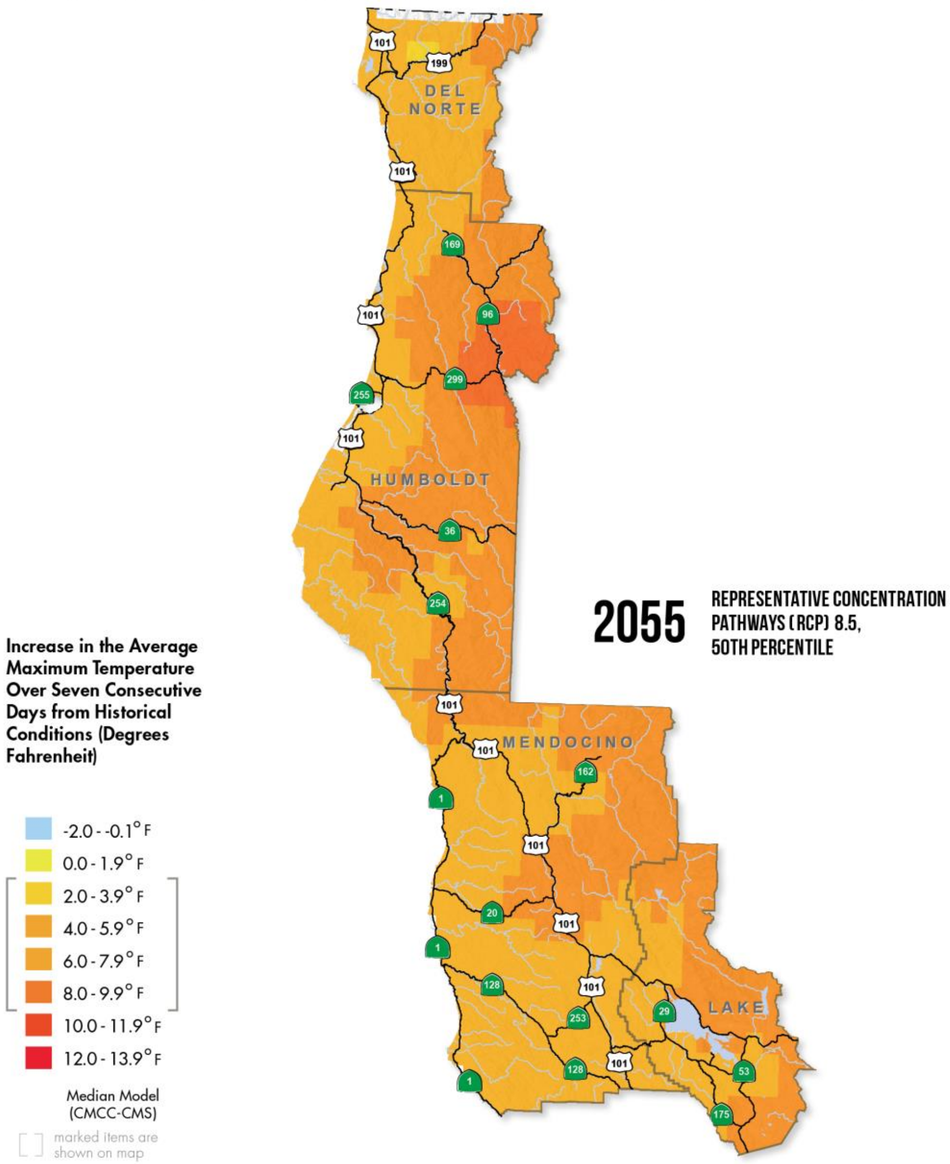
Future Change in the Average Maximum Temperature over Seven Consecutive Days within District 1, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 1. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown was generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

Results represent the 50th percentile of downscaled climate model outputs under RCP 8.5 for the metric shown, as calculated across the state using the area weighted mean.

FIGURE 4-5: CHANGE IN THE AVERAGE MAXIMUM TEMPERATURE OVER SEVEN CONSECUTIVE DAYS 2055

CHANGE IN THE AVERAGE MAXIMUM TEMPERATURE OVER SEVEN CONSECUTIVE DAYS A REQUIRED MEASURE FOR PAVEMENT DESIGN

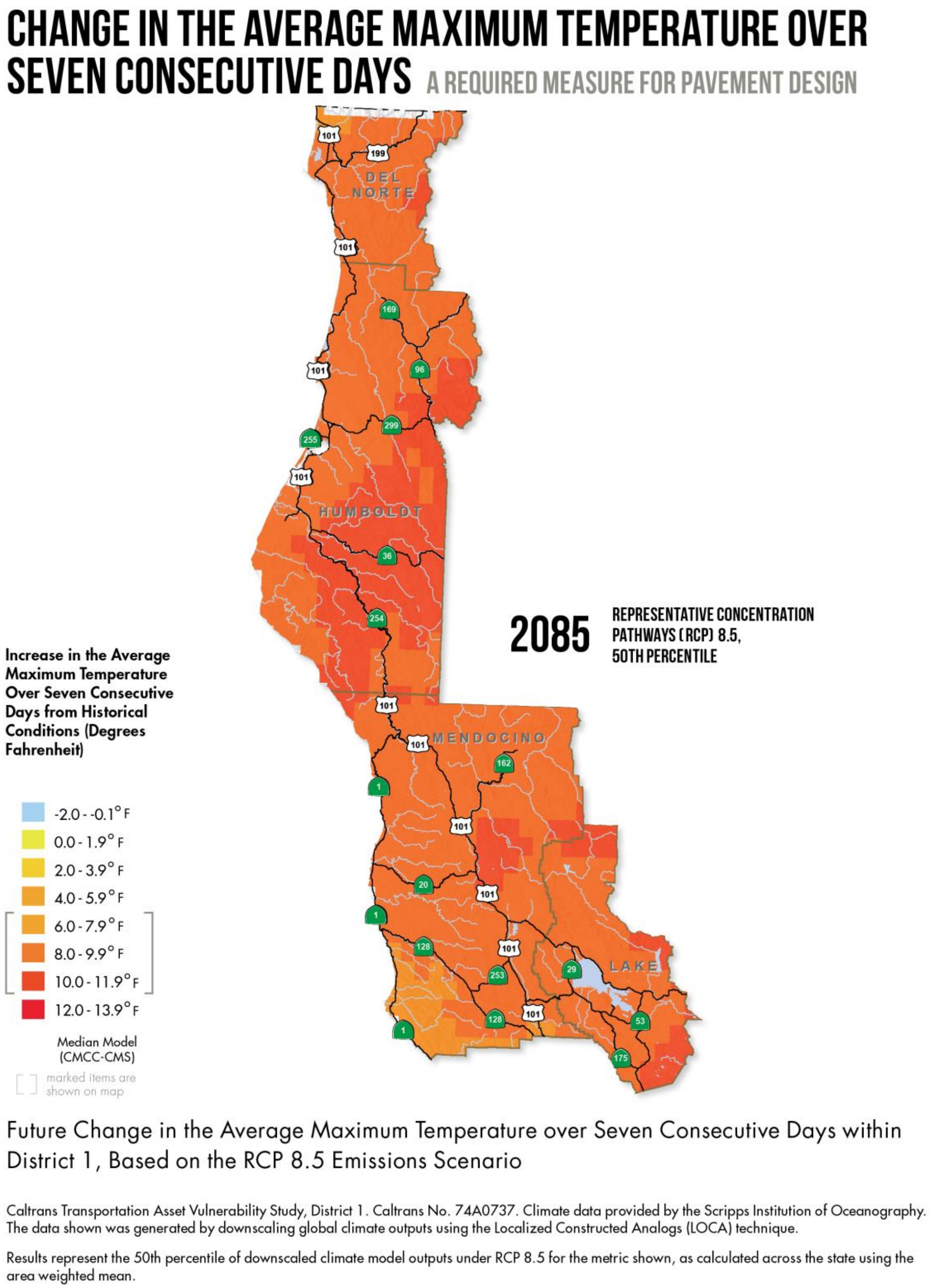


Future Change in the Average Maximum Temperature over Seven Consecutive Days within District 1, Based on the RCP 8.5 Emissions Scenario

Caltrans Transportation Asset Vulnerability Study, District 1. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown was generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

Results represent the 50th percentile of downscaled climate model outputs under RCP 8.5 for the metric shown, as calculated across the state using the area weighted mean.

FIGURE 4-6: CHANGE IN THE AVERAGE MAXIMUM TEMPERATURE OVER SEVEN CONSECUTIVE DAYS 2085



5. PRECIPITATION

According to the US National Climate Assessment, the Southwest region of the United States is expected to experience less precipitation overall[37], but with the potential for heavier individual events and with more precipitation falling as rainfall. This section of this report focuses on how these heavy precipitation events may change and become more frequent over time.

Analysis of future precipitation is, in many ways, one of the most challenging tasks in assessing long-term climate risk. Modeled future precipitation values can vary widely. Thus, analysis of trends is considered across multiple models to identify predicted values and help drive effective decisions. Future precipitation was analyzed through a broad range of potential effects predicted by a set, or ensemble, of models. 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.

Transportation assets in California are affected by precipitation in a variety of ways—from inundation/flooding, to landslides, washouts, or structural damage from heavy rain events. Current transportation design uses return period storm events as a variable to include in asset design criteria. A return period storm event is the historical intensity of storms based on how often such level of storms have occurred in the past. A 100-year design standard is often applied in the design of transportation facilities and is cited as a design consideration in Section 821.3, Selection of Design Flood, in the *Caltrans Highway Design Manual*.[38] The 100-year storm rainfall was chosen for analysis in this vulnerability assessment, using best available precipitation projections for the state.

The Scripps Institution for Oceanography, other academic institutions, and state agencies are working to better understand future precipitation projections. The most up-to-date precipitation research for the state was compiled as a part of *California's Fourth Climate Change Assessment*. Scripps and the researchers behind *California's Fourth Climate Change Assessment* developed daily rainfall data for a set of climate models, and RCPs 4.5 and 8.5, for every day to the year 2100. Climate change specialists from the study team worked with researchers from Scripps to estimate extreme precipitation changes over time. Specifically, the team requested precipitation datasets across the set of 10 international GCMs that were identified as having the best applicability for California, for both RCPs 4.5 and 8.5.[39]

These raw datasets were then processed to provide the percent change in the 100-year storm precipitation depth over a 24-hour period. The historical data used to calculate the percentage changes are synthetic historical backcasted data from the climate models over the period 1950 to 2005.[40] Standard practice in climate science is to derive the percentage changes using backcasted historical

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[37] Jerry Melillo, Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: Climate Change Impacts in the United States: The Third National Climate Assessment. US Global Change Research Program, 841 pp. doi:10.7930/J0Z31WJ2. Last accessed August 29, 2019, https://www.nrc.gov/docs/ML1412/ML14129A233.pdf

[38] Ibid.

[39] These were the only RCPs available.

[40] "Backcasting" data is when a GCM is run in "reverse," or provides outputs for historical periods.

modeled data and future projected modeled data. This mitigates against model bias affecting the derivation of the percent change.

This newly processed data were analyzed for three time periods to determine how precipitation might change through the end of century. The years shown in the following figures represent the mid-points of the same 30-year statistical analysis periods used for the temperature metrics and explained in the Time Periods Section. To reiterate, these time periods are: 1) 2010 to 2039, where the mid-point year is 2025, 2) 2040 to 2069, where the mid-point year is 2055, and 3) 2070 to 2099, where the mid-point year is 2085.

The model results were used to answer two important questions:

- Were there indications of change in return period storms across the models that should be considered in decision making when considering estimates for future precipitation?
- What was the magnitude of change for a 100-year return-period storm that should be considered as a part of facility design looking forward?

The results of this assessment are shown in the District 1 maps below. The three maps depict the percentage change in the 100-year storm rainfall event predicted for the three analysis periods, and for the RCP 8.5 emissions scenario (the RCP 4.5 results are not shown here). The median precipitation model (HadGEM2-CC) was used in this mapping.[41] Note that the change in 100-year storm depth is positive throughout District 1, indicating heavier rainfall during storm events.

Indications of increased precipitation in District 1 means that Caltrans must assume higher rainfall and associated flooding, and plan improvements to the SHS accordingly. This situation can be exacerbated by increased development, which reduces the natural absorption capacity of the land in drainage areas. Complex conditions like these require a longer-term view be considered for design and flood response for facilities in these areas to ensure that they remain operational to the end of their design lives. Improving long-term resiliency will require that Caltrans conduct a comprehensive assessment of future conditions and incorporate new values for precipitation in design.

At first glance, the precipitation increases may appear to conflict with the wildfire analysis, which shows that wildfire events are expected to increase due to drier conditions. However, precipitation conditions in California are expected to change so that there are more frequent drought periods, but heavier, intermittent rainfall. These heavy storm events may have implications for the SHS and understanding those implications may help Caltrans engineers and designers implement an adaptive design solution.

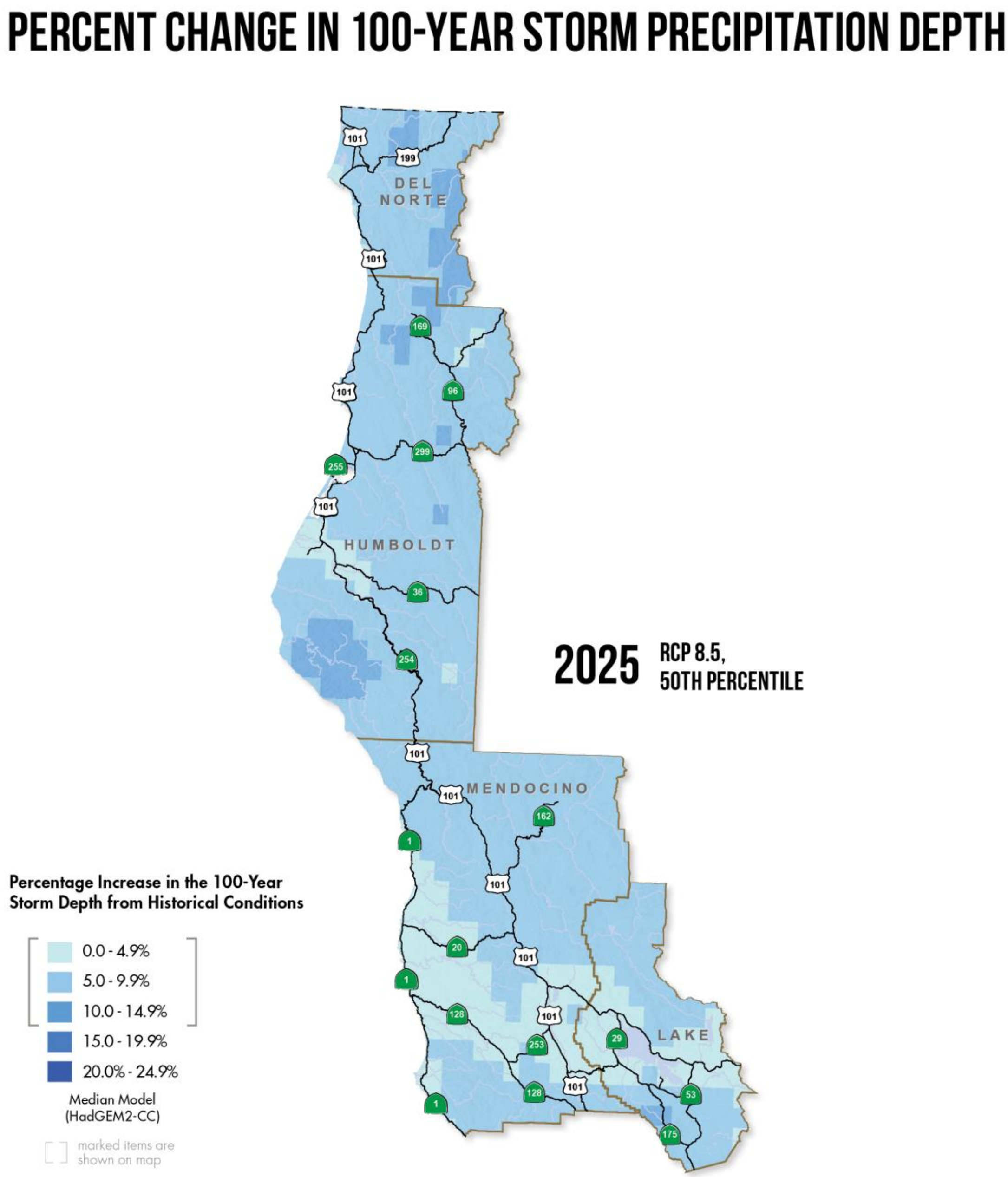
5.1. Precipitation Analysis Results in District 1

As seen in the figures on the following pages, 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,

[41] There were two models that lay at the center point of the distribution. Only one of these models was chosen (HadCEM2-CC) because the best practice in climate science is not to merge the results of multiple climate models.

