


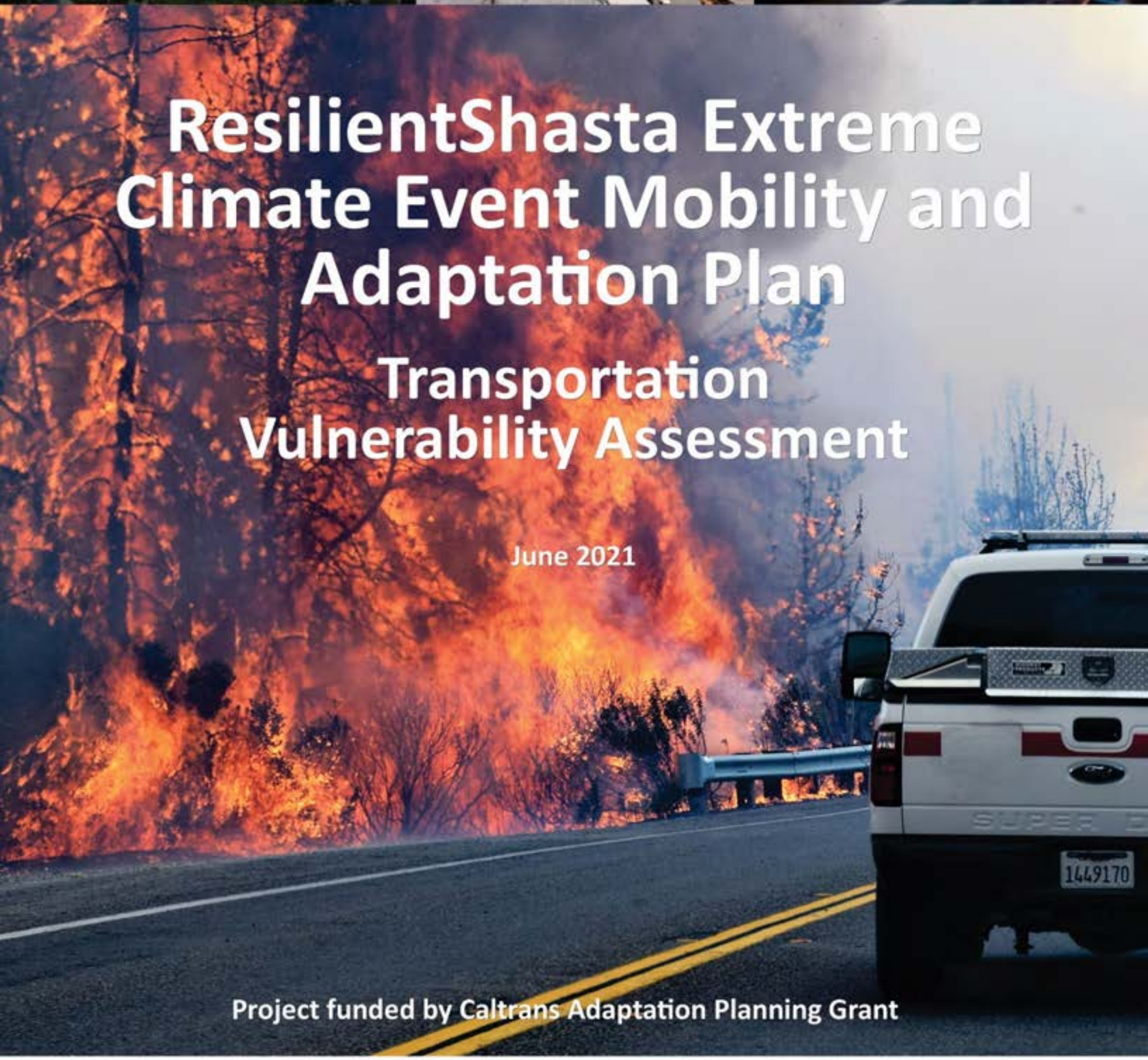

ResilientShasta Extreme Climate Event Mobility and Adaptation Plan

Transportation Vulnerability Assessment

June 2021

Project funded by Caltrans Adaptation Planning Grant

SHASTA REGIONAL TRANSPORTATION AGENCY

ResilientShasta Extreme Climate Event Mobility and Adaptation Plan

Phase 1:

Transportation Vulnerability Assessment

Executive Summary

The Shasta Region is confronted with a wide range of extreme weather hazards, many of which are expected to grow more hazardous over the course of the century. Rising temperatures, wetter winters, drier summers, and more frequent and severe extreme precipitation events will all affect the way in which every citizen of the Shasta Region lives their life. These changing weather patterns will also likely increase the danger of extreme weather events like wildfires, flooding, and landslides. This study evaluates the ways that these hazards are expected to change, and how they are expected to threaten the mobility of Shasta residents.

This study focuses on the key transportation systems that Shasta residents and communities rely on, including roads and highways, rail, airports, bus transit, and pedestrian and cyclist infrastructure. Among the extreme weather hazards evaluated in this study are extreme temperatures, average and extreme precipitation, wildfire, flooding, and landslides. Table ES-1 provides projected changes to each of these hazards over the coming century, as well as some examples of how these hazards can affect mobility in the Shasta Region.

Table ES-1. Hazards, projected changes, and example impacts to the Shasta Region's mobility.

Hazard	Projected Changes	Example Mobility Impacts
Extreme Temperatures	Hotter summers, warmer winters, much hotter heat waves	Accelerated damage to roads, more heat-related vehicle breakdowns
Extreme Precipitation	More frequent and severe extreme precipitation events	Reduced transit ridership, localized flooding
Wildfire	More frequent and more severe wildfires, especially in the north and central region	Damage to infrastructure, extensive road closures
Flooding	Increased likelihood of flood conditions	Washout of roads/bridges, inundation of pedestrian routes
Landslides	Potential increased risk of debris flows and landslides near highways	Blockage of road segments

Another focus of this study is the role that specific transportation links play in providing access between the region's vulnerable communities, including communities with higher social vulnerability scores (factoring in socioeconomic, household composition, minority status/language, and housing and transportation characteristics).

Wildfires stand out as the most pressing issue of concern for the Shasta Region's mobility. Shasta residents are no strangers to the hazards of wildfire, but over the coming century both the probability of wildfires, and the intensity of fires are projected to increase rapidly throughout the entire Shasta Region. For example, in Shingletown, the probability of wildfires is projected to quadruple by 2085, assuming greenhouse gas (GHG) emissions continue to increase, and the severity of wildfires is projected to increase by over 341%. Shingletown is one of the Shasta Region's more vulnerable communities, with significantly higher-than-average rates of residents living with disabilities, aged over 65, and/or living in mobile homes. Figure ES-1 shows the expected change in the probability of wildfires (expressed as the percent chance that a wildfire will occur within each decade) across the Shasta Region, starting with historical experience, and including projected probabilities in 2025, 2055, and 2085.

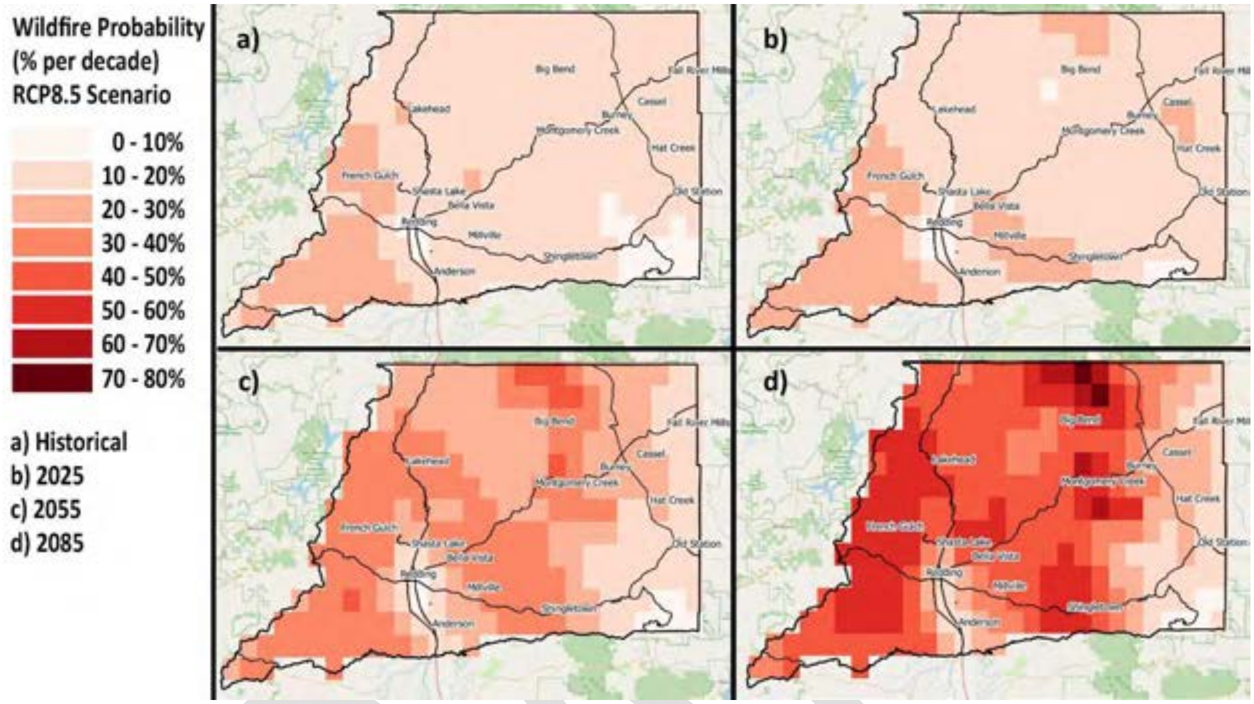

Figure ES-1. Historical and projected decadal wildfire probability across the Shasta Region. a) Historical, b) 2025, c) 2055, d) 2085.

Extreme precipitation and resultant flooding are another major hazard in the Shasta Region. Current floodplains threaten significant transportation infrastructure, including major highways like I-5, 299, and 273, the railroad, and many surface streets in communities like Redding. But projected increases in extreme precipitation events indicate that future floods may be even larger than current expectations. For example, at the Redding Municipal Airport, the 100-year precipitation event (i.e., a rain or snowstorm with a 1% chance of occurring each year) is projected to have 31% more precipitation by 2085.

Higher temperatures and heat waves also threaten the region. Historically, the average heat wave in Redding has been 106°F – by the end of the century, this could increase to over 115°F. Similar increases are projected across the region. Higher temperatures don't just make working outside harder for humans and machines, they also reduce ridership on transit systems, reduce the use of pedestrian and cyclist routes, and even accelerate the wear and tear on road surfaces.

Finally, landslides are a potential future impact that may affect the region's road and rail network. While the Shasta Region has not historically experienced many damaging landslides, the combination of wildfires and heatwaves with the potential to kill hillside vegetation (including the root systems that sustain slope soils). Combined with more frequent and intense extreme precipitation events, these extreme weather hazards may expose many steep hillsides to debris flow or landslide hazard, particularly above Highway 299 west of Whiskeytown Lake and between Bella Vista and Montgomery Creek.

This vulnerability assessment is a part of a multi-stage effort on the part of SRTA to identify and prepare for challenges to mobility in the Shasta Region stemming from extreme weather and climate change. The subsequent phase of this study – the Resilient Shasta Transportation Adaptation Plan – will identify recommendations for adapting the region's infrastructure to changing extreme weather threats.

Introduction

Extreme weather – including wildfires, floods, heatwaves, extreme storms, and landslides – threaten the transportation infrastructure of the Shasta Region and the mobility of its residents. Extreme weather poses a growing threat as the warming climate intensifies existing hazards and introduces new ones. Rising temperatures and changing precipitation patterns are interacting with local weather, hydrology, forests, and geology to create a changing set of circumstances for the infrastructure systems that the Shasta Region relies on.

What is Mobility Infrastructure?

Rather than focusing just on the region's transportation infrastructure, this study focuses on the Shasta region's mobility, a concept that includes ***all of the systems that enable the residents of the Shasta region to move around freely and easily, including during emergencies***. Mobility includes both the necessary built infrastructure, as well as the organizations such as RABA, SRTA, Caltrans, Amtrak, and beyond.

This study focuses on the mobility network in the Shasta Region, including the cities of Shasta Lake, Redding, and Anderson, as well as Shasta County. It is part of a multi-step effort called ResilientShasta to understand the vulnerabilities of the Shasta Region's mobility infrastructure to climate change and extreme weather, identify adaptation actions that will respond to those vulnerabilities, and integrate those actions into a long-term transportation network planning effort for the Region. This report evaluates the transportation infrastructure and systems in the Region and assesses their vulnerability to extreme weather and climate change hazards. This study is also informed by input from the region's governments and stakeholders, as well as through public input. Subsequent studies will include a ResilientShasta Mobility Adaptation Plan that identifies adaptation actions, and a final ResilientShasta Extreme Climate Event Mobility and Adaptation Plan that will lay out the findings of these studies and recommend mitigation actions.

Why Extreme Weather and Climate Change?

Figure 1. The Carr Fire burned extremely close to downtown Redding. The extent of the Carr Fire's burn scar in Lake Redding Estates, with central Redding in the distance. Source: City of Redding 2018.

In 2018, the Carr Fire started near Whiskeytown Lake due to a blown tire and resulting sparks igniting roadside vegetation. The fire burned through multiple communities, down the hillside through Old Shasta and Keswick and into Redding, jumping the Sacramento River along the way. After burning for over a month and merging with two other wildfires (the Delta and Hirz Fires), the Carr Fire left

230,000 acres burned, over a thousand homes destroyed, and eight lives lost in its wake.[1] Among the deceased were two firefighters, another Cal Fire equipment mechanic, a PG&E employee, and four residents of Keswick who were unable to evacuate in time. The Carr Fire also came extremely close to extending the devastation into the heart of Redding. Figure 1 shows the extent of the burn scar in Lake Redding Estates, just over a mile from downtown Redding. At the time, the Carr Fire was the sixth most destructive fire in recorded California history.

While wildfires are a familiar and essential part of California's forests, the types of intense, fast-moving fires that threaten the survival and prosperity of the Shasta Region's communities are becoming more frequent and more severe, and the overall hazard associated with wildfire is growing: the lessons of the Carr Fire were still fresh in 2020 when the Zogg Fire was sparked in the hills north of Igo, triggered by a pine tree striking electricity transmission lines.[2] By the time the fire had burned through Igo and Ono, four people were killed and over 200 buildings damaged.[3]

The factors that contribute to this increasing hazard – particularly hotter, drier summers – also create many other challenges to mobility by damaging or destroying transportation infrastructure, disrupting transportation operations, and increasing the costs associated with maintaining a functioning mobility system: extreme heat can degrade asphalt and cause damage to roads requiring more frequent repairs, extreme precipitation can lead to flooding which can wash out roadbeds and cause road closures, and wildfire can work alongside precipitation to create landslides that threaten entire segments of transportation infrastructure.

Project Overview and Goals

The ResilientShasta project aims to contribute to the following goals:

- Development of a mobility vulnerability assessment explaining extreme weather (e.g., fire intensity, flood hazards, precipitation frequency and intensity, etc.) likely to affect the Shasta Region's mobility infrastructure through the year 2099, the regional impacts of climate change on Shasta Region communities, and the detailed vulnerabilities of the Shasta Region's transportation systems.
- Development of a mobility adaptation plan identifying, evaluating, and recommending adaptation strategies for SRTA, the County of Shasta, the cities of Anderson, Redding, and Shasta Lake, Redding Area Bus Authority (RABA), Dignity Health Connected Living, and applicable state agencies to consider in creating a resilient transportation network, including planning, operational, and capital investment strategies.
- Engage with the broad set of Shasta Region stakeholders about the vulnerability assessment and adaptation plan effort, and provide clear communication on how it affects residents, businesses, and public stakeholders alike.

This assessment seeks to satisfy the first goal of the ResilientShasta project, while partially completing the third. The next phase of this project will address adaptive strategies to minimize the impact of climate change and extreme weather vulnerabilities in the Shasta Region's transportation network.

[1] Estrada 2019
[2] Brannon 2021
[3] Arthur 2020

Contributors

This assessment has solicited with input from the following agencies and stakeholder groups:

- Butte County Association of Governments (BCAG)
- California Department of Transportation, District 2
- Cal Fire
- California OES
- California Highway Patrol
- City of Anderson
- City of Redding
- City of Shasta Lake
- Dignity Health Connected Living
- Federal Emergency Management Agency (FEMA)
- The McConnell Foundation
- Pacific Gas & Electric
- Pit River Tribe
- Redding Area Bus Authority (RABA)
- Redding Electric Utility
- Redding Rancheria
- Shasta County Fire Safe Council
- Shasta County GIS Office
- Shasta County Planning
- Shasta County Public Works
- Shasta County Sherriff's Office
- Shasta Lake Electric Utility
- Shasta Regional Transportation Agency
- Siskiyou County Public Works
- Tehama County Public Works
- U.S. Bureau of Land Management (BLM)
- U.S. Forest Service (USFS)
- U.S. National Park Service (NPS)
- Western Shasta Resource Conservation District
- Winnemem Wintu tribe

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Glossary

100-Year Flood (1% Flood)

In the context of Federal Emergency Management Agency (FEMA) flood insurance rate maps (FIRMs), the 100-year flood is a theoretical flood stage with a 1-in-100 chance of occurring each year (also called a 1% flood). Because FEMA FIRMs are the most ubiquitous flood hazard mapping product available, many planning decisions are made around the regulatory 100-year floodplain. However, the 100-year floodplain is both derived from historical data and thus does not account for changes to future precipitation under climate change. Because floodplains are modeled, the hazard area contains significant uncertainty.

500-Year Flood (0.2% Flood)

The 500-year flood (also called a 0.2% flood) is a flood with a probabilistic return period of 500 years, or a 0.2% annual chance of occurring. The 500-year floodplain is the area expected to be inundated in a 500-year flood. As with the 100-year floodplain, the 500-year floodplain is derived from historical data and does not reflect projected changes to future precipitation from climate change. For resilience planning purposes, locating a facility or asset outside of the 500-year floodplain is one approach to mitigating flood hazard when detailed flood hazard analyses are unavailable.

25-Year Precipitation Event

The 25-year precipitation event (also called a 4% precipitation event) is an extreme precipitation event with a 4% chance of occurring each year (i.e., 1-in-25 chance). Like the 100- and 500-year precipitation events, this type of extreme precipitation event is said to have occurred when more rain (or an equivalent amount of water in the form of snow) falls within a set duration (e.g., 72 hours) than in 96% of other periods. While extreme precipitation events can cause flooding, the occurrence of floods depends on a number of other factors such as how much water is contained by soils prior to the precipitation event, and the capacity of existing flood control systems to contain and prevent flooding downstream.

100-Year Precipitation Event

The 100-year precipitation event (also called a 1% precipitation event) is an extreme precipitation event with a 1% chance of occurring each year (i.e., 1-in-100 chance). This type of extreme precipitation event is said to have occurred when more rain (or an equivalent amount of water in the form of snow) falls within a set duration (e.g., 72 hours) than in 99% of other periods. While extreme precipitation events can cause flooding, the occurrence of a 100-year precipitation event does not mean that a 100-year flood will result. The occurrence of floods depends on a number of other factors such as how much water is contained by soils prior to the precipitation event, and the capacity of existing flood control systems to contain and prevent flooding downstream.

500-Year Precipitation Event

The 500-year precipitation event (also called a 0.2% precipitation event) is an extreme precipitation event with a 0.2% chance of occurring each year (i.e., 1-in-500 chance). This type of extreme precipitation event is said to have occurred when more rain (or an equivalent amount of water in the form of snow) falls within a set duration (e.g., 72 hours) than in 99.8% of other periods. While extreme precipitation events can cause flooding, the occurrence of a 500-year precipitation event does not mean that a 500-year flood will result. The occurrence of floods depends on a number of other factors such as how much water is contained by soils prior to the precipitation event, and the capacity of existing flood control systems to contain and prevent flooding downstream.

Adaptation
In the context of climate change, adaptation refers to the adjustment of any human or natural system to changing climate parameters (e.g., temperature, water availability, extreme weather, or sea level rise). Adaptation is frequently used to refer to intentional steps taken by humans to anticipate climate change and reduce the costs of climate change impacts. In practice, adaptation is frequently interchanged with the term 'resilience.'

Base Flood Elevation (BFE)
Base flood elevation is a concept defined within the scope of FEMA flood hazard mapping products, and refers to the elevation to which floodwaters are expected to rise during a base flood (e.g., a 100-year flood). The BFE for each flood condition is shown on flood insurance risk maps (FIRMs). BFE differs from design flood elevation (DFE), as BFE defines the region for the flood hazard area, while DFE includes some additional margin of safety for the design of structures and infrastructure (e.g., BFE + 1'). When determining BFE for a site, use the highest of any elevation shown on the FEMA FIRM or other flood hazard product.

Climate
The term "climate" refers to the general weather conditions in an area over a long period of time. Typically, climate averages are measured over a 30-year period.

Climate/Extreme Weather Hazard
Climate change/extreme weather hazards are the changes to climate factors (for example temperature or precipitation) that have the potential to damage or disrupt natural or built systems, communities, government or business operations, and the economy. Climate hazards can include sudden extreme weather events such as fires, floods, or storms, as well as long-term changes to 'normal weather such as average temperatures or precipitation.

Climate/Extreme Weather Impact
Climate change/extreme weather impacts are the specific instances of damage or disruption caused by climate hazards. For example, a climate hazard may be the increased probability of wildfire that could damage a community, but a climate impact is the occurrence of a wildfire that damages a community.

Climate/Extreme Weather Vulnerability
A climate/extreme weather vulnerability is the exposure of a specific system, asset, facility, organization, or community to a climate hazard. For example, a community is vulnerable to wildfire hazards if the occurrence of a fire could be expected to damage the community. For infrastructure systems, a system said to be vulnerable to a hazard if the probability of a climate impact is expected to exceed an acceptable risk threshold over the asset's useful lifetime. Depending on the type of system, asset, organization, or community, "useful lifetime" may not apply.

Climate/Extreme Weather Risk
Risk describes both the likelihood of a climate/extreme weather event *and* the consequences of the event. In application to climate/extreme weather adaptation planning, climate risk describes the overall likelihood of a climate impact (e.g., heat wave, fire, flood, etc.), as well as the cost of damage to

infrastructure or disruption to critical services associated with such an impact. Explicit quantification of climate risk can be achieved using multiple modeling approaches for estimating the probability of a climate change impact and for estimating the cost of an impact for specific systems or regions, however such approaches can be difficult. Alternative approaches to risk characterization may use binned estimates of likelihood and cost based on orders of magnitude.

Extreme Heat/Temperatures

Temperatures outside the normal historical experience for a place or season. In summer, extreme heat can include temperatures above which normal activities can become strenuous, or at which normal processes are affected. For humans and for infrastructure systems, there is no defined threshold for extreme heat, however identifying the projected shift in the highest temperatures is useful for providing planners with an indication of the change in frequency of extreme heat conditions.

Extreme Precipitation

Precipitation whose intensity exceeds a threshold typical for a region can be considered to be extreme precipitation. In this study, extreme precipitation is evaluated by comparing historical precipitation extremes to projected precipitation extremes for 25-, 100-, and 500-year precipitation events.

Extreme Weather

Weather events that are unexpected or unusual for a place or season. Extreme weather can refer to weather events (including temperature or precipitation extremes, storms, winds, drought, floods, or fires) that cause significant damage to human or natural systems. These can also be defined as weather events that are statistically unlikely to occur when compared to historical climate for a place and time of year.

FEMA Flood Insurance Rate Map (FIRM)

The official map of a community prepared by FEMA that shows the BFE, along with the special flood hazard areas and the risk premium zones for flood insurance purposes. Special flood hazard areas include the 100-year (1% annual probability) flood areas, and some maps include 500-year flood areas (0.2% annual probability). FEMA FIRMs are a useful flood hazard screening tool, but do not reflect projected future changes to precipitation, runoff, sea level rise, and storm recurrence periods.

Floodplain

Also called fluvial or riverine floodplain, areas adjacent to or near inland watercourses and wetlands subject to river or stream flood hazards.

Fluvial Flooding

Fluvial or riverine flooding results from excessive precipitation or snowmelt, resulting in surface runoff that exceeds the capacity of water channels (including creeks, rivers, and drainage systems), resulting in water levels exceeding water channel banks. Fluvial flooding can be caused by sudden extreme precipitation

Geographic Information System (GIS)

GIS tools are software that allow users to connect any type of data to a geographic reference. Common GIS software allows users to create maps, conduct geospatial analyses, and identify threats from climate hazards by linking hazard projections to maps of assets.

Heat Wave

For the purposes of this study, heat waves are defined as the average high temperature of the hottest consecutive seven-day period in the year.

Long-Term Resilience Measures

Actions taken to increase infrastructure resilience that require new capital investments in infrastructure or upgrades to existing systems, large increases in labor force, or other changes to existing systems that would require investments beyond a five-year window.

National Flood Hazard Layer (NFHL)

The NFHL is FEMA's current compilation of regulatory flood hazard products, including Flood Insurance Rate Maps (FIRMs). The NFHL exclusively includes flood hazard maps based on historical data, and does not include flood hazard projections that take into account climate change.

Reduced Emissions Scenario (RCP4.5)

This assessment uses two emissions scenarios which incorporate divergent assumptions about the future. The reduced emissions scenario assumes that global greenhouse gas emissions peak in 2040 and decline afterwards, resulting in an elevated but stable amount of warming by 2100. The scenario is defined by the amount of radiative forcing (i.e., solar energy) trapped by the atmosphere in 2100 in units of watts per square meter. Thus, the Representative Concentration Pathways (RCP) scenario corresponding to an emissions pathway that produces 4.5 W/m^2 of radiative forcing in 2100 is rerferred to as RCP4.5.

This scenario is considered very unlikely given current international emissions outlooks, but serves as an illustrative 'minimum' in terms of projected change. Both the RCP4.5 and RCP8.5 scenarios were created as part of the Intergovernmental Panel on Climate Change's (IPCC) fifth assessment report (AR5), published in 2014.[4] These scenarios have become the industry standard for anticipating potential outcomes of climate change.

Unconstrained Emissions Scenario (RCP8.5)

This assessment uses two emissions scenarios which incorporate divergent assumptions about the future. The unconstrained emissions scenario corresponds to a world where global greenhouse gas emissions continue to rise throughout the century, leading to rapid and escalating warming by 2100. The scenario is defined by the amount of radiative forcing (i.e., solar energy) trapped by the atmosphere in 2100 in units of watts per square meter. The RCP8.5 scenario corresponds to an emissions pathway that produces 8.5 W/m^2 of radiative forcing in 2100.

This scenario is considered a 'worst case' scenario, but one that reflects current global trends in emissions and assumes no change in trajectory. Both the RCP4.5 and RCP8.5 scenarios were created as part of the IPCC's fifth assessment report, published in 2014.[5] These scenarios have become the industry standard for anticipating potential outcomes of climate change.

[4] IPCC 2014
[5] IPCC 2014

Vulnerable Communities

Vulnerable communities are populations or places at higher risk for certain bad outcomes. In California, two definitions of vulnerable communities are commonly used, however additional definitions can be helpful, depending on the context. Disadvantaged communities are defined by SB 535 and determined by California Environmental Protection Agency. Low-Income Communities are defined by AB 1550, either as areas with a median income below 80% of the state median income, or through designation by the California Department of Housing and Community Development.

Wildfire

Wildfires are fires that are unplanned and initially out of control, typically in forests, grasslands, or other areas with combustible vegetation. Wildfires can grow very large and be very destructive, but many are also small. Wildfire is a natural process, but can cause severe damage when fires occur in populated areas. Wildfires can be among the most deadly and costly extreme weather events.

Shasta Regional Transportation Vulnerabilities

The Shasta Region's exposure to climate and extreme weather impacts is characterized in five sections, describing vulnerabilities associated with each of the following climate and extreme weather hazards:

- Temperature and Heat Waves
- Precipitation
- Wildfire
- Flooding
- Landslides

Each section characterizes the typical impacts associated with the hazard, how climate change affects the hazard, and projected changes to the exposure of the Shasta Region's mobility systems at a Region-wide level, and/or at the level of individual infrastructure assets or systems. Because some hazards (e.g., extreme temperatures) only operate at a region-wide level, detailed infrastructure-level vulnerabilities are not characterized for these hazards. Likewise, for hazards that only operate at a local level (e.g., flooding), region-wide vulnerabilities are not characterized.

Temperature and Heat Wave Impacts and Vulnerabilities

Rising temperatures are the most well-known effect of climate change, but the implications of hotter summers and warmer winters for the Shasta Region's transportation network are significant and oftentimes unexpected. Elevated temperatures affect transportation systems in a number of ways: higher average temperatures can affect transit ridership, more frequent and severe heat waves may damage road surfaces, and changing patterns in daily freeze-thaw cycles (FTCs) may increase the wear and tear on major and minor roads across the county. Table 1 lists many of the various ways that rising temperatures can affect the region's transportation systems.

Table 1. Example table of sector-specific impacts for temperature hazards

	Increasing Average & Summer Temperatures	Heat Waves	Changing Freeze-Thaw Cycles
Roads & Bridges	• Changing binder regimes and accelerated damage	• Changing binder regimes and accelerated damage • Overheating vehicles	• Accelerated asphalt & concrete wear and tear
Rails	• Rail warping (i.e., "sun-kinking")	• Rail warping (i.e., "sun-kinking")	• Accelerated concrete failure
Transit Systems	• Reduced ridership • Increased wear on heat-sensitive components like tires or batteries in electric buses	• Reduced ridership • Increased cooling costs for transit buildings • Increased risk of heat-related breakdowns	• Wear and tear on rolling stock from potholes • Reduced ride quality for bus passengers
Airports	• Increased cooling costs • Increased asphalt damage	• Delays/cancellations due to hot runways • Increased asphalt damage	• Accelerated asphalt & concrete wear and tear
Pedestrians & Bicycles	• Reduced usage during hot season	• Reduced pedestrian & cyclist activity due to heat stress • Increased air pollution impacts	• Accelerated road & trail surface wear and tear

Regionwide Projections

Across the Shasta Region, temperatures are projected to increase over the coming century. A changing climate means hotter days, more frequent and severe heat waves, and fewer freeze-thaw cycles (FTCs). Rising temperatures will have significant effects on almost every natural and human system in the Shasta Region, although in many cases these impacts are felt through the cascading effect of rising temperatures on intermediary systems (e.g., higher temperatures contributing to greater tree die-offs, increasing wildfire frequency or severity). However, in some cases, the direct effects of elevated temperatures may lead to negative outcomes all on their own.

Increasing Temperatures

In every community, the average temperature is projected to increase, but daily weather and seasonal cycles still means that the temperature of the region will change on a day-to-day basis. To visualize what this shift towards warmer temperatures means for daily weather, Figure 2 shows the distribution of daily high temperatures in Redding for each month, comparing the historical record to the projected record for 2055 (i.e., 2040 – 2069). As the curves show, the primary year-round effect is to shift the monthly temperatures up.

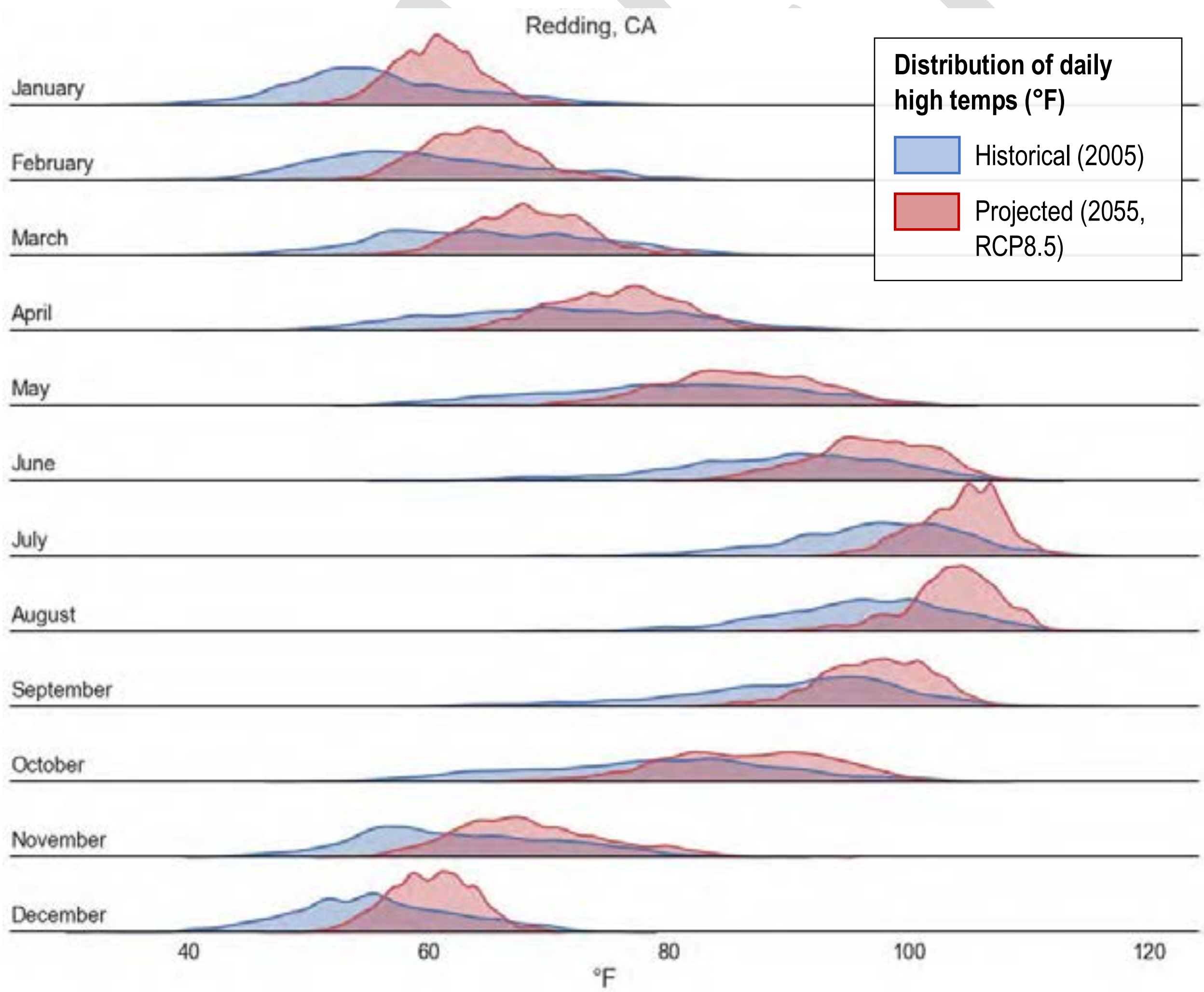

Figure 2. Projected changes to the distribution of daily high temperatures in Redding, CA.

Similar trends are visible in other parts of the Shasta Region. Figure 3, Figure 4, and Figure 5 show the distribution of temperatures in Shingletown, Burney, and at Lake Helen in the Lassen National Volcanic Park.

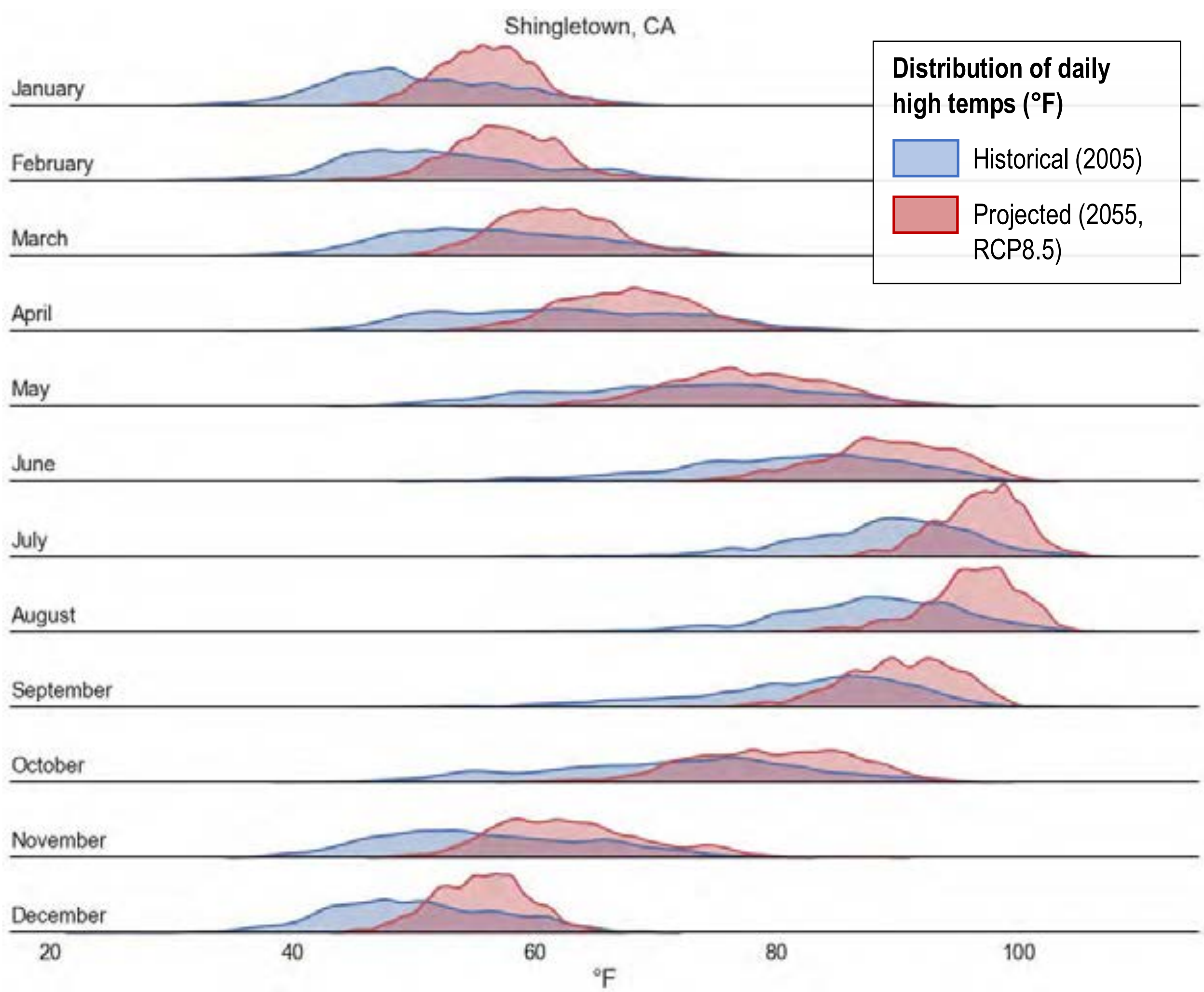

Figure 3. Projected changes to the distribution of daily high temperatures in Shingletown, CA.

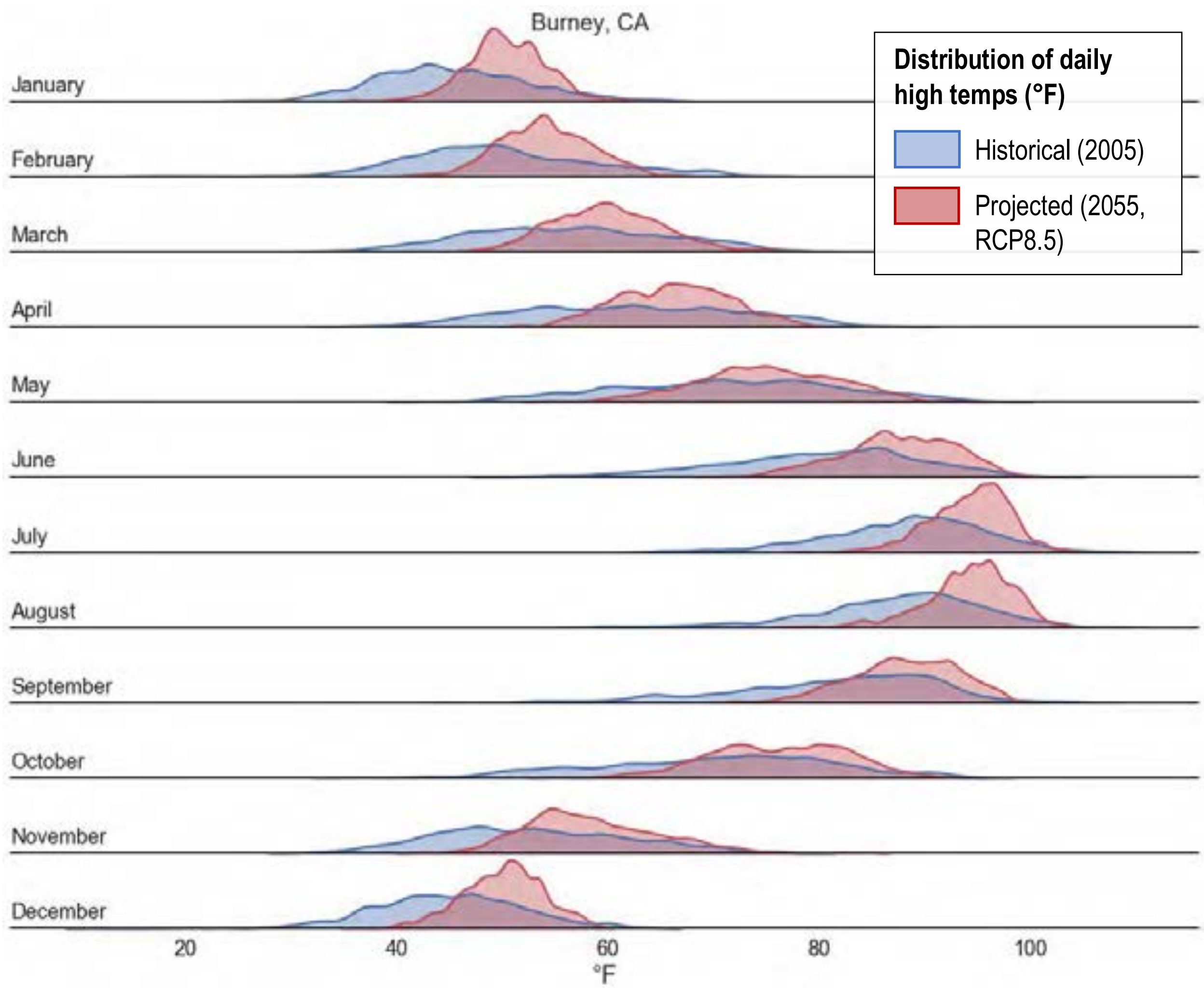

Figure 4. Projected changes to the distribution of daily high temperatures in Burney, CA.

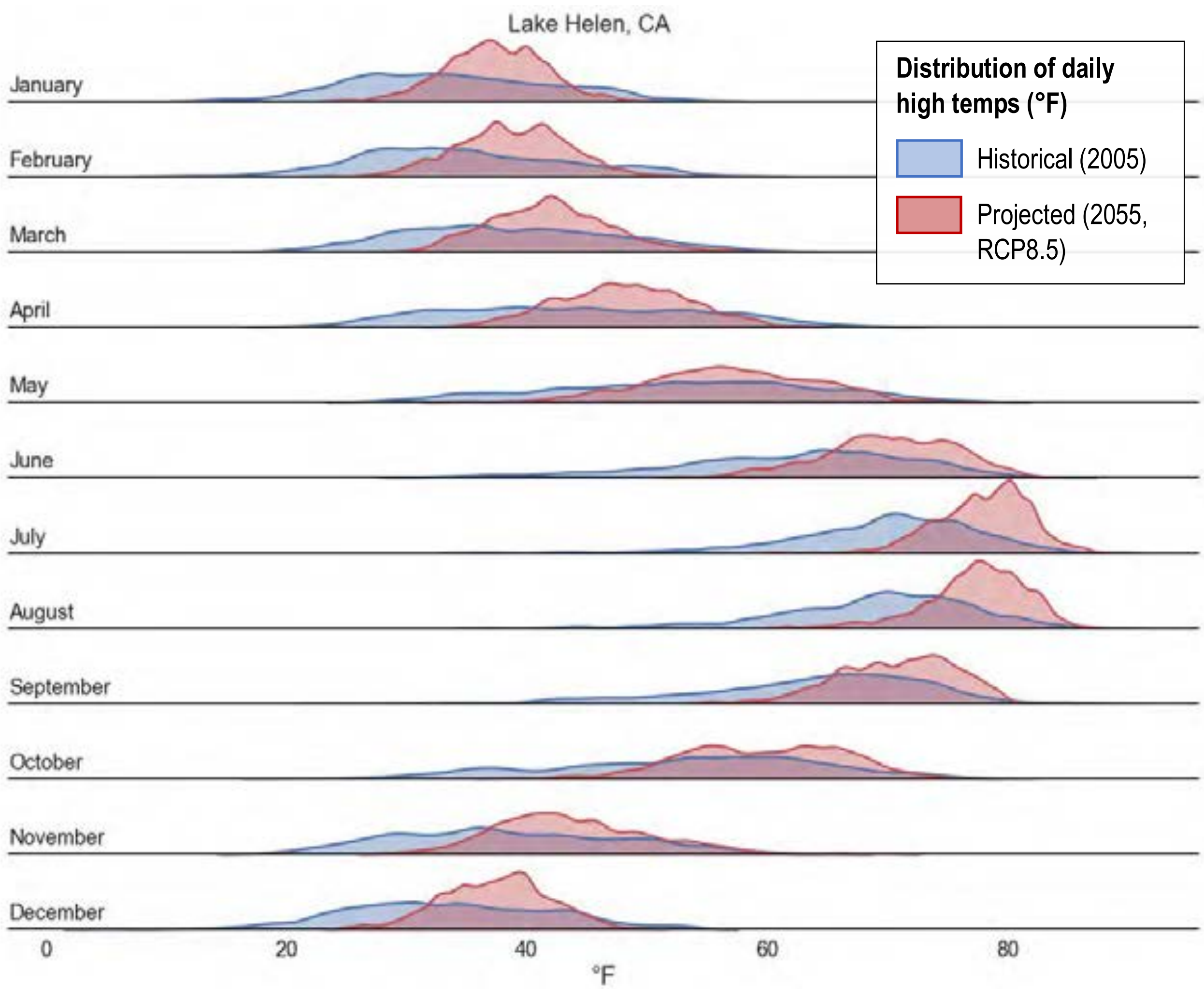

Figure 5. Projected changes to the distribution of daily high temperatures at Helen Lake.

In the Shasta Region, temperatures are projected to increase significantly over the coming century, with average annual high temperatures in Redding and the upper Sacramento River Valley increasing by approximately 13% by 2055 and 20% by 2085 in the unconstrained emissions scenario (RCP8.5). By contrast, if global emissions are reduced substantially, these increases can be reduced to 11% by 2055 and 14% by 2085. Table 2 shows the projected average annual high temperatures across the Shasta Region.

Table 2. Projected changes to average annual high temperatures in select locations throughout the Shasta Region. Temperatures are indicated in °F.

	Redding		**Shingletown**		**Burney**		**Pollard Flat**		**Old Station**	
Period	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
Historical	75.2		67.6		66.0		68.2		61.3	
2025	78.3	78.6	71.2	71.6	68.2	68.5	71.8	72.1	63.5	63.9
2055	79.9	81.1	73.0	74.3	70.0	71.2	73.6	74.8	65.3	66.7
2085	81.3	84.4	74.5	77.5	71.4	74.8	74.8	78.1	66.7	70.2

Elsewhere in the county, increases in average annual high temperatures are higher. At higher elevations, the projected increase in annual average high temperatures generally increases. The Burney area seeing a 16% increase by 2055 and a 26% increase by 2085 in the unconstrained emissions scenario. In general, higher elevation locations see larger projected increases in temperatures over the time horizon of this analysis. Accordingly, projected increases for other higher-elevation communities like Burney (~3,100’), Shingletown (~3,500’), and the Sacramento River Canyon resemble each other. Figure 6 shows the historical and projected increases in average annual high temperatures in the unconstrained emissions scenario. Additional figures can be found in Appendix A.

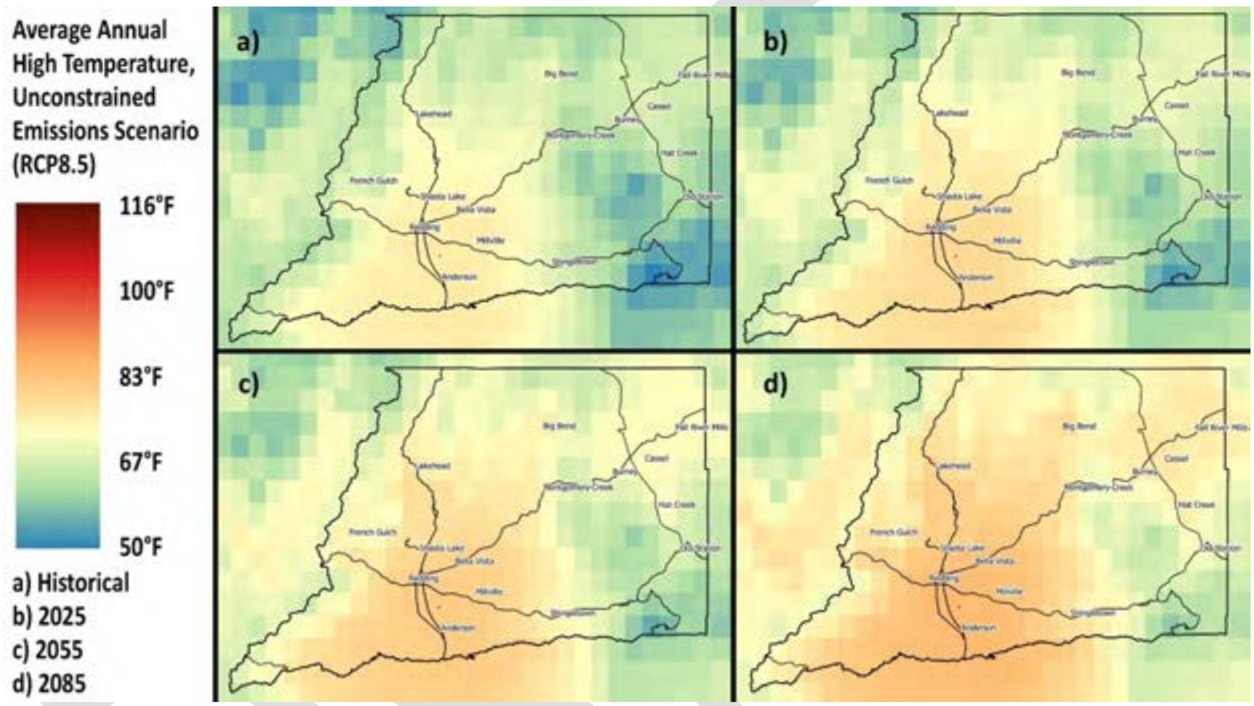

Figure 6. Projected changes to annual average high temperature over the course of the 21st century in an unconstrained emissions scenario. The upper Sacramento River Valley bears the brunt of increasing temperatures, but all parts of the Shasta Region see higher annual temperatures.

The areas around Mt. Lassen are projected to experience particularly high increases in annual average high temperatures: Lake Helen located near the summit of Mt Lassen in the Lassen National Volcanic Park is projected to experiences increases in annual high temperatures of 31% by 2055 and 50% by 2085 in the unconstrained emissions scenario. Even in the reduced emissions scenario, these increases are 23% and 32%, respectively.

Trends in summer high temperatures are important for planning around what the “normal” hot day in the Shasta Region will look like. Historically (1975 – 2004), the average high temperature in Redding in the summer months (June, July, and August) has been 94.5°F. By 2055 this temperature is projected to reach 102°F, and 106°F by 2085 in the unconstrained emissions scenario. As with average high temperatures, a reduced emissions scenario could keep these increases down, to 101°F in 2055 and 102°F in 2085. Regardless of emissions path, projected average summer high temperatures will exceed 100°F in much of the upper Sacramento River Valley by midcentury. Table 3 shows projected changes to average summer high temperatures in select locations across the Shasta Region.

Table 3. Projected changes to average summer high temperatures in select locations throughout the Shasta Region, accounting for the months June, July, and August. Temperatures are indicated in °F.

	Redding		Shingletown		Burney		Pollard Flat		Old Station	
Period	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
Historical	94.6		86.0		85.6		87.8		79.5	
2025	98.6	99.1	90.5	91.0	88.7	89.1	91.4	91.9	83.3	83.8
2055	100.6	102.0	92.7	94.1	90.7	92.1	93.4	94.8	85.6	87.3
2085	102.2	106.0	94.5	98.4	92.5	96.3	95.0	99.0	87.4	91.4

Outside the upper Sacramento River Valley, projected increases in both annual and summer average high temperatures are larger than those in the valley. In Shingletown, for example, the historical average summer temperature has been 86°F, but it is projected to increase to 94°F by 2055 and 98°F by 2085 in the unconstrained emissions scenario. In Burney, a similar increase from a historical average summer high temperature of 86°F to 92°F by 2055 and to 96°F by 2085 is projected. Figure 7 shows the historical and projected increases in average summer high temperatures across the region in the unconstrained emissions scenario. Additional and larger figures are located in Appendix A.

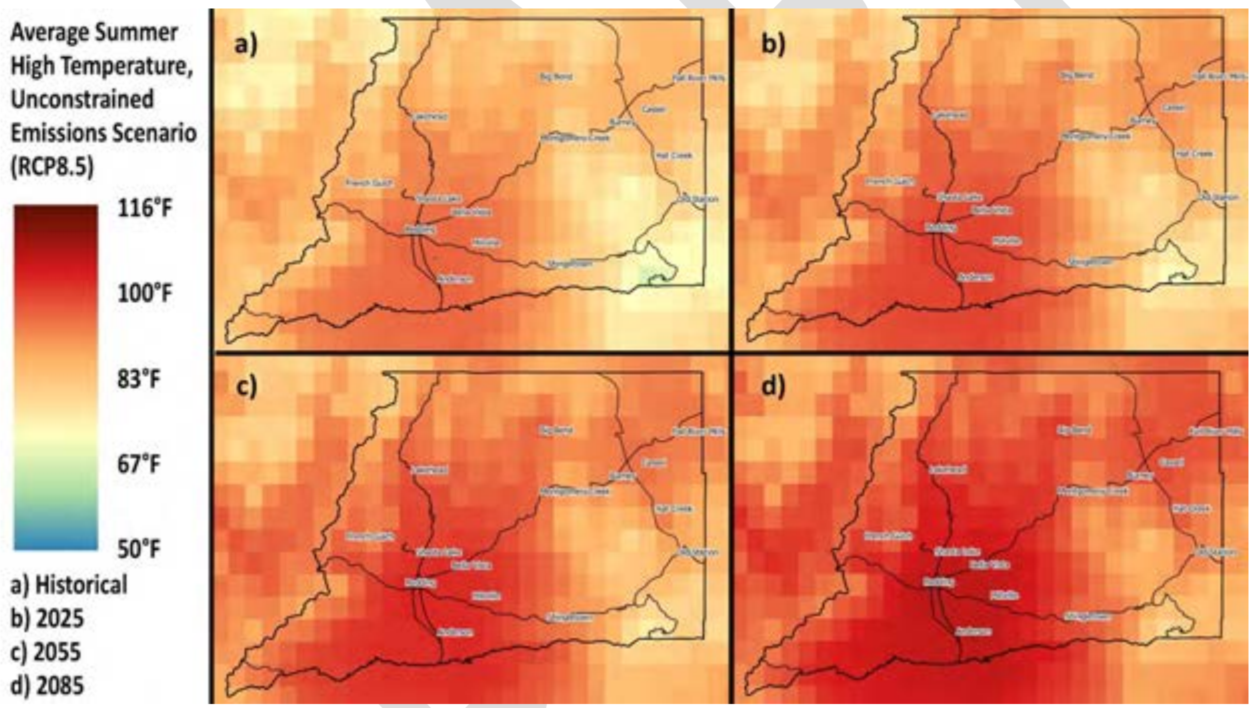

Figure 7. Projected changes to average summer high temperatures over the course of the 21st century in an unconstrained emissions scenario. Average summer temperatures in Redding and the upper Sacramento River Valley are projected to exceed 100°F by midcentury in both the unconstrained and reduced emissions scenarios.

Heat Waves

Heat wave temperatures are defined as the average high temperature of the hottest consecutive seven-day period in the year. By looking at historical and projected daily temperatures for the 30-year climate periods, we can evaluate how the average heat wave is projected to get more severe in the future. Historical heat wave temperatures in the Shasta Region in the lower elevation regions of the Sacramento River Valley (including Anderson, Redding, and Shasta Lake, where historical heat wave temperatures of 106°F are typical. At higher elevations, heat wave temperatures are lower. In Shingletown, for example, historical heat wave temperatures are 97°F. Likewise, temperatures are 97°F in Burney and 99°F in Pollard Flat (~1,500'). Locations with little population, but recreational assets like Manzanita Lake (~5,900') have significantly lower temperatures, from 82°F to 86°F. However, the bulk of the Shasta Region's population is located at lower elevations with higher heat wave exposures. Figure 99 shows the distribution of heat wave temperatures throughout the Region under current conditions.

What is a Heat Wave?

While the concept seems simple, there are many different ways to define a heat wave. For most people, a heat wave is simply a period of hotter-than-usual weather, typically during the summer. But for different user groups, the type of heat wave may make a big difference. For example, public health professionals are often less interested in the peak temperatures of a heat wave, and more interested in how warm the nights get, since overnight recovery is an important way to avoid heat exhaustion. By contrast, for transportation infrastructure, the highest sustained temperatures are important for understanding wear and tear on roads. **For this study, we define heat waves as the average daily high temperature of the hottest consecutive seven-day period in a year.**

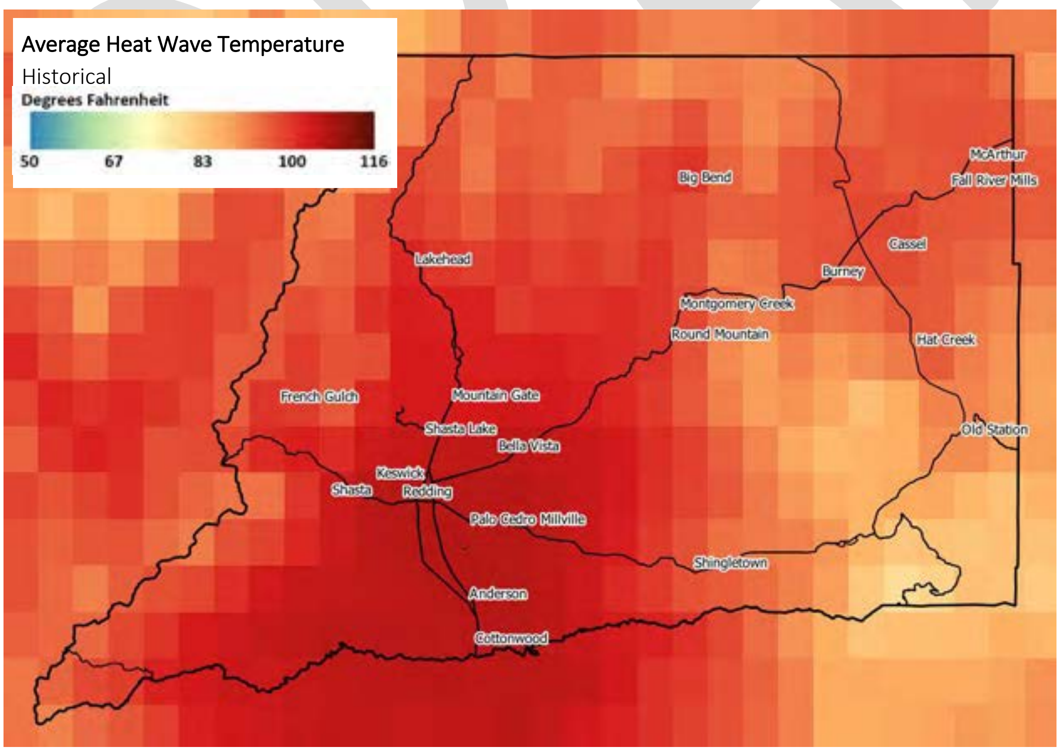

Figure 8. Average heat wave high temperatures in the Shasta region under historical conditions (1975 - 2004).

Under current conditions, human exposure to dangerous heat conditions is mitigated by the traditionally low humidity of the region's weather. However, infrastructure such as road surfaces is directly affected by air temperatures, and increases above historical conditions can affect the asphalt binders used in asphalt surfaces.

Future heat waves are projected to be significantly more severe than historical heat wave conditions. Table 4 and Figure 9 show how the hottest seven-day period of each year can be expected to change over the coming century, with severe increases projected in Redding and the upper Sacramento River Valley. Additional figures are in Appendix A.

Table 4. Projected changes to the average annual heat wave temperature, defined as the average high temperature of the hottest consecutive seven-day period of the year. Significant increases are projected across the region, with the largest increases in severe heat in the upper Sacramento River Valley. Temperatures are indicated in °F.

	Redding		**Shingletown**		**Burney**		**Pollard Flat**		**Old Station**	
Period	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
Historical	106.2		97.0		97.2		99.3		90.7	
2025	109.0	109.8	100.9	101.5	99.1	99.7	102.2	102.9	93.6	94.3
2055	110.8	112.1	102.7	104.4	100.9	102.2	104.0	105.3	95.5	97.2
2085	111.9	115.7	104.2	108.0	102.4	106.0	105.3	108.9	97.2	100.9

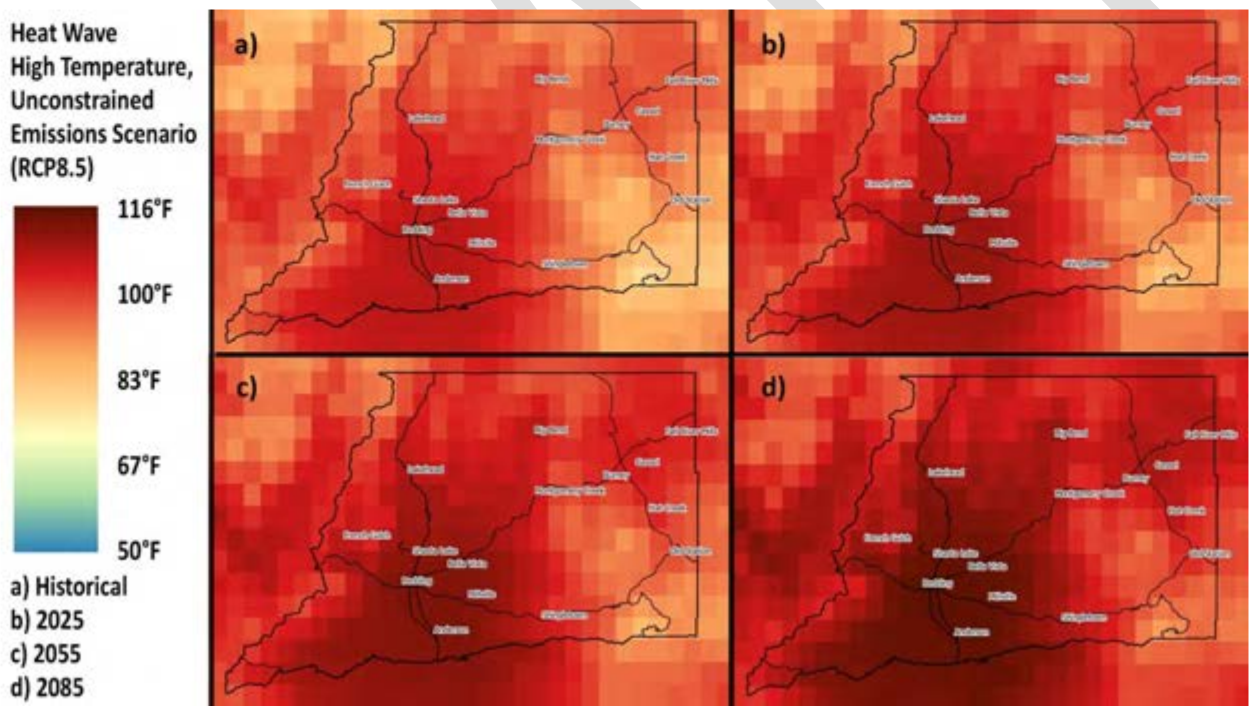

Figure 9. Historical and projected heat wave temperatures in the Shasta Region in an unconstrained emissions scenario (RCP8.5).

In 2025 (representing the average climate for the years 2010 – 2039), the average annual heat wave temperatures are projected to increase to 109.8°F in Redding and Anderson, and 109°F in Shasta Lake in the unconstrained emissions scenario. The Sacramento River Canyon is projected to increase above 100°F, with Pollard Flat experiencing an annual heat wave temperature of 102.9°F. In Shingletown, heat wave temperatures of 101.5°F are expected, and in Burney projected temperatures may reach 99.7°F. Temperatures at higher elevations are also projected to increase, with Manzanita Lake experiencing heat wave temperatures of 86°F – 89°F and Old Station seeing heat wave temperatures of 94.3°F. Under a reduced emissions scenario (which is considered unlikely by 2025), projected heat wave temperatures are generally approximately 0.6°F – 0.8°F lower than the high emissions scenario.

In 2055, heat wave temperatures are projected to increase further. In the high emissions scenario, Redding is projected to reach 112.1°F; Shasta Lake, 111°F; Pollard Flat, 105.3°F; Shingletown, 104.4°F; and Burney, 102.2°F. At Manzanita Lake, heat wave temperatures may reach 89°F – 92°F, and 97.2°F in Old Station. Under a reduced emissions scenario, slightly lower temperatures are projected, although increases over historical temperatures are still significant: 110.8°F in Redding, 110°F in Shasta Lake, 104.0°F in Pollard Flat, 102.7°F in Shingletown, 100.9°F in Burney, 88°F – 91°F at Manzanita Lake, and 95.5°F in Old Station.

By 2085, the average annual heat wave temperatures are projected to climb to levels almost 10°F warmer than current conditions in the upper Sacramento River Valley. In Redding and Anderson, the heat wave temperature is expected to increase to 115.7°F in the high emissions scenario. Likewise, extreme heat waves averaging 108.9°F are projected in Pollard Flat, 108.0°F in Shingletown, and 106.0°F in Burney. Even at Manzanita Lake, heat wave temperatures are projected to reach 96°F, with temperatures of 100.9°F in Old Station. In a reduced emissions scenario, lower temperatures are achievable, although increases over historical temperatures are still significant: 111.9°F in Redding, 111°F in Shasta Lake, 105.3°F in Pollard Flat, 104.2°F in Shingletown, 102.4°F in Burney, 89°F – 92°F at Manzanita Lake, and 97.2°F in Old Station.

Freeze-Thaw Cycles (FTCs)

Each time a road surface freezes, water embedded in pores and cracks within the asphalt or concrete expands, creating new cracks. When rising daytime temperatures cause this ice to thaw, water then seeps further down into the new cracks. Over time, these cracks allow fracturing of the road surface, spalling, and eventually the formation of potholes. This pattern of freezing followed by thaws is one of the most damaging processes of natural road surface degradation. To a lesser extent, FTCs also affect reinforced concrete structures (such as concrete road surfaces, bridge piers and abutments, culverts, and other reinforced concrete used in road applications. FTCs can also cause pitting of unpaved roadbeds and trails, where gaps in soil around gravel and rocks created by freezing water may allow accelerated erosion once water thaws.

Across the Shasta Region, climate change is causing fewer FTCs, with extreme reductions in FTCs for some areas. Reduced FTCs will likely extend the lifetimes of many road surfaces, albeit with added risks associated with higher temperatures. Table 5 shows the historical and projected numbers of freeze thaw cycles at select locations across the Shasta Region. Figure 10 shows the distribution of average annual FTCs across the Shasta Region in recent history (1975 – 2004). While the upper Sacramento River Valley has typically seen very few FTCs (only four per year at Shasta College, compared to 19 at the Redding Municipal Airport), higher elevations see rapidly increasing numbers of FTCs. In Shingletown, 70 FTCs is average, in Burney 186, and on Highway 89 at Helen Lake, 227.

Table 5. Projected changes to the average annual number of diurnal freeze-thaw cycles. Significant decreases are projected across the region, with much of the upper Sacramento River Valley seeing an average of zero FTCs each year.