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.

FIGURE 5-1: PERCENT CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH 2025



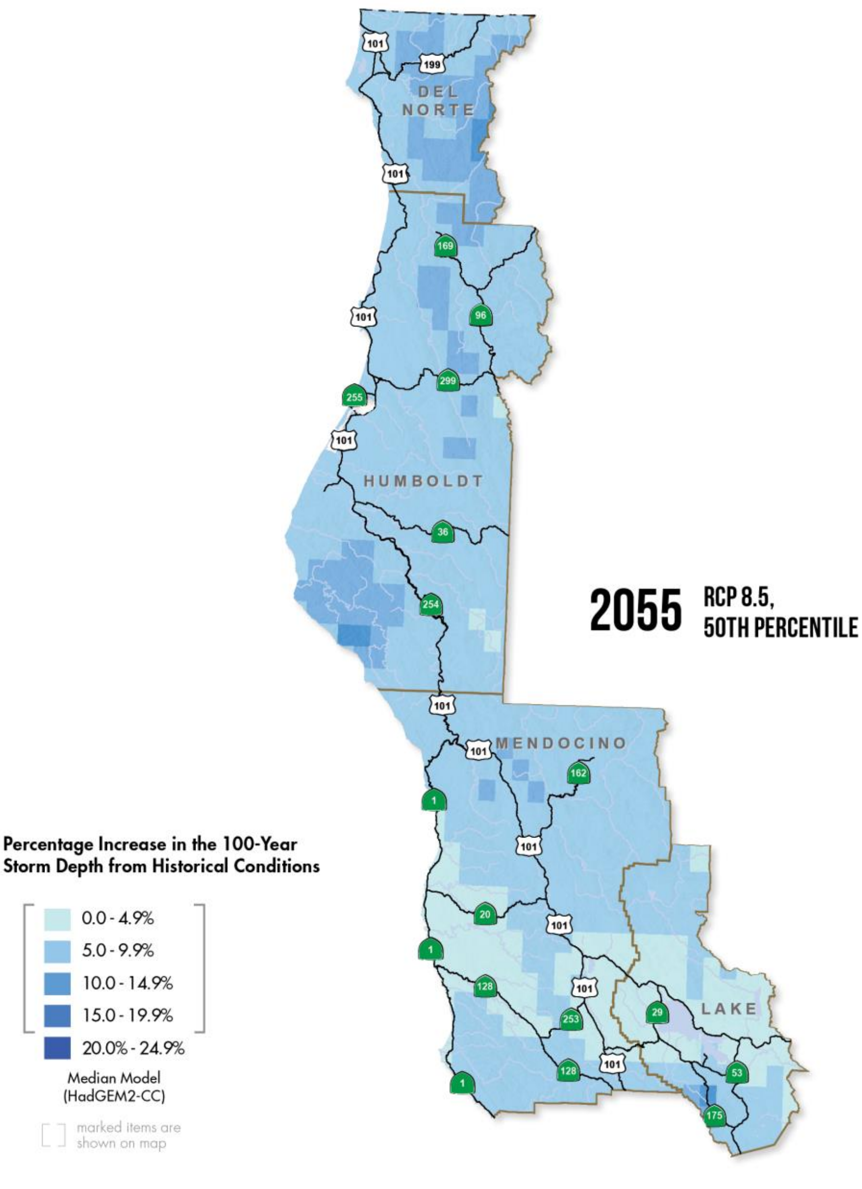
Future Percent Change in 100-year Storm Precipitation Depth within District 1, Based on the RCP 8.5 Emissions Scenario

Caltrans Transpotation Asset Vulnerability Study, District 1. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown were generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

Results represent the 50th percentile of downscaled climate model outputs under RCP 8.5 for the metric shown, as calculated across the state using the area weighted mean.

FIGURE 5-2: PERCENT CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH 2055

PERCENT CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH



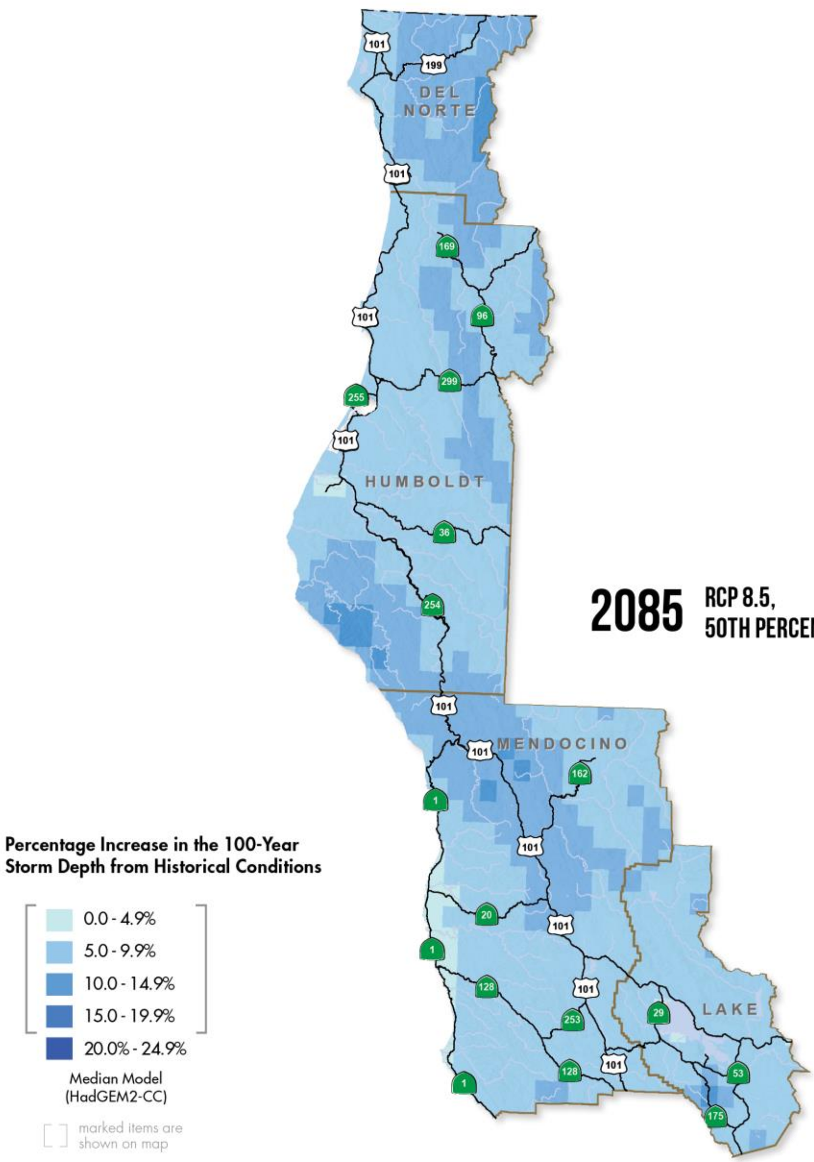
Future Percent Change in 100-year Storm Precipitation Depth within District 1, Based on the RCP 8.5 Emissions Scenario

Caltrans Transpotation Asset Vulnerability Study, District 1. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown were generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

Results represent the 50th percentile of downscaled climate model outputs under RCP 8.5 for the metric shown, as calculated across the state using the area weighted mean.

FIGURE 5-3: PERCENT CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH 2085

PERCENT CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH



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

Caltrans Transpotation Asset Vulnerability Study, District 1. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown were generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

Results represent the 50th percentile of downscaled climate model outputs under RCP 8.5 for the metric shown, as calculated across the state using the area weighted mean.

6. WILDFIRE

Increasing temperatures, changing precipitation patterns, and resulting changes to land cover, are expected to affect wildfire frequency and intensity. Human infrastructure, including the presence of electrical utility infrastructure, or other sources of fire potential (mechanical, open fire, accidental or intentional) may also influence the occurrence of wildfires. Wildfire is a direct concern for driver safety, system operations, and Caltrans infrastructure, among other issues.

Wildfires can indirectly contribute to:

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

The years 2017 and 2018 were notable for the significant wildfires that occurred in northern California. These devastating fires caused property damage, loss of life, and damage to roadways. The wildfires in many cases stripped the land of protective cover and damaged the soils, such that subsequent rain storms led to disastrous mudslides that caused catastrophic damage to state highways in several locations. The costs to Caltrans for repairing such damage could extend over months for individual events and could require years of investment to maintain the viability of the SHS for its users. The conditions that contributed to these impacts, notably a wet rainy season followed by very dry conditions and heavy winds, are likely to occur again in the future as climate conditions change and storm events become more dynamic.

The information gathered and assessed to develop wildfire vulnerability data for District 1 included research on the effect of climate change on wildfire recurrence. This is of interest to several agencies, including the U.S. Forest Service (USFS), the Environmental Protection Agency (EPA) and the California Department of Forestry and Fire Protection (CalFire), who have developed their own models to understand the trends of future wildfires throughout the US and in California.

6.1. Wildfire Models Applied

Determining the potential impacts of wildfires on the SHS included coordination with other agencies that have developed wildfire models for various applications. Models used for this analysis included the following:

- **MC2 - EPA** Climate Impacts Risk Assessment (CIRA), developed by John Kim, USFS
- **MC2 - Applied Climate Science Lab (ACSL)** at the University of Idaho, developed by Dominique Bachelet, University of Idaho
- **University of California Merced model,** developed by Leroy Westerling, University of California Merced

The MC2 models are second generation models, developed from the original MC1 model made by the USFS. The MC2 model is a Dynamic Global Vegetation Model, developed in collaboration with Oregon

State University. This model considers projections of future temperature, precipitation and changes these factors will have on vegetation types/habitat area. The MC2 model outputs used for this assessment are from the current IPCC Coupled Model Intercomparison Project 5 (CMIP5) dataset. This model was applied in two different studies of potential wildfire impacts at a broader scale by researchers at USFS of the University of Idaho. The application of the vegetation model and the expectation of changing vegetation range/type is a primary factor of interest in the application of this model.

The second wildfire model used was developed by Leroy Westerling at the University of California, Merced. This statistical model was developed to analyze the conditions that led to past large fires (defined as over 1,000 acres) in California and uses these patterns to predict future wildfires. Inputs to the model included climate, vegetation, population density, and fire history. This model then incorporated future climate data and projected land use changes into project wildfire recurrence in California to the year 2100.

Each of these wildfire models used inputs from downscaled climate models to determine future temperature and precipitation conditions that are important for projecting future wildfires. The efforts undertaken by the EPA/USFS and UC Merced used the LOCA climate dataset developed by Scripps, while the University of Idaho effort used an alternative downscaling method, the Multivariate Adaptive Constructed Analogs (MACA).

For the purposes of this report, these three available climate models will be identified from this point forward as:

- MC2 - EPA
- MC2 - ASCL
- UC Merced

6.2. Global Climate Models Applied

Each of the efforts used a series of GCM outputs to generate projections of future wildfire conditions. In this analysis, the project study team used the four recommended GCMs from Cal-Adapt for wildfire outputs (CAN ESM2, CNRM-CM5, HAD-GEM2-ES, MIROC5). In addition, all three of the modeling efforts used RCPs 4.5 and 8.5, representing realistic lower and higher ranges for future GHG emissions. Table 6-1 graphically represents the wildfire models and GCMs used in the assessment.

TABLE 6-1: WILDFIRE MODELS AND ASSOCIATED GCMS USED IN WILDFIRE ASSESSMENT

Wildfire Models								
MC2 - EPA			MC2 - ACSL			UC Merced		
CAN ESM2	HAD-GEM2-ES	MIROC5	CAN ESM2	HAD-GEM2-ES	MIROC5	CAN ESM2	HAD-GEM2-ES	MIROC5

6.3. Analysis Methods

The wildfire projections for all model data were developed for the three future 30-year time periods used in this study (median years of 2025, 2055, and 2085). These median years represent 30-year averages, where 2025 is the average between 2010 and 2039, and so on. These are represented as such on the wildfire maps that follow.

The wildfire models produce geospatial data in raster format, which is data that are expressed in individual “cells” on a map. The final wildfire projections for this effort provides a summary of the percentage of each of these cells that burns for each time period. The raster cell size applied is 1/16 of a degree square for the MC2 - EPA and UC Merced models, which matches the grid cell size for the LOCA climate data applied in developing these models. The MC2 - ACSL effort generated data at 1/24 of a degree square, to match the grid cells generated by the MACA downscaling method.

The model data were collected for all wildfire/GCM combinations, for each year to the year 2100. Lines of latitude (the east to west lines on the globe) are essentially evenly spaced when measuring north to south; however, lines of longitude (the north-south lines on the globe, used to measure east-west distances) become more tightly spaced as they approach the poles, where they eventually converge. Because of this, the cells in the wildfire raster are rectangular instead of square and are of different sizes depending on where one is (they are shorter when measured east-west as you go farther north). The study team ultimately summarized the data into the 1/16th grid to enable comparisons and to summarize across multiple models. The resulting area contained within these cells ranged in area between roughly 8,000 and 10,000 acres for grid cells sizes that are 6 kilometers on each side.[42]

An initial analysis of the results of the wildfire models for the same time periods for similar GCMs noted differences in the outputs of the models, in terms of the amount of burn projected for various cells. This difference could be caused by any number of factors, including the assumption of changing vegetation that is included in the MC2 models, but not in the UC Merced model.

6.4. Categorization and Summary

The final method selected to determine future wildfire risks throughout the state takes advantage of the presence of three modeled datasets to generate a broader understanding of future wildfire exposure in California. The project team decided this would provide a more robust result than applying only one of the available wildfire models. A cumulative total of percentage cell burned was developed for each cell in the final dataset. These data are available for future application by Caltrans and their partners.