	Redding		**Shingletown**		**Burney**		**Pollard Flat**		**Old Station**	
Period	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
Historical	7		70		186		51		181	
2025	0	0	24	23	173	167	24	22	173	169
2055	0	0	15	11	156	137	13	9	156	140
2085	0	0	9	2	139	93	8	1	143	97

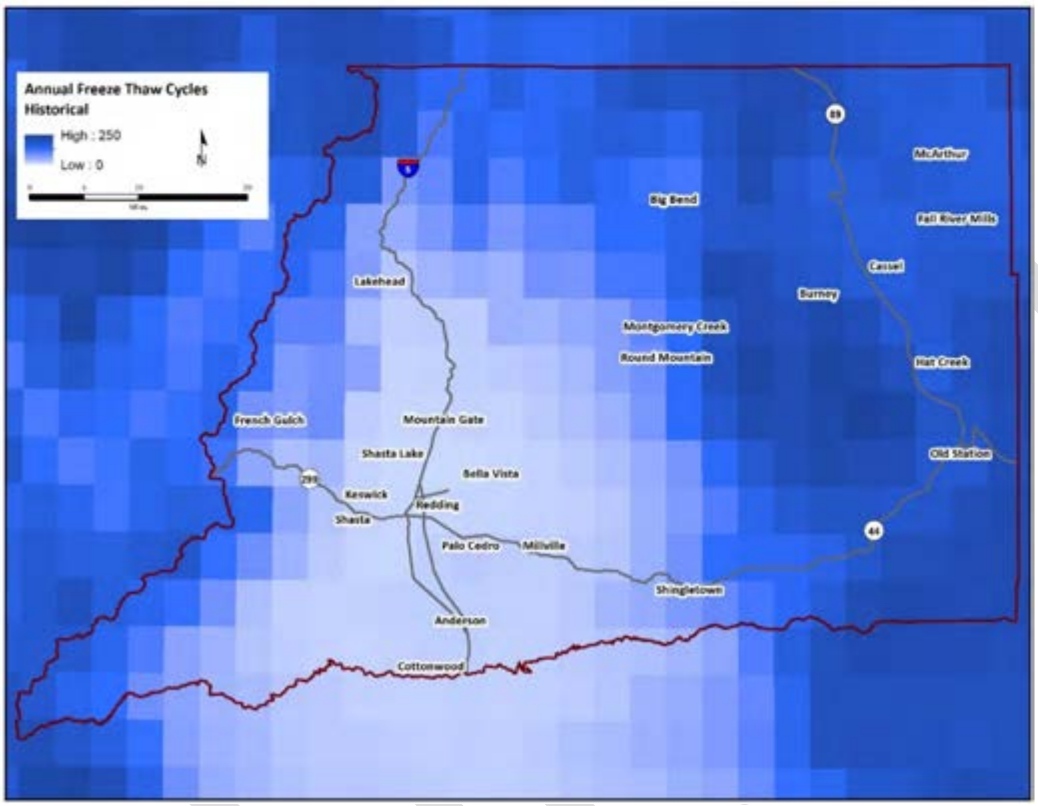

Figure 10. Annual average number of freeze-thaw cycles per year, historical average (2005).

Figure 11 shows the projected average annual FTCs by 2055 in an unconstrained emissions scenario. By midcentury, the entire upper Sacramento Valley is projected to experience zero FTCs each year. Even in Shingletown, the average year is expected to see only 11 FTCs. Higher elevations see reductions (Burney is projected to see 137), and projected FTCs barely fall at Helen Lake (222).

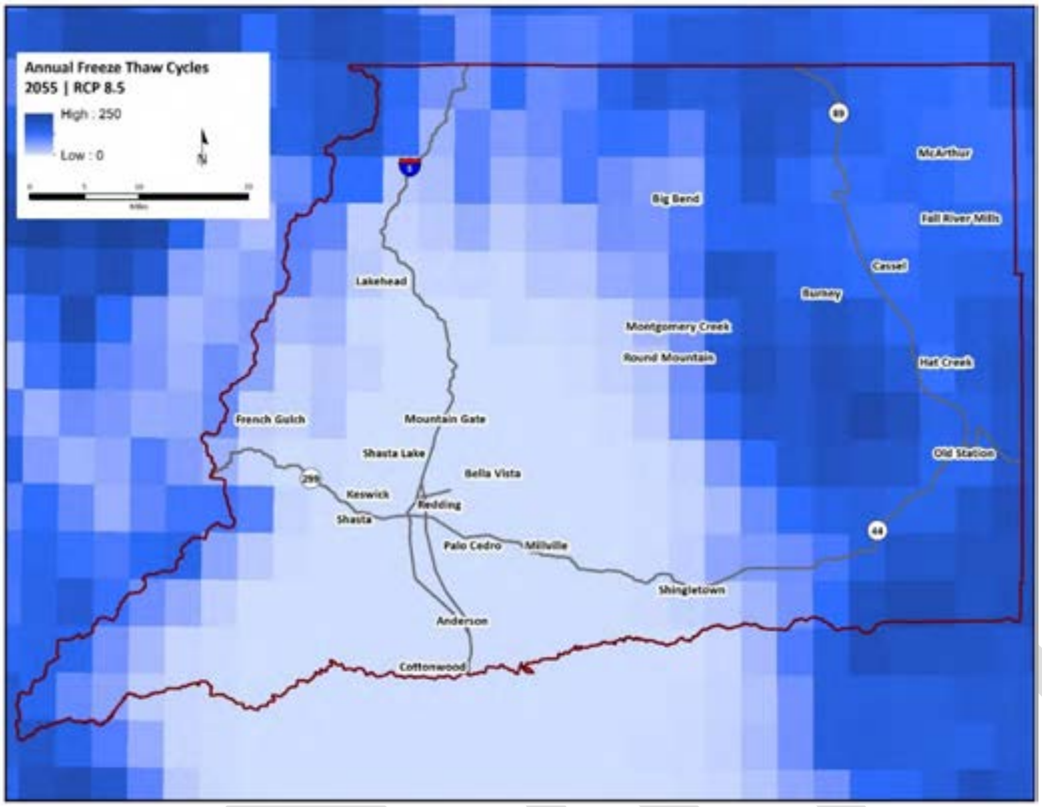

Figure 11. Annual average number of freeze-thaw cycles per year, projected (2055, RCP8.5).

Infrastructure Vulnerabilities

Projected increases in extreme temperature affect the entire Shasta Region. While significant increases in elevation can mitigate projected extreme temperature, areas at similar elevation will share exposures to temperature hazards. For example, projections of extreme temperatures in and around Redding and Anderson demonstrate the exposure of critical transportation systems to elevated average and extreme temperatures. The Redding Municipal Airport, RABA's downtown Redding passenger terminal, and bus stops across the urban core of the Region are all projected to experience more extreme summer temperatures, and more severe heat waves.

Impacts to road surfaces face a mixed set of projections, with roads across the Shasta Region exposed to elevated temperatures in the summer, challenging current asphalt binders and potentially aging roads more rapidly than expected. However, the reduction of FTCs across the Region (and in particular in higher elevations) may slow damage to roads caused by freeze-thaw cracking. For example, Hatchet Mountain Pass is projected to see a reduction of 80 FTCs per year by 2085 in the unconstrained emissions scenario, however the average summer temperature is projected to increase by 11°F over the same period, from 80.6°F to 91.6°F.

Precipitation Impacts and Vulnerabilities

Climate change affects many of the processes essential to the water cycle, and one of the key outcomes of these changes are changes to the historical patterns of rainfall around the world. The Shasta Region is not unique, and projected changes to precipitation will result in significantly drier dry seasons, wetter wet seasons, and more severe extreme precipitation in most areas (with some areas seeing reductions in extreme precipitation). These changes to precipitation both directly affect mobility (e.g., through hazardous road conditions during severe precipitation) and through the effects that flooding can have on mobility. This section focuses on the direct impacts of changes to average and extreme precipitation. Table 6 provides examples of the ways that these impacts affect the region's mobility and transportation systems.

Table 6. Example table of sector-specific impacts for precipitation hazards

	Polarizing Wet and Dry Seasons	Extreme Rain	Extreme Snow
Roads & Bridges	• Increased loading of road drainage during wet season, including debris accumulation • Increased risk of pavement damage due to movement of expansive soils	• Road closures due to localized flooding • Accelerated washouts and erosion of roadbeds	• Increased disruptions from road closures • Accelerated deterioration due to salting, grit, and plowing • Increased costs of snow clearing
Rails	• Increased loading of rail drainage, risking localized flooding of rails at stream crossings & culverts	• Accelerated erosion of railbed and embankments • Route disruptions due to localized flooding	• Delays due to snow clearing
Transit Systems	• Reduced ridership where sufficient bus shelters are not present	• Reduced ridership where sufficient bus shelters are not present	• Route delays and closures due to snow
Airports	• Increased risk of pavement damage due to movement of expansive soils	• Disrupted operations during extreme rain events	• Disrupted operations during extreme snow events
Pedestrians & Bicycles	• Reduced ridership during precipitation events	• Increased risk of vehicle-pedestrian/cyclist collisions • Sidewalk closures resulting from local ponding	• Reduced ridership during snow events • Lowered priority of clearing pedestrian/ cyclist routes

Regionwide Projections

Across the Shasta Region, four trends in precipitation are notable: the dry season (May – October) is projected to see less precipitation overall, the wet season (November – April) is projected to see more precipitation overall (including both rain and snow), in most places, the most extreme precipitation events are projected to become more frequent and intense, and projected changes to precipitation in the wet season are significantly wetter by the end of the century in the unconstrained emissions scenario than in the reduced emissions scenario or compared to other periods.

Historical Average Precipitation

The Shasta Region spans the meeting of the Klamath mountains to the west and the southern tier of the Cascade Range to the east. South of these two ranges, the upper Sacramento River Valley is largely level, with a steady grade descending to the south. Historically, the Shasta Region has experienced the greatest amount of rainfall at higher elevations, with the Klamath Range (including the Sacramento River Canyon) and the Cascade peaks seeing the highest totals, and the upper Sacramento River Valley seeing less. The exception to this pattern is the Modoc Plateau, which reaches east of the Cascade Range. From Old Station in the south to Four Corners in the north, and east along the high-elevation plateau, this area sees the lowest amount of precipitation in the Region. Figure 12 shows the average historical precipitation across the Shasta Region.

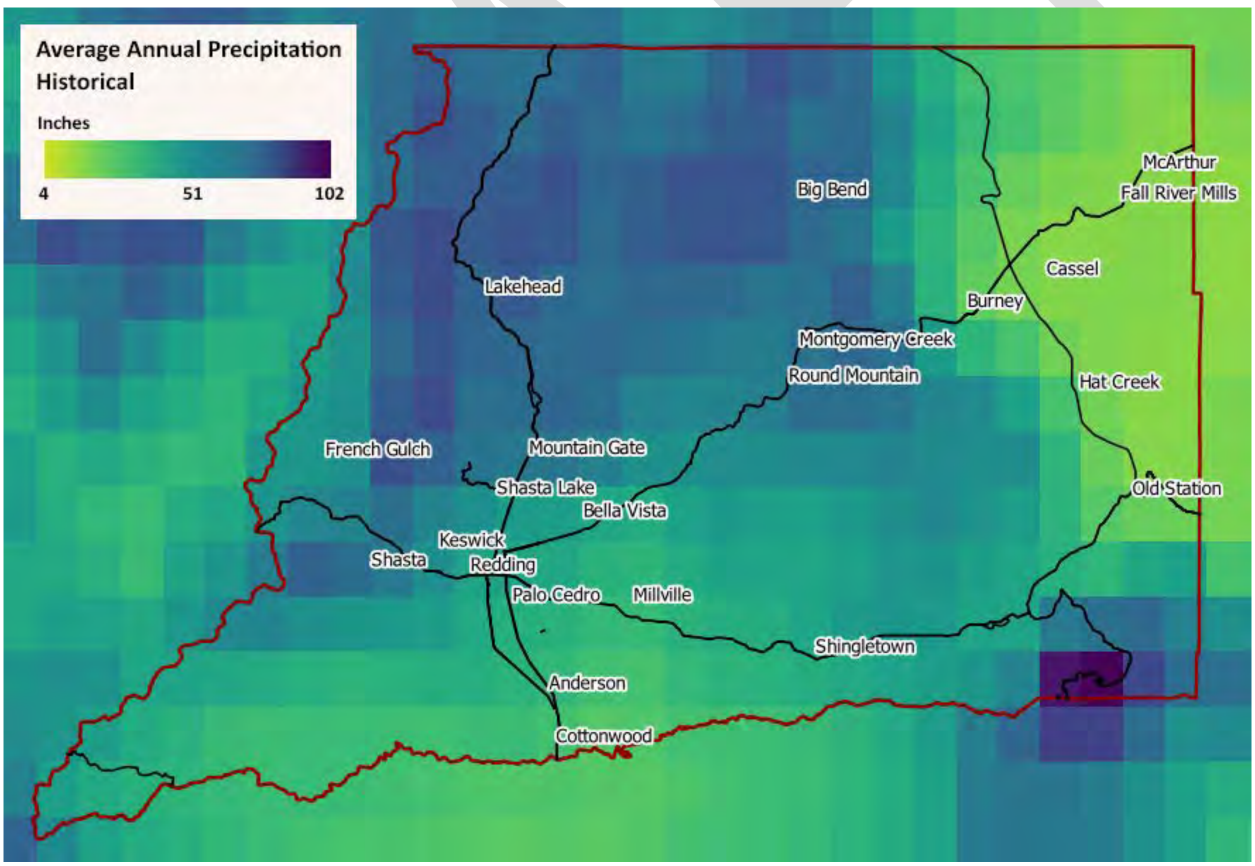

Figure 12. Historical annual average precipitation across the Shasta Region.

The majority of annual precipitation falls during the Shasta Region's wet season, and the pattern of precipitation is similar to the pattern of annual average precipitation, with higher volumes at higher elevations, and a notably drier pattern east of the Cascade Range. Figure 13 shows the historical average pattern of precipitation across the Shasta Region during the wet season.

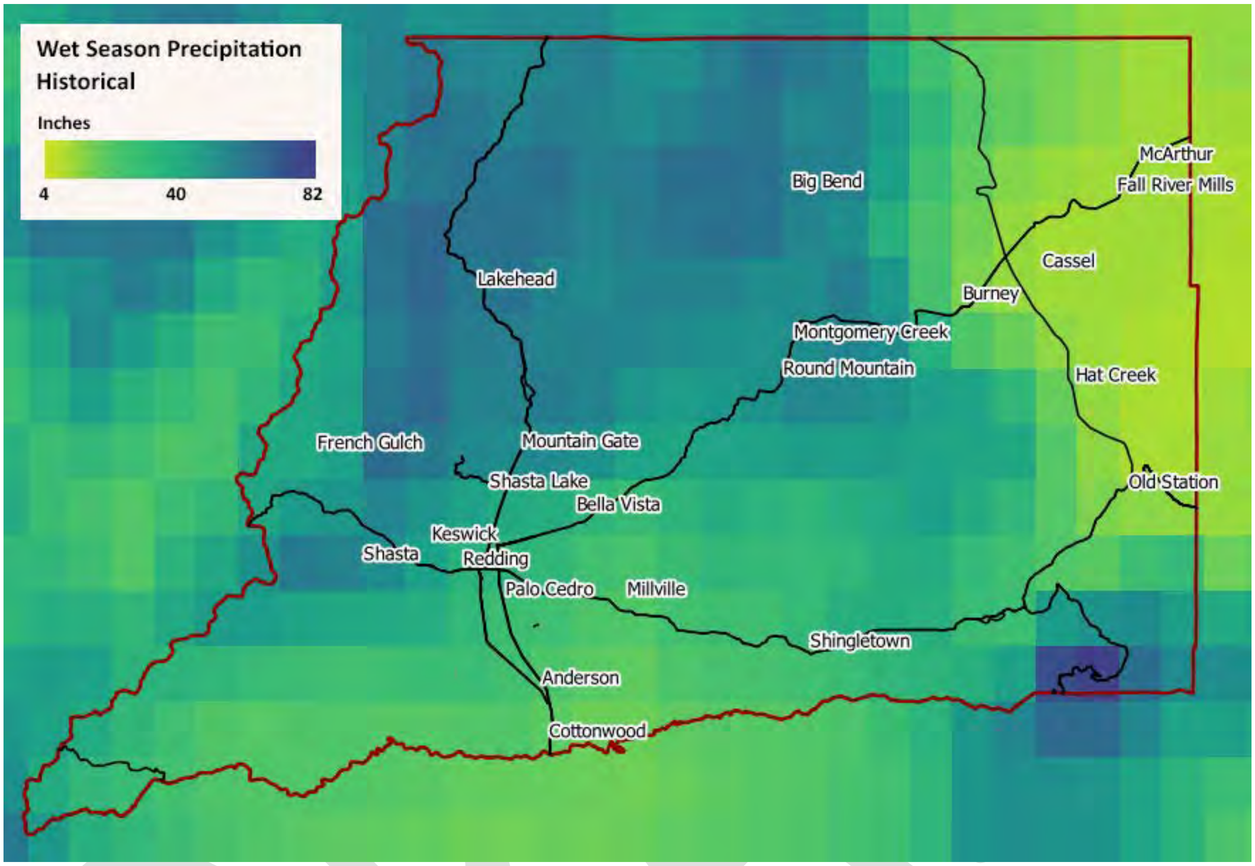

Figure 13. Historical average wet season precipitation in the Shasta Region.

During the Shasta Region's dry season much less precipitation falls overall, but the distribution of this pattern is similar to the wet season. The Region experiences average dry season rainfall totals (during summer months, precipitation is predominantly rainfall) about 1/3rd to 1/6th the amount as in the wet season. The Modoc Plateau is similarly the driest part of the Region. Figure 14 shows the historical average dry season precipitation in the Shasta Region.

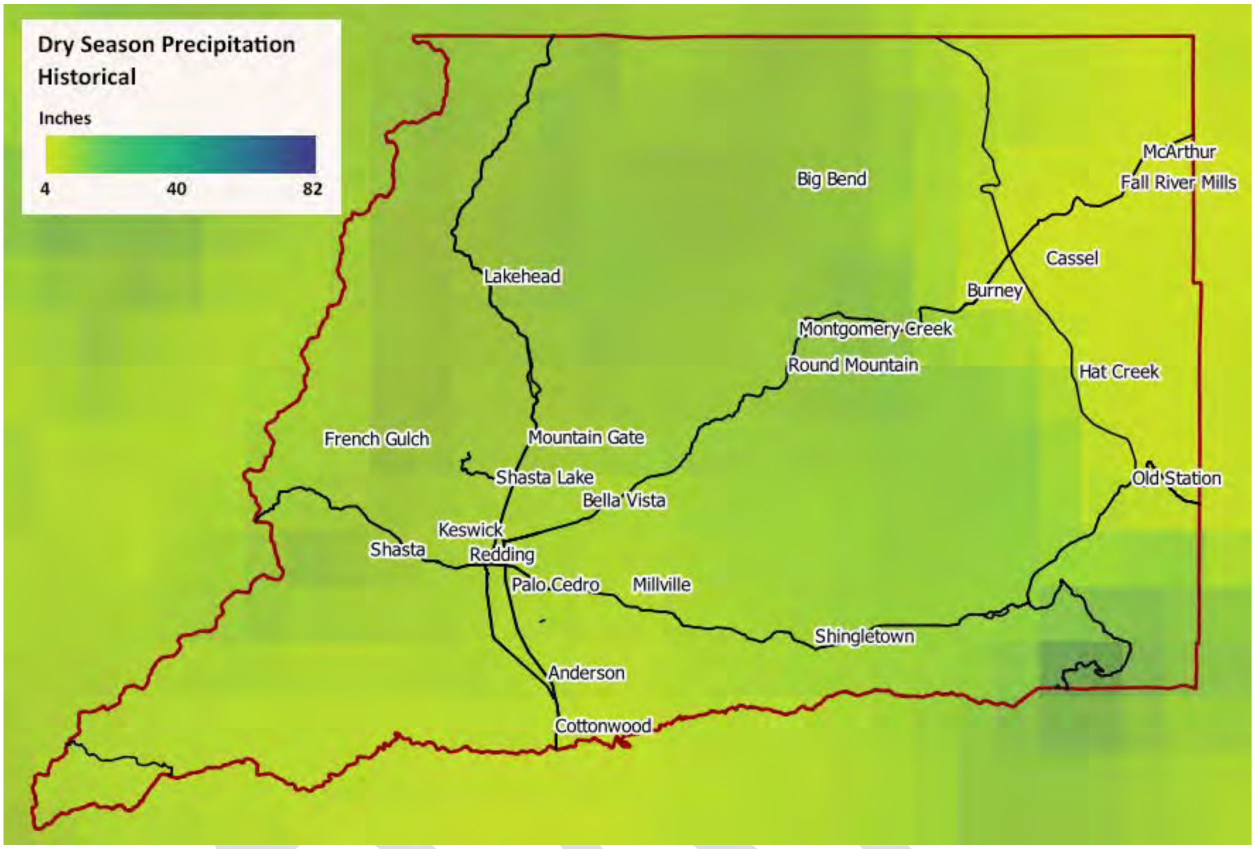

Figure 14. Historical average dry-season precipitation across the Shasta Region.

Projected Changes to Annual and Seasonal Precipitation

Average Annual Precipitation

Projected changes to average annual precipitation show a common geographic pattern across all time periods and both the unconstrained and reduced emissions scenarios (Table 7). Projected increases to annual precipitation are highest in the Klamath Mountains and Cascade Mountains on and north of Highway 299, in the southeastern corner of the Region (around Lassen National Volcanic Park), and in the upper Sacramento River Valley east of the urbanized core. Small reductions (or smaller increases) are projected for the area between Whiskeytown Lake, Ono, and Redding, and along a belt stretching from Wagoner in the southeast, across Burney Mountain, to Fall River Mills in the northeast.

While this pattern remains consistent across all projections, the aggregate region is projected to experience increases in average annual precipitation. Figures showing the distribution of projected changes to annual average precipitation across the Shasta Region can be found in Appendix A.

Table 7. Projected changes to average annual precipitation, in percent difference compared to the historical period (1975 – 2004).

	Redding		Anderson		Shingletown		Burney		Pollard Flat		Old Station	
Period	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
2025	-4.5%	-3.6%	6.6%	7.1%	4.7%	4.6%	2.2%	2.3%	10.7%	11.6%	5.3%	5.3%
2055	-4.6%	-4.5%	5.8%	4.9%	3.2%	0.8%	2.2%	0.6%	10.4%	10.0%	5.3%	4.0%
2085	-5.0%	1.7%	4.9%	14.5%	2.2%	8.5%	0.5%	8.8%	10.2%	17.8%	3.7%	12.1%

Notably, the urbanized core of the Shasta Region is split between areas projected to see increases and decreases in total precipitation. For example, by 2055 downtown Redding and neighborhoods directly north of the Sacramento River are projected to see a 4.5% decrease in average annual precipitation, while east of the river, virtually zero change is projected in an unconstrained emissions scenario (Figure 15). By contrast, south Enterprise and Pacheco are projected to see a 4.9% increase, as will the City of Anderson, and the Redding Municipal Airport is projected to see a 7.7% increase.

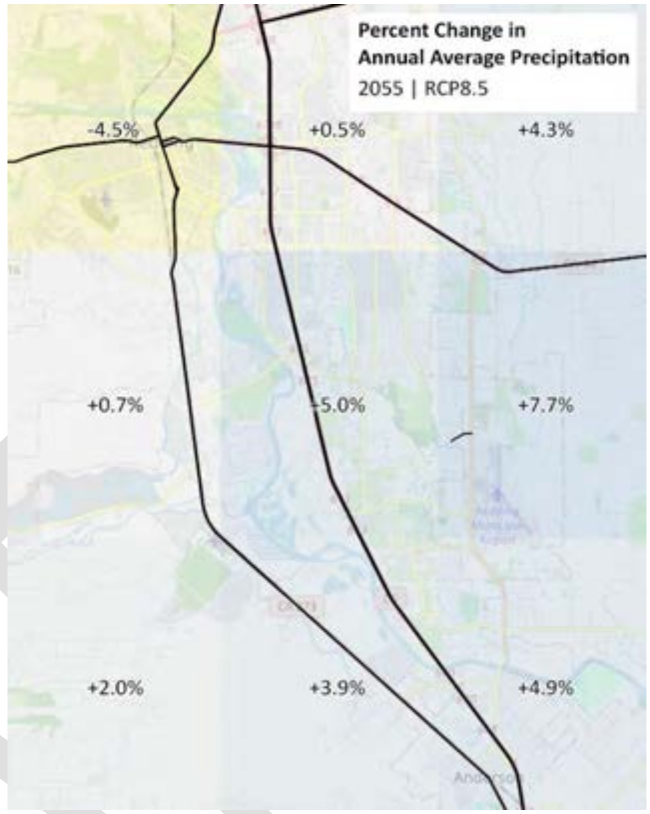

Figure 15. Detail of projected change in annual average precipitation in the Redding - Anderson area. 2055, RCP8.5.

One important caveat when considering changes to projected precipitation is that while the regional variation in precipitation projections is consistent across scenarios, the implications for extreme weather hazards like flooding are not straightforward. All of these areas (and indeed, virtually all of the Shasta Region) share a common drainage via the Sacramento River, and many of the flood channels in the Shasta Region are controlled by dams, tunnels, and reservoirs designed to mitigate flood risk.

Average Seasonal Precipitation

In the Shasta Region, projected changes to seasonal precipitation show a consistent pattern of wetter wet seasons (November – April) and drier dry seasons (May – October), and projected changes are higher in the unconstrained emissions scenario, and further in the future. Projected changes to wet season in select areas of the Shasta Region are shown in Table 8.

Table 8.Projected changes to wet season precipitation (November – April) in the Shasta Region. Change is measured in percent difference compared to the historical period (1975 – 2004).

	Redding		Anderson		Shingletown		Burney		Pollard Flat		Old Station	
Period	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
2025	-0.5%	-0.1%	11.6%	11.1%	9.8%	7.9%	6.5%	5.1%	13.8%	13.1%	10.8%	9.1%
2055	-1.1%	0.6%	10.7%	11.0%	8.3%	6.7%	7.4%	6.4%	13.7%	14.4%	10.5%	10.7%
2085	-0.5%	7.1%	11.2%	22.1%	8.7%	15.6%	7.2%	16.5%	14.2%	23.5%	11.1%	20.5%

By 2055, projected changes to wet season precipitation in the upper Sacramento River Valley range from a reduction of over 1% to an increase of 11% in an unconstrained emissions scenario (Figure 16). In the Sacramento River Canyon, a maximum increase of 21% is projected near Lamoine. Near Shingletown, Round Mountain, and Burney, projected increases are 6.7%, 9.9%, and 6.4%, respectively. On the Modoc Plateau, projected increases are 6.4% in Four Corners, 3% in Fall River Mills, and 10.7% in Old Station.

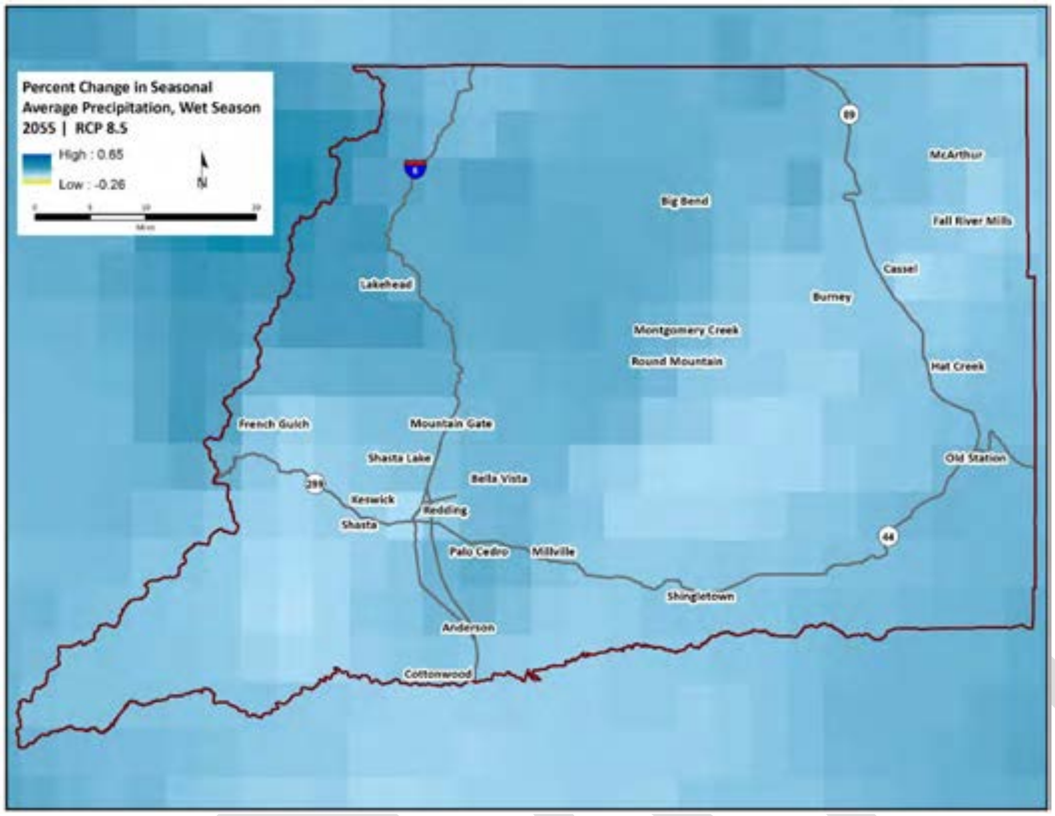

Figure 16. Projected change in average wet season precipitation in the Shasta Region. 2055, RCP8.5 scenario.

By 2085, every part of the Shasta Region is projected to see increased wet-season precipitation, with most increases significant (Figure 17). The upper Sacramento River Valley is projected to see increases of 5 – 25%, with increases of 15 – 22% in and around Anderson. In the Sacramento River Canyon, increases of 29% in Sugarloaf and 32% east of Lamoine are projected. In Shingletown, projected increases are 15.6%, while in Round Mountain, Montgomery Creek, and Burney, projected increases are 19.3%, 17.4%, and 16.5%, respectively. On the Modoc Plateau, projected increases are 11.4% in Fall River Mills, 16.2% in Four Corners, and 20.5% in Old Station.

In a reduced emissions scenario, projected increases are very similar by 2055; the Redding area still shows a large range in projected change, from a 1% decrease to a 10% increase, just as in the unconstrained emissions scenario. By 2085, reducing global emissions would have a significant impact on regional wet-season precipitation, with very little additional change compared to the 2055 projection. Together, these projections show that reducing emissions, even by midcentury, could help avoid more extreme outcomes. Projected changes to average wet season precipitation across the Shasta Region in the reduced emissions scenario are shown in Appendix A.

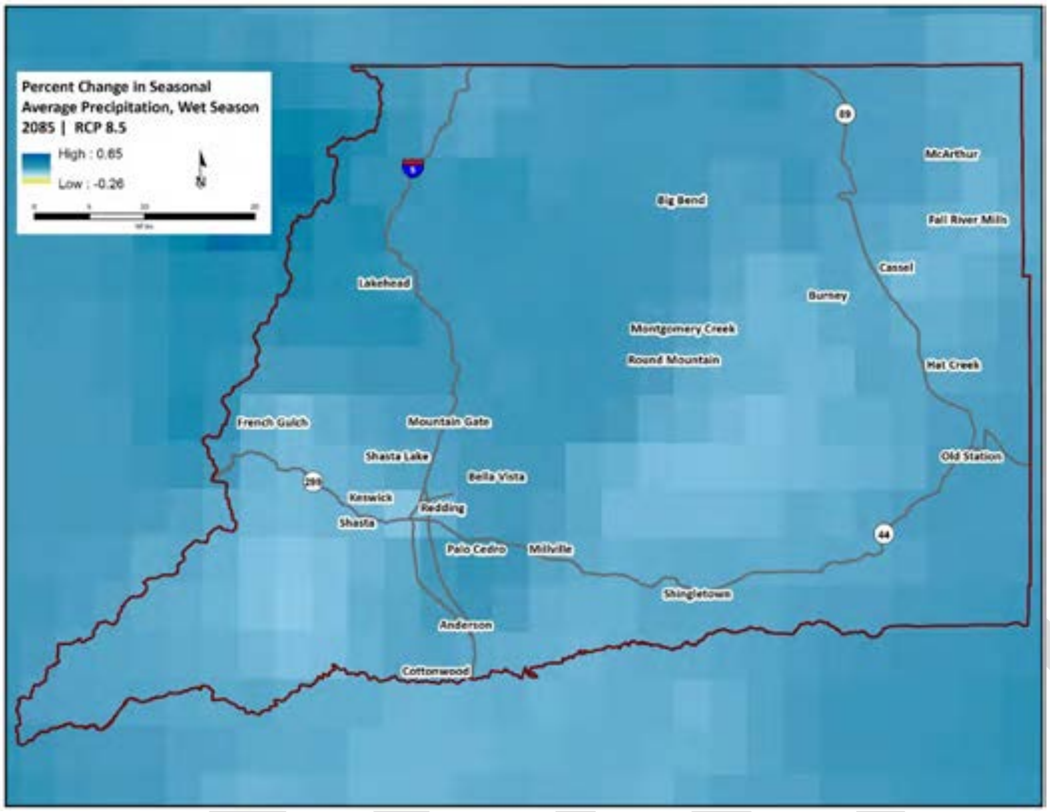

Figure 17. Projected change in average wet season precipitation in the Shasta Region. 2085, RCP8.5 scenario.

While impacts to transportation infrastructure are predominantly concerned with extreme precipitation and flooding, the polarization of wet and dry seasons can lead to direct infrastructure impacts, particularly in regions with expansive clay soils. According to the Shasta County Hazard Mitigation Plan, the Shasta Region contains moderately expansive soils, but with areas of low expansiveness in the south-central and southeastern parts of the region.[6] As the precipitation regime in the county polarizes, the risk of soil movement and asphalt cracking may also increase.

Projected changes to dry season precipitation show less regional variation than changes to wet season precipitation. Projected changes to dry season precipitation are shown in Table 9. By 2055 in an unconstrained emissions scenario, the upper Sacramento River Valley is projected to experience reductions in dry season precipitation of 25% and up (Figure 18). In and around Redding, reductions are 26 – 32%. Reductions in the Sacramento River Canyon range 13 – 20%, and reductions along Highway 299 from Bella Vista to Four Corners range 21 – 25%. Reductions in the Lassen Volcanic National Park are the lowest in the Region, ranging from 12 – 15%.

Table 9. Projected changes to dry season precipitation (May – October) in the Shasta Region. Change is measured in percent difference compared to the historical period (1975 – 2004).

	Redding		**Anderson**		**Shingletown**		**Burney**		**Pollard Flat**		**Old Station**	
Period	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
2025	-25.5%	-18.8%	-19.2%	-13.9%	-15.8%	-8.7%	-14.5%	-8.6%	-8.4%	1.8%	-10.5%	-5.6%
2055	-23.4%	-31.9%	-19.8%	-27.0%	-17.6%	-22.5%	-18.4%	-22.1%	-10.4%	-18.2%	-9.6%	-15.5%
2085	-29.9%	-28.0%	-28.0%	-25.4%	-23.9%	-20.1%	-26.0%	-21.3%	-14.5%	-18.1%	-17.7%	-12.2%

[6] Shasta County 2017

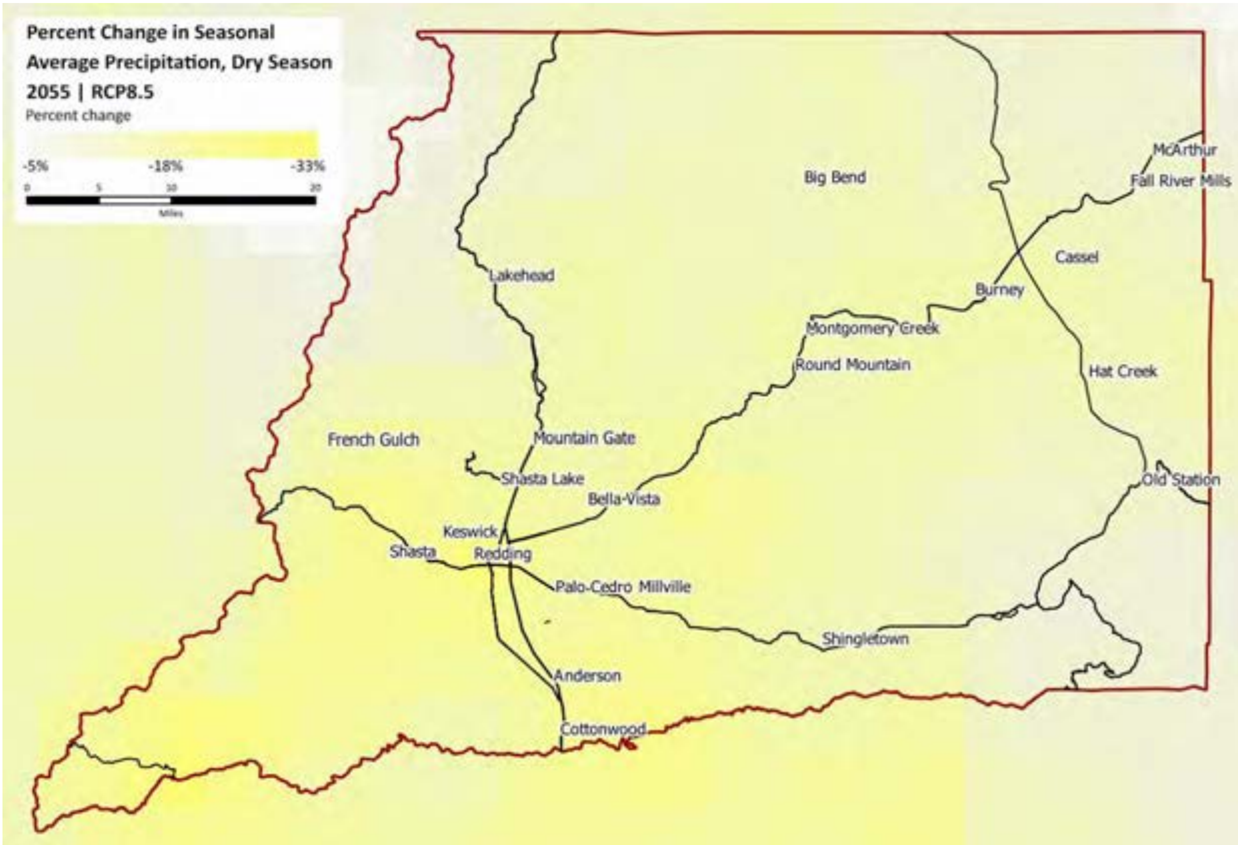

Figure 18. Percent change in dry season precipitation, 2055 RCP8.5.

By 2085 in the unconstrained emissions scenario, projected reductions in dry season precipitation are less severe than in midcentury, but with a similar pattern across the county. Reductions in the Redding area are still largest (21 – 28%), but reductions in the Lassen Volcanic National Park are 9 – 13%.

Cutting emissions could have a larger impact on dry season precipitation than on wet season precipitation. In the reduced emissions scenario, declines in dry season precipitation are less severe by midcentury than in the unconstrained emissions scenario (Figure 19). In and around Redding, dry season precipitation is projected to fall only 17 – 23% by midcentury, with similarly smaller impacts across the Region, compared to the unconstrained emissions scenario. However, the effect of emissions reductions on mitigating dry season precipitation declines is lessened by the end of the century, when projected reductions in dry season precipitation are comparable to the unconstrained emissions scenario.

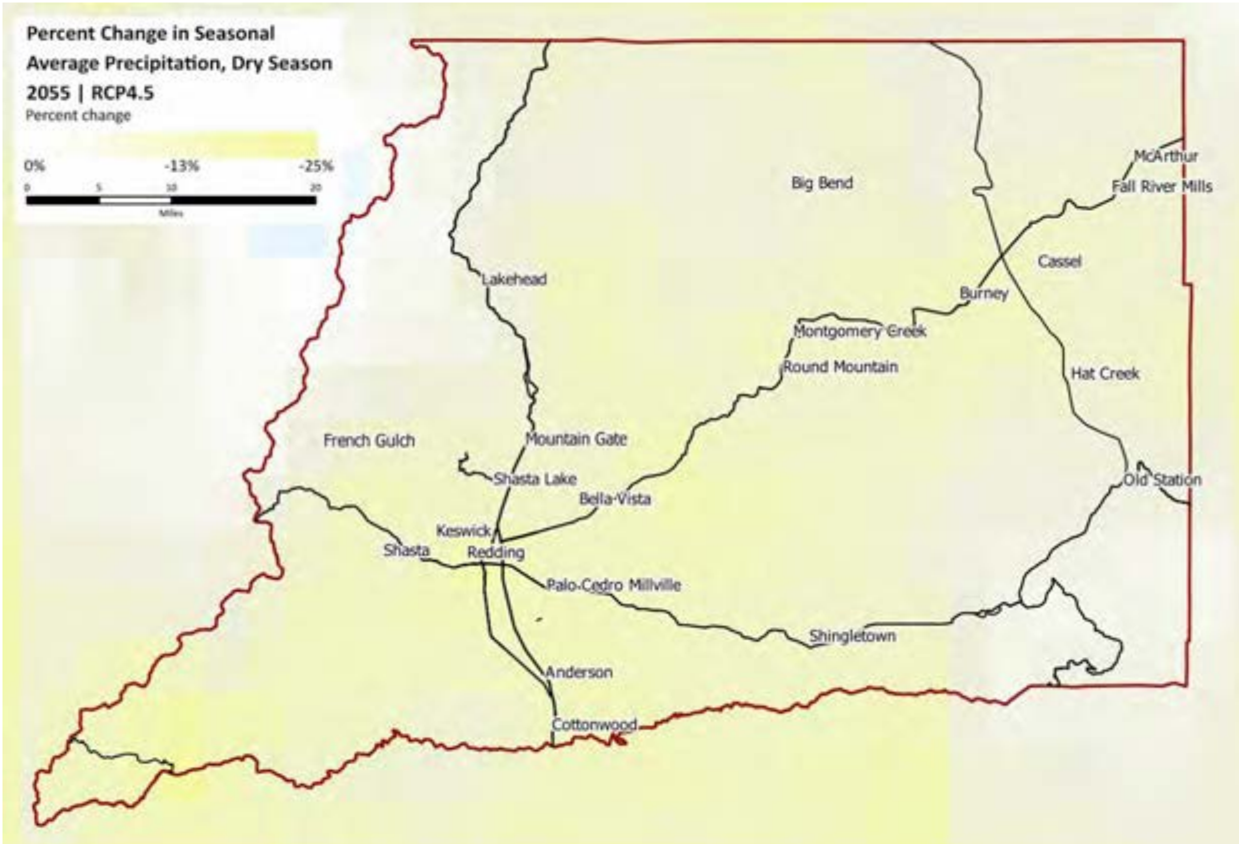

Figure 19. Percent change in dry season precipitation, 2055 RCP4.5.

Projected Changes to Extreme Precipitation

Extreme precipitation occurs when large amounts of precipitation – either as rain or snow – fall in a short amount of time. Extreme precipitation events are defined relative to an area's climate history, so areas that have historically little precipitation such as the Modoc Plateau may experience very different extreme precipitation events as areas which historically receive large amounts of precipitation (such as the Klamath Mountains). Additionally, extreme precipitation includes both rain and snow, so both severe rainstorms and snow events are included.

Extreme precipitation events in this study are defined as the three-day periods with higher amounts of precipitation than most other three-day periods. This study considers extreme precipitation events at three levels of increasing intensity: 1-in-25-year events (i.e., precipitation events with a 4% annual chance of occurring), 1-in-100-year events (i.e., a 1% annual chance of occurring), and 1-in-500-year events (i.e., a 0.2% annual chance of occurring). A 1-in-25 year event means that over the three days, so much precipitation fell that it exceeded all but 4% of 3-day periods in the historical record.

Historically, a 25-year extreme precipitation event is oftentimes sufficient to cause localized flooding, while a 100-year event is more likely to lead to widespread flooding (or, if precipitation falls as snow, increased avalanche activity, dangerous snow loads on structures, and potential transportation network disruptions to clear snow loads). 500-year precipitation events are so rare that infrastructure is rarely built to contain the resulting volumes of runoff. Projected increases (or decreases) in the intensity of extreme precipitation events mean that the total volume of precipitation during these events will be larger (or smaller). Extreme precipitation events are especially important for understanding flooding and landslide hazards in areas subjected to wildfire hazard. Hillsides which have recently experienced wildfire are much more likely to contribute to increased surface runoff, debris flows, and mud or landsliding. Surface runoff is a primary contributor to flash flooding, and debris flows can block roads, clog culverts and drainage systems, and exacerbate flooding, particularly at road crossings. One implication of increasing extreme precipitation event severity is that the frequency of precipitation event that would be considered extreme by today's standards will also increase.

When compared to the rest of northern California, the Shasta Region contains areas subject to both relatively high and relatively low-intensities of extreme precipitation. Extreme precipitation events in higher elevation areas of the Klamath Mountains and Cascade Mountains are typically more intense (i.e., larger volumes of precipitation) than lower-lying areas. However, the northeastern parts of the Shasta Region include the high-elevation Modoc Plateau, which features some of the lowest-intensity extreme precipitation events in the Region (particularly around Four Corners and east of Highway 89).

In most scenarios, projected changes to extreme precipitation in the Shasta Region are positive, with many areas with severe increases in extreme precipitation intensity. However, in some cases, projections show areas of falling intensity of extreme precipitation events. Where reductions (or smaller increases occur, they are generally in the southwestern and northeastern corners of the Shasta Region. By contrast, the Klamath Mountains – especially in the center of the Region, and west of the I-5 corridor – and the Lassen Volcanic National Park show some of the largest projected increases in extreme precipitation.

For both the 25-year and 100-year extreme precipitation events, the long-term trend in precipitation intensity is positive. By 2055, the intensity of a 100-year precipitation event is projected to increase by up to 16% in the upper Sacramento River Valley. The city of Redding is the major exception, showing a range of outcomes, from a reduction of 5% to an increase of 10%. Very similar patterns are shown in the projections of a smaller 25-year storm. Table 10 shows the projected changes to extreme precipitation events in 2055 in both the reduced and unconstrained emissions scenarios. Figure 20 and Figure 21 show the projected change in 100-year and 25-year extreme precipitation events by 2055 in an unconstrained emissions scenario. Figure 22 and Figure 23 show the same projections for the 2025 time period.

Table 10. Projected changes to the intensity of extreme precipitation events (25-year, 100-year, and 500-year) in 2055.

	Redding		**Anderson**		**Shingletown**		**Burney**		**Pollard Flat**		**Old Station**	
Event	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
25-Year	-1.1%	0.2%	12.0%	9.1%	4.0%	3.7%	10.6%	7.9%	17.0%	17.1%	8.8%	8.7%
100-Year	-4.0%	-4.7%	13.8%	12.9%	8.2%	3.7%	4.0%	1.4%	12.8%	13.5%	11.5%	10.6%
500-Year	-15.8%	-14.4%	5.2%	3.3%	14.1%	9.7%	-5.2%	-6.6%	6.1%	7.8%	11.1%	17.0%

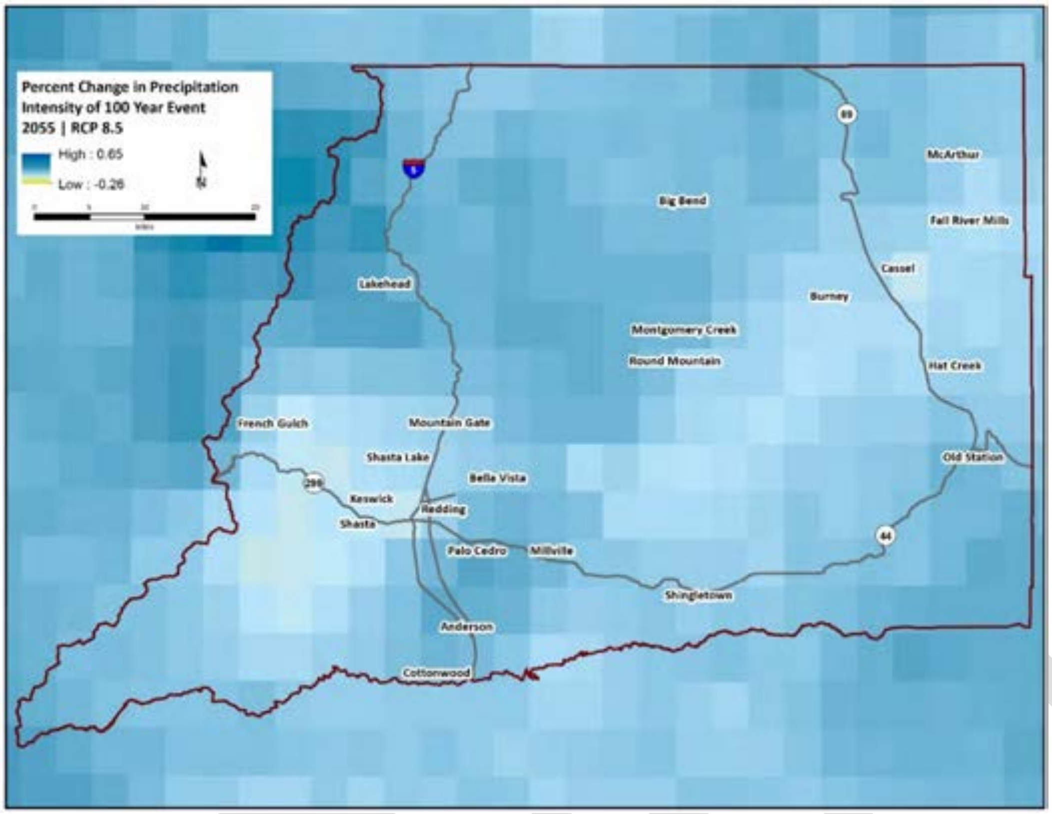

Figure 20. Projected percent change in intensity of 100-year extreme precipitation event. 2055, RCP8.5.

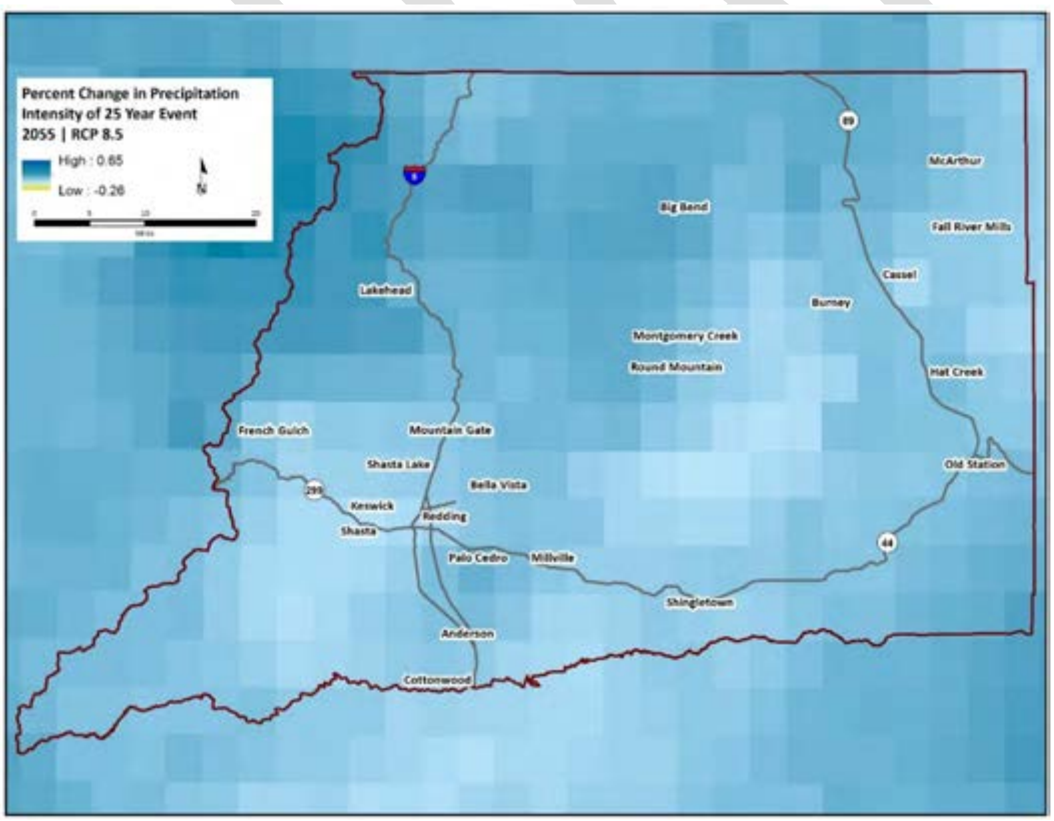

Figure 21. Projected percent change in intensity of 25-year extreme precipitation event. 2055, RCP8.5.

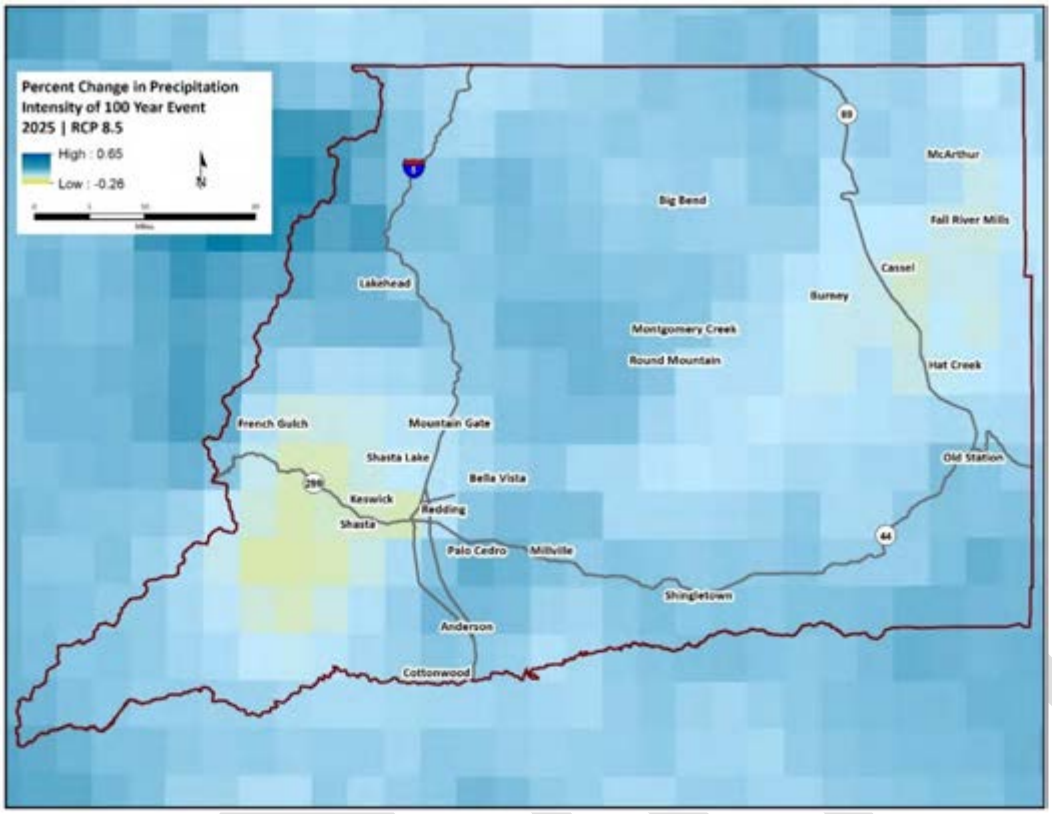

Figure 22. Projected percent change in intensity of 100-year extreme precipitation event. 2025, RCP8.5.

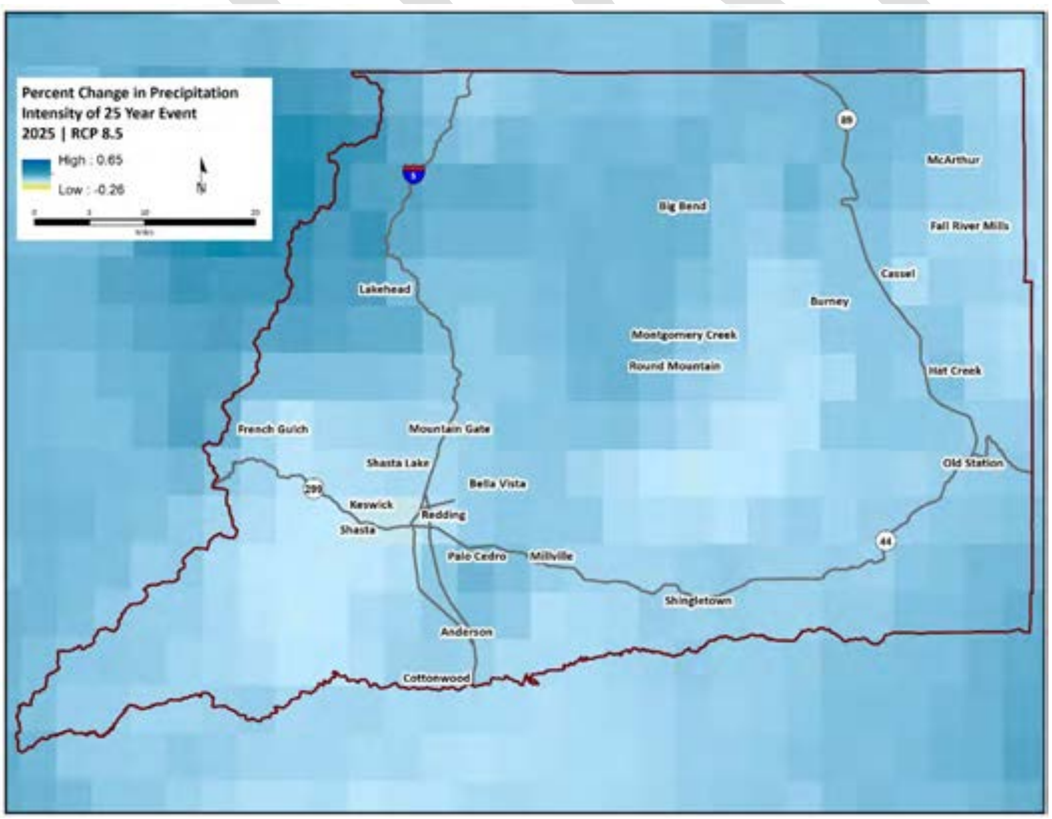

Figure 23. Projected percent change in intensity of 25-year extreme precipitation event. 2025, RCP8.5.

By contrast, the 500-year extreme precipitation event (representing much more catastrophic precipitation) is projected to increase in severity in many areas, but shows wider areas of smaller increases, and many areas with decreases. By 2055, projected increases are maximums around Mt. Lassen (17%), Old Station (17%), Vollmers (17%), Shingletown (10%), Round Mountain (9%), and Bella Vista (5%), while decreases in the intensity of the 500-year precipitation event are largest in Redding (-14%), Cassel (-24%), Fall River Mills (-19%), Burney (-7%), Castle Crag (-7%), and Ono (-11%). Many areas are projected to see only small changes, like Shasta Lake (-1%) and Anderson (3%). Figure 24 shows the projected change for the 500-year extreme precipitation event by 2055 in an unconstrained emissions scenario; Figure 25 shows the same in 2025.

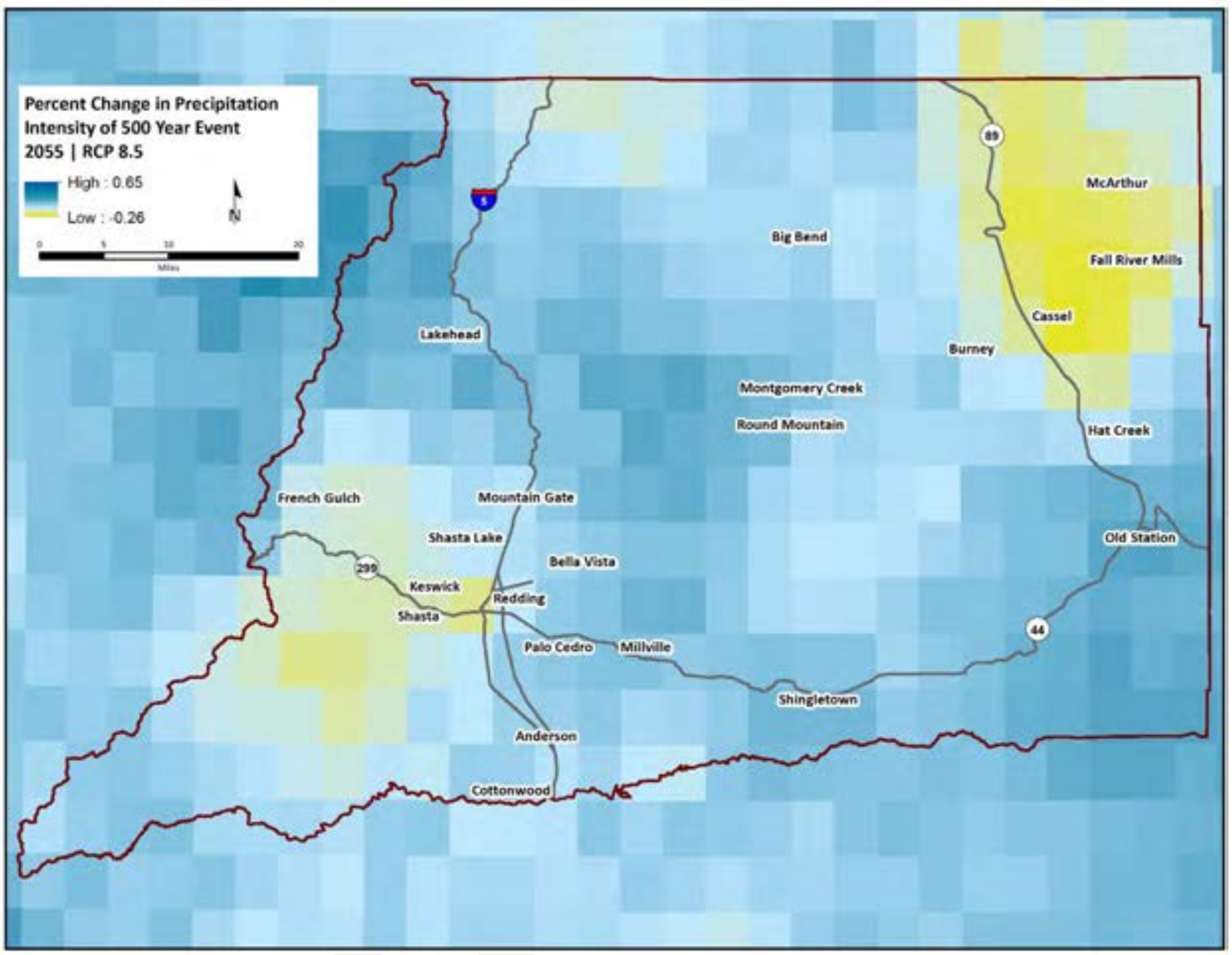

Figure 24. Projected percent change in intensity of 500-year extreme precipitation event. 2055, RCP8.5.

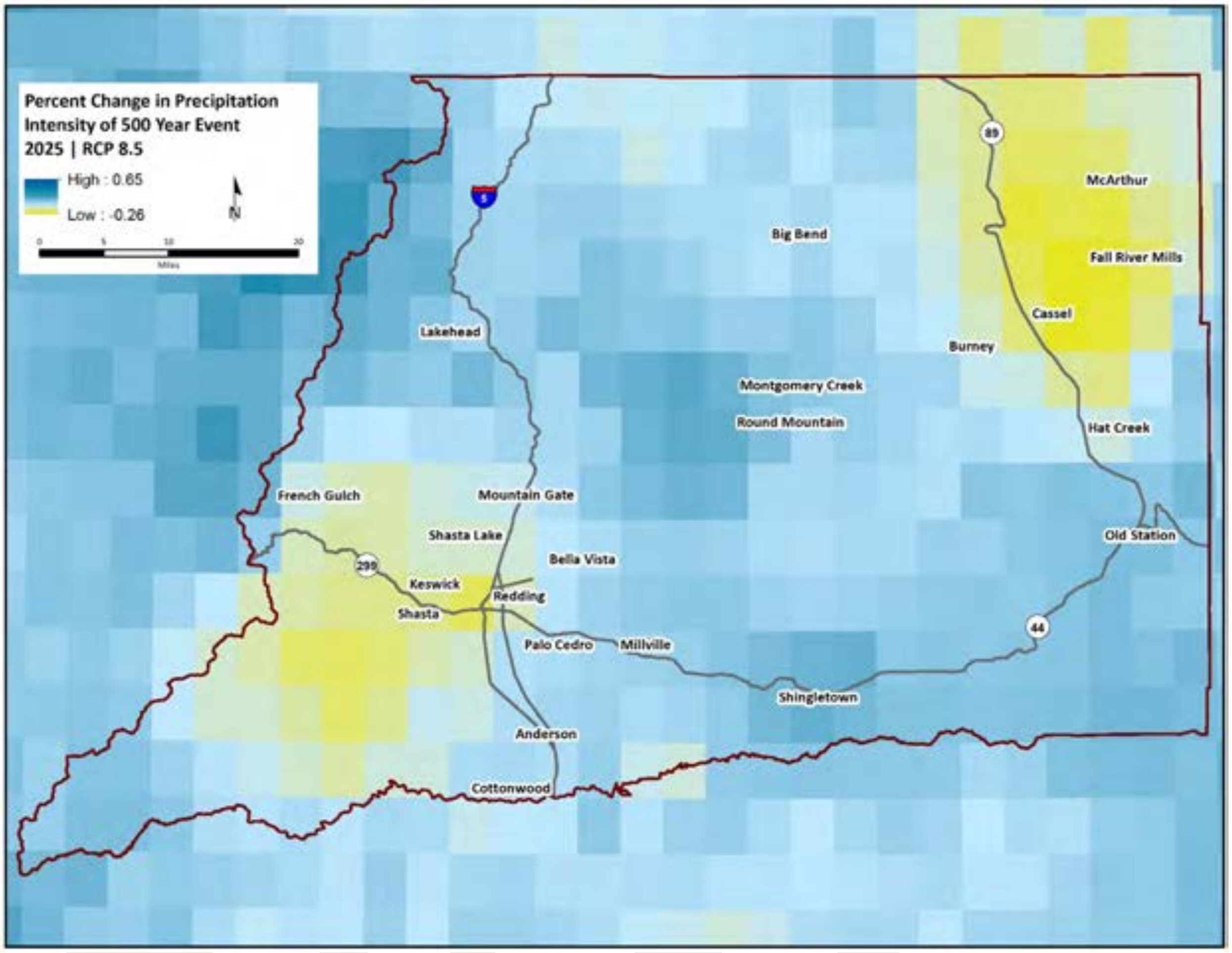

Figure 25. Projected percent change in intensity of 500-year extreme precipitation event. 2025, RCP8.5.

By 2085, projected changes to extreme precipitation are larger for all exceedance thresholds (including the 25-, 100-, and 500-year events), even as each projection reflects similar Regional distribution to the 2055 projections. For the 25- and 100-year events, this means that virtually every part of the Shasta Region will see large increases in the severity of extreme precipitation events in an unconstrained emissions scenario. For the 500-year event, this smaller declines in areas where severity is projected to fall, and larger increases in areas where severity is projected to increase. Figure 26, Figure 27, and Figure 28 show the projected change for the 25-, 100-, and 500-year extreme precipitation events in 2085 in an unconstrained emissions scenario, respectively.

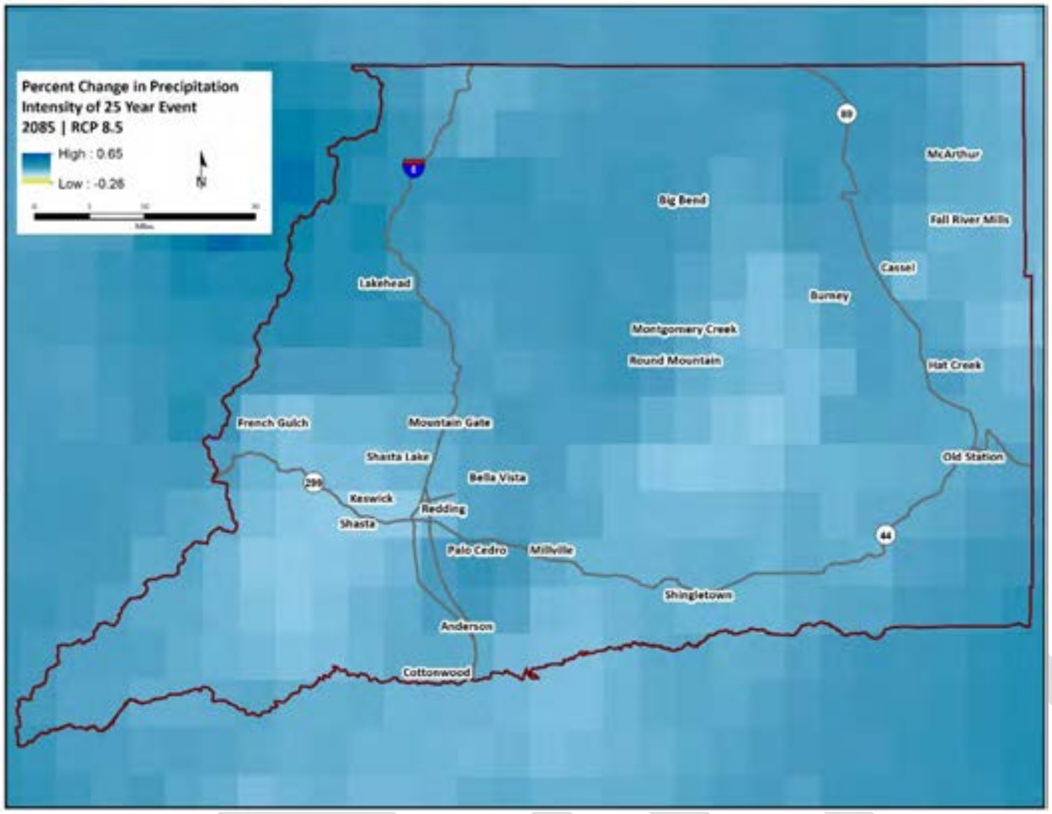

Figure 26. Projected percent change in intensity of 25-year extreme precipitation event. 2085, RCP8.5.