As a means of establishing a level of concern for wildfire impacts, a classification was developed based on the expected percentage of cell burned. The classification is as follows:

- Very Low 0-5%,
- Low 5-15%,

[42] Lines of latitude (the east to west lines on the globe) are essentially evenly spaced when measuring north to south; however, lines of longitude (the north-south lines on the globe, used to measure east-west distances) become more tightly spaced as they approach the poles where they eventually converge. Because of this, the cells in the wildfire raster are rectangular instead of square and are of different sizes depending on where one is (they are shorter when measured east-west as you go farther north).

- Medium 15-50%,
- High 50-100%,
- Very High 100%+.[43]

Thus, if a cell were to show a complete burn or higher (8,000 to 10,000 acres+) over a 30-year period, that cell was identified as a very high wildfire exposure cell. Developing this categorization method included removing the CNRM-CM5 data point from the MC2 - ACSL and UC Merced datasets to have three consistent points of data for each cell in every model. This was done to provide a consistent number of data points for each wildfire model.

Next, the project study team looked at results across all models to see if any one wildfire model/GCM model combination indicated a potential exposure concern in each grid cell. The categorization for any one cell in the summary identifies the highest categorization for that cell across all nine data points analyzed. For example, if a wildfire model result identified the potential for significant burn in any one cell, the final dataset reflects this risk. This provides Caltrans with a more conservative method of considering future wildfire risk.

Finally, the project study team assigned a score for each cell where there is relative agreement on the categorization across all the model outputs. An analysis was completed to determine whether 5 of the 9 data points for each cell (a simple majority) were consistent in estimating the percentage of cell burned for each 30-year period.

6.5. Wildfire Analysis Results in District 1

The figures on the following pages show the results of this analysis, using the classification scheme explained above. These figures show projections for RCP 8.5 only and red highlights show portions of the Caltrans SHS that are likely to be most exposed to wildfire. Table 6-2 and Table 6-3 summarize the centerline miles of District 1 SHS exposed to Medium to Very High wildfire risk, by District 1 county.

The more-densely forested areas in the eastern portion of the district have the highest wildfire risk, with the greatest occurring in Lake County. District 1 can mitigate wildfire risk in these areas by using fire-resistant materials and maintaining defensible space for district assets and using fire-safe landscaping along roadways. The district can also limit wildfire concern by actively reducing fuel through dead or diseased tree removal in District 1 right-of-way.

[43] A cell can have greater than 100% burn if burned twice or more in the same time period.

TABLE 6-2: CENTERLINE MILES EXPOSED TO MEDIUM TO VERY HIGH WILDFIRE CONCERN UNDER RCP 8.5

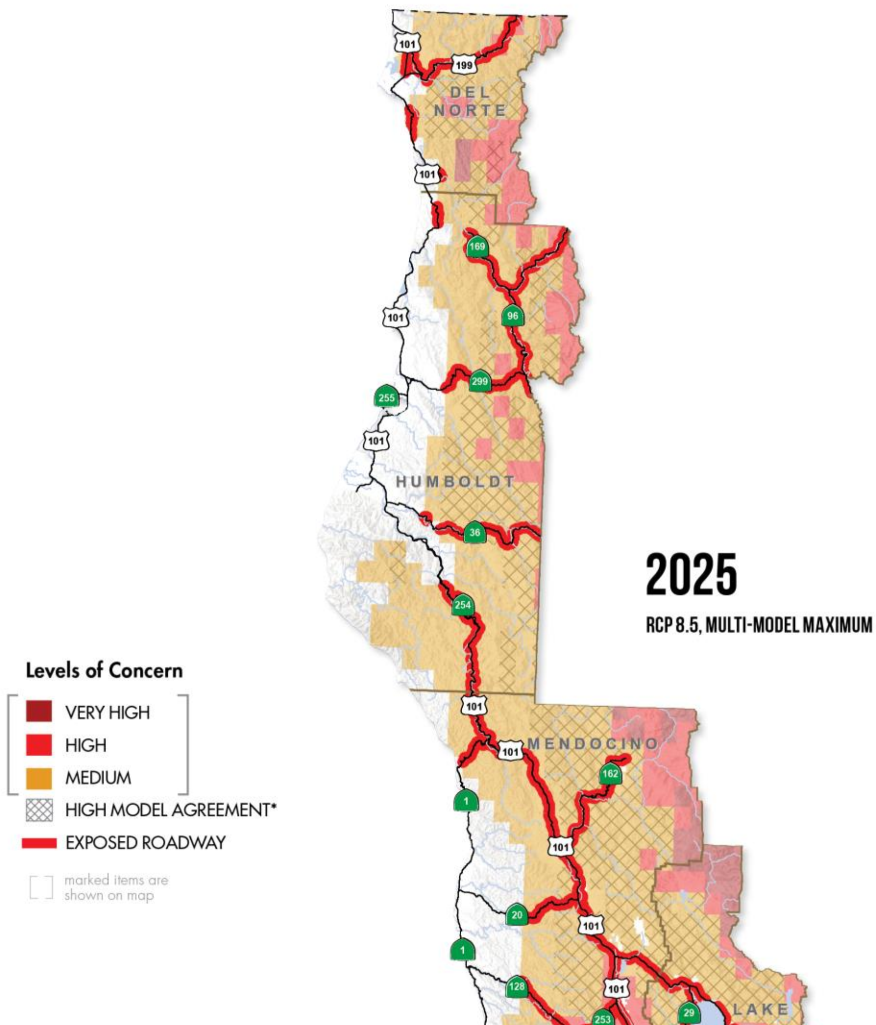
District 1 County	2025			2055			2085		
	Med	High	Very High	Med	High	Very High	Med	High	Very High
Del Norte	37	11	0	74	8	0	50	33	4
Humboldt	175	5	0	188	54	0	101	162	18
Lake	63	52	0	3	115	0	6	115	0
Mendocino	188	54	0	139	59	62	42	212	40
District 1 Totals by Level of Concern and Year	**462**	**122**	**0**	**405**	**236**	**62**	**199**	**523**	**62**
District 1 Total by Year	**585**			**702**			**784**		

TABLE 6-3: CENTERLINE MILES EXPOSED TO MEDIUM TO VERY HIGH WILDFIRE CONCERN UNDER RCP 4.5

District 1 County	2025			2055			2085		
	Med	High	Very High	Med	High	Very High	Med	High	Very High
Del Norte	62	0	0	63	5	0	74	8	0
Humboldt	203	5	0	217	35	0	205	55	5
Lake	36	79	0	0	115	0	0	115	0
Mendocino	154	77	0	121	106	12	126	129	5
District 1 Totals by Level of Concern and Year	**456**	**162**	**0**	**401**	**261**	**12**	**405**	**307**	**10**
District 1 Total by Year	**618**			**674**			**722**		

FIGURE 6-1: INCREASE IN WILDFIRE EXPOSURE 2025

LEVEL OF WILDFIRE CONCERN



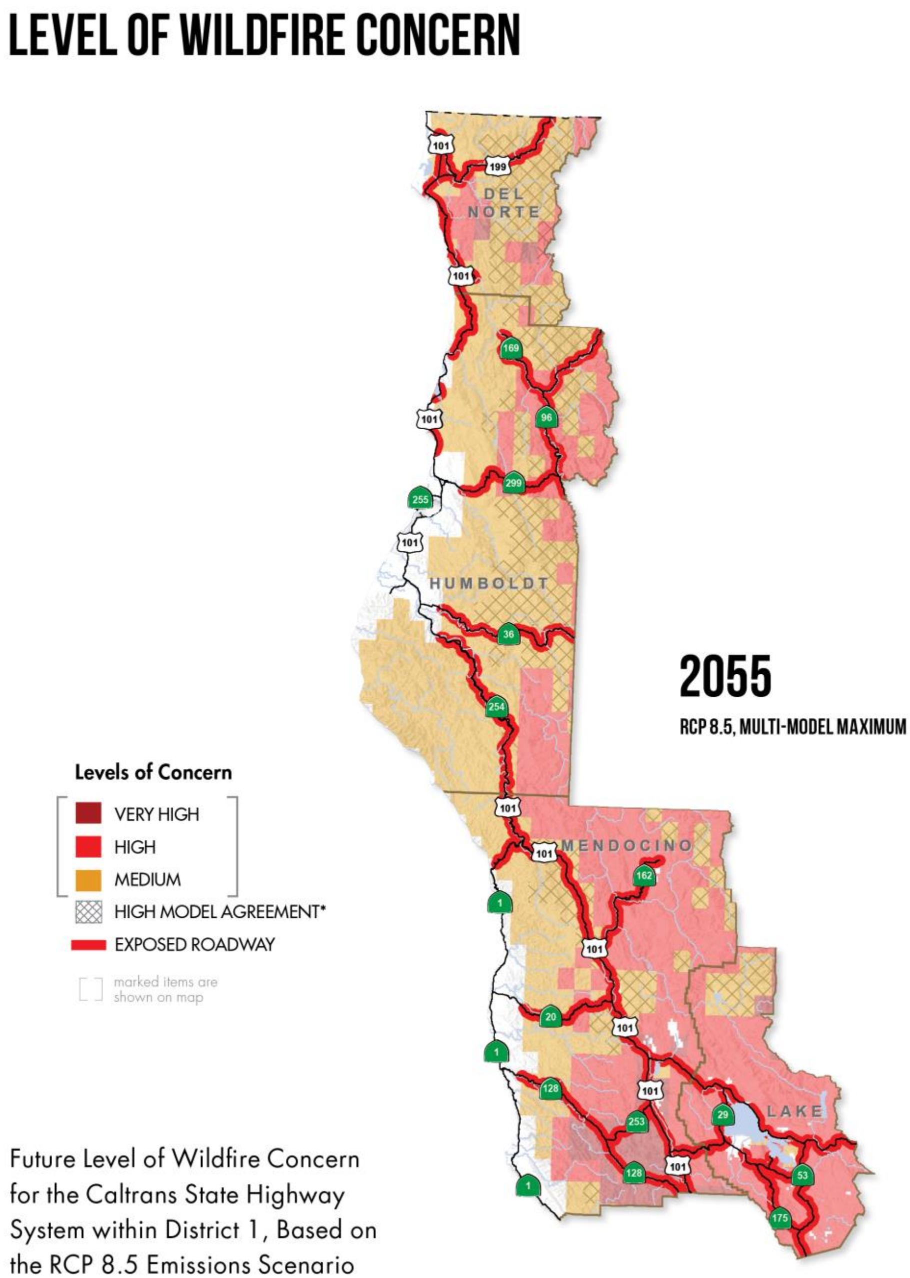
Future Level of Wildfire Concern for the Caltrans State Highway System within District 1, Based on the RCP 8.5 Emissions Scenario

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

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

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

FIGURE 6-2: INCREASE IN WILDFIRE EXPOSURE 2055

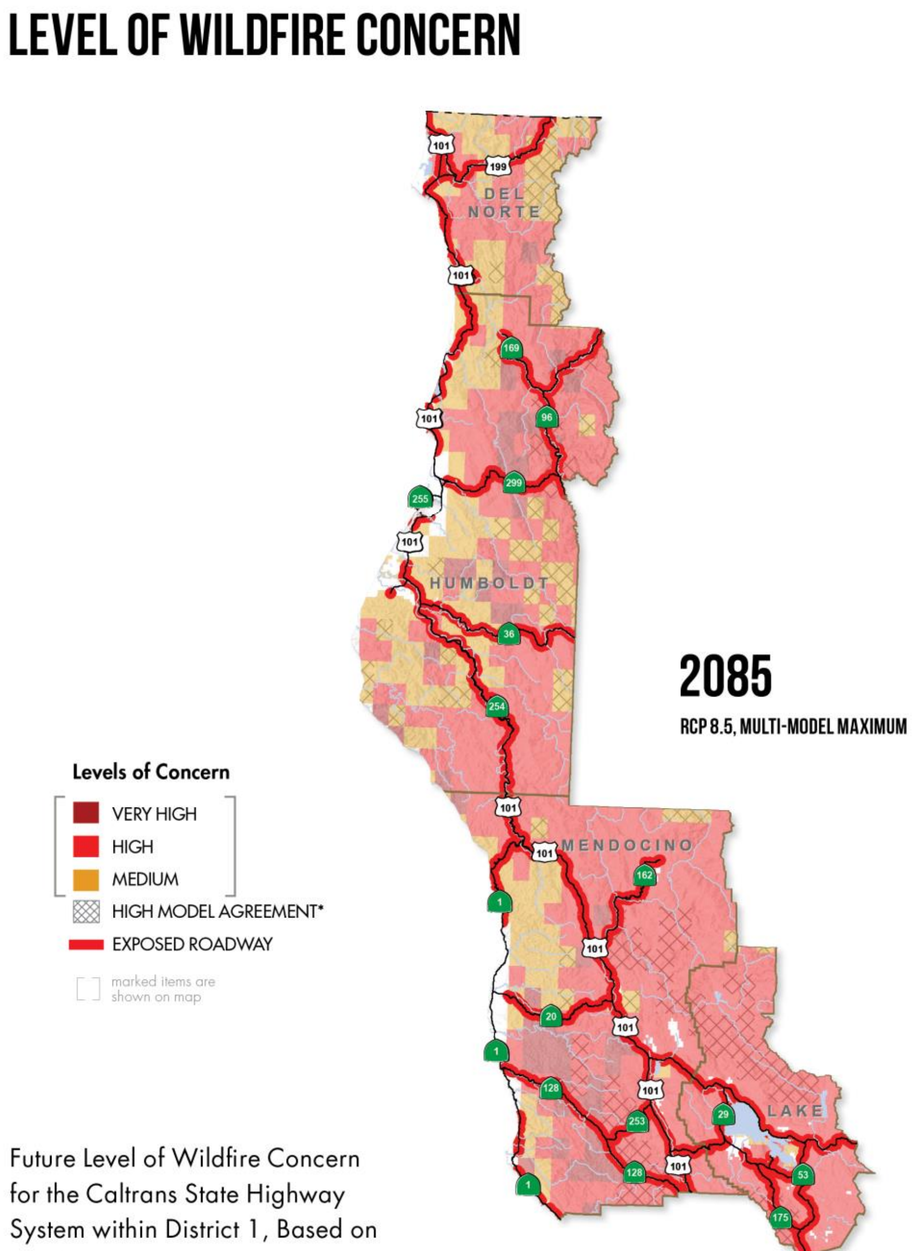


The fire model composite summaries shown are based on wildfire projections from three models: (1) MC2 - EPA Climate Impacts Risk Assessment, developed by John Kim, USFS; (2) MC2 - Applied Climate Science Lab at the University of Idaho, developed by Dominque Bachelet, University of Idaho; and (3) University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

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

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

FIGURE 6-3: INCREASE IN WILDFIRE EXPOSURE 2085



Future Level of Wildfire Concern for the Caltrans State Highway System within District 1, Based on the RCP 8.5 Emissions Scenario

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

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

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

7. SEA LEVEL RISE

The datasets considered for this analysis came from the Ocean Protection Council (OPC) and the National Oceanic and Atmospheric Administration (NOAA). The OPC developed a new set of sea level rise projections and scenarios for the state, which were chosen for consideration in this analysis to follow state guidance on sea level rise planning and use the best available sea level rise projections.[44] These projections were paired with a NOAA sea level rise model, which was used to identify potential impacts to the SHS in District 1. Each of these datasets is explained in more detail below.