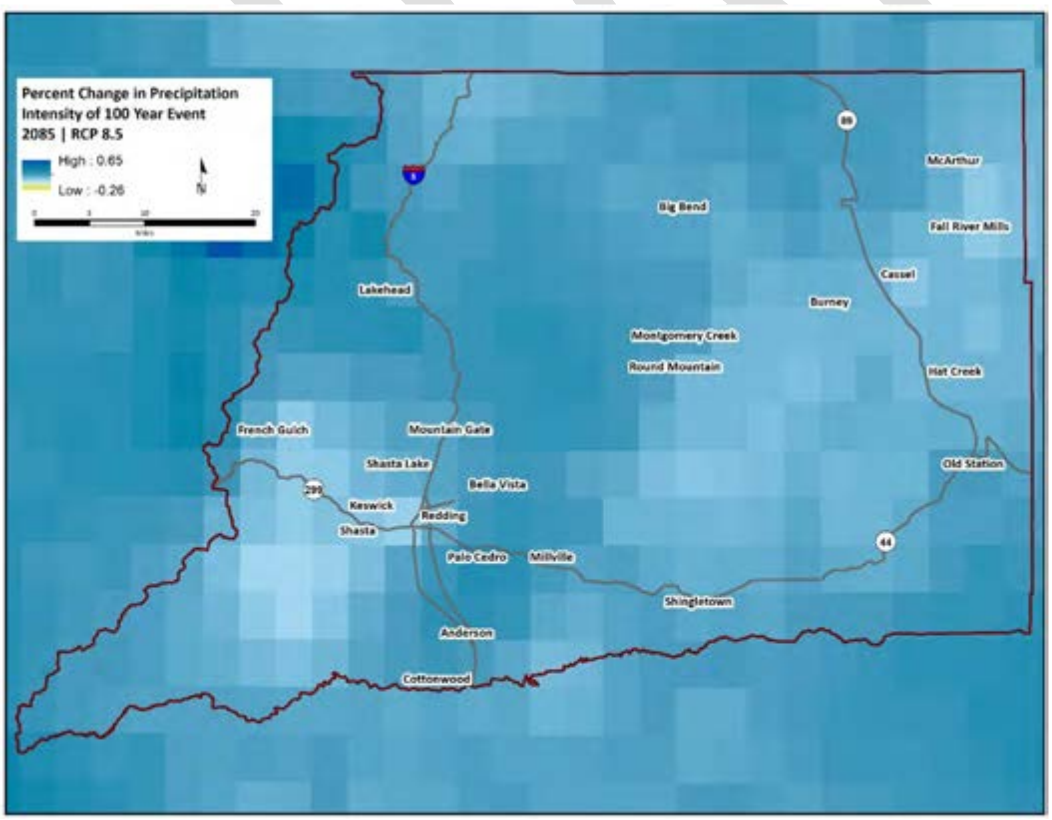

Figure 27. Projected percent change in intensity of 100-year extreme precipitation event. 2085, RCP8.5.

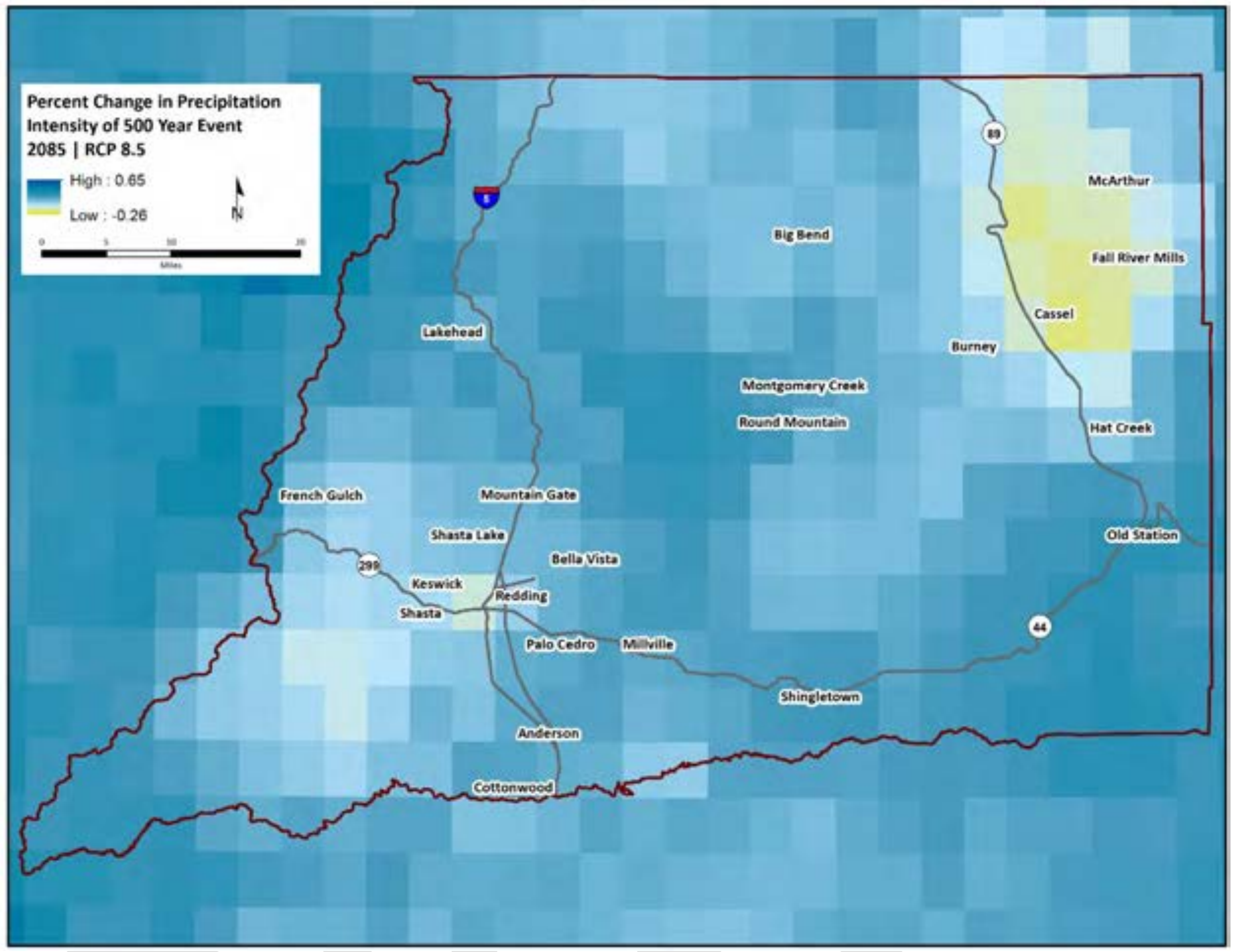

Figure 28. Projected percent change in intensity of 500-year extreme precipitation event. 2085, RCP8.5.

The reduced emissions scenario shows that projected changes to extreme precipitation events are generally similar to the unconstrained emissions scenario in both the 2025 and 2055 time periods. However, substantial reductions in projected increases in precipitation intensity are seen in the reduced emissions scenario by 2085, when compared to the unconstrained emissions scenario. This end-of-century reduction in severity is notable in all exceedance thresholds (25-, 100-, and 500-year extreme precipitation events), indicating that reducing emissions could have significant effects on late-century extreme weather. Figure 29, Figure 30, and Figure 31 show the projected changes in 25-, 100-, and 500-year extreme precipitation events in 2085 under a reduced emissions scenario, respectively. Additional figures are located in Appendix A.

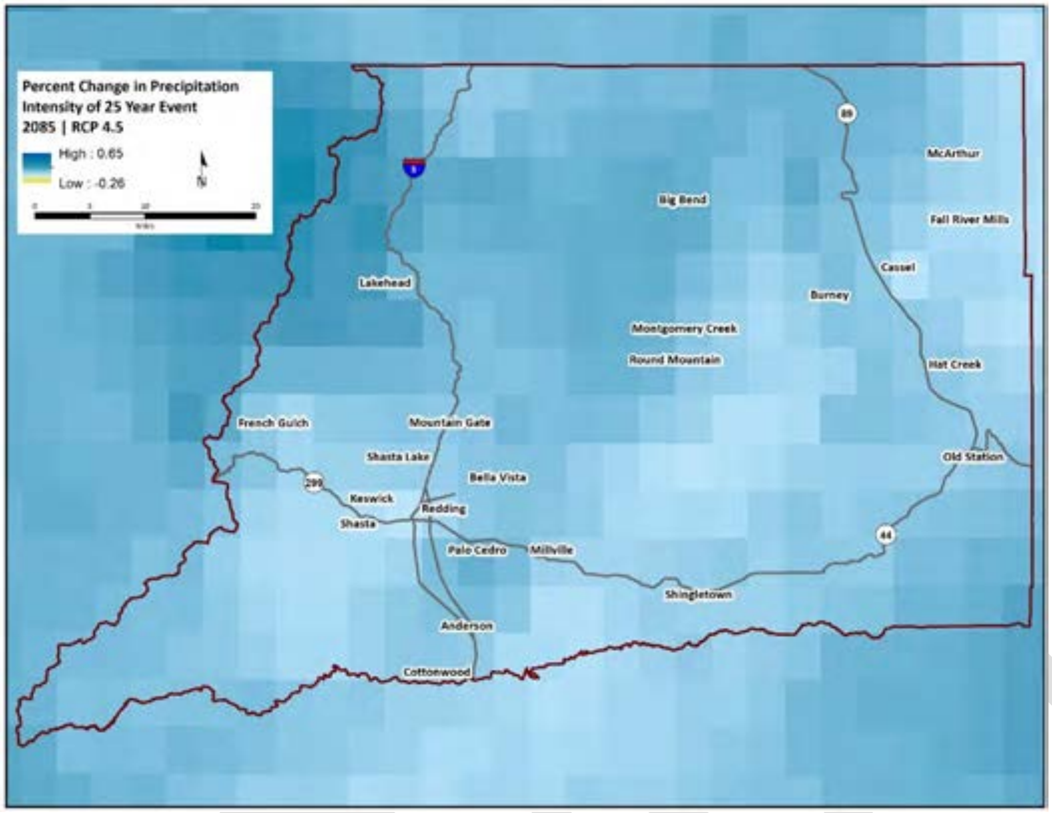

Figure 29. Projected percent change in intensity of 25-year extreme precipitation event. 2085, RCP4.5.

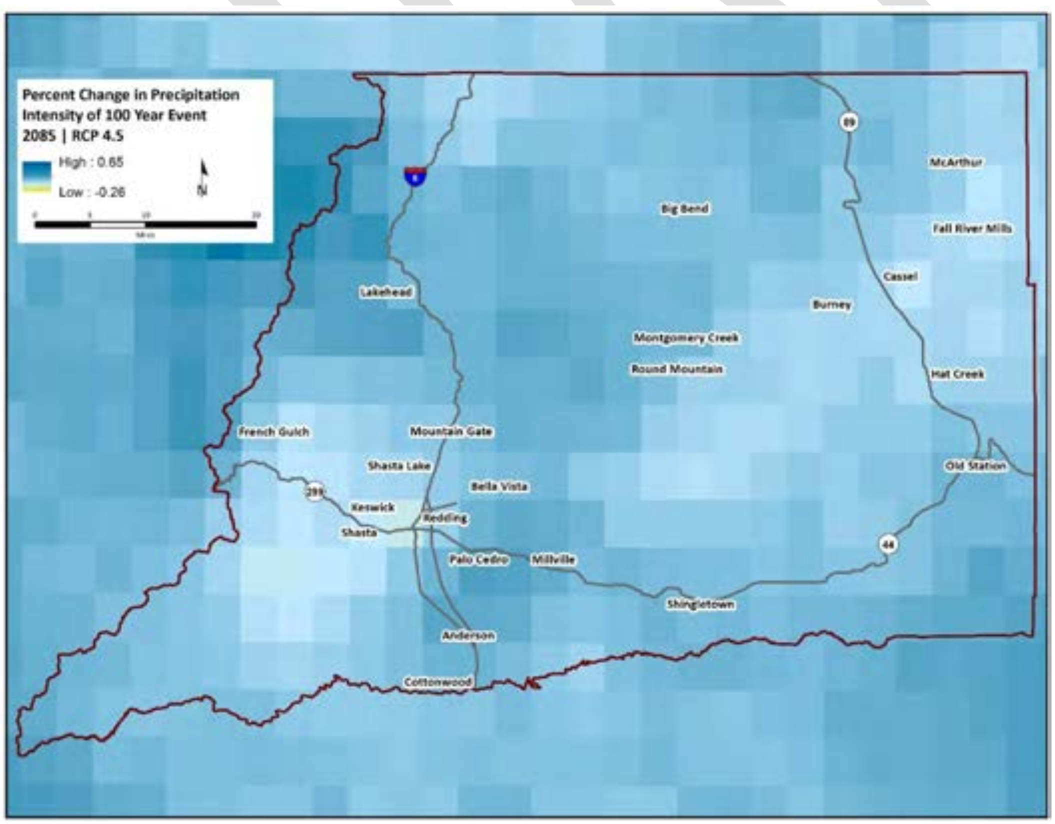

Figure 30. Projected percent change in intensity of 100-year extreme precipitation event. 2085, RCP4.5.

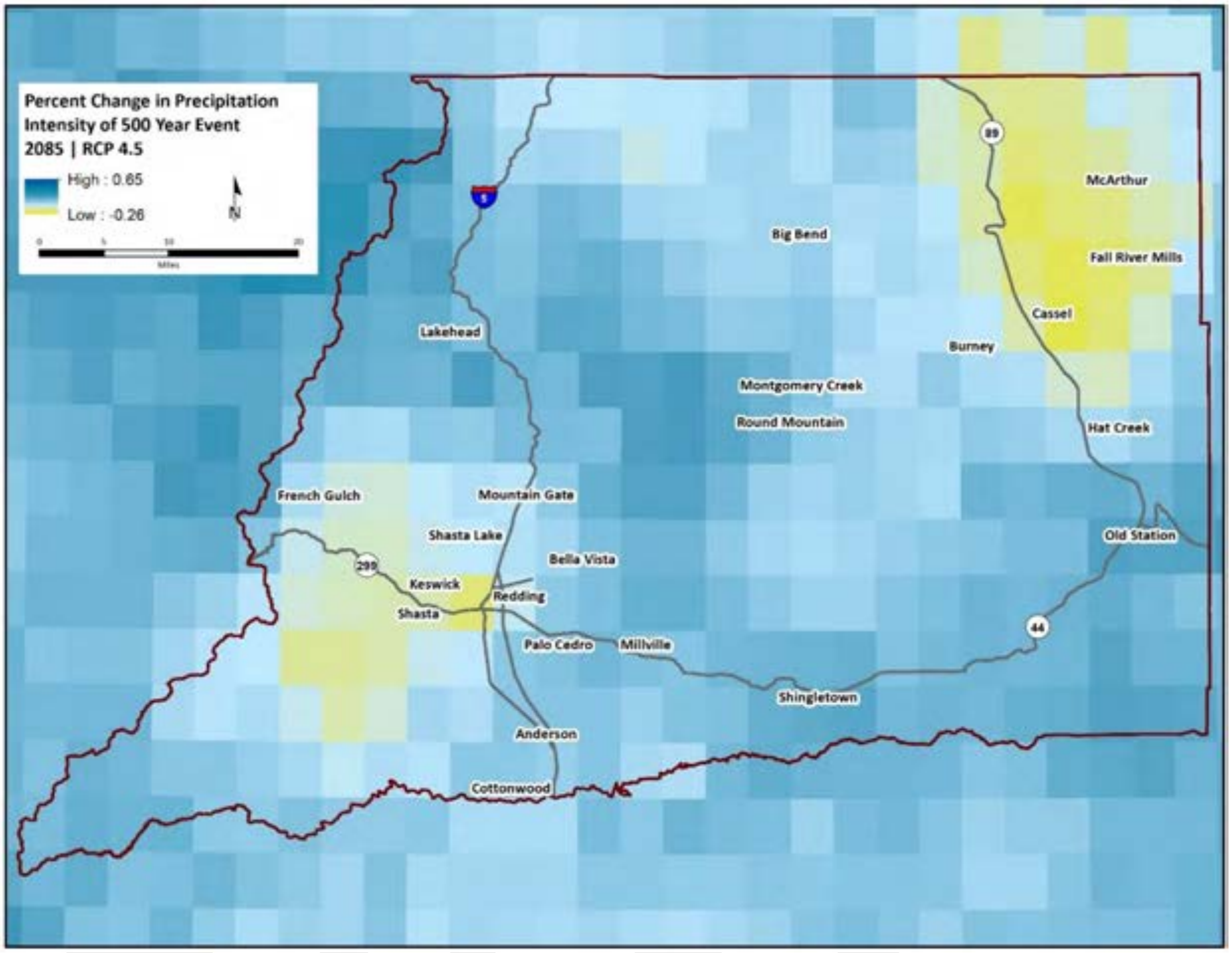

Figure 31. Projected percent change in intensity of 500-year extreme precipitation event. 2085, RCP4.5.

Infrastructure Vulnerabilities

With high enough rates of precipitation, severe rainstorms or snowstorms can disrupt any road or transportation facility. For this reason, specific infrastructure vulnerabilities are not mapped. The exception is the I-5 corridor in the Sacramento River Canyon where the unique combination of historically intense snowstorms, high through traffic of freight trucking, and a narrow corridor with a high number of turns has created a unique, repeated problem of road closures due to extreme precipitation.

Along I-5 in the Sacramento River Canyon, intense snowstorms can outpace the ability of Caltrans to clear snow, leading to temporary closures, as well as other disruptions like mandatory tire chain checkpoints. In the Shasta Region, these closures usually occur north of the Fawndale Road exit, north of the city of Shasta Lake. These closures frequently result in extended backups, especially of truck traffic which has nowhere else to go. Historically, backed-up truck traffic has reached as far south as Redding and even Anderson, with the large numbers of stranded trucks creating severe mobility hazards for other road users, including emergency vehicles. One particular problem is the tendency of stranded trucks to block exit lanes.

Figure 32. On January 28th, 2021, closure of the I-5 corridor north of Fawndale Road due to heavy snow resulted in a backup of traffic along I-5 all the way to Anderson. Source: Chapman 2021

One such backup occurred on the morning of January 28, 2021 following a large snowstorm. In order to reduce the risk of crashes and further closures, Caltrans limited vehicles north of Fawndale Road to only passenger vehicles with chains onboard, and only 30 tractor-trailer trucks per hour. By late morning, trucks had backed up all the way south to Anderson, and the I-5/Highway 44 junction was blocked. Even after the mandatory chain check was lifted, traffic interruptions lingered throughout the rest of the day.[7]

Projected changes to extreme precipitation are likely to make these types of events occur more often and with greater severity. Increases in the intensity of extreme precipitation events in the Sacramento River Canyon are positive in all scenarios and future periods over the majority of I-5's route. Table 11 shows the projected change in intensity of 100-year precipitation events in the Sacramento River Canyon across each scenario and timeframe. In all cases, the largest projected increases in extreme precipitation intensity occur between Lamoine and Vollmers. This area is projected to see at least 21% greater intensity in a 100-year storm than in the historical period by 2025. Because the 2025 period includes the 2010 – 2039, the Shasta Region is already experiencing this projected increase.

Table 11. Projected changes to the intensity of a 100-year extreme precipitation event in the Sacramento River Canyon.

Timeframe	Reduced Emissions Scenario (RCP4.5)	Unconstrained Emissions Scenario (RCP8.5)
2025	(-1.7%) – 22.1%	(-0.1%) – 21.0%
2055	2.1% – 26.1%	4.5% – 26.2%
2085	0.1% – 25.8%	10.0% –37%

[7] Chapman 2021

Wildfire Impacts and Vulnerabilities

Wildfires challenge transportation systems primarily through direct physical damage, and secondarily through closures and delays necessary to contain, evacuate, fight, and recover from fires. In the Shasta Region, human settlements and their connecting transportation infrastructure are exposed to significant wildfire hazard. The wildland urban interface in the Shasta Region exposes not only rural communities like Shingletown to fire hazard, but also the communities in the main urban core of the Region. There have been 278 reported and recorded wildfires in the Shasta Region since 1970, as depicted in Figure 33.

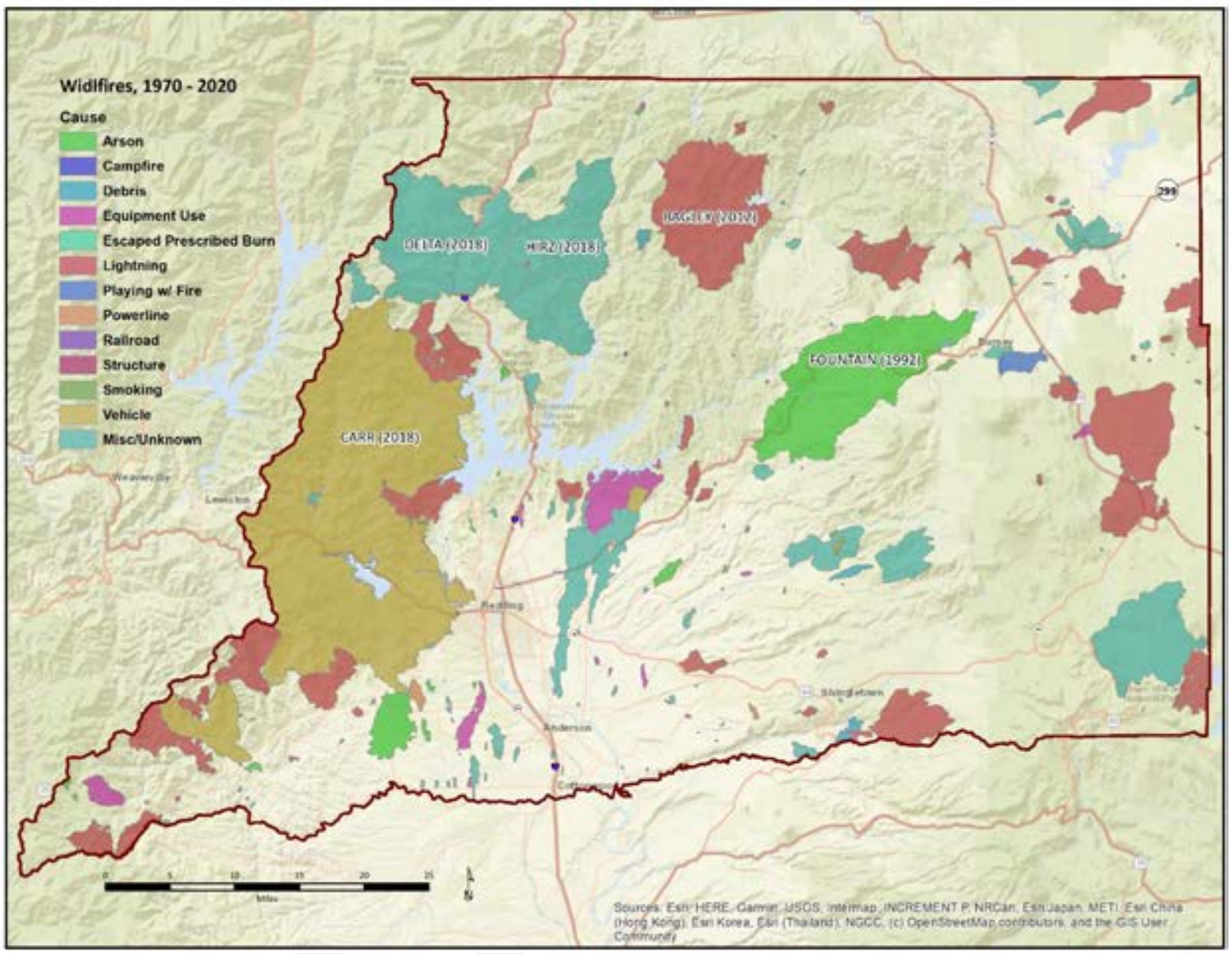

Figure 33. Wildfires in the Shasta region, 1970 – 2020.

The specific effects of wildfires on transportation infrastructure differ depending on the type of infrastructure systems and their vulnerability to the extreme heat, soot, fire debris, and even high winds that come with wildfires. These impacts are described in Table 12.

Table 12. Example table of sector-specific impacts for wildfire hazards

	Wildfires
Roads & Bridges	• Road and bridge closures during and following fires due to firefighting operations and safety considerations • Damage to road surfaces and reinforced concrete structures from extreme heat and fire debris • Damage to road furniture (e.g., guard rails, signage, etc.) and signaling systems (e.g., traffic lights, traffic cameras, ITS infrastructure) • Disruptions to support systems for transportation (e.g., fuel supply)
Rails	• Rail corridor closures during fires due to firefighting operations and safety considerations • Damage to trestles, rails, ties, and railbeds • Damage to signaling infrastructure (e.g., switches)
Transit Systems	• Route disruptions (due to road closures/detours) and delays • Diversion of rolling stock for evacuations/emergency response • Direct damage to facilities (incl. bus shelters, signage, and road furniture) and transit centers • Reduction in service following fires due to road damage and closures, diverted rolling stock, and damage to facilities
Airports	• Damage to runway and tarmac pavements from extreme heat • Damage to outlying infrastructure (e.g., signaling lights, radio and microwave equipment, pipelines, fences, and service roads) • Direct damage to terminals, hangars, fuel tanks, and airplanes • Delays associated with damage to facilities • Delays due to firefighting activities staged in airports
Pedestrians & Bicycles	• Route closures due to direct wildfire damage and debris • Closures due to firefighting activity • Impaired regional air quality inhibits pedestrian/cycling activity over wide area

Regionwide Projections

Across the entire Shasta Region, models of wildfire activity project increasing probability and intensity of fires. However, these increases are greater in some areas than others. For example, historical conditions show that the average decadal probability of wildfires in the forests around French Gulch and north of Whiskeytown Lake range around 20 – 25% (i.e., a 1-in-5 to 1-in-4 chance of a significant wildfire each decade). By 2085, that probability increases to 25 – 30% in a reduced emissions scenario (RCP4.5) and a 50 – 58% probability in an unconstrained emissions scenario (RCP8.5). While the unconstrained emissions scenario represents an approximate doubling by 2085, the increases are much greater in other parts of the region. For example, in Lassen National Forest between Snow Mountain and Burney Mountain, historical wildfire probabilities range from 11 – 13%, while projected probabilities range 56 – 60% by 2085 in the unconstrained emissions scenario. More concerningly, forests around Shingletown with a historical 13 – 17% decadal fire probability show dramatic increases to 50 – 56% decadal fire probabilities in 2085 in the unconstrained emissions scenario.

Projected changes to fire intensity also differ across the region. For example, in the suburban subdivisions west of downtown Redding, the intensity of wildfires (as measured by the projected area burned, given the outbreak of fire) is projected to increase roughly 40% by 2085 in an unconstrained emissions scenario. But in the Shasta-Trinity National Forest north of Big Bend, the intensity of wildfires is projected to increase by up to 850% over the same timeframe. These variations across the region demonstrate that future exposure to wildfire hazard is not just increasing, the increases are highly location-specific.

Decadal Fire Probability

Across the Shasta Region, projections of change in decadal fire probability are almost all increasing. Additionally, projections all increase over time, and with greater emissions. Historically, decadal fire probability has been greatest in the mountainous areas of the Shasta-Trinity National Forest around Big Bend and in the southwestern corner of Shasta County. In these areas, the historical decadal fire probability is up to 10 times greater than in the Anderson-Redding area and around Lake Shasta (Figure 34).

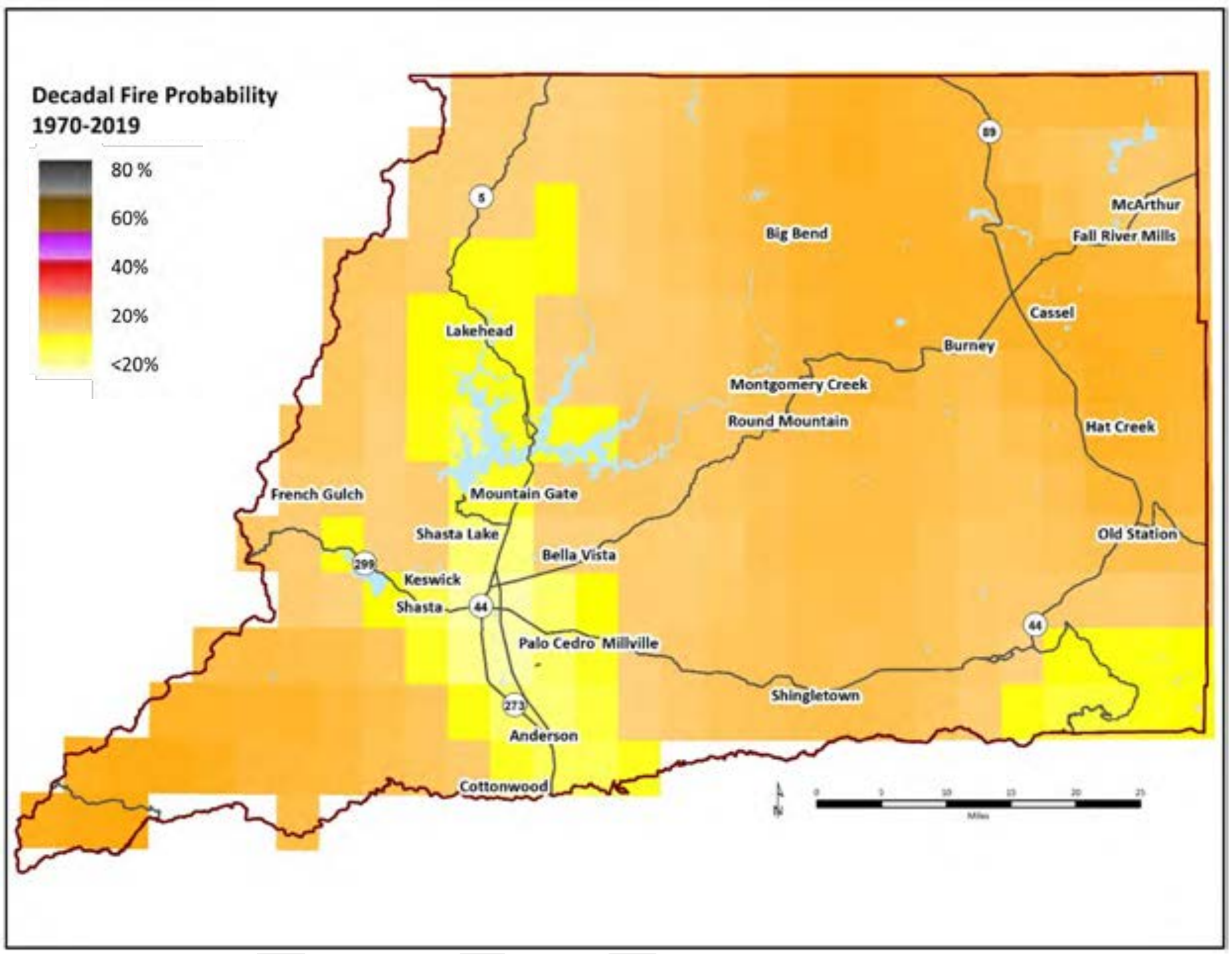

Figure 34. Average decadal Fire Probability in the historical period (1970 - 2019).

With rising temperatures, the decadal probability of fires is projected to increase across the region. By 2025, the steepest projected rise in decadal fire probability is in southwestern Shasta County. By midcentury and beyond, a sharper rise is seen in the band of forests stretching from the northern border of Shasta County (northeast of Big Bend) southward through the western flanks of the Cascade Range to Burney Mountain, Ward Butte, and Snow Mountain. By 2055, decadal fire probability is projected to rise to 40% or greater across approximately two-thirds of the region. By 2085, decadal fire probability is projected to rise to over 50% across most of the region, with some of the highest probability exceeding 70%. Figure 35, Figure 36, and Figure 37 show the expected changes in decadal wildfire probability across the Shasta Region in the unconstrained emissions scenario.

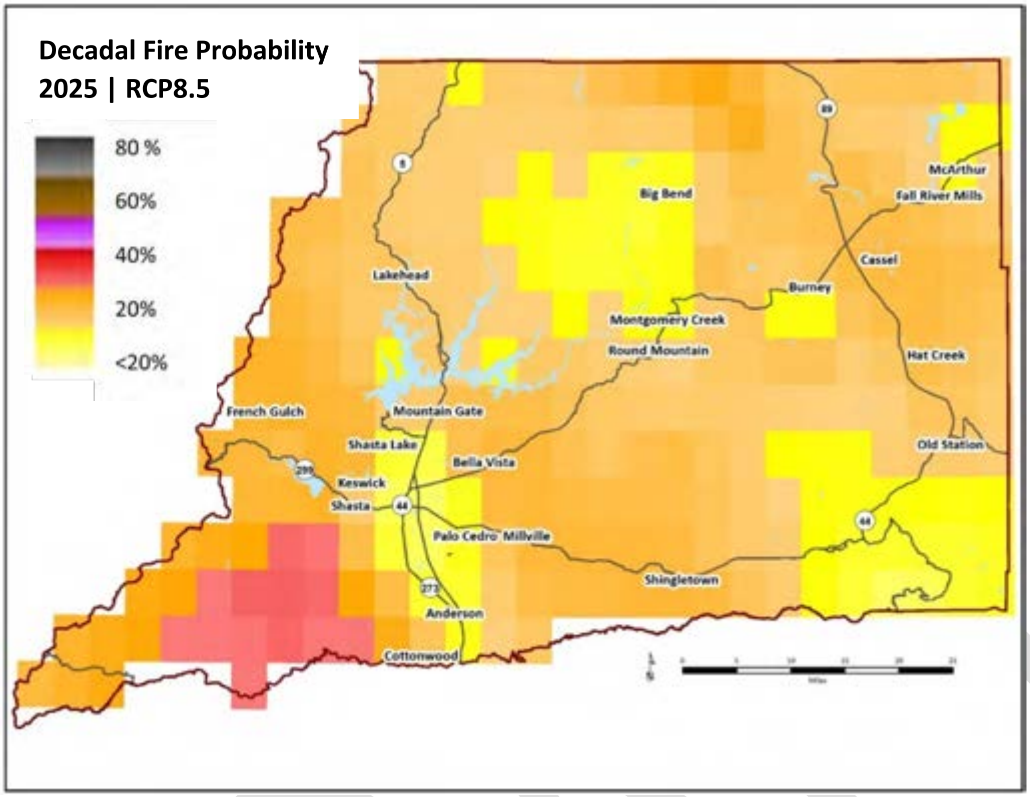

Figure 35. Decadal Fire Probability in 2025, RCP8.5.