7.1. OPC State of California Sea Level Rise Guidance: 2018 Update

Estimates of sea level rise have been developed for California by various agencies and research institutions. Figure 7-1 below reflects estimates recently developed for the North Spit, CA tide gauge by a scientific panel for the 2018 Update of the State of California Sea-Level Rise Guidance, an effort led by the OPC. 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 projection scenarios 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 pathways to provide information on the 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 best to consider certain projections, given the risks associated with projects of varying type:

- 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.

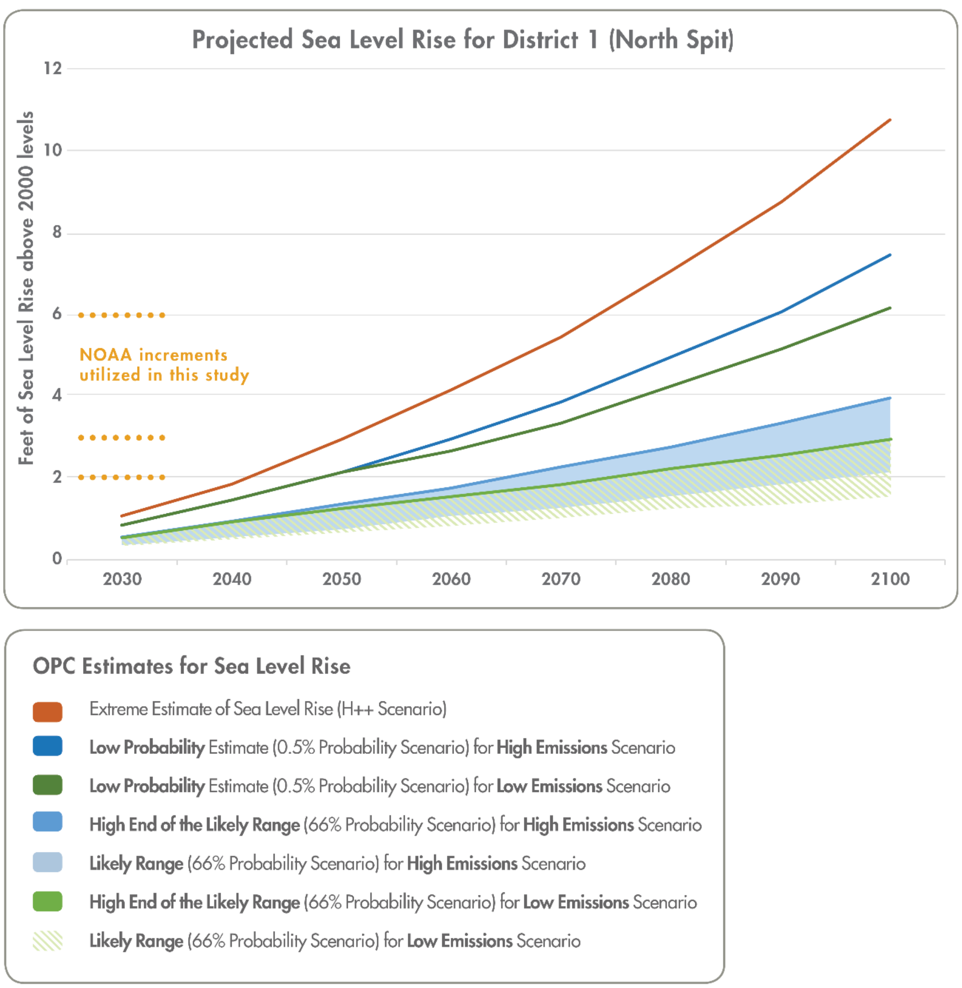
[44] California Ocean Protection Council (OPC), “State of California Sea-Level Rise Guidance: 2018 Update,” 2018. Last accessed August 29, 2019, http://www.opc.ca.gov/webmaster/ftp/pdf/agenda_items/20180314/Item3_Exhibit-A_OPC_SEA LEVEL RISE_Guidance-rd3.pdf

- 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 by the OPC 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. Given varying rates of subsidence and highway uplift in District 1 and given that many highway structures will last for many decades, planners and analysts need to carefully consider likely future sea levels depending on where the project is located along the coast. The Coastal Commission is recommending that projects be planned for the Medium-High Risk Aversion and the Extreme Risk Aversion/H++ scenarios. This is a good place to begin an analysis, but as noted varying rates of subsidence need to be considered as well.

The OPC recognizes that the science surrounding sea level rise projections is still improving and anticipates updating their 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.

FIGURE 7-1: OPC 2018 SEA LEVEL RISE PROJECTIONS FOR NORTH SPIT, CA



7.2. NOAA Model Used

The previous section described estimated sea level rise levels from the OPC and the guidance for using them; this section discusses the NOAA model used in this study alongside these projections. The model data can be viewed and downloaded from the *NOAA Sea Level Rise Viewer.*[45] The NOAA Office for Coastal Management developed the data to provide coastal managers and scientists with a preliminary view of sea level rise and coastal flooding impacts across the United States.

NOAA data are available in GIS shapefiles and for sea level rise from 1 to 10 feet above mean higher high water (MHHW). Each of these increments was used in this study to assess vulnerability to the SHS. However, the analysis presented in this report is specific to three increments of sea level rise: 2, 3, and 6 feet. See Figure 7-1 to identify approximately when the OPC sea level rise scenarios will reach these sea level rise heights and note the large range between projections for each height. For example, six feet of sea level rise may be reached as soon as around 2070, or as late as 2100 or later.

The NOAA data was developed through a modified bathtub approach that accounts for regional variability such as tidal patterns and hydrological connectivity.[46] NOAA used a Digital Elevation Model (DEM) to identify the base land elevation, which they added subsequent sea level rise heights on top of to identify areas that would be permanently inundated from sea level rise. The dataset also includes accompanying low-lying polygons for each level of sea level rise, which indicate areas that are low-lying enough to flood, but there is currently a barrier that prevents inundation as identified in the DEM. The analysis completed for District 1 also assessed which portions of the SHS will cross these low-lying areas, but to simplify the results presented in this report these are not shown in the maps on the following pages.

More details on the NOAA sea level rise data can be accessed through: https://coast.noaa.gov/sea level risedata/

7.3. Bridge Exposure

Bridges are often designed to historical water levels and flood conditions which may not be applicable as those conditions change. Changing water levels can cause a wide range of impacts to Caltrans bridges and a bridge does not necessarily need to be overtopped to be damaged. It will be important for Caltrans to consider all potentially at-risk bridges and pursue additional analysis as necessary. For example, as sea levels rise, Caltrans bridges may be exposed to the following risks:

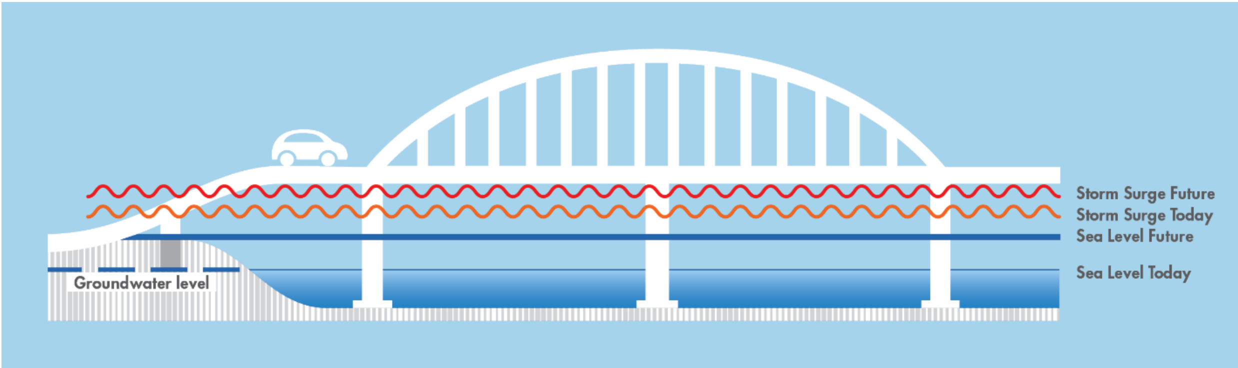
- A rising groundwater table may inundate supports that were not built to accommodate saturated soil conditions, leading to erosion of soils and loss of stability.
- Higher sea levels can mean greater forces on the bridge during normal tidal processes, increasing scour effects on bridge support structures.
- Higher water levels mean storm surges will be higher and have more force than today. These forces could cause scour on bridge substructure elements.
- Bridge approaches (where the roadway transitions to the bridge deck) may be damaged during storms.

[45] Our Coast Our Future can be accessed here: http://ourcoastourfuture.org/

[46] The model does not account for erosion, subsidence, or any future changes in an area's hydrodynamics.

- Surge and wave effects may loosen or damage portions of the bridge, requiring securing, re-attaching, or replacing these parts.

FIGURE 7-2: BRIDGE EXPOSURE



For these reasons, this sea level rise assessment of the SHS in District 1 includes bridges that may not be overtopped, but could be affected by sea level rise in other ways. More detailed, site-specific assessments of these bridges and their elevations will be necessary to understand the range of potential impacts to each from sea level rise.

7.4. Sea Level Rise Analysis Results in District 1

The SHS centerline miles exposed to the three, mapped sea level rise increments are summarized in Table 7-1 by county. These centerline miles include bridges, as explained above. District 1 may choose to prioritize adaptation efforts where these exposed roadways are, using the GIS data provided by the project study team. Full district-scale maps of sea level rise exposure on the SHS are provided in the following pages. Figure 7-6 shows estimated impacts of varying levels of SLR on State highways near Humboldt Bay. One of the most vulnerable sections (as indicated by the NOAA data) of the SHS is where SR 255 and US 101 surround and traverse Humboldt Bay. The term "inundation" is used to describe sea level rise impacts as these areas may be permanently inundated from future sea level rise. The storm surge section refers to "flooding" as those areas may only be temporarily flooded by surge.

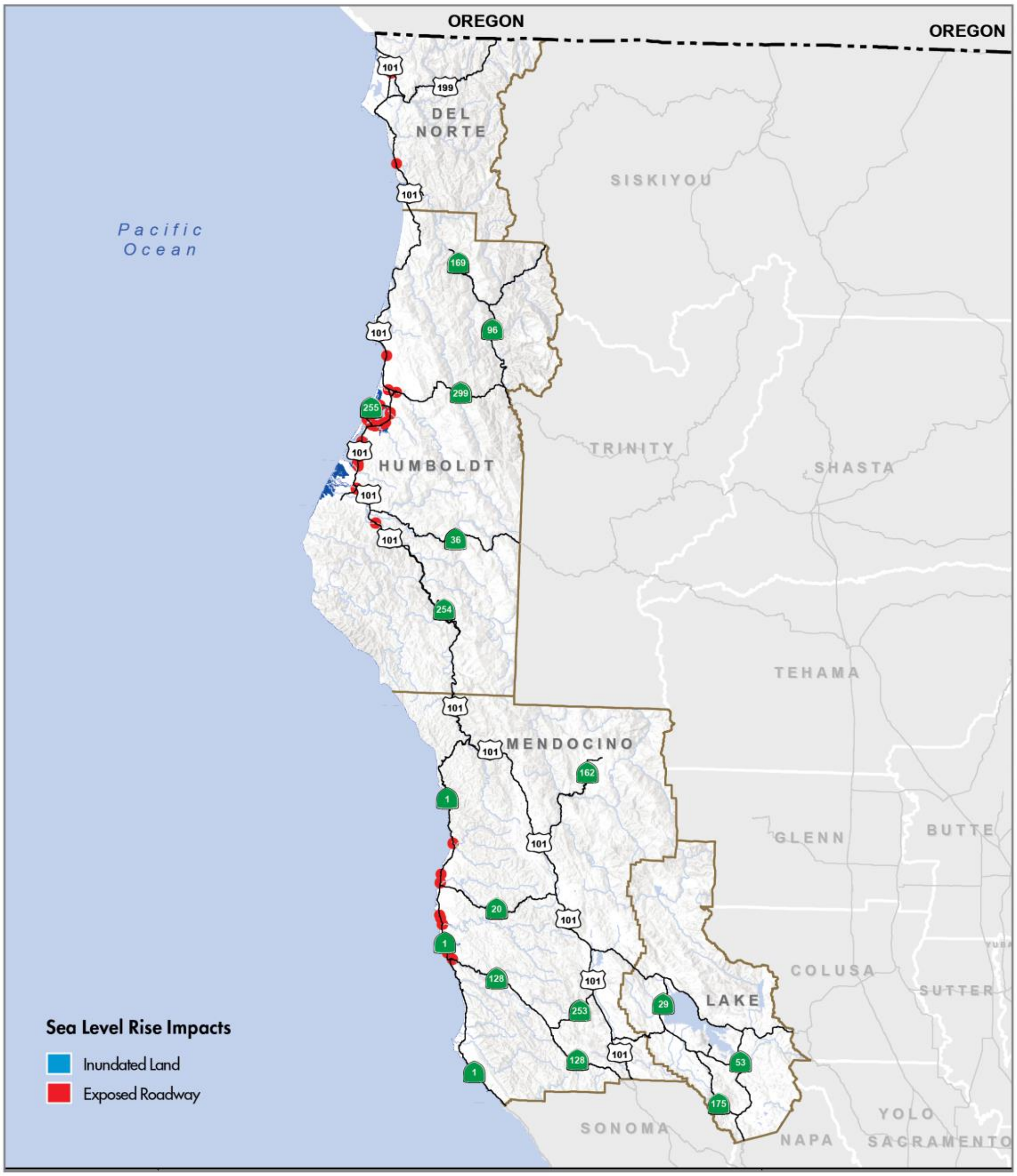
TABLE 7-1: DISTRICT 1 CENTERLINE MILES EXPOSED TO SEA LEVEL RISE

	Sea Level Rise		
District 1 Counties	**0.60 m (2 ft)**	**0.91 m (3 ft)**	**1.83 m (6 ft)**
Del Norte	0.2	0.2	0.9
Humboldt	2.7	5.3	13.2
Mendocino	0.4	0.5	0.7
Total	**3.4**	**6.1**	**14.9**

NOTE: LAKE COUNTY IS NOT INCLUDED AS THERE IS NO COASTLINE.