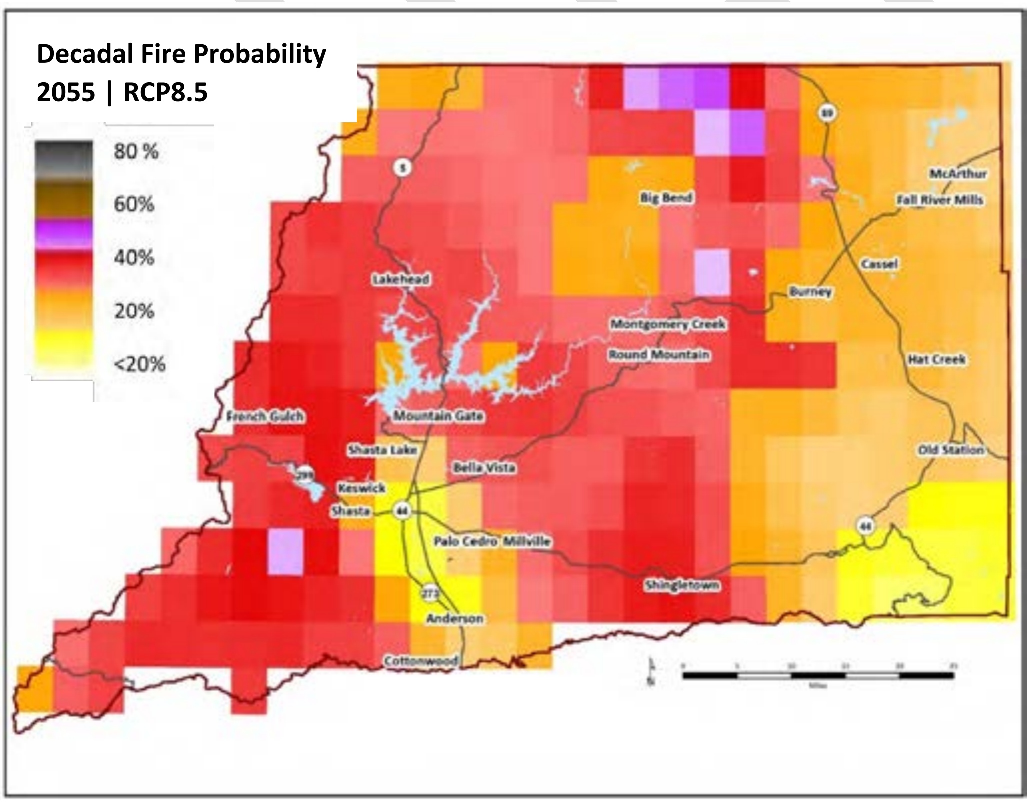

Figure 36. Decadal Fire Probability in 2055, RCP8.5.

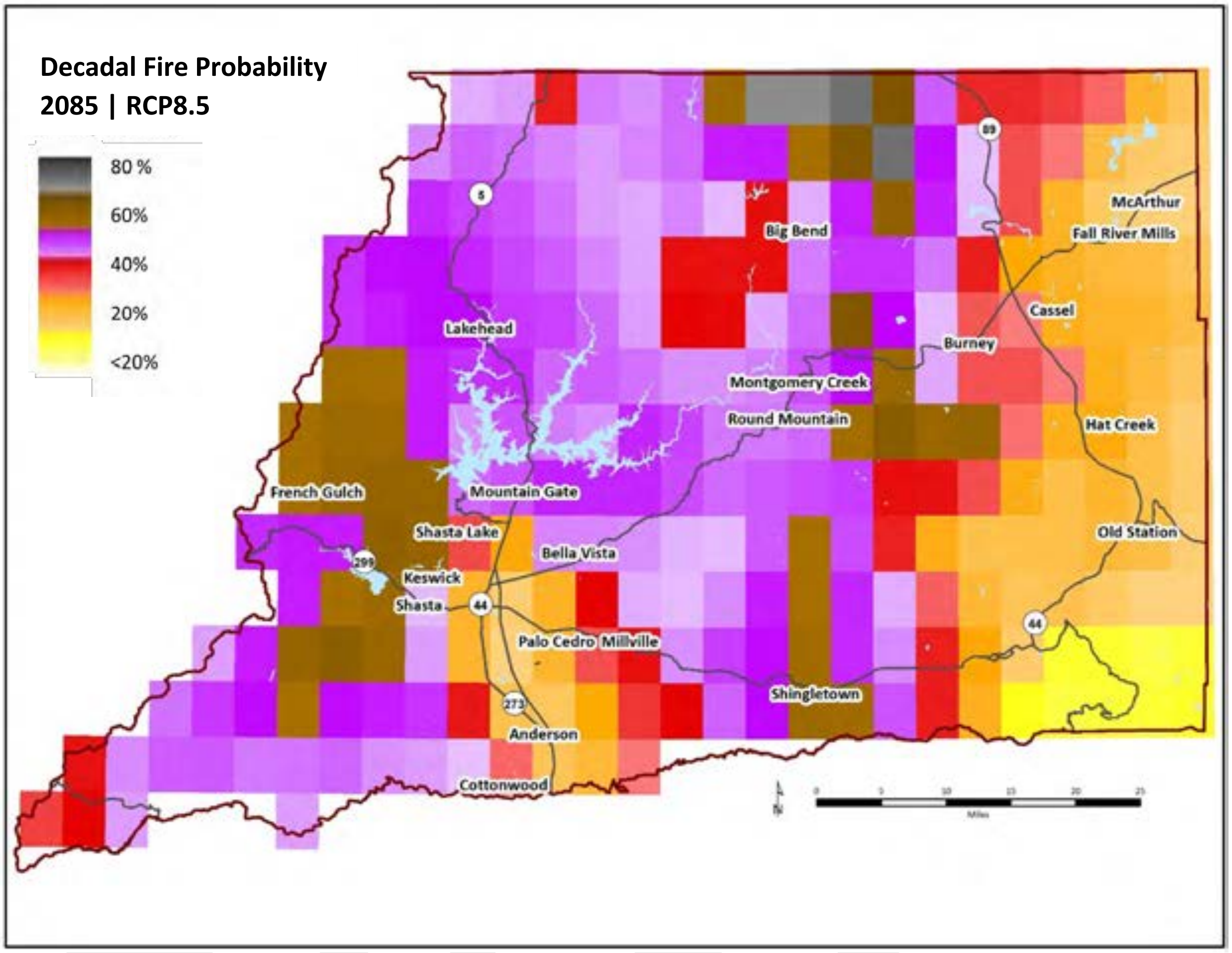

Figure 37. Decadal Fire Probability in 2085, RCP8.5.

Under a reduced emissions scenario, projected increases in decadal fire probability are smaller, but still significant. In the 2025 scenario, projected increases in the central band of the Shasta Region are mostly small, and holds nearly steady in the most densely developed portion of Shasta County.

Even under the reduced emissions scenario, a sharp rise is seen in the band of forests stretching from the northern border of Shasta County (northeast of Big Bend) southward through the western flanks of the Cascade Range to Burney Mountain, Ward Butte, and Snow Mountain. As in the unconstrained emissions scenario, decadal fire probability is projected to rise to 30% or greater across approximately two-thirds of the region by 2055. By 2085, decadal fire probability is projected to rise to over 40% across most of the region, only slightly lower than in the unconstrained emissions scenario. Although somewhat more localized in the reduced emissions scenario, some areas of northern and central Shasta County are still projected to approach 70% by 2085. Figure 39, Figure 38, and Figure 40 show projected changes to decadal fire probability across the Shasta Region in a reduced emissions scenario.

Together, the reduced emissions scenarios demonstrate that reductions in decadal fire probability in the Shasta Region are achievable if global temperatures are held at a lower level. However, regardless of greenhouse gas emissions, localized increases are projected by midcentury with a widespread increase projected by 2085.

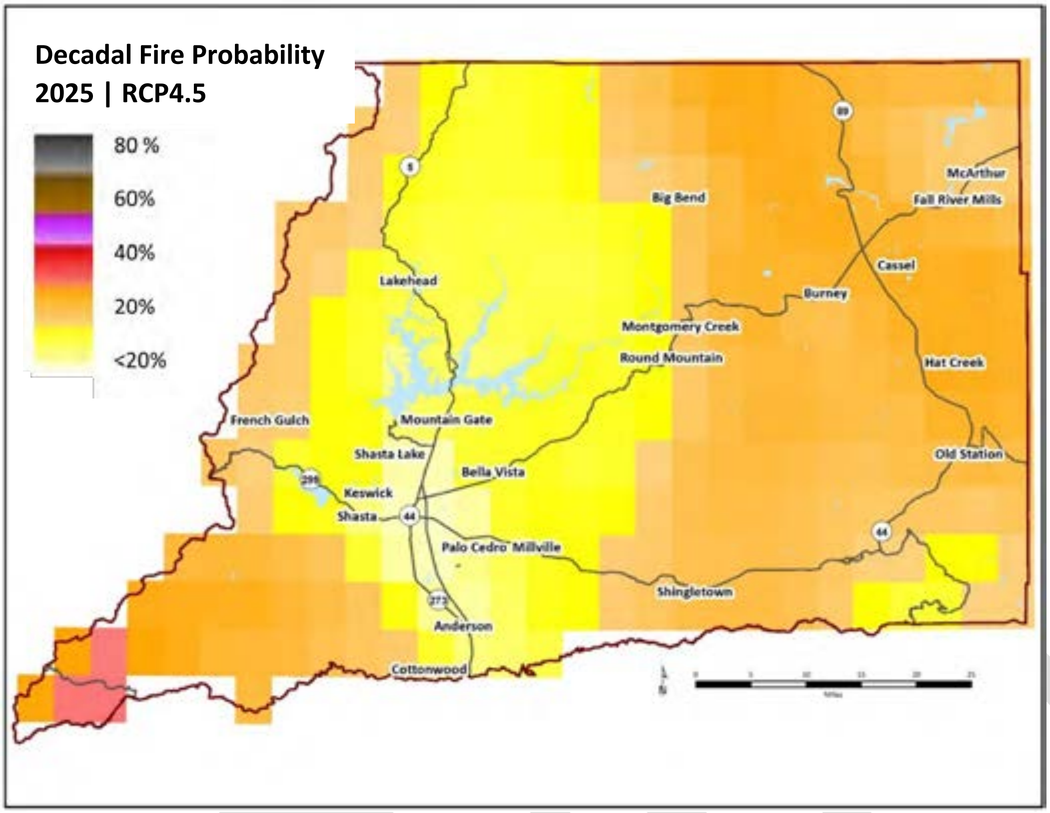

Figure 39. Decadal Fire Probability in 2025, RCP4.5.

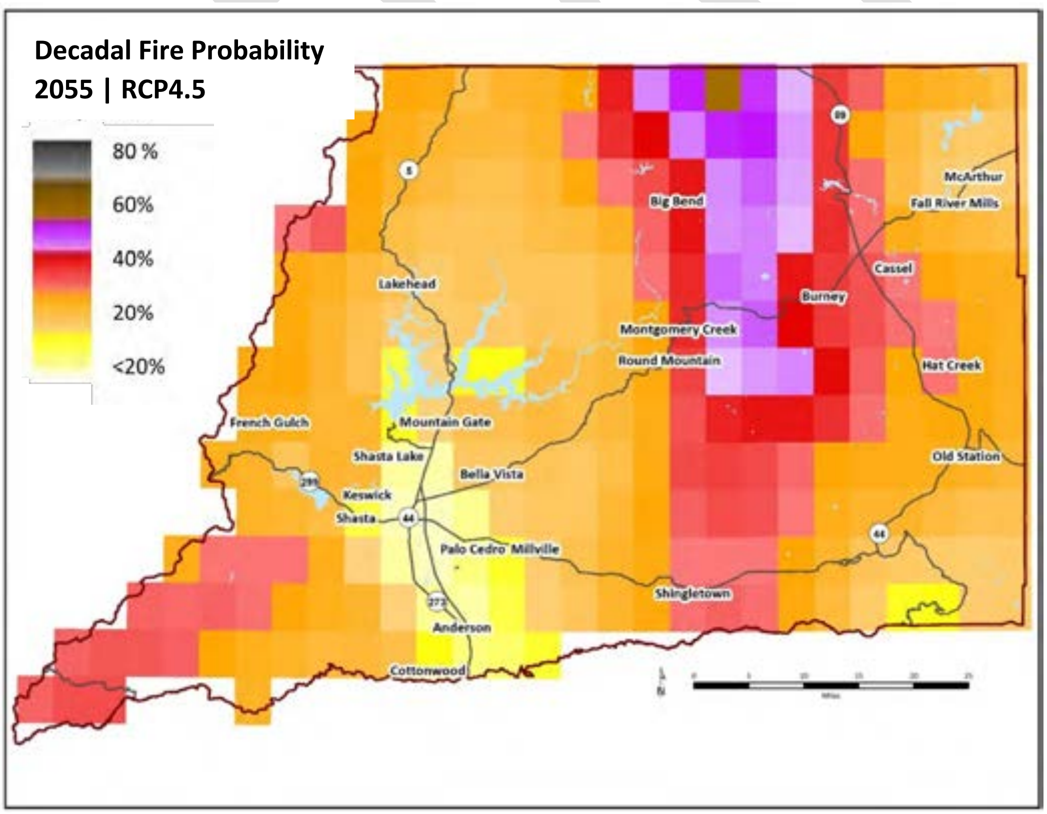

Figure 38. Decadal Fire Probability in 2055, RCP4.5.

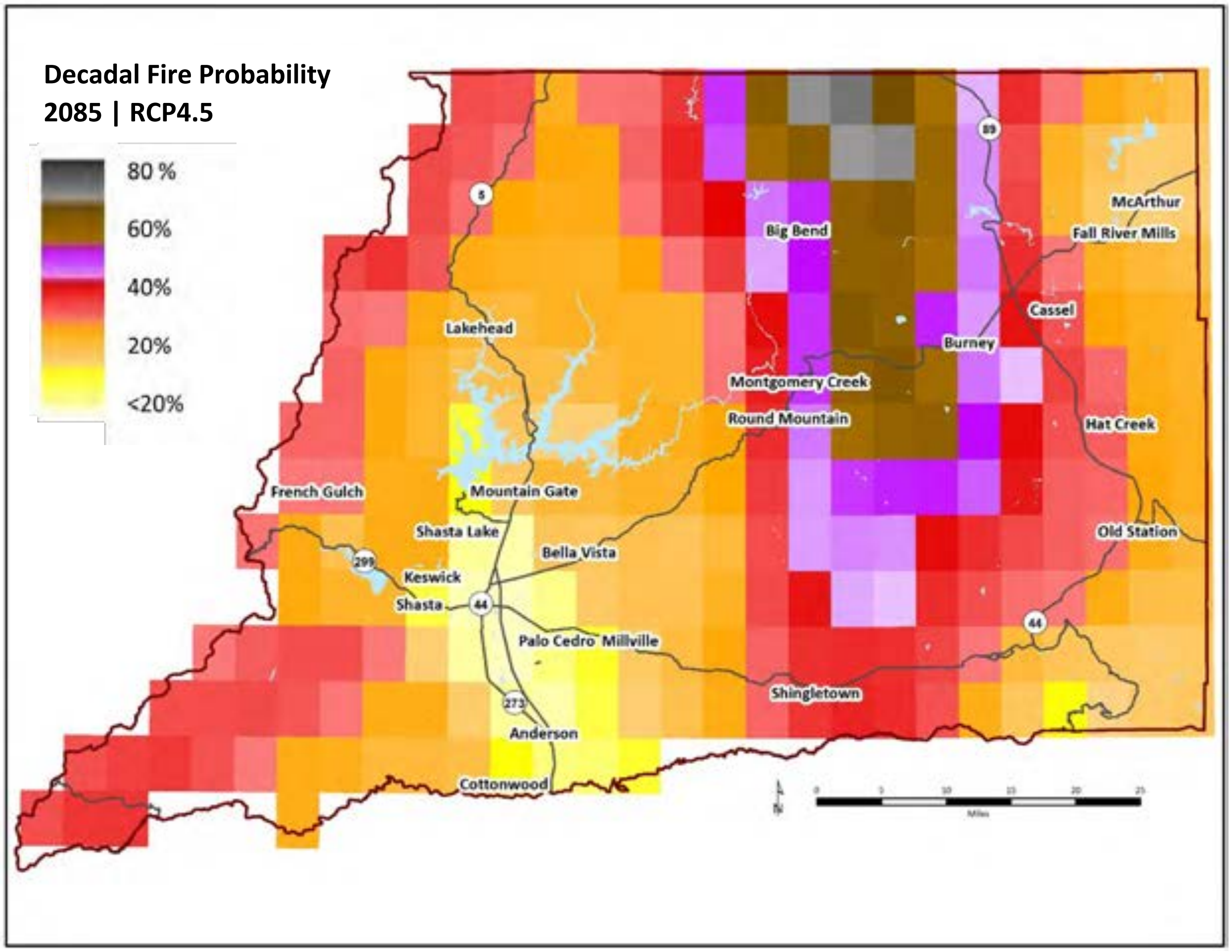

Figure 40. Decadal Fire Probability in 2085, RCP4.5.

Wildfire Area Burned

The same models used to evaluate the probability of wildfires given future climate conditions are also capable of producing estimates of the area burned within a grid cell, given the occurrence of a fire. This metric is used here as an analog for *fire intensity,* as a more intense fire is expected to burn larger areas. Projections of fire intensity are expressed as the area burned in hectares per grid cell. Figure 41 shows the historical average area burned in the Shasta Region.

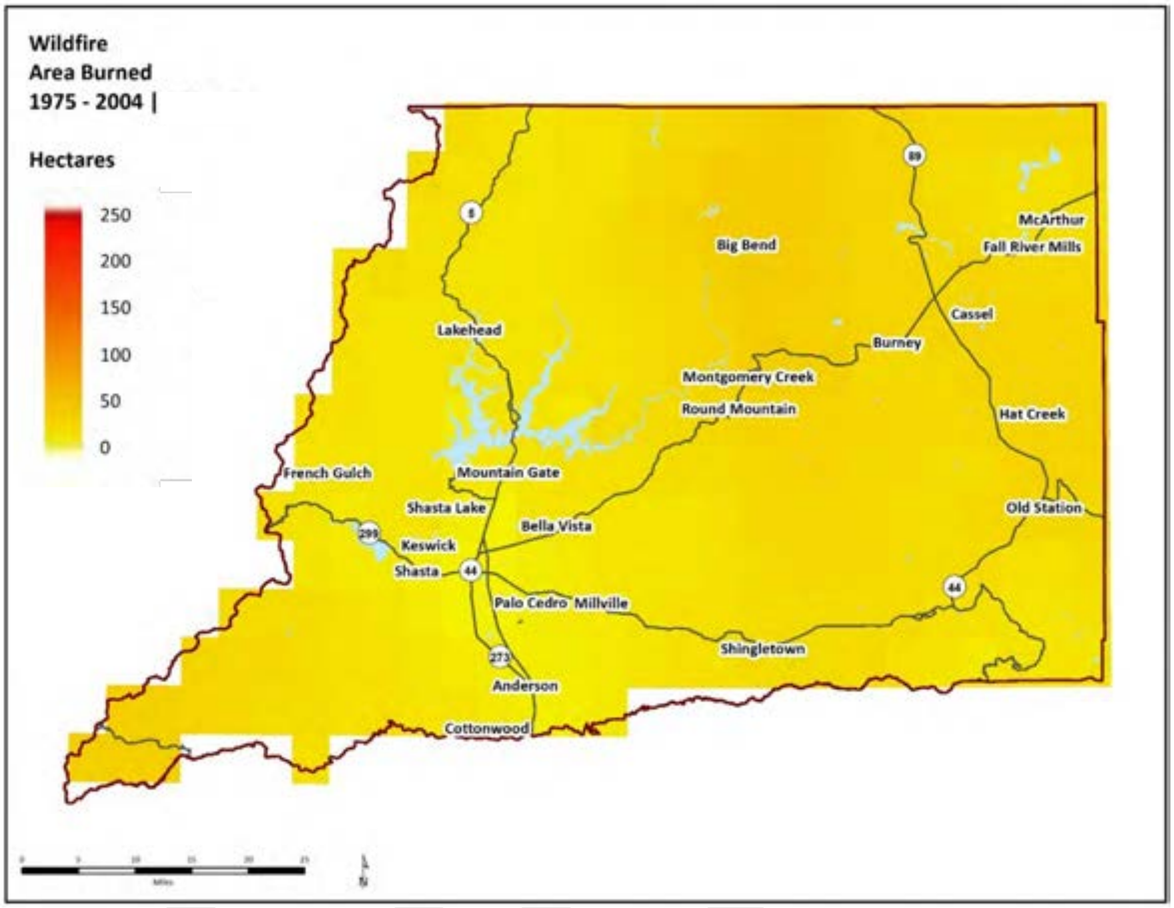

Figure 41. Average annual area burned in the historical period (1975 - 2004).

Across the Shasta Region, projections of change in fire intensity are almost all positive, and increase over time, and with greater emissions. Historically, fire intensity has been greatest in the mountainous areas of the Shasta-Trinity National Forest around Big Bend. Here, area burned is roughly double to four times the area burned in areas around French Gulch and Whiskeytown Lake.

With rising temperatures, the intensity of fires is projected to increase across the Region. Figure 42, Figure 43, and Figure 44 show the expected changes in wildfire intensity across the Shasta Region in an unconstrained emissions scenario. Most notably, the band of forests stretching from the northern border of the Shasta Region (northeast of Big Bend) southward through the western flanks of the Cascade Range to Burney Mountain, Ward Butte, and Snow Mountain are projected to experience significant increases in fire intensity, ranging from 5-fold to greater than 8-fold increases in fire intensity by 2085.

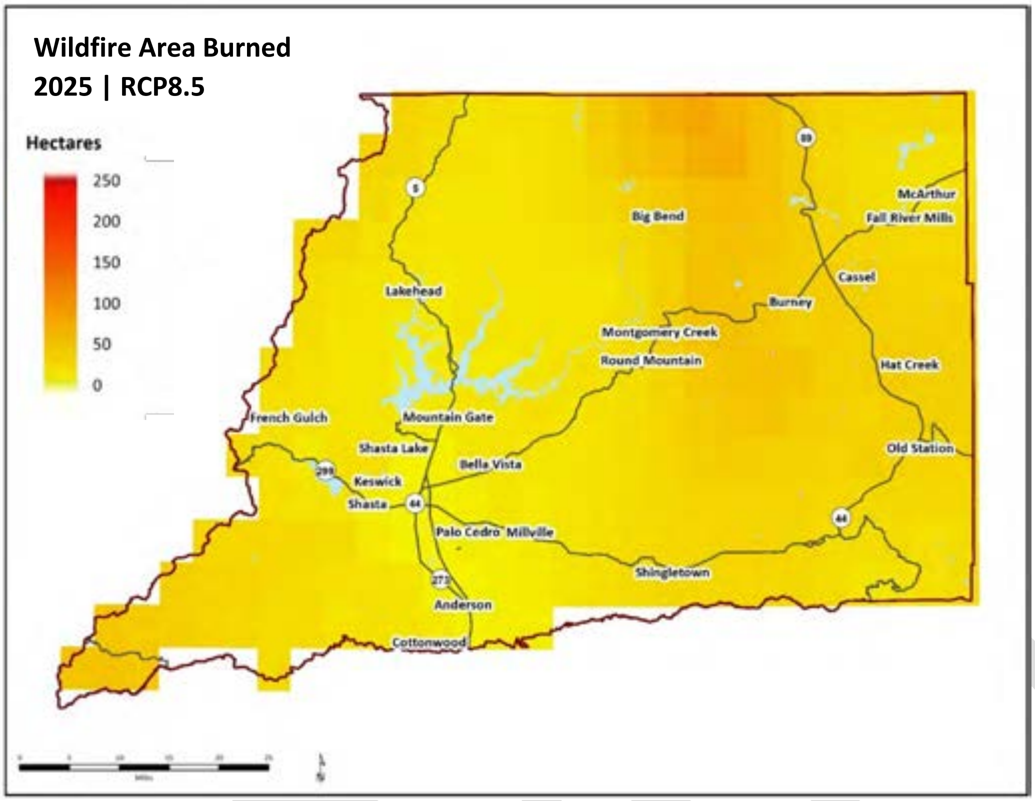

Figure 42. Average annual area burned in 2025, RCP8.5.

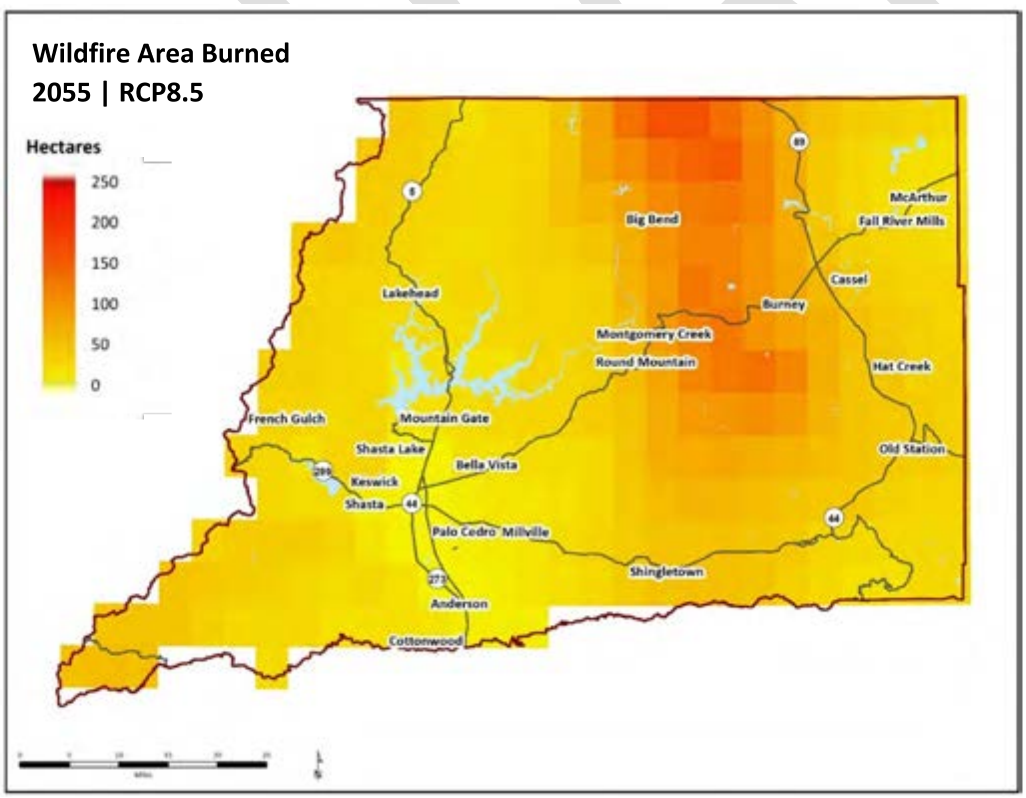

Figure 43. Average annual area burned in 2055, RCP8.5.

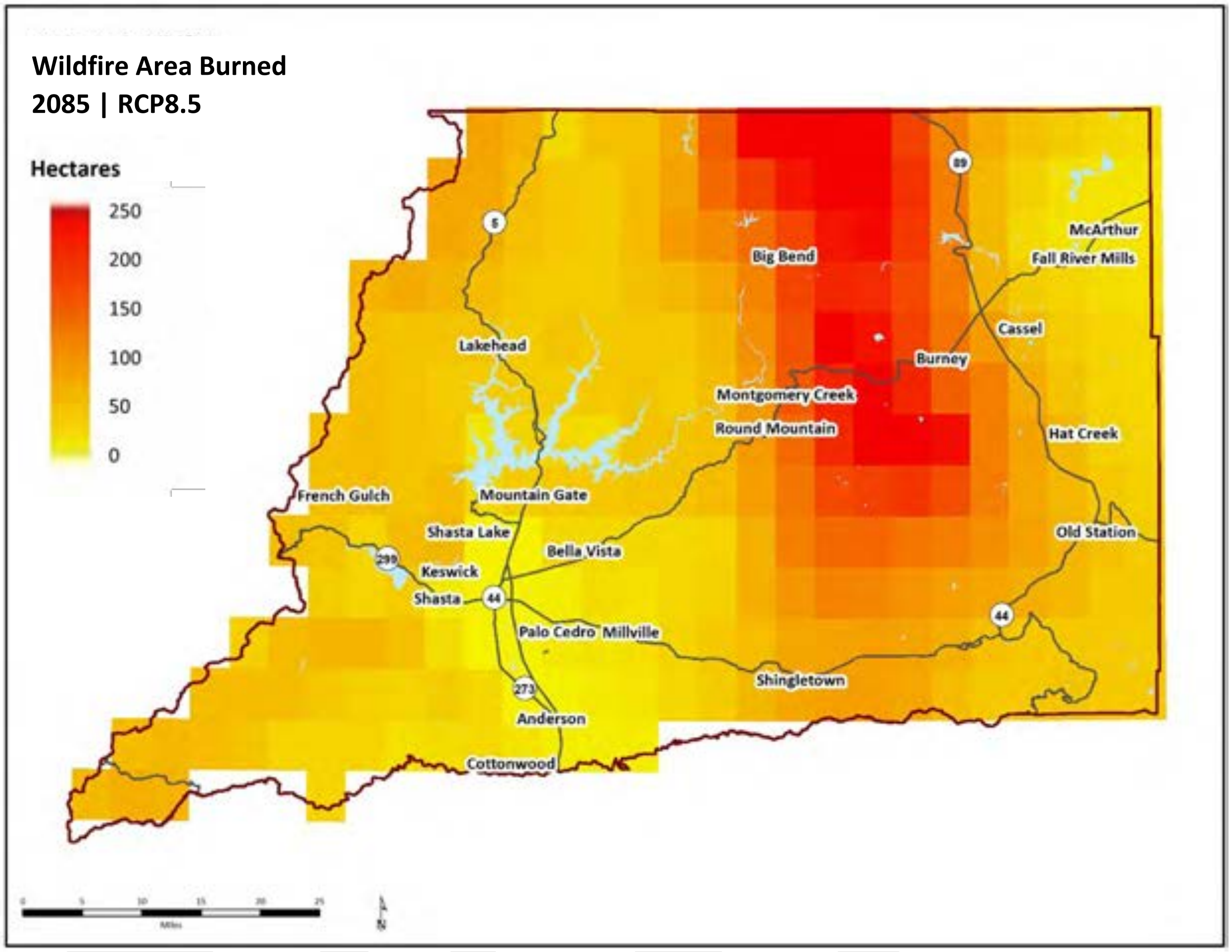

Figure 44. Average annual area burned in 2085, RCP8.5.

This area of significant increases in intensity includes Burney (and the Pit River Tribal Trust lands located there) and the Montgomery Creek communities, as well as large stretches of Highway 299 transiting the Hatchet Mountain Pass.

Smaller, but still very large increases in fire intensity are also present in the upper Sacramento River Valley where the majority of the region's residents live. Projected increases in fire intensity include a four-fold increase in fire intensity on the eastern slopes of Democrat Mountain, just north of Keswick, and a large area of 2-fold to 4-fold increases in fire intensity around Whiskeytown Lake and French Gulch. In Shingletown, fire intensity is projected to increase almost 4-fold from historical experience, as well as in Pollard Flat, located in the Sacramento River Canyon.

Under a reduced emissions scenario, projected increases to fire intensity are smaller, but still significant. In 2025 projected increases in the central band of the Shasta Region are mostly small. In some areas projected fire intensity falls, including communities due west of Redding like Keswick. In the midcentury projection, fire severity increases across the Shasta Region. And by 2085, the projected fire intensity in the central band of the region will exceed five-fold increases over historical experience, while in Burney and Montgomery Creek, this is a three-fold increase. The reduced emissions scenario projections demonstrate that significant reductions in fire intensity in the Shasta Region are achievable if global temperatures are held at a lower level. However, regardless of greenhouse gas emissions, significant increases in fire intensity are projected by midcentury. Figure 45, Figure 46, and Figure 47 show projected changes to wildfire intensity across the Shasta Region in a reduced emissionss scenario.

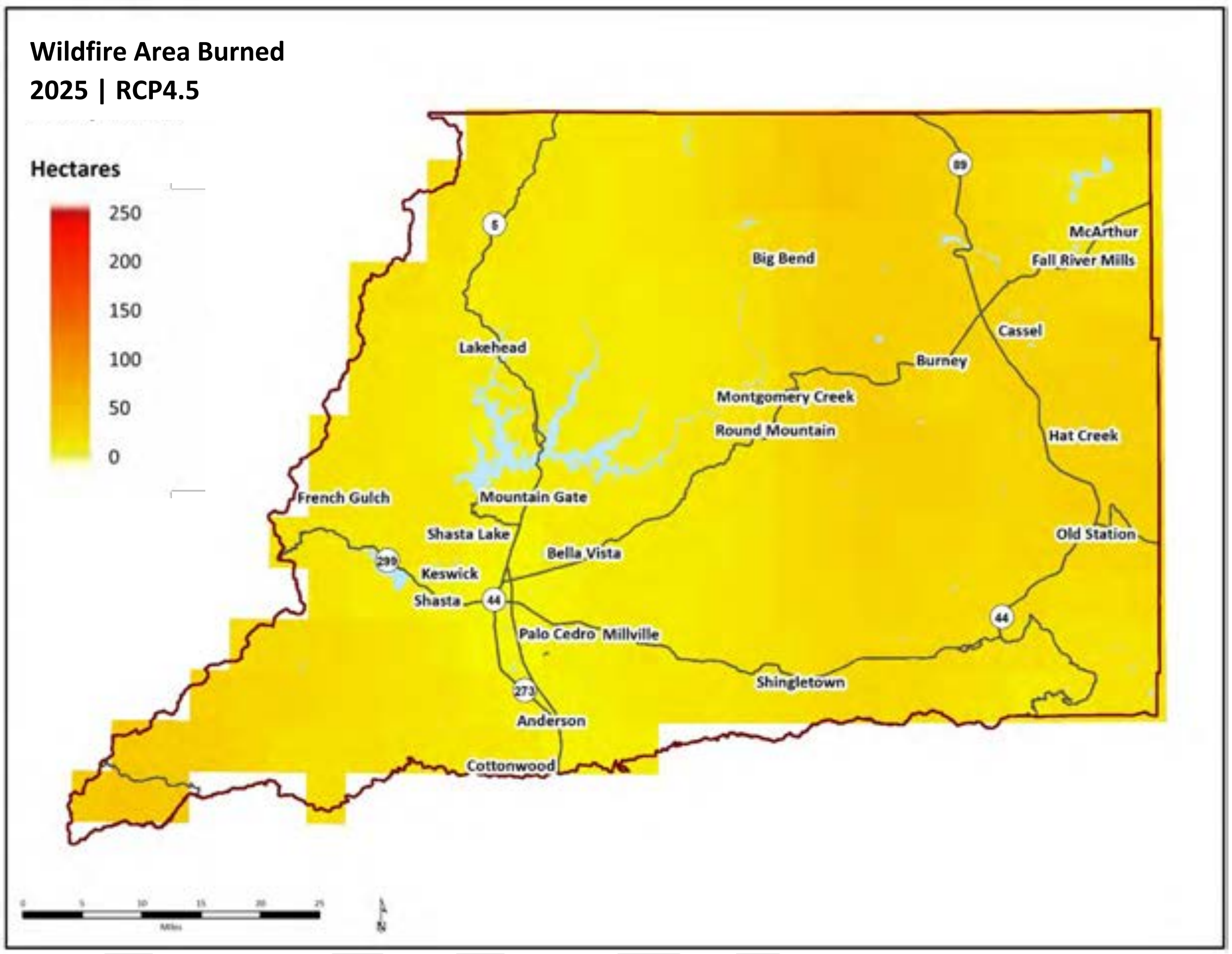

Figure 45. Average annual area burned in 2025, RCP4.5.