FIGURE 7-3: INUNDATION FROM 2 FT (0.60 M) OF SEA LEVEL RISE

SEA LEVEL RISE IMPACTS IN DISTRICT 1

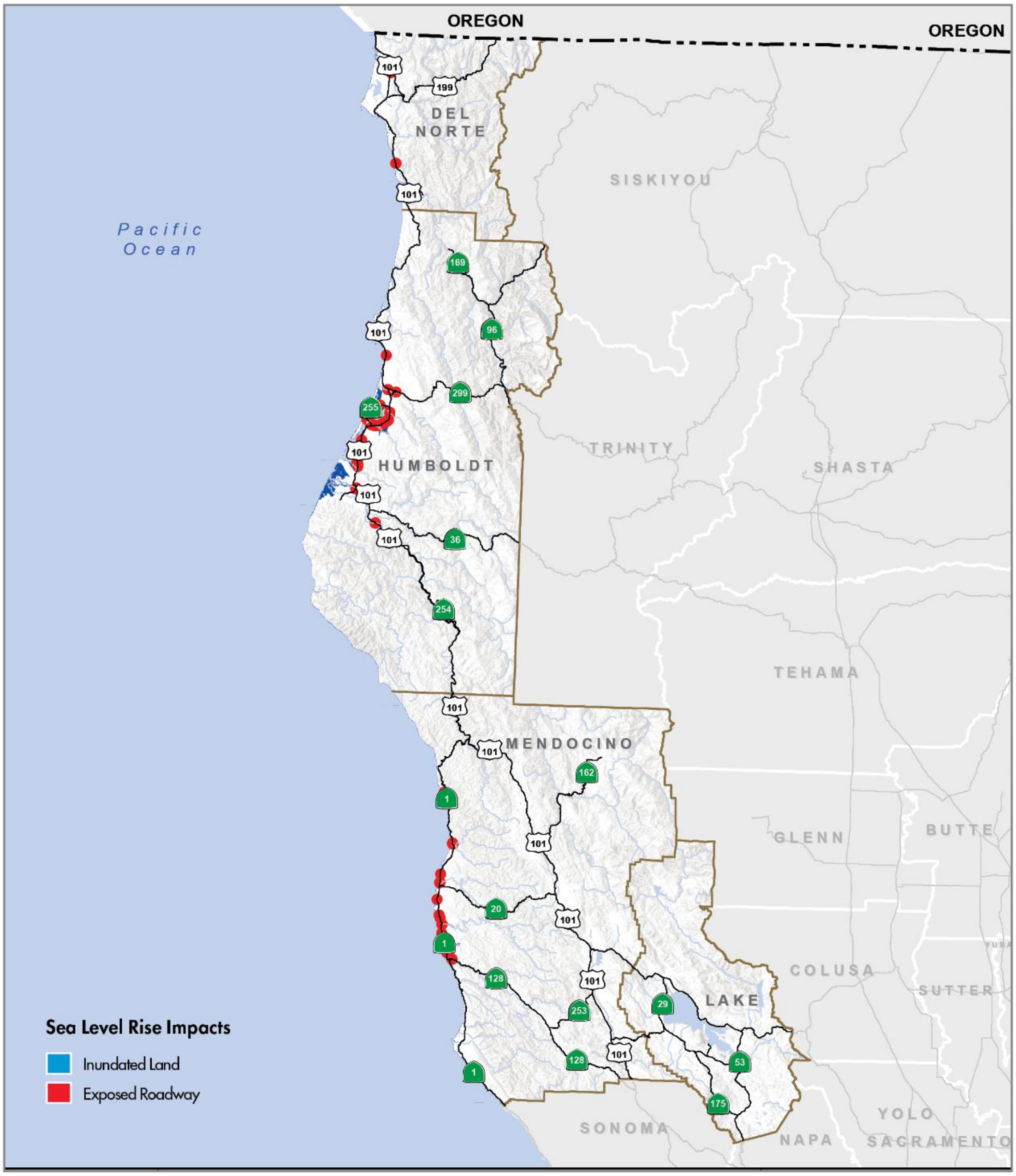


2 FT (0.60 M)

SEA LEVEL RISE DATA ARE FROM NOAA. SEE THE NOAA SEA LEVEL RISE VIEWER FOR MORE INFORMATION.

FIGURE 7-4: INUNDATION FROM 3 FT (0.91 M) OF SEA LEVEL RISE

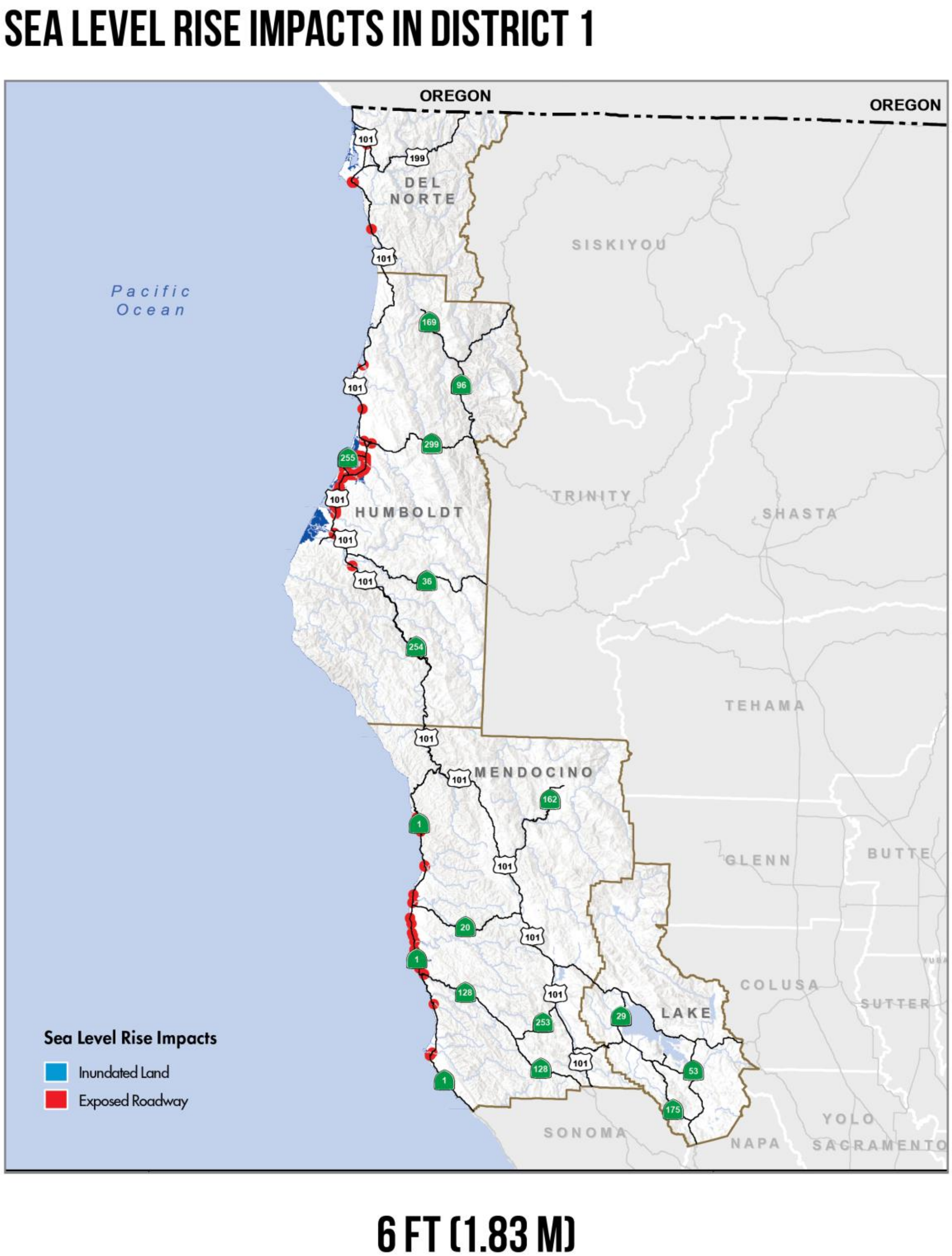
SEA LEVEL RISE IMPACTS IN DISTRICT 1



3 FT (.91 M)

SEA LEVEL RISE DATA ARE FROM NOAA. SEE THE NOAA SEA LEVEL RISE VIEWER FOR MORE INFORMATION.

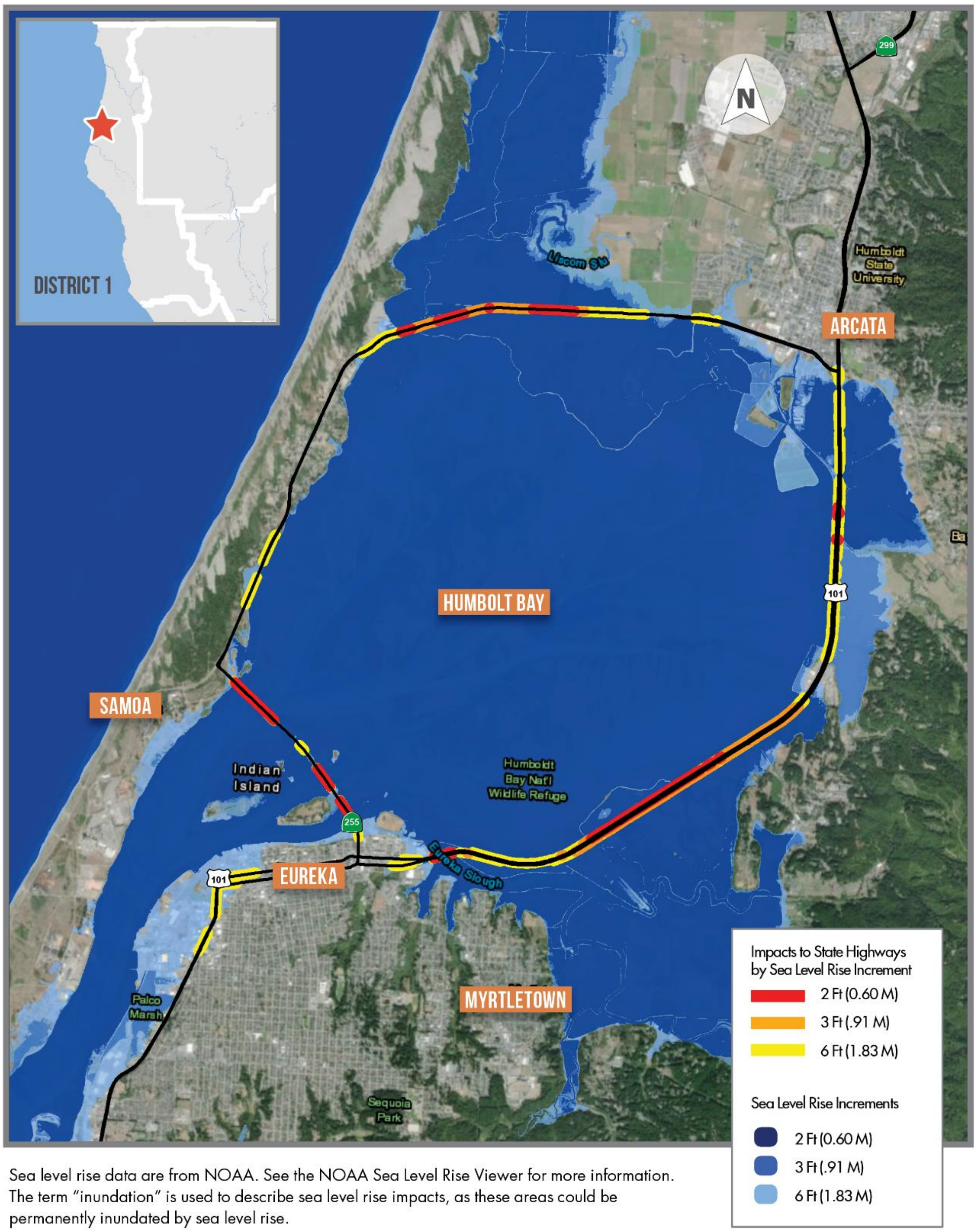
FIGURE 7-5: INUNDATION FROM 6 FT (1.83 M) OF SEA LEVEL RISE



SEA LEVEL RISE DATA ARE FROM NOAA. SEE THE NOAA SEA LEVEL RISE VIEWER FOR MORE INFORMATION.

FIGURE 7-6: IMPACTS OF SEA LEVEL RISE ON STATE HIGHWAYS NEAR HUMBOLDT BAY

MODELED SEA LEVEL RISE INUNDATION AROUND HUMBOLDT BAY

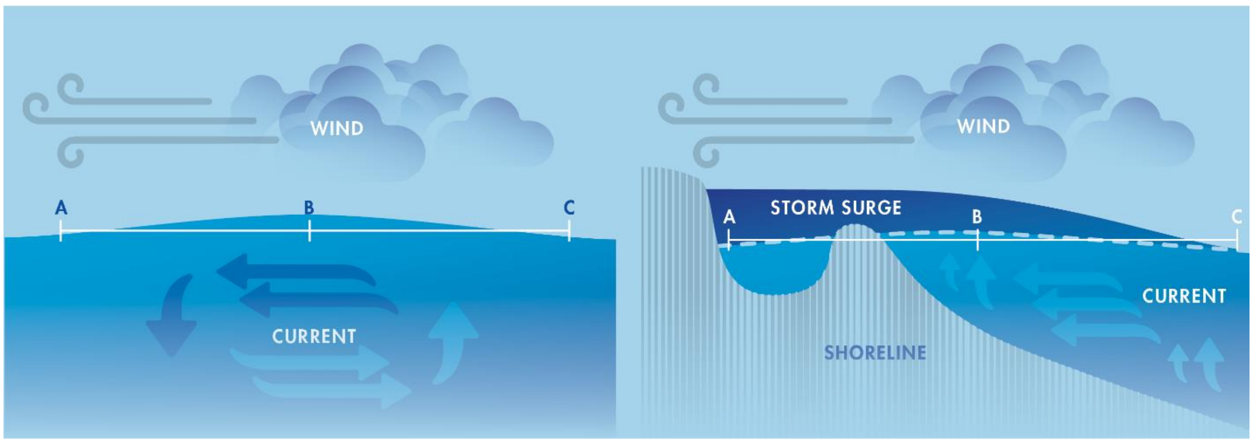


Sea level rise data are from NOAA. See the NOAA Sea Level Rise Viewer for more information. The term "inundation" is used to describe sea level rise impacts, as these areas could be permanently inundated by sea level rise.

8. STORM SURGE

As seas rise and move inland over low-lying areas, there is a greater potential for storm surge due to meteorological events to become more devastating. Storm surge is defined as “an abnormal rise of water generated by a storm, over and above the predicted astronomical tide.”[47] Surges are caused primarily by strong winds during a storm event. Winds blowing over the top of the water causes “vertical circulation.” When the storm reaches shallow water or coastline, the disrupted vertical circulation pushes water onshore.[48] Figure 8-1 below, developed by NOAA, shows the process of how wind-driven vertical circulation leads to storm surge.

FIGURE 8-1: VERTICAL CIRCULATION DURING A STORM EVENT



SOURCE: NOAA

Surge events are typically not as frequent or devastating for the West Coast as hurricanes and nor’easters are along the Gulf of Mexico and the Atlantic coastline, but can still raise sea levels during severe winter storms. Heavy rain during these events can also contribute to coastline flooding. Higher river levels can channel additional water into affected areas, where it flows into coastal waters.

An analysis of the potential effects of sea level rise, combined with storm surge, was completed using data from the 3Di model developed by John Radke (et al.) of University of California, Berkeley.[49] 3Di is a three-dimensional hydrodynamic model that simulates water movement during flood events based on observed water levels from a past near-100-year storm event.[50] Three future water levels associated with sea level rise were used as the baseline water elevation and combined with the identified storm event to determine future surge levels. The levels used were 1.64, 3.28, and 4.62 feet (or 0.50, 1.00, and 1.41 meters, respectively), and, except for the highest, they align closely with the sea level rise data used in the previous section. The different methodologies and inputs used in each model result in different outcomes for what parts of the SHS may be exposed, and when. The resulting flood impacts are identified in the sections below.