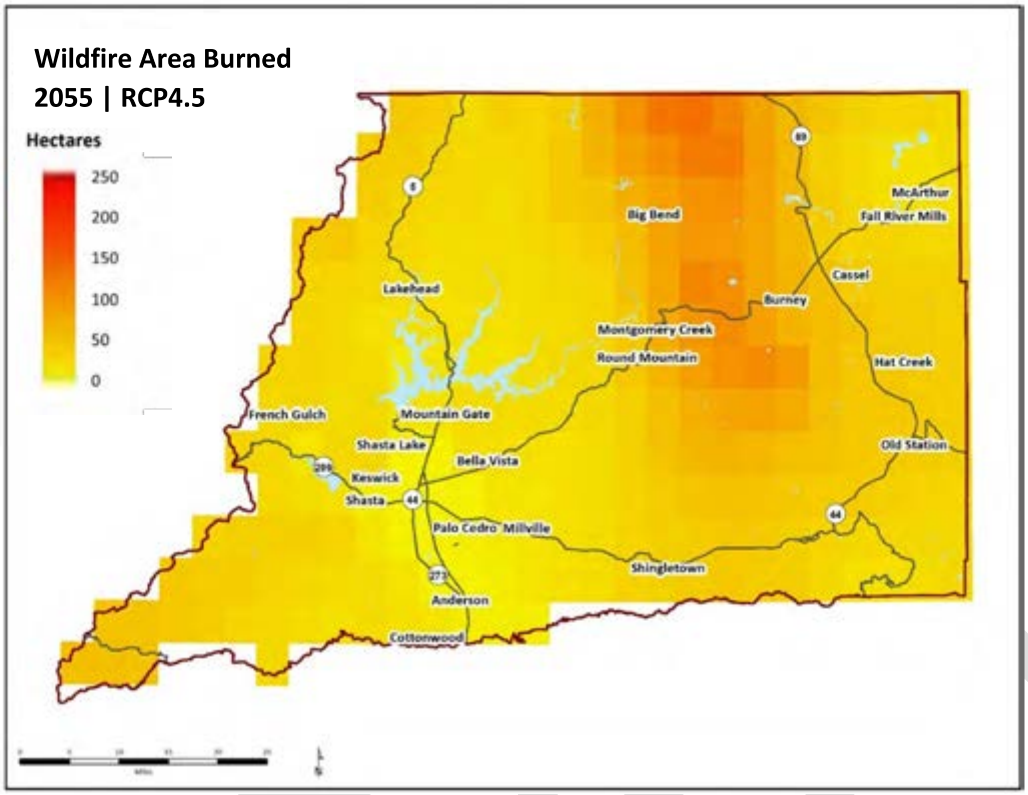

Figure 46. Average annual area burned in 2055, RCP4.5.

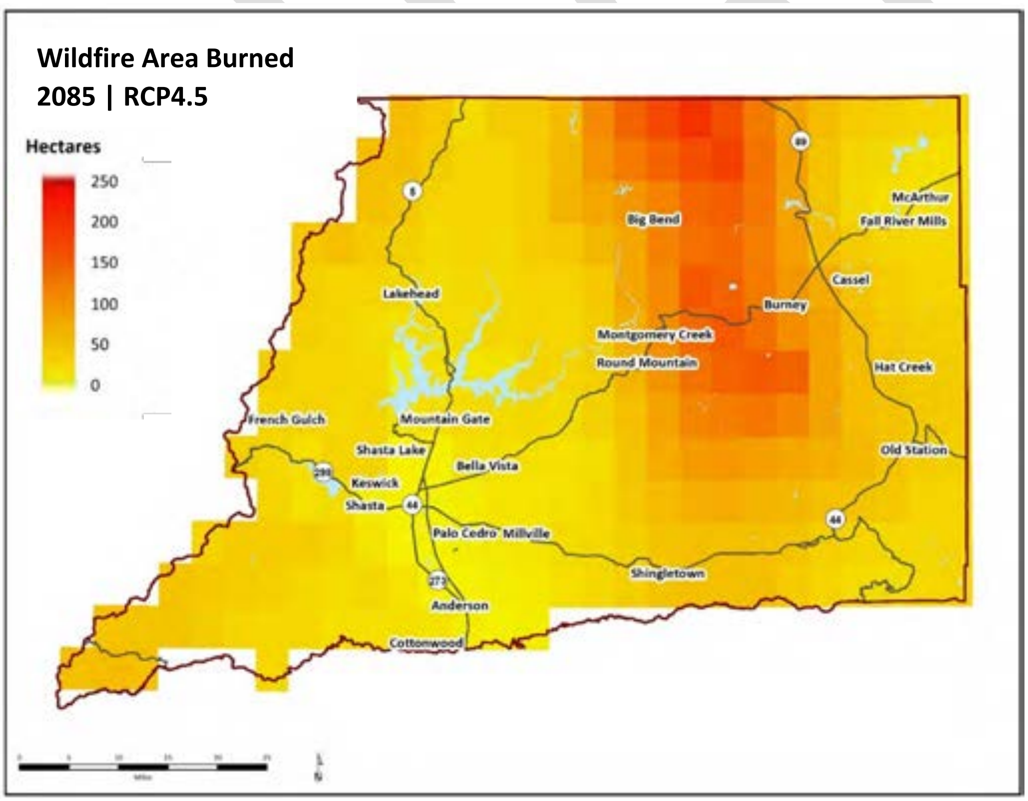

Figure 47. Average annual area burned in 2085, RCP4.5.

Infrastructure Vulnerabilities

While fire hazard projections provide a good indication of change, local fire hazards can change from one lot to another, so higher resolution maps of fire hazard are important for distinguishing when a transportation asset is threatened or not. The West-Wide Wildfire Risk Assessment (WWA) is used to show the current wildfire hazard at a much higher resolution than climate change projections can provide.[8] The WWA provides a metric called the Fire Threat Index (FTI) to indicate the likelihood and severity of fires in a given location. FTI levels in the Shasta Region range from 'Very Very Low' to 'Extreme,' depending on the geographic, environmental, climatological, and historical fire data. It allows for comparison and ordination of areas as to the likelihood of an acre burning. Figure 48 shows the current-conditions FTI across the Shasta Region.

Table 13. Classifications of fire hazard in the FTI.

Fire Threat Index Level	Expected Acres Burned per Year per 1000 Acres
Very Very Low	< 1
Very Low	1 - 2
Low	2 - 3
Low-Moderate	3 - 5
Moderate	5 - 8
Moderate-High	8 - 17
High	17 - 35
Very High	35 - 66
Extreme	>66

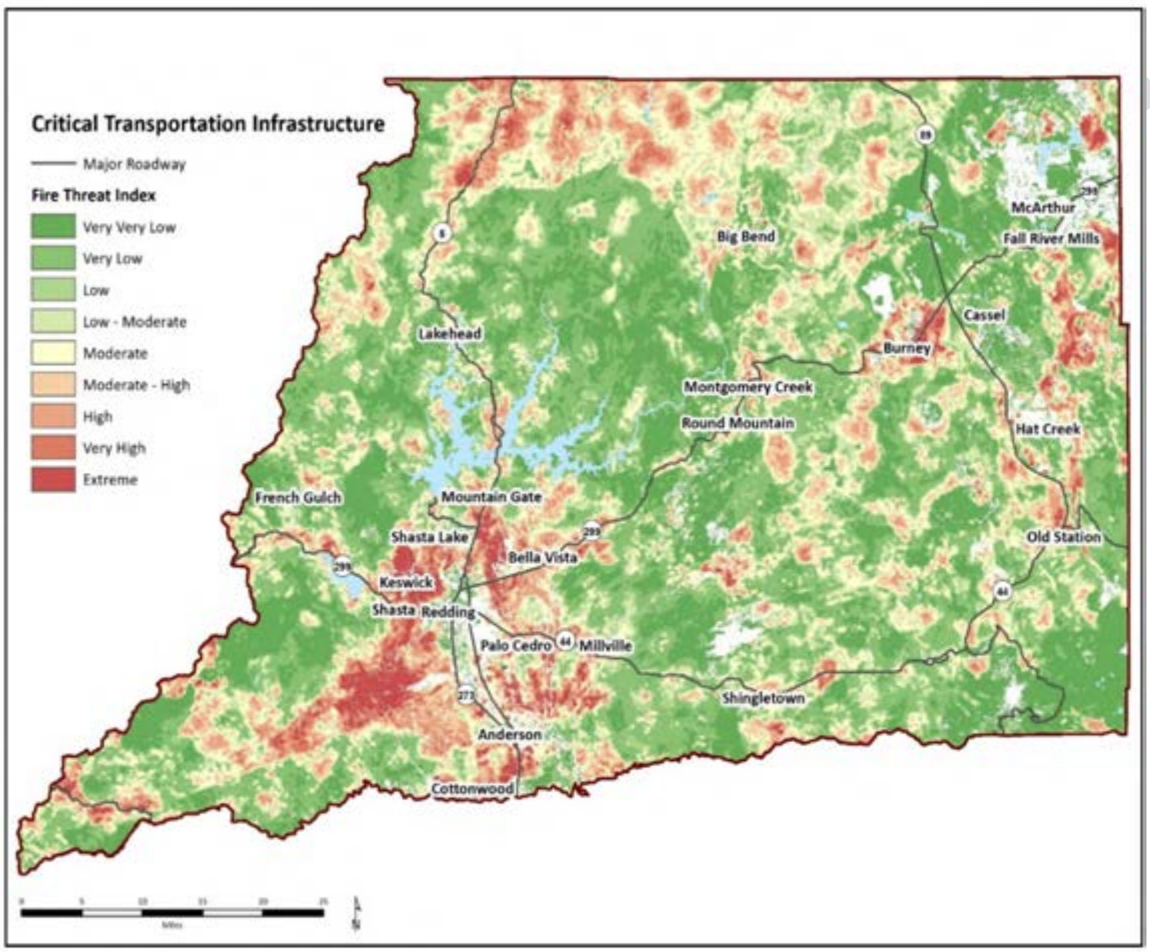

Figure 48. Current Regionwide Fire Threat Index.

[8] Oregon Department of Forestry 2013

The impact of wildfire on transportation highways, bridges, and tunnels has both immediate and lasting effect on the region. Road closures during a fire limit the ability for residents to evacuate and cut off access for first responders. After a fire, repair to highways, bridges, and tunnels can take many weeks or months, creating prolonged hardship to affected communities. This lasting impact is exaggerated in mountain and rural communities where few alternative routes exist. Segments of Route 299 near French Gulch, Shasta, and Burney; Interstate 5 in Anderson, north of Redding and in the Sacramento River Canyon; and Route 89 near Old Station are particularly vulnerable to disruption due to wildfire.

Sacramento River Canyon

The transportation network in northern Shasta County centers around I-5 and the parallel freight/passenger rail line that parallels the highway. Access to the interstate relies on a collection of paved and unpaved roads built within constraints of the local topography. Although development density is low in the northern I-5 corridor, the limited number of potential evacuation and detour routes contributes to the challenge of managing the hazard of wildfires. In the I-5 corridor, the Fire Threat Index is highest from the where I-5 crosses Shotgun Creek, near the confluence with the Sacramento River, to the Dirigo area where the Pacific Crest Trail passes under the highway (Figure 49). The Fire Threat Index is also moderate-high to high in the area extending east from I-5 where the Pacific Crest Trail traverses through Shasta-Trinity National Forest. The adjacent Hirz Fire (including the Moore and Point Fires) and Delta Fire in 2018, and the Bagley fire in 2012 are among the largest in the area since 1970.

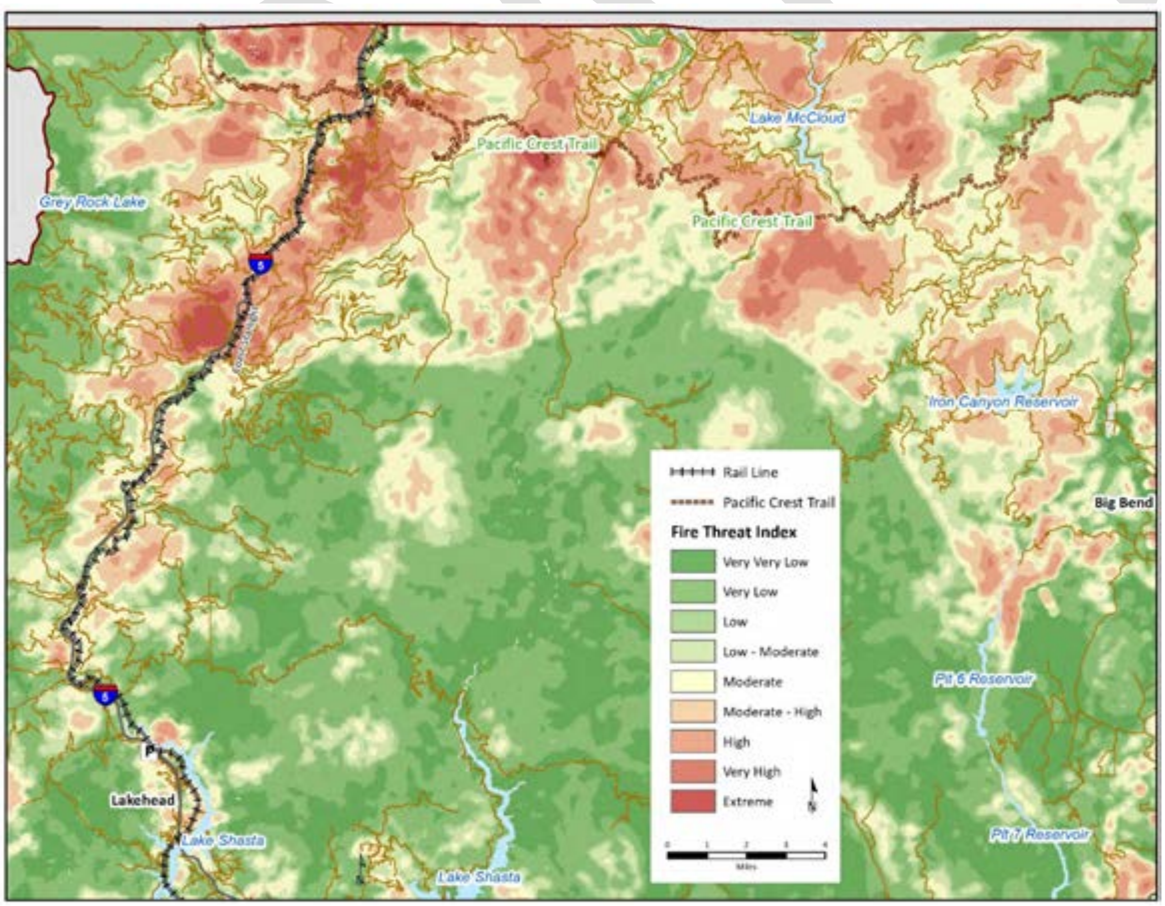

Figure 49. Current Fire Threat Index in Northwestern Shasta Region.

Burney – Old Station

The transportation network in eastern Shasta County, from Burney to Old Station, centers around Highways 299 and 89, which are fed by a moderately dense network of local roads (Figure 50). Fire hazards along Highway 299 in and outside of Burney are particularly concerning, as this segment of Highway is a crucial link between the upper Sacramento River Valley and eastern Shasta communities. Development density is slightly higher in the eastern portion of the Region compared to the Sacramento River Canyon but considerably less dense than in Redding and surrounding communities. Although the overall Fire Threat Index in this area is lower than in the Sacramento River Canyon and Redding, areas of moderate-high to extreme hazard coincide with development in Burney, Old Station, and to a lesser extent, Hat Creek. The Pacific Crest Trail traverses north-south in this part of the Region as it exits Lassen Volcanic National Park. Fire history in this area includes the Lost Fire in 1987, Fountain Fire in 1992 and the Sugarloaf Fire in 2009. The Fountain Fire, the third largest in the Shasta Region since 1970, burned more than 60,000 acres in 1992 and is surpassed only by the Carr and Delta fires in 2018.

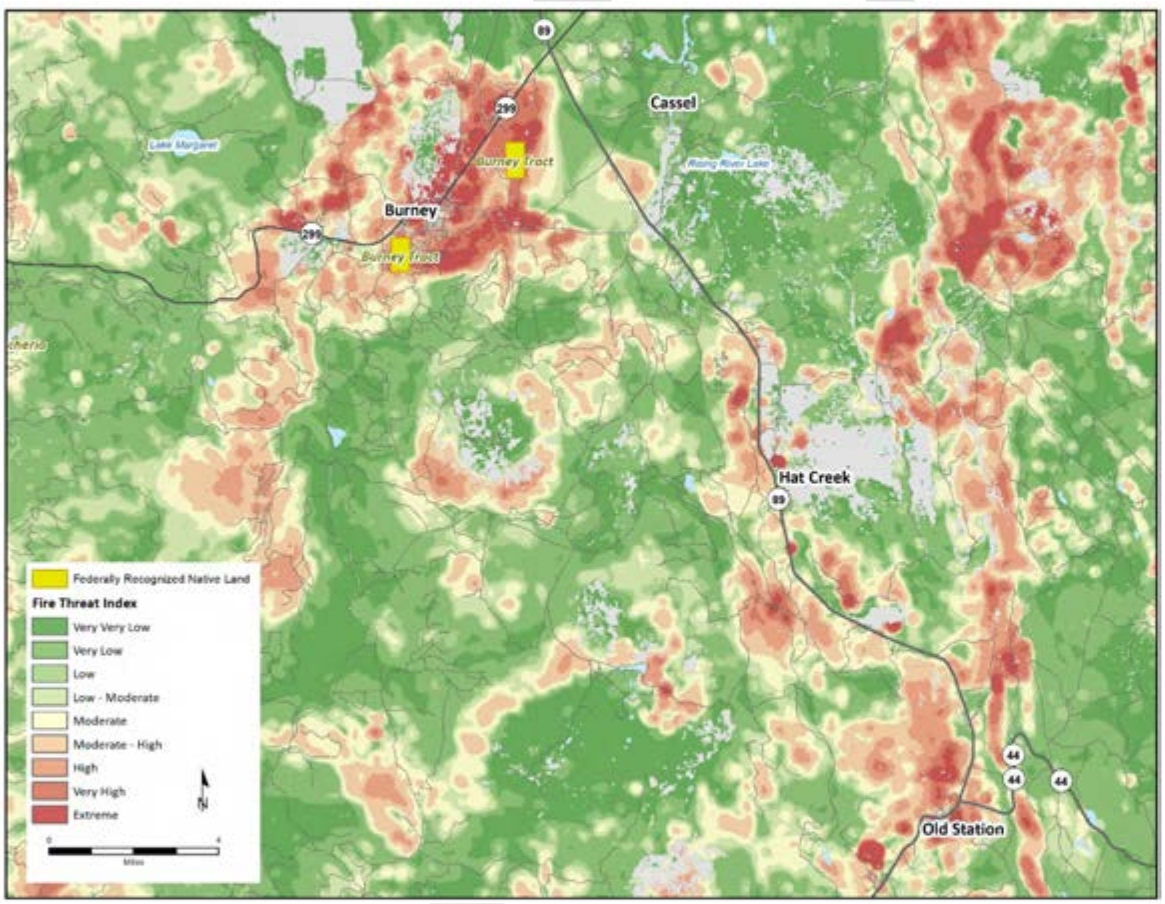

Figure 50. Current Fire Threat Index in Burney, Hat Creek, and Old Station.

This area includes several communities with high social vulnerability indicators. The communities of Hat Creek, Old Station, Cassel, and Fall River Mills all rank among the highest in the nation for the share of residents older than 65, living with a disability, or living in mobile homes. Fire hazards here should be considered especially concerning due to the very large projected increases in both fire probability and intensity.

Montgomery Creek – Round Mountain

The transportation network in central Shasta County, near Montgomery Creek, centers around Highway 299, which is fed by a sparse network of local roads (Figure 51). Development density is slightly higher in this portion of Shasta County compared to the Sacramento River Canyon but considerably less dense than in Redding and surrounding communities. Although the overall Fire Threat Index in this area is lower than in the Sacramento River Canyon and Redding, areas of moderate-high to extreme hazard coincide with development in Montgomery Creek and Round Mountain. Fire hazards are particularly concerning here due to the high indicators of social vulnerability in this region (especially the high percentage of people living with disabilities, living in mobile homes, or living in a group setting).[9] The Fountain Fire burned more than 60,000 acres in this area in 1992 and is the third largest fire to occur in the Shasta Region since 1970 (surpassed only by the Carr and Delta fires in 2018).

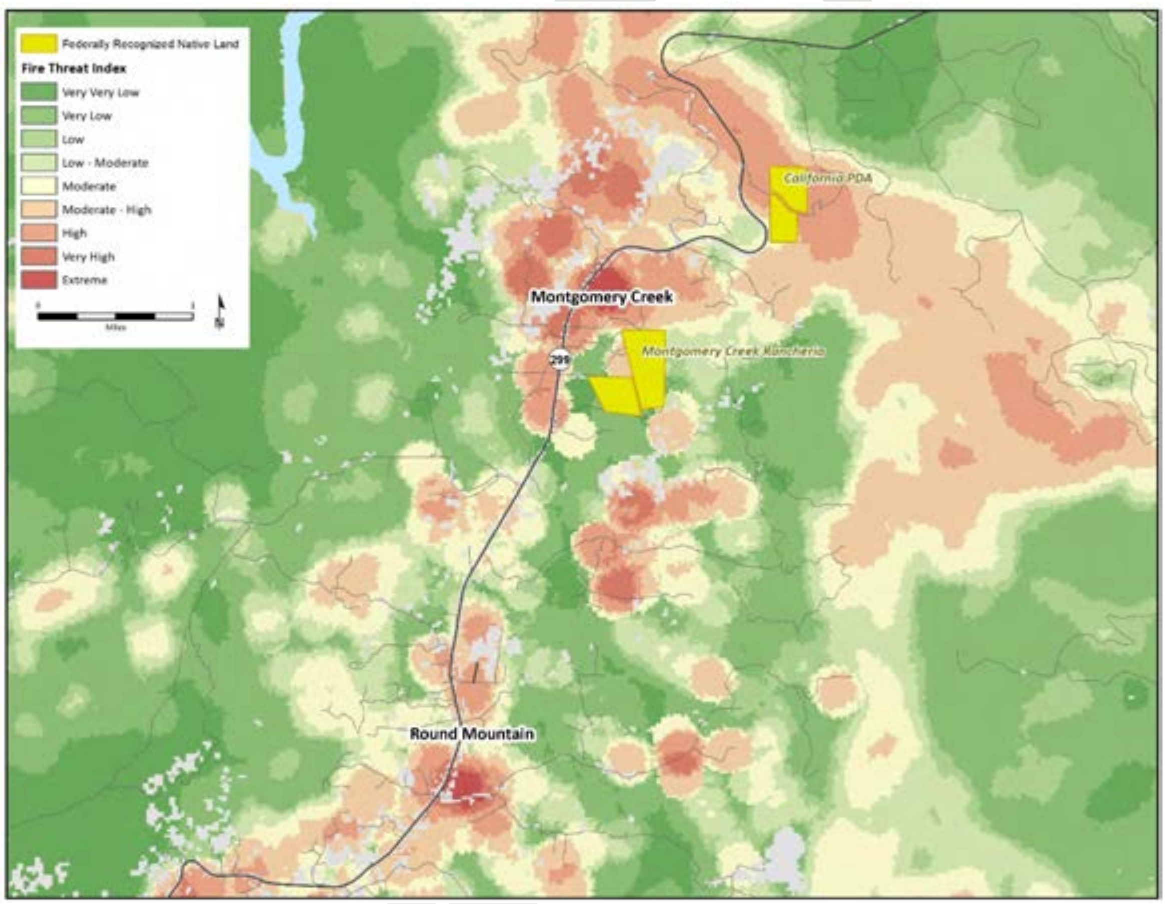

Figure 51. Current Fire Threat Index in Montgomery Creek and Round Mountain.

[9] CDC 2020

Shingletown

The transportation network in southern Shasta County, near Shingletown, centers around Highway 44, which is fed by a network of local roads. Development density is similar in this portion of Shasta County to that in the eastern and central portions of the Region but considerably less dense than in Redding and surrounding communities. Although the overall Fire Threat Index in this area is lower than in the Sacramento River Canyon and Redding, areas of moderate-high to extreme exist to the east and south of Shingletown. Additionally, new development pressure in recent years, as well as high indicators of social vulnerability (particularly due to the large portion of the population older than 65, living with disabilities, and living in mobile homes) in the area make the hazards associated with Highway 44 in Shingletown a relatively higher concern.[10] Additionally, areas of High to Extreme fire hazard exist south of Shingletown, especially along Wilson Hill Road, which serves as a crucial connection for the community of Manton in Tehama County. Except for the Ponderosa Fire that burned 27,000 acres to the southeast of Shingletown in 2012 there has been considerably little wildfire activity in the past decade. Of particular interest is the lack of wildfire occurrences in the areas of high Fire Threat Index values shown in Figure 52.

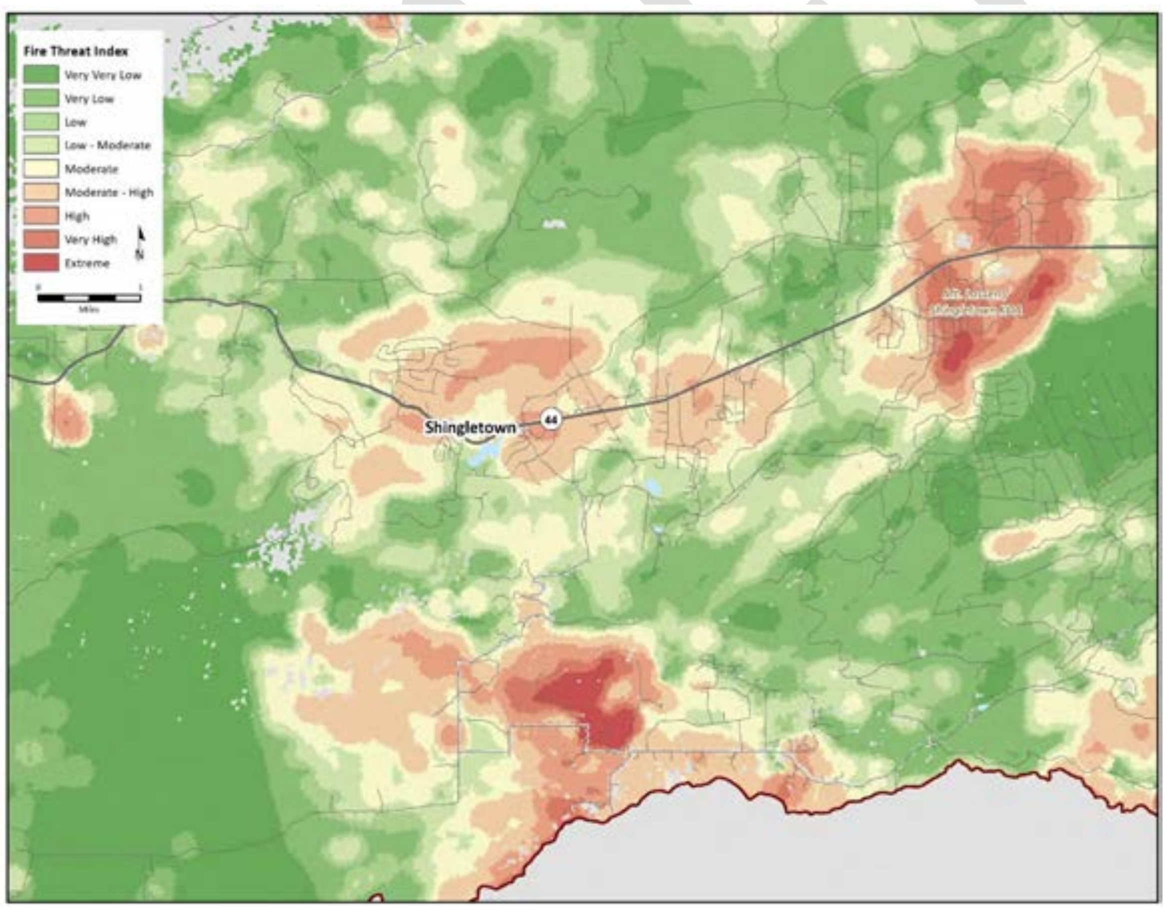

Figure 52. Current Fire Threat Index in Shingletown.

[10] CDC 2020

Upper Sacramento River Valley

The transportation network in and around Redding is bisected north to south by I-5/Highway 273 (and the parallel Union Pacific rail line) and east to west by Highways 299 and 44. This part of the Region is, by far, the most densely developed. Fire Threat Index values are elevated in the eastern, western, and southern suburbs (Figure 53). The wildland urban interface is often the place where the threat from wildfire is elevated and this pattern holds true in and around Redding. The population in Redding and surrounding communities is supported by additional infrastructure that does not exist in other parts of the region, but is also challenged with multiple census tracts with high social vulnerability indicators. For example, the neighborhoods along Lake Boulevard between North Market Street and Keswick Dam Road (including Chapparral Terrace, Northpoint, Panorama Estates, Angelus, Hidden Haven, Patterson, Santa Claus, Lake Forest Estates, Golden Heights, and Village Way subdivisions) have the highest number of social vulnerability indicators in the region, with a large share of the residents living in poverty, older than 65, living with disabilities, living in mobile homes, or without vehicles. Downtown Redding likewise features many blocks with high levels of residents older than 65 and living in poverty, as well as high levels of residents without vehicles and living in group settings.

Like other parts of the region, the upper Sacramento River Valley is served by highways, as well as a dense network of local roads. Communities along the Sacramento River are particularly reliant on a number of bridges with substantial spans, and the area is the only group of communities with bus transit via RABA. The Redding Municipal Airport is the only airport in the Region with commercial service. The area also features a more complex pattern of land use, creating increased exposure of residential areas to fire hazards.

The most significant fire to affect the Redding area in recent decades was the Carr Fire in 2018. In one of California's most destructive wildfires, 229,651 acres burned, 38,000 people were evacuated, eight lives were lost and more than $1.6 billion in property was destroyed. Prior to the Carr Fire, the largest fire in the Redding area had been the 2008 SHU Lightning Complex that burned 86,500 acres in Shasta and Trinity counties and cost more than $56M to suppress. The Bully Fire burned nearly 13,000 mostly undeveloped acres of southwestern Shasta County in 2014.

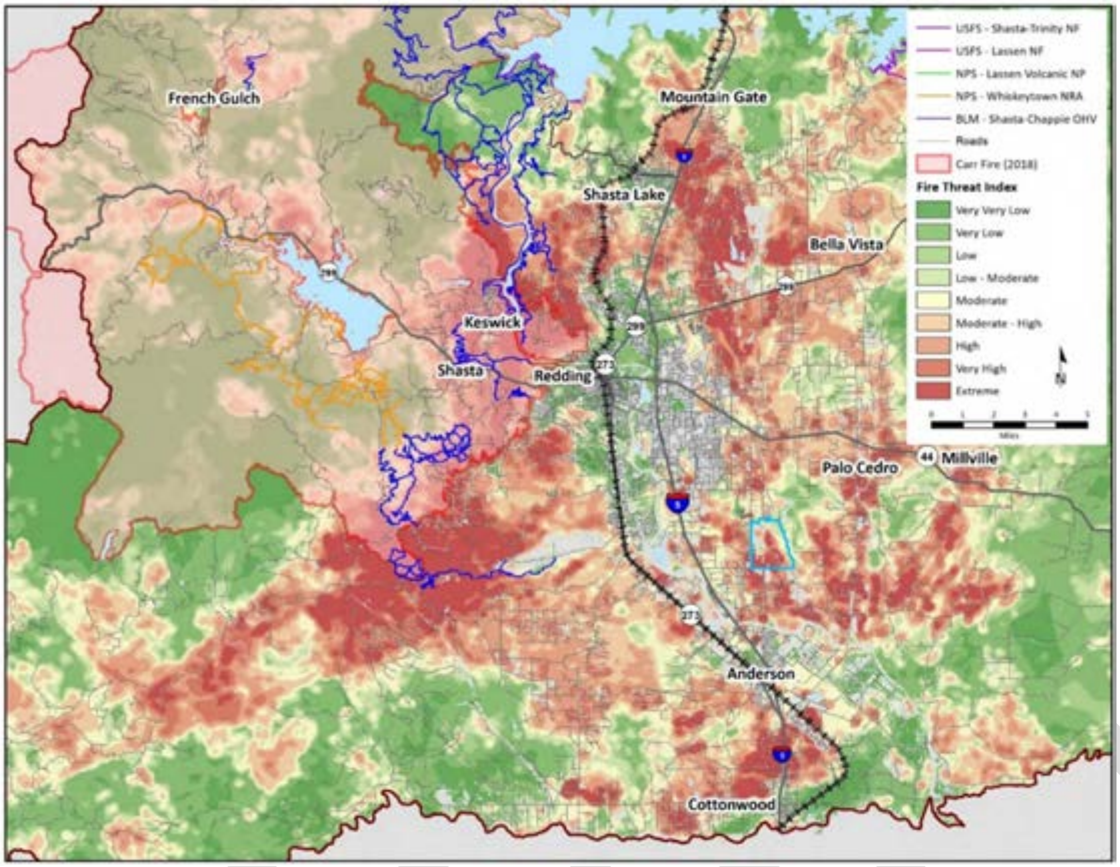

Figure 53. Current Fire Threat Index in the upper Sacramento River Valley.