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[47] National Oceanic and Atmospheric Administration (NOAA). Undated, Website. “Introduction to Storm Surge.” Last accessed August 29, 2019, . https://www.nhc.noaa.gov/surge/surge_intro.pdf
[48] Ibid.
[49] Cal-Adapt. “Sea Level Rise CalFloD-3D.” 2018. Last accessed August 29, 2019, http://cal-adapt.org/data/sea level rise-calflod-3d/
[50] J. Radke, G. S. Biging, M. Schmidt-Poolman, H. Foster, E. Roe, Y. Ju, O. Hoes, T. Beach, A. Alruheil, L. Meier, W. Hsu, R. Neuhausler, W. Fourt, W. Lang, U. Garcia I. Reeves (University of California, Berkeley). 2016. Assessment of Bay Area Natural Gas Pipeline Vulnerability to Climate Change. California Energy Commission. Publication number: CEC-500-2017-008

8.1. Surge Analysis Results 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 includes the district's northern portion along SR 255 and US 101. The 3Di model also suggests that there will be large, vulnerable portions of SR 1 in Mendocino County that may be affected by sea level rise alone (but not to the degree modeled for a 100-year storm surge). Table 8-1 provides the centerline miles of District 1 SHS exposed to sea level rise with a 100-year storm, for all 3Di model heights available. This includes a "0 feet" or "current" sea level rise height, which indicates the mileage of SHS that is currently at-risk from a 100-year storm event.

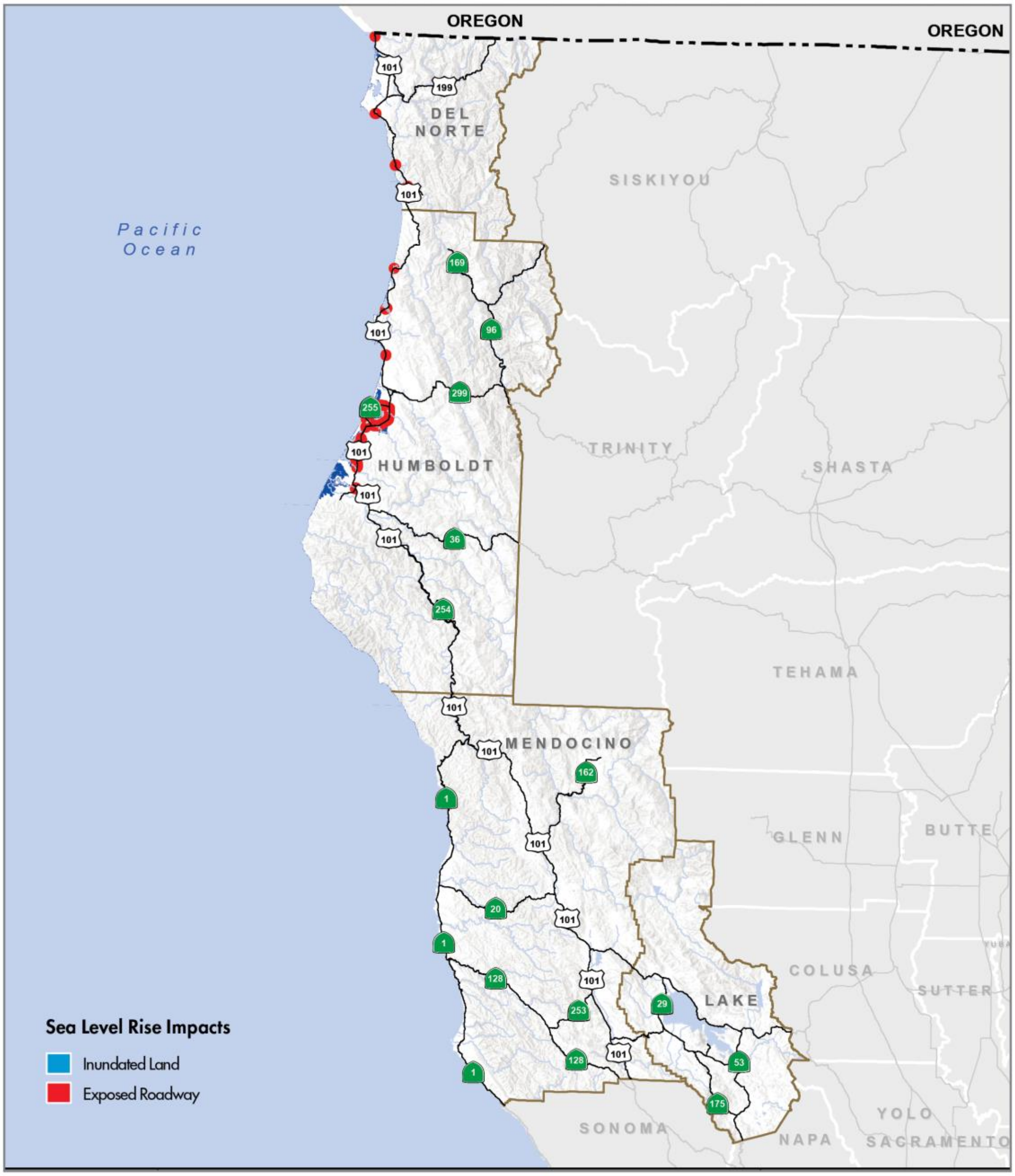
TABLE 8-1: DISTRICT 1 CENTERLINE MILES EXPOSED TO SEA LEVEL RISE AND A 100-YEAR STORM

	Sea Level Rise			
District 1 County	**0 ft (0 m)**	**1.64 ft (0.50 m)**	**3.28 ft (1.00 m)**	**4.62 ft (1.41 m)**
Del Norte	0.2	0.3	1.0	1.9
Humboldt	6.6	10.4	14.9	16.9
Mendocino	0.3	0.0	1.1	1.7
Total	**7.1**	**10.7**	**17.0**	**20.4**

NOTE: LAKE COUNTY IS NOT INCLUDED AS THERE IS NO COASTLINE.

FIGURE 8-2: FLOODING FROM 1.64 FT (0.50 M) OF SEA LEVEL RISE AND A 100-YEAR STORM EVENT

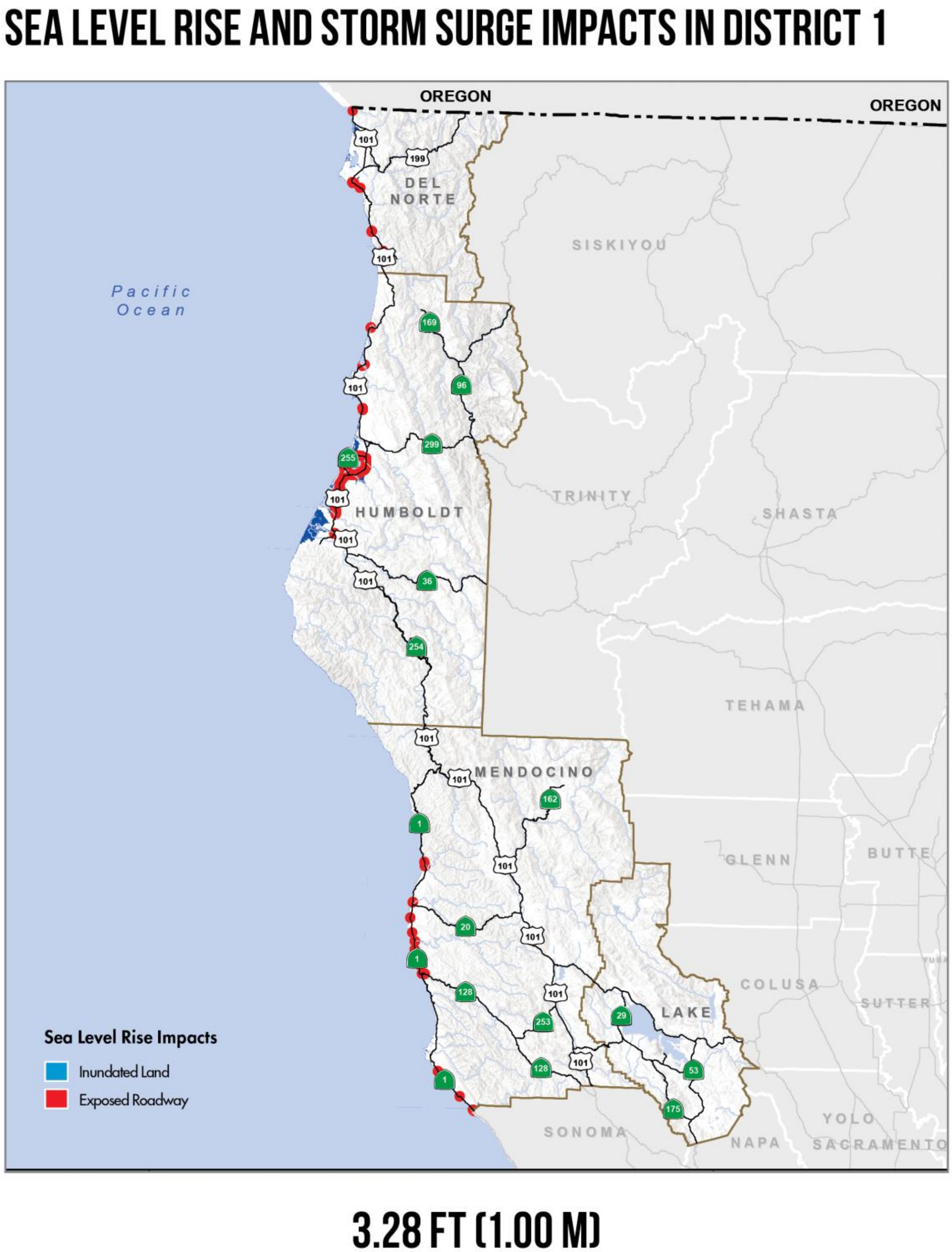
SEA LEVEL RISE AND STORM SURGE IMPACTS IN DISTRICT 1



1.64 FT (0.5 M)

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.

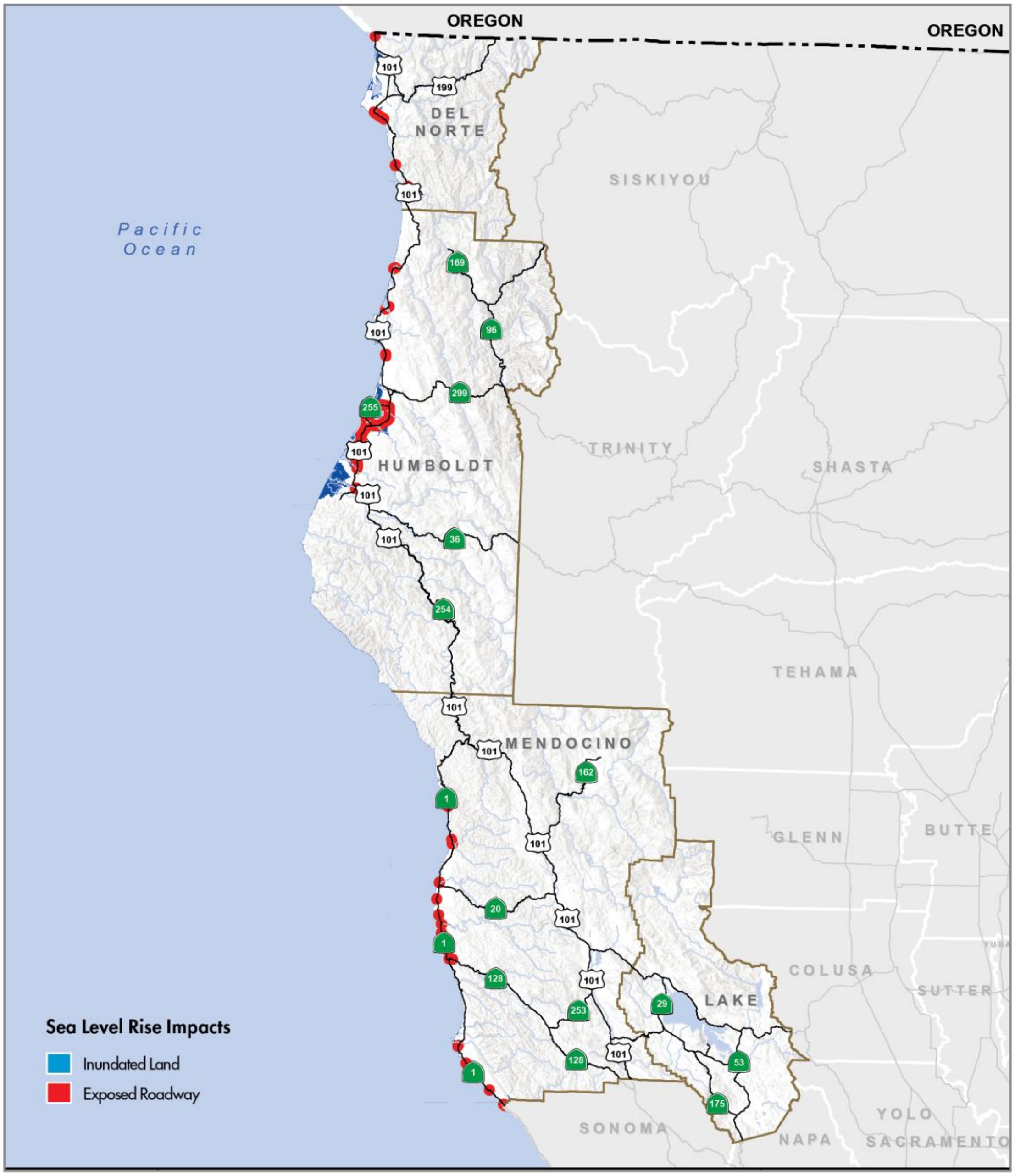
FIGURE 8-3: FLOODING FROM 3.28 FT (1.00 M) OF SEA LEVEL RISE AND A 100-YEAR STORM EVENT



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.

FIGURE 8-4: FLOODING FROM 4.62 FT (1.41 M) OF SEA LEVEL RISE AND A 100-YEAR STORM EVENT

SEA LEVEL RISE AND STORM SURGE IMPACTS IN DISTRICT 1



4.62 FT (1.41 M)

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.

9. CLIFF RETREAT

The 1,100 mile California coastline has been shaped by various forces over time and is well known for its active areas of erosion, landslides, and cliff retreat. Estimates from a recent study of the coastline identified that approximately 72% of the California coast is eroding because of ocean wave energy on beaches and cliffs.[51]. Another study documenting past cliff erosion rates statewide noted that highest rates were found in San Onofre, Portuguese Bend, Palos Verdes, Big Sur, Martins Beach, Daly City, Double Point, and Point Reyes.[52]

Recent erosive effects on the California coast are occurring at the same time as a period of rapid development and actions are being taken to reduce loss of land at the coast. Over the past century, sea levels have risen roughly six inches[53] and are continuing to rise, which will result in more regular inundation, higher tides and an increase in wave forces during coastal storms. The effects of all tidal and storm events are anticipated to stretch farther inland and with higher water and wave elevation than what has been observed and planned for in the past.

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 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.

It should be noted that, although the Pacific Institute and USGS use different types of models to try to assess the progress of coastal retreat as a function of potential sea level rise, hard data for Northern California is very scarce. The USGS is presently working to develop a model suitable for the Northern California coastline, however, the project is still a year from completion. In addition, none of the models consider site-specific geological settings, which is ultimately essential for accurate assessment of site-specific risk.

In this review the at-risk coastal areas identified by the Pacific Institute were checked against imagery on Google Earth to identify sites with evidence of currently active erosion. The topography at these sites was the obtained from the 2009-11 DEM and the 2016 DEM models so that the rate of erosion could be assessed and, to the extent possible, quantified. For the most part, the analysis of this data shows minimal coastal retreat over the roughly 6-year period at most sites, even if there is evidence of active erosion in the aerial imagery.

[51] Hapke, C. & Reid, D., *National Assessment of Shoreline Change, Part 4: Historical Coastal Cliff Retreat along the California Coast*, 2007. Last accessed September 9, 2019, https://pubs.usgs.gov/of/2007/1133/of2007-1133.pdf

[52] University of California, San Diego. Study identified California cliffs at risk of collapse," Dec. 20, 2017. Phys Org, Last accessed August 29, 2019, https://phys.org/news/2017-12-california-cliffs-collapse.html

[53] NOAA. "Sea Level Trends," Tides & Currents, n.d. Last accessed August 29, 2019, https://tidesandcurrents.noaa.gov/sltrends/sltrends.html

To date, the Northern California coastline has been relatively stable, with few sites exhibiting erosion. However, as sea levels rise there is an expectation that erosion rates will accelerate. Some sites may be more at-risk than others due to local conditions. This assessment attempted to identify the most vulnerable locations for cliff retreat in District 1.

A rating scheme was developed to characterize 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 9-1 on the following page provides a district-wide view of locations where there are projected "medium" and "critical" concern areas. Table 9-1 provides the centerline miles of highways in medium or critical concern areas across the district.

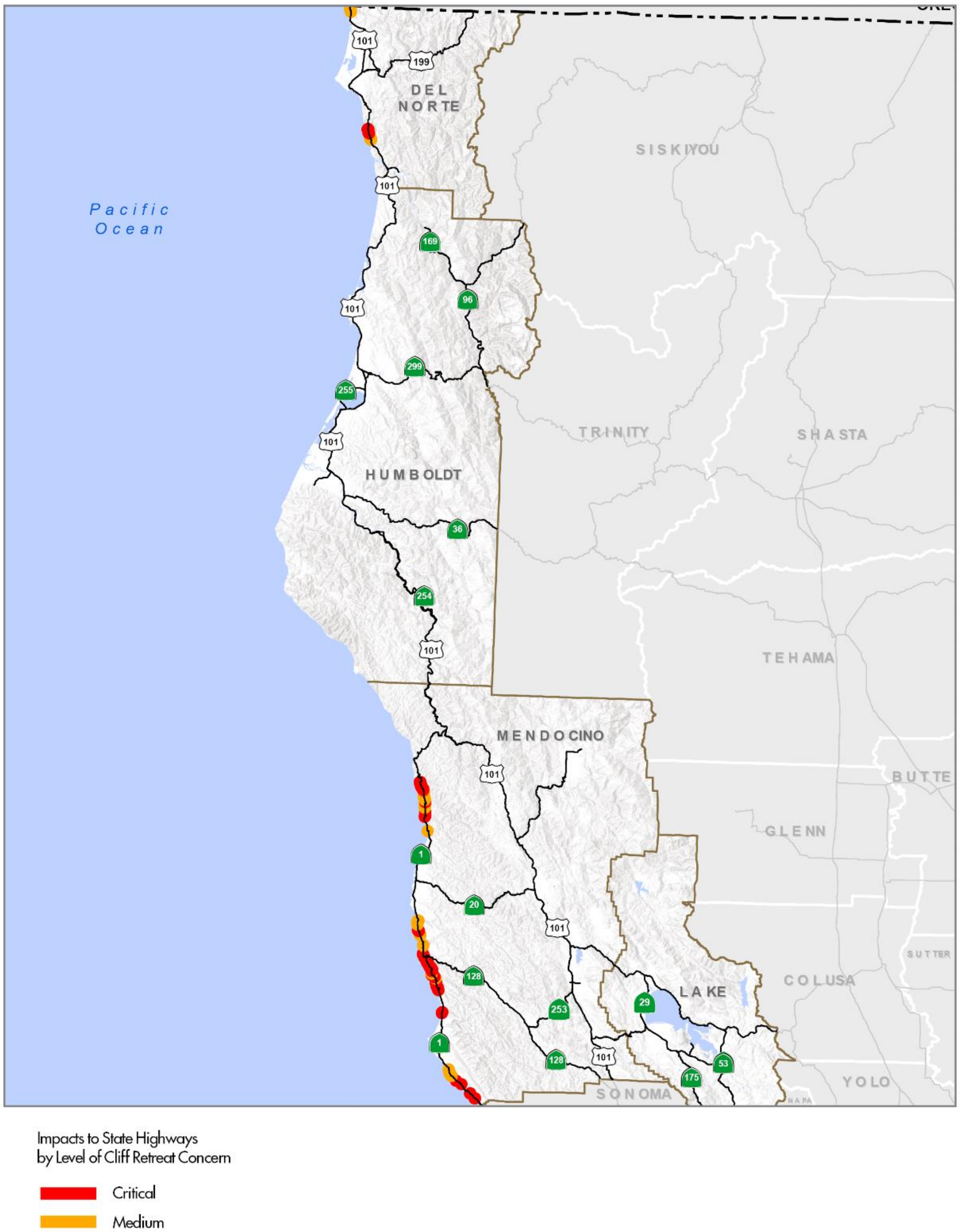
TABLE 9-1: DISTRICT 1 CENTERLINE MILES EXPOSED TO CLIFF RETREAT

District 1 Counties	Exposure in Medium and Critical Concern Areas
Del Norte	1.97
Humboldt	0.07
Mendocino	11.14
Total	**13.17**

NOTE: LAKE COUNTY IS NOT INCLUDED AS THERE IS NO COASTLINE.

FIGURE 9-1: DISTRICT 1 AREAS VULNERABLE TO CLIFF RETREAT

CLIFF RETREAT IMPACTS IN DISTRICT 1



10. INFRASTRUCTURE IMPACT EXAMPLES

As climate changes, California could 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 most deadly and severe wildfire season on record (2018), and deadly mudslides in Southern California (2018). These emergencies demonstrate what could become more commonplace for California in the future. It is important to learn from these events, take actions to prevent them wherever possible, and increase the resiliency of transportation infrastructure for near- and long-term threats. This section provides two examples of District 1 efforts to protect against weather-related disruptions.

10.1. Confusion Hill Bridges - U.S. 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.[54]

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.

10.2. Lake County SR 20 and 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 precipitation.

[54] 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

FIGURE 10-1: US 101 INUNDATION

FIGURE 10-2: SR 1 NEAR LEGGETT MUDSLIDE

FIGURE 10-3: MELTED CULVERTS DUE TO WILDFIRES

11. INCORPORATING CLIMATE CHANGE INTO DECISION MAKING

11.1. Risk-Based Design

A risk-based decision approach considers the broader implications of damage and economic loss in determining the approach to design. Climate change is a risk factor that is often omitted from design but is important for an asset to function over its design life Incorporating climate change into asset-level decision-making has been a subject of research over the past decade, much of it led or funded by the Federal Highway Administration (FHWA). The FHWA undertook a few projects to assess climate change and facility design – including the Gulf Coast II project (Mobile, AL) and the Transportation Engineering Approaches to Climate Resiliency (TEACR) study. Both assessed facilities of varying types, which were exposed to different climate stressors. They then identified design responses that could make the facilities more resilient to change.

One outcome of the FHWA studies was a step-by-step method for completing facility (or asset) design, such that climate change was considered and inherent uncertainties in the timing and scale of climate change were included. This method, termed the Adaptation Decision-Making Assessment Process (ADAP),[55] provides facility designers with a recommended approach to designing a facility when considering possible climate change effects. The key steps in ADAP are shown in Figure 11-1: FHWA's Adaptation Decision-Making Process.

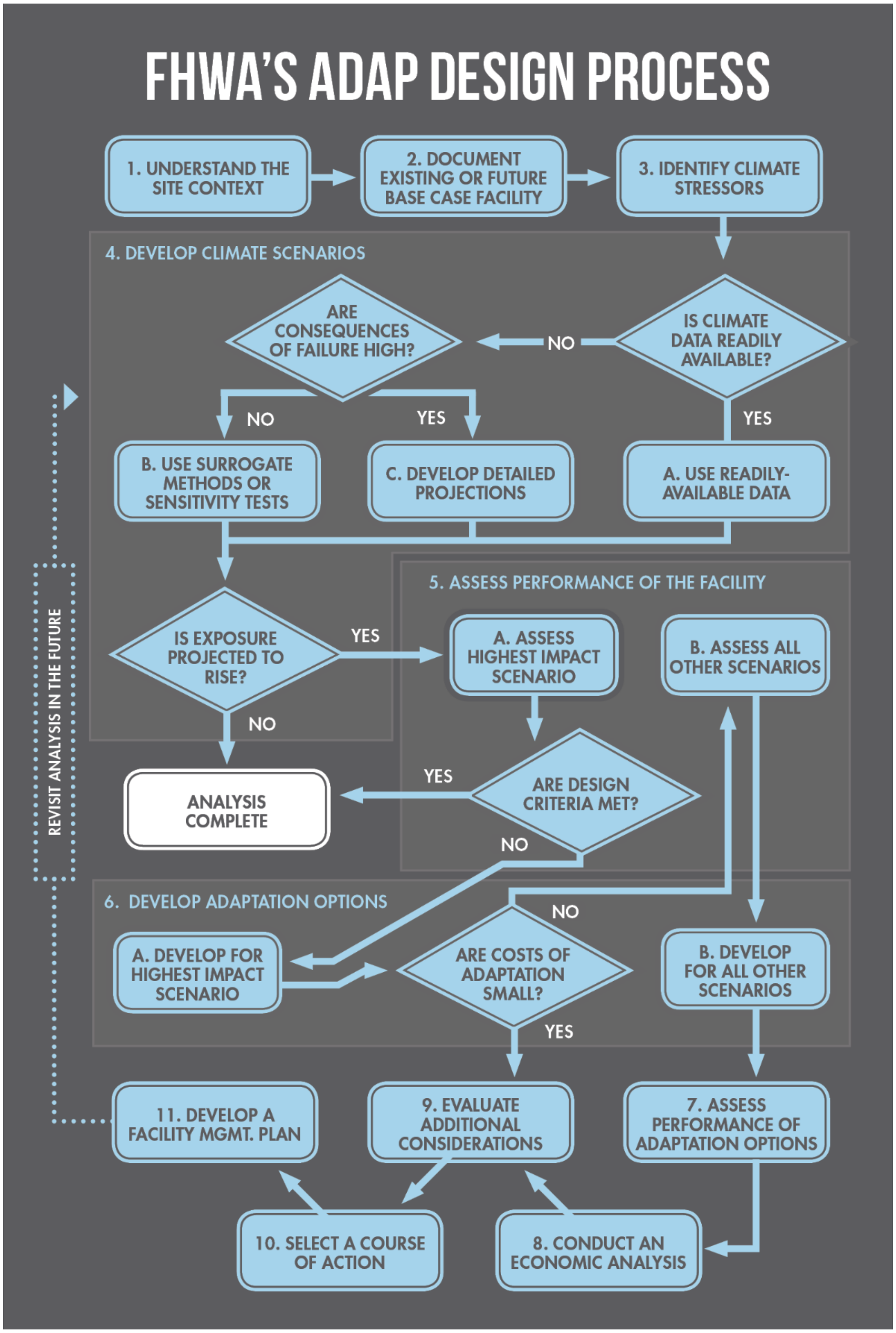
The first five steps of the ADAP process cover the characteristics of the project and the context. The District 1 Vulnerability Assessment has worked through these first steps at a high level and the data used in the assessment has been provided to Caltrans for future use in asset level analyses. These five steps should be addressed for every exposed facility during asset level analyses.

Step five focuses on conducting a more detailed assessment of the performance of the facility. When analyzing one facility, it is important to assess the highest impact scenario. This does not necessarily correspond to the highest temperature range, or largest storm event. In this case, the analysis should determine which scenarios will have the greatest effect on a facility. For example, a 20-year storm may cause greater impacts than a 100-year storm, depending on wind and wave directions. If the design criteria of the facility are met even under the greatest impact scenario, the analysis is complete. Otherwise, the process moves onto developing adaptation options.

Options should be developed that will adapt the facility to the highest impact scenario. If these options are affordable, they can move to the final steps of the process. If they are not, other scenarios can be considered to identify more affordable options. These alternative design options will need to move through additional steps to critique their performance and economic value. Then, they also move to the final steps of the process. These last three steps are critical to implementing adaptive designs. Step nine involves considering other factors that may influence adaptation design and implementation. For example, California Executive Order B-30-15 requires consideration of:

[55] FHWA. "Adaptation Decision-Making Assessment Process (ADAP)." January 12, 2018. Website. Last accessed August 29, 2019, https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/teacr/adap/index.cfm

FIGURE 11-1: FHWA'S ADAPTATION DECISION-MAKING PROCESS



For additional information about ADAP please see the FHWA website at: https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/teacr/adap/index.cfm

- Full life cycle cost accounting
- Maladaptation
- Vulnerable populations
- Natural infrastructure
- Adaptation options that also mitigate GHGs, and
- Use of flexible approaches where necessary.

At this step in the ADAP process, it is important to understand the greater context of the designs developed and whether they meet state, Caltrans, and/or other requirements. This also allows for the opportunity to consider potential impacts of the project outside of design and economics, including how it may affect the surrounding community and environment. After evaluating these additional considerations, a course of action can be identified and a facility management plan implemented.

11.2. Prioritization of Adaptive Response Projects

The project prioritization approach outlined below is based on a review of the methods developed by other transportation agencies and lessons learned from other adaptation efforts. These methods—mostly developed and used by departments of transportation in other states—address long-term climate risks and are intended to inform project priorities across the range of diverse project needs. This prioritization approach is specific to climate change effects only providing a process by which to guide decisions. It is not intended as the sole factor in agency prioritization which includes broader measures, but instead forwards a method to choose among projects that are identified as having potential climate change risks. The method outlined below recognizes the following issues when considering climate change adaptation for transportation projects:

- The implications of damage or failure to a transportation facility due to climate change-related stresses.
- The likelihood or probability of occurrence of an event.
- The timeframe at which the events may occur, and the shifting of future risks associated with climate change.

The recommended prioritization method is applied to those facilities with high exposure to climate change risk; thus, it is not applied to the entire transportation network. The method assumes that projects have been defined in sufficient detail to allow some estimate of implementation costs.

Guiding principles for the development of the prioritization method included the following:

- It should be straightforward in application, easily discernable, describable and it should be relatively straightforward to implement with common software applications (Excel, etc.).
- It should be based on best practices in the climate adaptation field.

- It should avoid weighting schemes and multi-criteria scoring, since those processes tend to be difficult to explain and are open to interpretation among professionals with varying perspectives.
- It should be focused on how departments of transportation do business, reflect priorities for program delivery to stakeholders and recognize the relative importance of various assets.
- It should have the ability to differentiate between projects that may have different implications of risk—like near-term minor impacts and long-term major impacts—to set project priorities.
- It should facilitate decisions among different project types, for example, projects for repairs or for continuous minor damage as compared to one-time major damage events.
- It should enable the comparison among all types of projects, regardless of the stressor causing impacts.

The prioritization method requires the following information:

- Facility loss/damage estimates (supplied by Caltrans engineering staff) should capture both lower level recurring impacts and larger loss or damage. These should include a few key pieces of information, including:

    What are the levels for stressors (sea level rise, surge, wildfire, etc.) that would cause damage and or loss?

    What are the implications of this damage in terms of cost to repair and estimated time to repair?

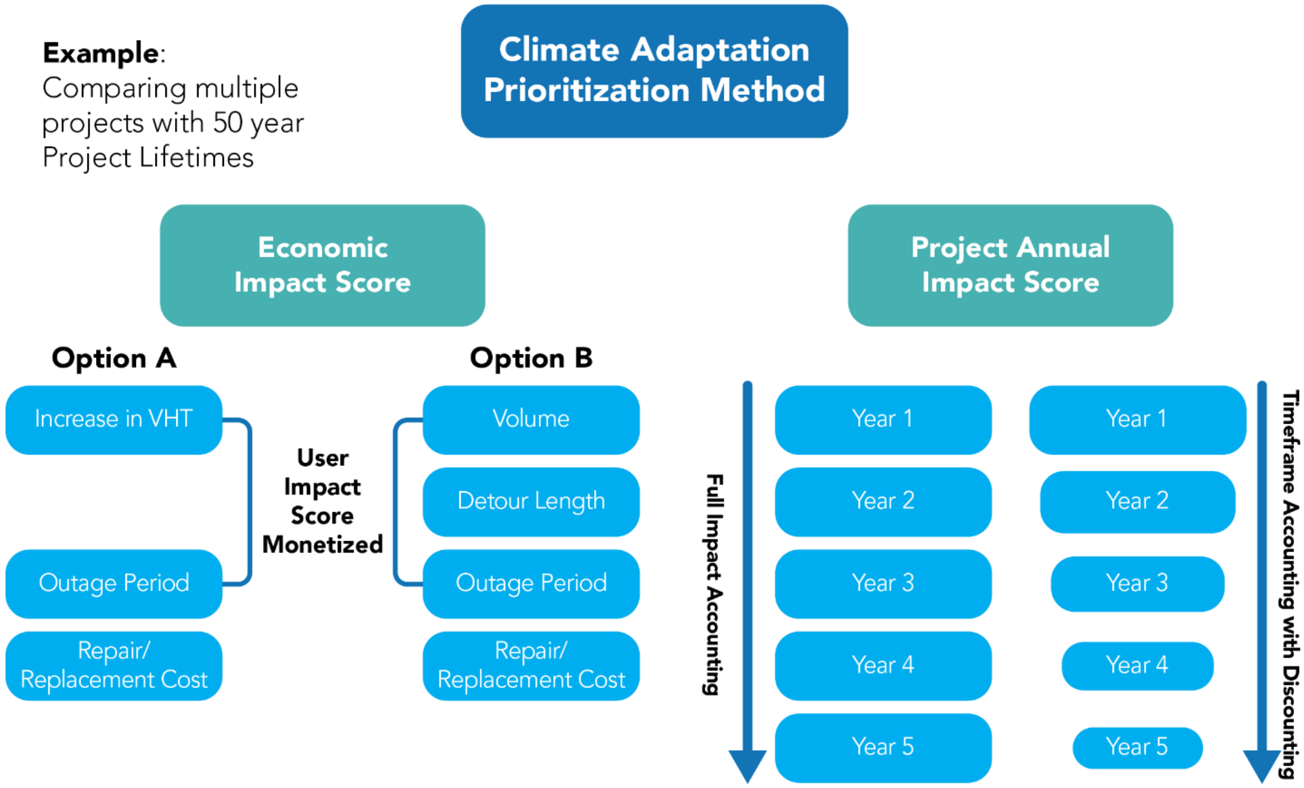
- System impacts (supplied by Caltrans planning staff) – the impacts of the loss of the facility on the broader system. This could be in terms of increase in Vehicle Hours Traveled (VHT) if using a traffic model, or an estimated value using volume and detour length as surrogates.
- Probability of occurrence (supplied by Caltrans climate change staff through coordination with state climate experts) – the probability of events occurring as estimated from the climate data for chosen climate scenarios. Estimated for each year out to the end of the facility lifetime.

A project annual impact score is used to reflect two conditions, summarized by year:

- The expected cumulative loss estimated for the project over the project lifetime (full impact accounting).
- A method of discounting losses over years– to enable prioritization based on nearer term or longer-term expected impacts (timeframe accounting).

These two pieces of information are important to better understand the full cost of impacts over time. Figure 11-2 shows the general approach for the prioritization method.

FIGURE 11-2: APPROACH FOR PRIORITIZATION METHOD



The two side-by-side charts represent various approaches to calculating values to be used for prioritization. The left side (Economic Impact Score) shows two methods for determining costs to the system user. The right-side show how costs could be counted in two ways, one which utilizes a full impact accounting that basically sums all costs to the end of the asset useful life while the other uses annual discounting to reflect "true costs" or current year dollar equivalent values to calculate the final impact score for the asset. These are presented as shown in part to provide an option for determining these values and in part to outline the various methods that are being used on similar projects nationally. The final selected method would require input and leadership from Caltrans to define the parameters for the approach to inform decisions.

The prioritization method would need estimates of at a minimum repair/replacement cost (dollars) and, if broadened, a system users impact (in dollar equivalents). System user costs would be summarized for this effort as transportation service impacts, and would be calculated in one of two ways:

- Estimate the impacts to a transportation system by identifying an expected detour routing that would be expected with loss of access or a loss/damage climate event. This value would be combined with average daily traffic and outage period values to result in an estimate of VHT increase associated with the loss of use of a facility.
- Utilize a traffic model to estimate the impacts on the broader SHS from damage/loss of a facility or facilities anticipated to occur as a result of a climate event. The impact on the system would be summarized based on the net increase in VHT calculated in the model.

The advantage of the system method is that it determines impacts of multiple loss/failure assessments consecutively and is not confined to only the assessment of each individual project as an individual project concern. It also allows for comparisons to the broader system and scores facilities with heavier use and importance to an integrated system as higher in terms of impact and prioritization.

Probabilities of an event occurring over each year would be used to summarize costs per year as well as a summarized cumulative total cost for the project over the lifetime. The resulting values would set the prioritization metric in terms of net present value for Caltrans to apply in selecting projects. The identification of an annual cost metric, which includes discounting, enables the important decision-making process on which project should advance given limited project resources. Table 11-1 highlights how the method would be implemented, with the project selected in the out years selected by the calculated annual cost metric. The impacts noted in the time period beyond the selected year (shown in shaded color) would be expected to have been addressed by the adaptation strategy. Thus, in the table, Project 1 at year 5 has the highest annual cost associated with disruptions connected to an extreme weather event. The project with the next greatest annual cost is Project 2, where this cost is reached at year 15. The next project is Project 3 at year 35 and the final project is Project 4 at year 45.

TABLE 11-1: EXAMPLE PROJECT PRIORITIZATION

Year	5	10	15	20	25	30	35	40	45	50
Project 1		$5	$5	$5	$7	$7	$7	$9	$9	$9
Project 2			$6	$6	$6	$6	$8	$8	$8	$8
Project 3								$8	$8	$8
Project 4									$10	$10

The project prioritization method outlined above requires the development of new approaches to determining how best to respond to climate change risks. It does not rely on existing methods as they are not appropriate to reflect climate risk effectively and facilitate agency level decision making. Climate change, with its uncertain timing and non-stationary weather/climate impacts, requires methods that incorporate this reality into Caltrans' decision-making processes.

It would be possible to implement a tiered prioritization process once work required to complete the steps as outlined above has been completed. Assets at risk from climate change with comparable present values could be compared for their capability to address other policy concerns – like goods movement, access for low income / dependent communities, sustainability measures, or other factors that would help Caltrans meet statewide policy goals. The primary focus of this assessment should be on the impacts to the system; however, these secondary measures can help clarify or reorder the final list and help guide implementation.

12. CONCLUSIONS AND NEXT STEPS

This report represents an initial effort to identify areas of exposure to potential climate change for facilities owned and operated by Caltrans District 1. The study utilized various data sources to identify how climatic conditions may change from today and where these areas of high exposure to future climate risks appear in District 1. The study distilled the larger context of climate change down to a more localized understanding of what such change might mean to District 1 functions and operations, District 1 employees, and the users of the transportation system. It is intended, in part, as a transportation practitioner's guide on how to include climate change into transportation decision making.

Much of today's engineering design is based on historical conditions, and it is emphasized throughout this report that this perspective should change. A review of climate data analyzed for this study shows that, for those stressors analyzed (sea level rise, storm surge, wildfire, temperature, and precipitation), there are clear indications that future conditions will be very different from today's, with likely higher risks to highway infrastructure. These likely future conditions vary in terms of when threshold values will occur (that is, when sea levels, or precipitation and temperature values exceed a point at which risks will increase for assets) and on the potential impact to the SHS. This is an important consideration given that transportation infrastructure investment decisions made today will have implications for decades to come given the long lifetimes for roadway facilities.

This report provides District 1 with the information on areas of climate change exposure it can utilize to proceed to more detailed, project-level assessments. In other words, the report has identified where climate change risks are possible in District 1 and where project development efforts for projects in these areas should consider changing future environmental conditions. There are several steps that can be taken to transition from a traditional project development process based on historical environmental conditions to one that incorporates a greater consideration for facility and system resiliency. This process can incorporate the benefits associated with climate change adaptation strategies and use climate data as a primary decision factor. District 1 staff, with its recent history of assessing long-term risks associated with climate change, has the capacity to adopt such an approach and ensure that travelers in the region are provided with a resilient system over the coming years.

The following section provides some context as to what the next steps for Caltrans and District 1 may be, to build upon this work and create a more resilient SHS.

12.1. Next Steps

The work completed for this effort answers a few questions and raises many more. The scope of this work was focused on determining what is expected in the future and how that may affect the Caltrans SHS. This analysis has shown that climate data from many sources indicate an expanded set of future risks – from increased extreme precipitation, to higher temperatures, and an increase in wildfires – all concerns that will need to be considered by District 1.

There are a few steps that will be required to improve decision making and help Caltrans achieve a more resilient State Highway Network in District 1. These include:

- Policy Changes
  - Agency leadership will need to provide guidance for incorporating findings from this assessment into decision making. This area is a new focus and requires a different perspective that will not be possible without strong agency leadership.
    - Addressing climate change should be integrated throughout all functional areas and business processes; including Planning, Environmental, Design, Construction, Maintenance and Operations.
  - Risk-based decision-making. The changing elements of climate change require the consideration of the implications of those changes and how they may affect the system. Caltrans will need to change its methods to incorporate measures of loss, damage and broader social or economic costs as a part of its policies. (See 11.1 Risk-Based Design).
- Acquisition of Improved Data for Improved Decision-Making
  - Determining potential impacts of precipitation on the SHS will require additional system/environmental data to complete a system-wide assessment. This includes:
    - Improved topographic data across District 1 (and the state of California).
    - Improved asset data – including accurate location of assets (bridges, culverts) and information on the waterway opening at those locations.
  - The assessment of wildfire potential along the SHS is an ongoing effort. Follow up will be required to determine the results of new research and whether updated models indicate any additional areas of risk.
  - The precipitation and temperature data presented in this report are based off of a dataset that is newly released. Methods to summarize this data across many climate models are ongoing and the conclusions of that work may yield information that may more precisely define expected future changes for these stressors.
  - There are efforts underway to refine the understanding of other stressors, including landslide potential. Further refinements of those efforts will require additional investment and coordination to complete. Research efforts are constantly being refined and Caltrans will need to be an active partner in participating in, and monitoring, the results of these efforts to determine how to best incorporate the results of these efforts into agency practices.
- Implementation
  - The data presented in this report indicate directions and ranges of change. These data points will need to become a part of Caltrans practice for planning and design for all future activities.
  - The use of this data will require the development of educational materials and the training of Caltrans staff to ensure effective implementation.

Not every concern and future requirement could be addressed or outlined in this report. Thus, the report should be considered the first step of many that will be required to address the implications of climate change to the SHS. Much work remains to create a resilient SHS across California.

13. GLOSSARY

50th percentile downscaled model outputs (for temperature and precipitation projections) – 50th percentile results represent the median of downscaled climate model outputs under RCP 8.5 for the metric shown, as calculated across the state using the area weighted mean.

100-year design standard: Design criteria for highway projects that address expected environmental conditions for the 100-year storm. Considered Base Flood Elevation by the Federal Emergency Management Agency.

Cal-Adapt: A web-based data hub and information guide on recent California-focused climate data and analysis tools. Visualization tools are available to investigate different future climate scenarios.

Climate change: Change in climatic conditions expected to occur due to the presence of GHG concentrations in the atmosphere. Examples include changing precipitation levels, higher temperatures, and sea level rise.

Downscaling: An approach to estimate climate predictions at a more localized level based on the outcomes of models that predict future climate conditions at a much larger scale of application.

Emissions Scenarios: Assumed future states of GHG concentrations in the atmosphere.

Exposure: The degree to which a facility or asset is exposed to climate stressors that might cause damage, disrupt facility operations, or otherwise asset condition.

Global Climate Model (GCM): Models used by climate scientists to predict future climate conditions. This term is sometimes used interchangeably with General Circulation Model.

Representative concentration pathways (RCP): Scenarios of future GHG emission concentrations based on assumed future emissions given economic development, population growth, technology, and other variables.

Resilient transportation facilities: Transportation facilities that are designed and operated to reduce the likelihood of disruption or damage due to changing weather conditions or other impacts.

Return period storm event: Historical intensity of storms based on how often such level of storms have occurred in the past. A 100-year storm event is one that has the intensity of a storm that statistically occurs once every 100 years (1% chance of occurring each year).

State Highway System (SHS): The designated highway network in California, which Caltrans is responsible for operating and maintaining.

Stressor/stresses: Climate conditions that could possibly apply stress to engineered facilities. Examples include temperature rise and precipitation change.

Tidal flooding: As sea level rises, tides will get progressively higher and lead to longer periods of inundation at high tide. Eventually rising sea levels will lead to permanent inundation.

Vulnerability assessment: A study of those areas likely to be exposed to future climate and weather conditions that will add additional stress to assets, in some cases, levels of stress that might exceed the assumed conditions when the asset was originally designed.

Vulnerable populations: “Vulnerable populations include, but are not limited to women; racial or ethnic groups; low-income individuals and families; individuals who are incarcerated or have been incarcerated; individuals with disabilities; individuals with mental health conditions; children; youth and young adults; seniors; immigrants and refugees; individuals who are limited English proficient (LEP); and Lesbian, Gay, Bisexual, Transgender, Queer, and Questioning (LGBTQQ) communities, or combinations of these populations."[56]

[56] Governor's Office of Planning and Research, "Planning and Investing for a Resilient California: A Guidebook for State Agencies," March 13th, 2018, last accessed June 20, 2019. http://opr.ca.gov/planning/icarp/resilient-ca.html

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