Infrastructure Networks

Rail

The rail network in the Shasta Region runs parallel to the I-5 corridor, sharing similar coincidence with high-hazard areas. While immediate wildfire impact on the rail network is not generally as severe, repairs to the rail network can take even longer and the ability to reroute freight shipments is limited and expensive. Particularly vulnerable segments of the rail network are in Anderson, Redding and in difficult-to-reach areas of the Sacramento River Canyon.

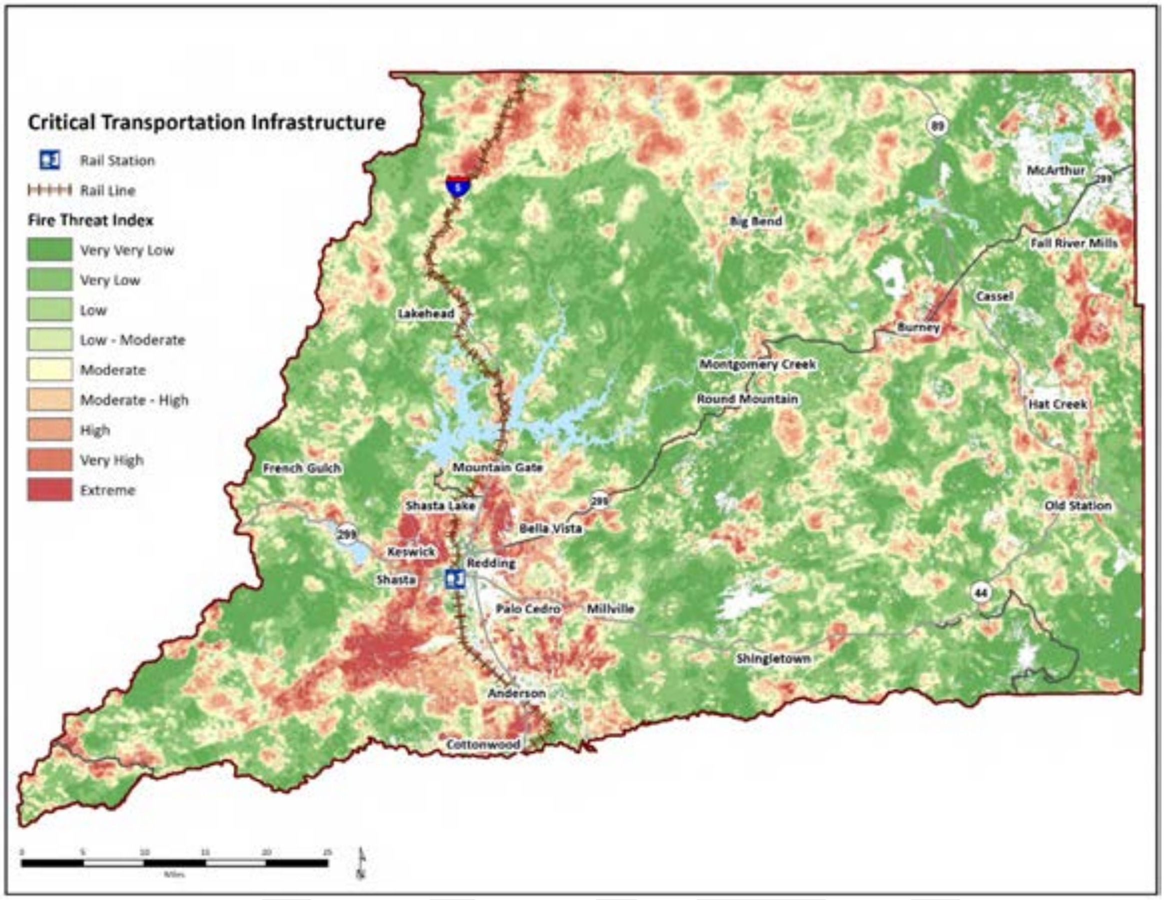

Figure 54. Rail network exposure to current fire hazards.

Airports

The Shasta Region is served by three airports (Figure 55). The Redding Municipal Airport provides commercial service to Los Angeles (LAX), San Francisco (SFO), and Seattle (SEA). The remaining two are general aviation airports: the Benton Airpark is owned and operated by the City of Redding, and the Fall River Mills airfield is owned and operated by the Shasta County Department of Public Works. Airports, large and small, serve a variety of functions when it comes to wildfire. In addition to their role as critical transportation assets, airport grounds and facilities can serve as staging areas for firefighting equipment, command centers for operations, and evacuation sites. For example, Benton Field is often used as such a site. Like other infrastructure types, airport facilities are susceptible to the hazards of wildfire and this dual role makes it critical to examine and evaluate this susceptibility.

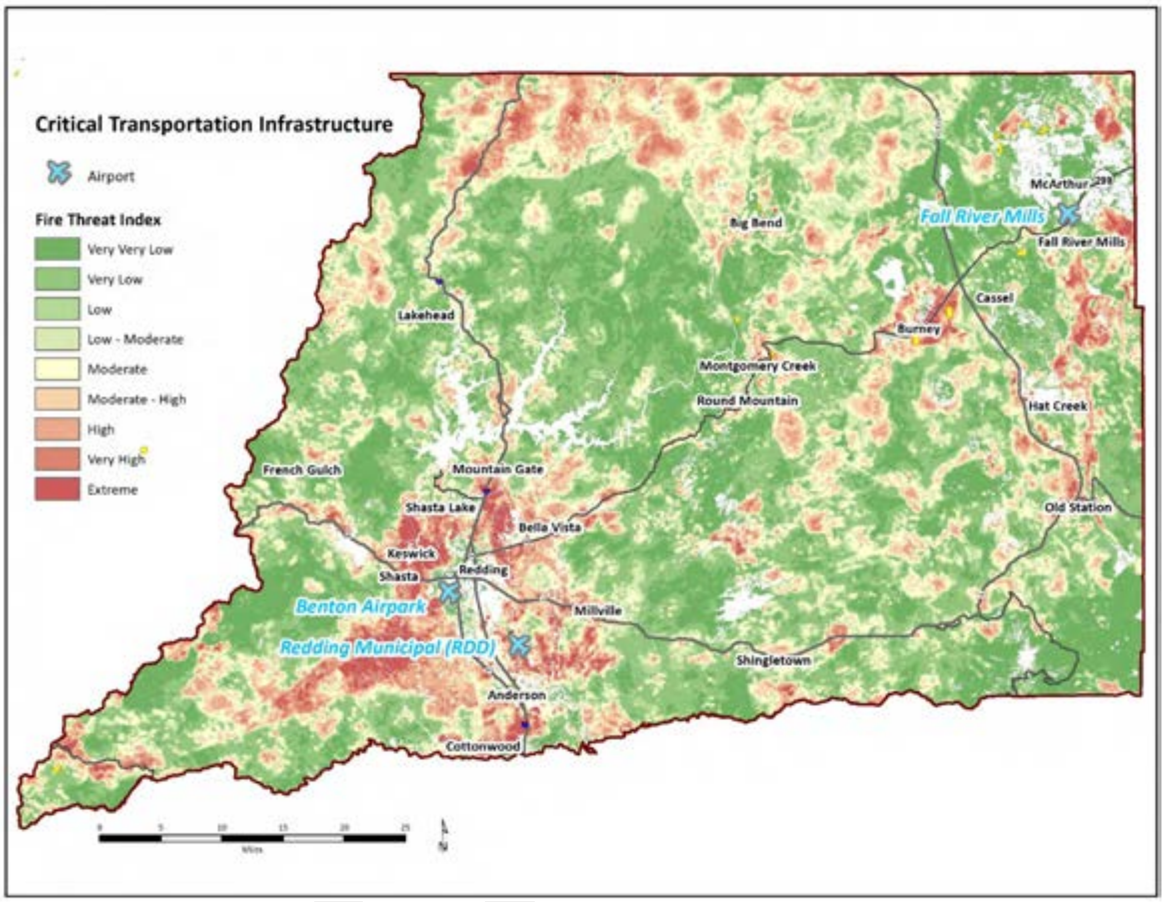

Figure 55. Public Airports in the Shasta Region overlaid with Fire Threat Index. Only Redding Municipal Airport serves commercial aviation traffic.

The Redding Municipal Airport (RDD) is located 6 miles southeast of the City of Redding. As a full-service commercial airport, RDD's grounds include extensive facilities necessary to support large aircraft, including aircraft hangars, refueling, and repair facilities. RDD's terminal, roads, parking, and other infrastructure is located on the western part of the grounds. In addition to airport operations, RDD's grounds include the regional coordinating center for Cal Fire in its northwest corner.

Much of the airport and the bulk of its facilities lie within areas with moderate-high to extreme Fire Threat Indices. Airport facilities are susceptible in ways like those of roads and other structures, with the included risk of combustible fuels and high-value airplanes and facilities. The operational implications of a wildfire on or in the vicinity of the airport are also substantial. Nearby fires could delay response time by limiting the arrival and departure of aircraft and supplies. Figure 56 shows the exposure of the airport's grounds to fire threats. While the threat of wildfire on airport grounds is high, much of the area consists of grasslands which are well-maintained by airport staff. Prospective fires in these areas would likely have reduced severity compared to woodlands.

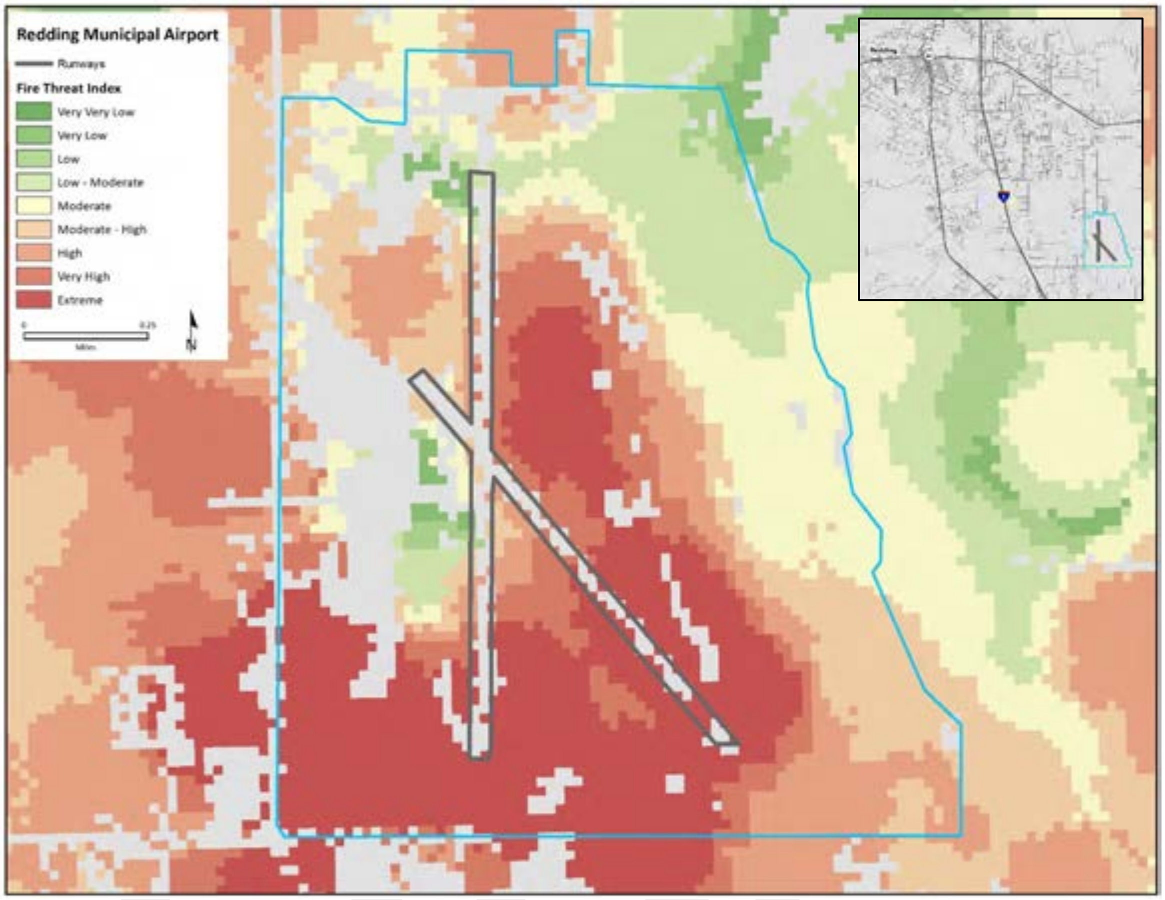

Figure 56. Current Fire Threat Index at Redding Municipal Airport.

Public Transportation

The Redding Area Bus Authority operates fixed-route and on-demand public transportation service in the City of Redding and surrounding communities, with a commuter line that runs between Redding and Anderson. Most routes fall within low Fire Threat Index areas, except for certain segments of three routes: Route 1, School Express, and the portion of the Anderson Commuter route running between the two communities. These exposed routes are identified in Figure 57. It is important to note that while the RABA fixed-route service is not particularly vulnerable, in the event of a nearby wildfire, RABA buses may be called upon to provide emergency transportation.

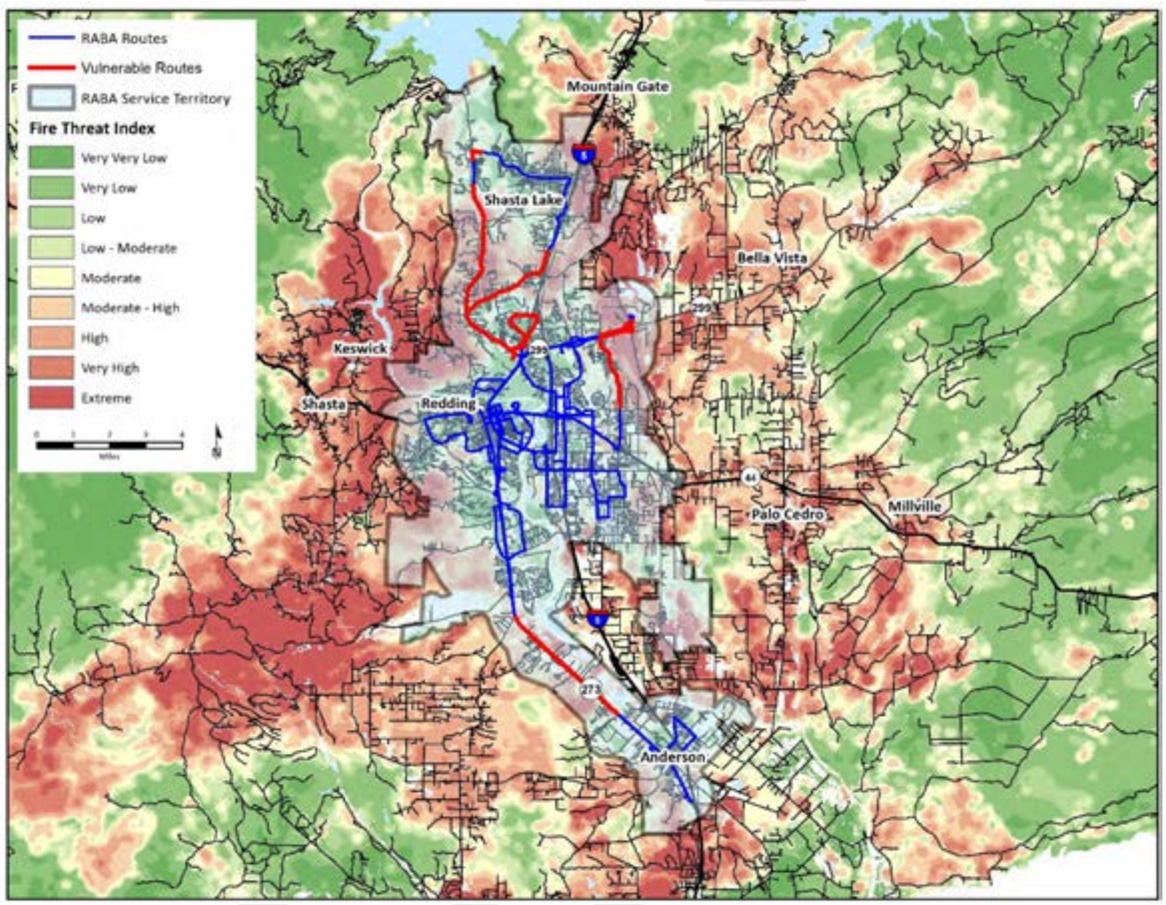

Figure 57. RABA Service Vulnerability based on Fire Threat Index.

RABA's bus network serves many of the vulnerable communities in the upper Sacramento River Valley, thus disruptions to bus service compound the vulnerability of these populations. Wildfire-triggered evacuations which disrupt regular bus service are a particularly acute vulnerability of populations without access to personal vehicles.

Recreation Areas

There are abundant opportunities for recreational access to public lands in the Shasta Region. The major recreational assets are managed by federal agencies, namely the US Forest Service (USFS), National Park Service (NPS), and Bureau of Land Management (BLM) (Figure 58). Public access to USFS and NPS land is generally limited to non-motorized use. While most trails on USFS and NPS land are within relatively low Fire Threat Index areas, portions of the Pacific Crest Trail pass through areas of high threat. By contrast, in terms of use, the BLM-managed Shasta-Chappie Off-Highway Vehicle Recreation Area (OHVRA) includes more than 250 miles of roads and trails open to motorcycles, ATVs, UTVs and other off-highway vehicles. While most non-highway roads and trails within the Shasta-Chappie OHVRA traverse relatively low Fire Threat Index areas, the most easily accessible areas are within moderate-high to extremely high Fire Threat Index areas. Approximately 4% of the 278 recorded fires in Shasta County since 1970 were caused by vehicles. Although the records do not indicate whether the vehicle as an on- or off-highway vehicle, it is important to note that motor vehicle activity does generally have a connection to wildfire.

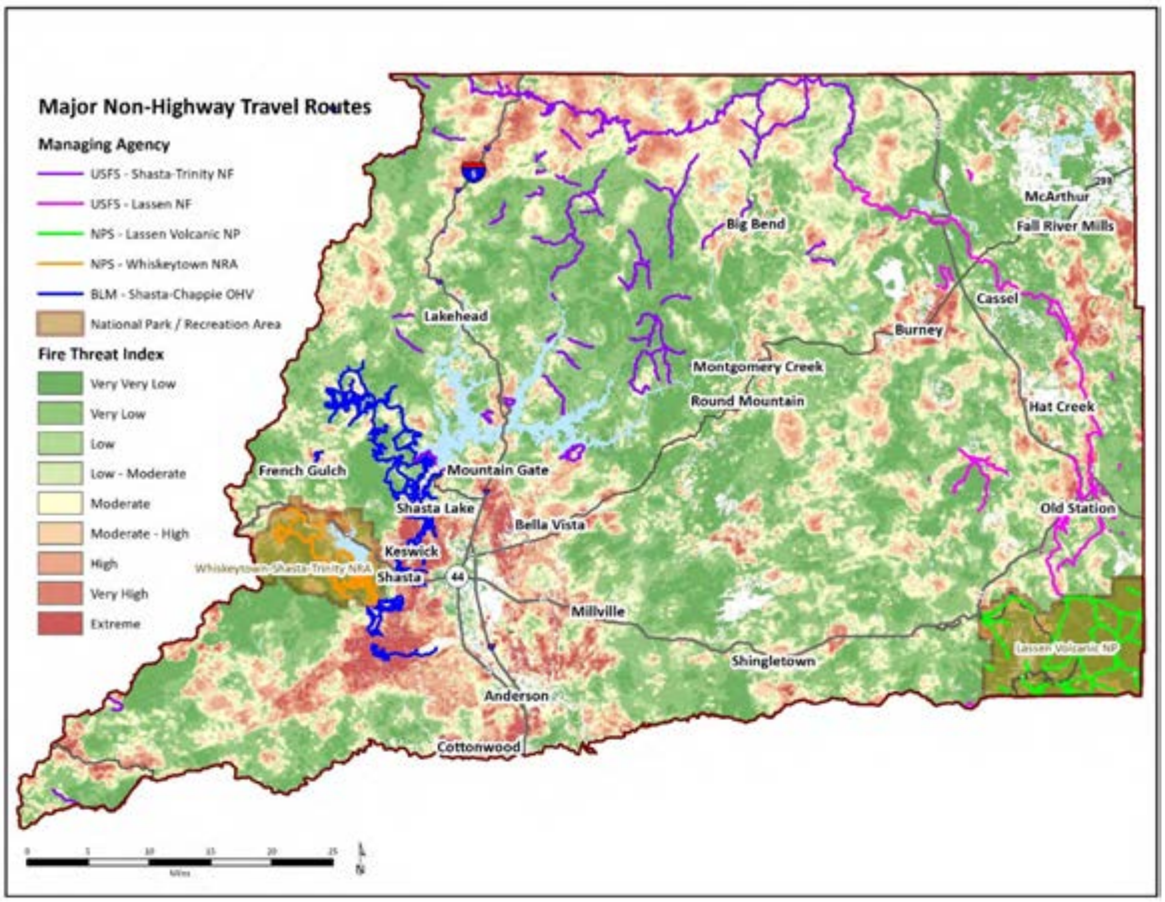

Figure 58. Vulnerable Off-Road Travel Networks and Corridors based on Fire Threat Index.

Evacuation Routes and Staging Areas

The Shasta Region relies on multiple transportation systems for evacuation in the event of wildfires. The evacuation plans dictate where equipment and firefighting crews should be pre-staged, as well as which routes will be designated evacuation routes. Evacuation plans can also specify which areas to close in response to imminent fire hazard. Previous evacuation efforts have made use of contraflow traffic on key highways in order to maximize the capacity of these roads for evacuation.

Although evacuation routes are planned ahead of time, these plans are not made available to the public, so this assessment does not address the fire hazards threatening evacuation routes. Additional work to propose adaptive responses to fire hazards along evacuation routes will be included in the Adaptation Plan phase of this project.

Flooding Impacts and Vulnerabilities

Flooding presents an obvious hazard to transportation systems: flooded roads, rails, airports, or pedestrian paths cannot be used until water is drained and debris is cleared. Flood waters will also deal extensive damage to most structures, mechanical or electrical equipment, storage tanks and pipelines, and even the soils that underlie paved surfaces. Even passive road furniture like signage can be uprooted or swept away by moving flood waters. Table 14 details sector-specific impacts of flooding in the transportation sector.

Table 14. Example table of sector-specific impacts for flooding hazards

	Flooding
Roads & Bridges	• Route disruptions • Accelerated bridge abutment deterioration • Subsurface material damage/washout • Storm drain infrastructure damage
Rails	• Event- related Route disruption • Swollen and/or rotting rail ties
Transit Systems	• Event-related route disruption • Decreased usage from competing transit options (e.g., ride sharing)
Airports	• Closed runways • Inundation of buildings and service equipment • Flotation of fuel storage tanks • Damage to electrical systems • Flight delays or cancellations
Pedestrians & Bicycles	• Sidewalk, path, and trail closures resulting from localized ponding (especially at curb cuts, low points in trails, and other areas with insufficient drainage) • Overtopping of trails, impeding access, including by mixed sewage overflow • Washout of small bridges, culverts, and trail drainage systems • Life-threatening hazards to pedestrians and cyclists • Extended disruptions as pedestrian/recreational asset damage is often de-prioritized in reconstruction efforts from extreme events

In the Sacramento River watershed (which includes all the major watersheds of the Shasta Region), flood hazards are at least partially controlled by the Central Valley Project.[11] The coordinated management of dozens of individual dams, waterways, and reservoirs has significant capacity to prevent flooding along the Region's main waterways. However, the capacity of these flood control systems is not infinite, and significant precipitation and runoff can still overwhelm key flood control systems. Moreover, the region contains a number of smaller channels that are not impounded by dams or other flood control measures, many of which are capable of flooding.

[11] USBR 2013

This study evaluates local flood hazards using the U.S. Federal Emergency Management Agency's (FEMA) Flood Insurance Risk Maps (FIRMs) that establish the 100-year flood zone and base flood elevation (BFE), as well as the 500-year flood zone in certain areas around Redding and the lower Sacramento River Valley.[12] The operations of Central Valley Project flood control systems are not analyzed in this assessment, but FEMA's flood hazard maps account for all risk factors in establishing the 100-year and 500-year floodplains. This assessment relies on FEMA's accounting of dam operations for establishing relative flood hazards.

In areas of the Shasta Region where extreme precipitation is projected to increase rapidly and/or areas where flood hazard is not subject to flood controls from the Central Valley Project of the U.S. Bureau of Reclamation, the use of 100-year floodplains as an indication of hazard should be understood in the context of the increasing frequency of 100-year and greater extreme precipitation events. In the lower Sacramento River Valley where the 500-year floodplain is mapped, and where much of the projected increases in extreme precipitation events are projected to drain, the 500-year floodplain can serve as an indication of which areas should be avoided for critical infrastructure systems.

Regionwide Projections

While the causes of flooding occur across entire watersheds, flood impacts are highly localized, depending on the slope, elevation, and more subtle characteristics of the land's geology and geomorphology. In the streams of the Klamath Mountains where flood control measures are not in place and extreme precipitation projections consistently show large increases, the threat of flash flooding is likely to grow. For example, streams like Dog Creek, Slate Creek, Boulder Creek, Shotgun Creek, Mears Creek, Flume Creek, and Root Creek intersect with I-5 and the railroad, as well as local roads. The watersheds of these creeks are projected to see significant increases in extreme precipitation by midcentury. Most of these watersheds are small and are not assessed in FEMA FIRMs, but projections of increasing extreme precipitation indicate the potential for elevated flash flooding hazards. Similar hazards may face Highway 89 in the mountains north of Cayton, as well as in the drainages around Lassen Peak.

Infrastructure Vulnerabilities

Specific hazards are mapped in several areas across the Shasta Region. Figure 59 shows the distribution of FEMA flood hazard mapping.

[12] FEMA 2021

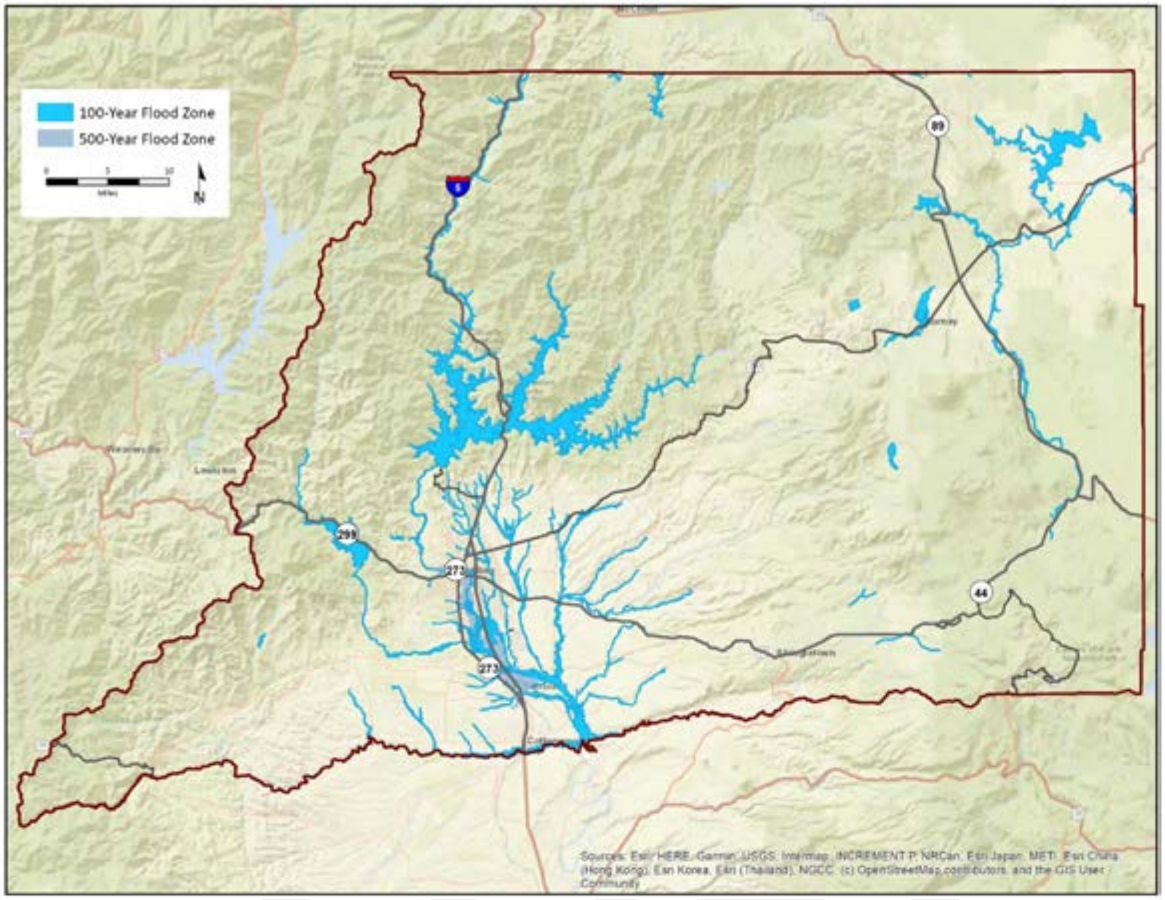

Figure 59. Areas where FEMA FIRMs provide flood hazard mapping in the Shasta Region.

Upper Sacramento River Valley

Below Lake Shasta, streamflow in the Sacramento River is controlled by a series of dams and diversionary tunnels that join the Sacramento River to the Trinity River watershed. Starting with Shasta Dam, water from the Sacramento River watershed is impounded in Shasta Lake. Below Shasta Dam, Keswick Dam forms the Keswick Reservoir, which aids in regulating flow from operations at Shasta Dam. Additionally, water diversions from the Trinity River via the Clear Creek Tunnel connect these two watersheds. The Trinity River is dammed at the Trinity Dam, impounding the Trinity Reservoir. Outflows from the Trinity Dam are again impounded downstream at the Lewiston Dam, where some water from this reservoir is diverted through the 10.7-mile Clear Creek Tunnel to Whiskeytown Lake. Flows through the Clear Creek Tunnel are regulated by the level of Whiskeytown Lake, which is controlled by Whiskeytown Dam. Water from the Whiskeytown Lake is further diverted via the 2.4-mile Spring Creek Tunnel to the Keswick Reservoir at the Spring Creek Power Plant, located near the base of the Spring Creek Debris Dam. The debris dam impounds runoff from abandoned mines in the Spring Creek watershed, and is primarily used to prevent the spills of highly-acidic mine tailing water into the Sacramento River. Water from the Spring Creek Tunnel is not typically mixed with the acidic water impounded by the Spring Creek Dam (although rare releases do occur). Additional flows out of Whiskeytown Lake are governed by the Whiskeytown Dam into Clear Creek, which flows into the Sacramento River at the Redding Rancheria.

Because flooding on the Sacramento River is governed by the combination of precipitation and dam operations, establishing flood hazard beneath the dams requires accounting for policy decisions about dam operations, including water resource management, power generation, pollution control and ecological management, as well as flood control.

In central Redding, the 100-year floodplain is mostly constrained to parklands on the riverbanks, including Turtle Bay Exploration Park and Turtle Bay East. Flooding of transportation infrastructure in the 100-year floodplain is limited to Park Marina Drive and small sections of park roads (Figure 60). However central Redding has significant exposure to a larger 500-year flood: sizable areas adjacent to Turtle Bay are exposed to flooding under higher streamflow conditions, as are areas north of the Sacramento River, particularly Caldwell Park and Lake Redding Estates (Figure 61).

Figure 60. Flooding exposure in Central Redding, Turtle Bay.

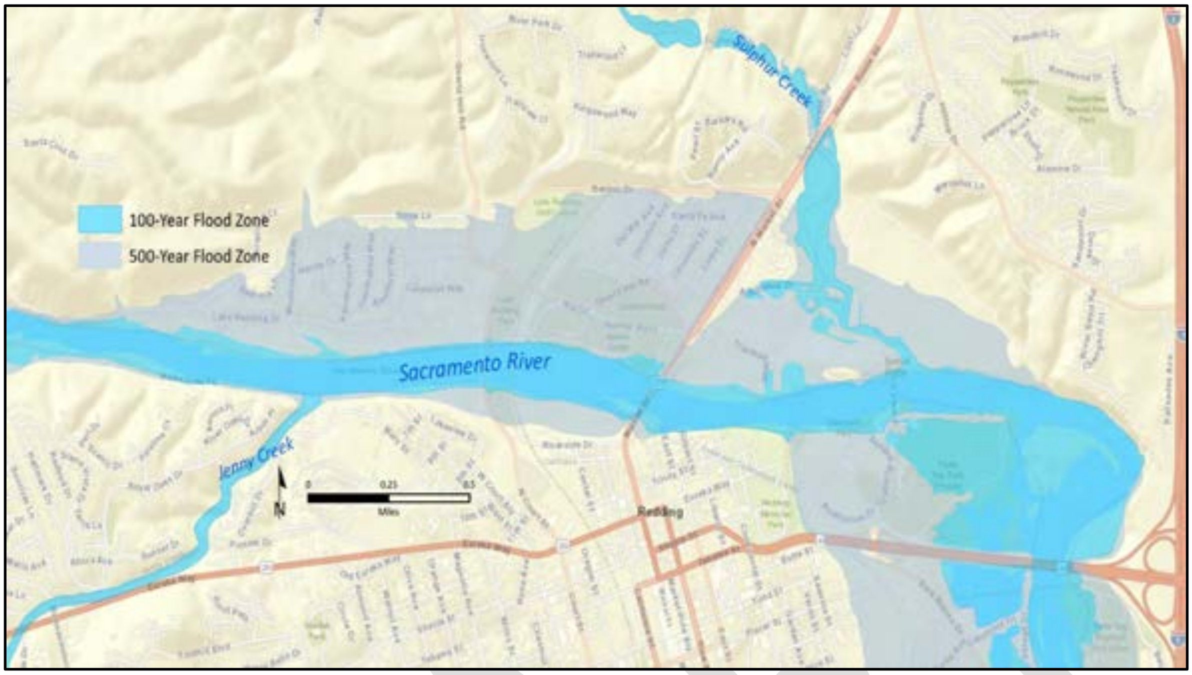

Figure 61. Flooding exposure in Central Redding, north of Highway 299.

The travel corridor between Redding and Anderson follows the Sacramento River, which is fed my multiple tributaries, canals and washes the flow into the river from the east and west. While development in the 100-year flood zone is relatively sparse, there are localized points where exposure to the 100-year and 500-year flood zones should be noted. Traveling south along Highway 273 (S. Market Street), there are several locations where tributaries to the Sacramento River flow up to and under the roadway via local bridges. In a flood event, water can back up at these bridges causing the commercial and residential areas to the west of 273 to flood (Figure 62).

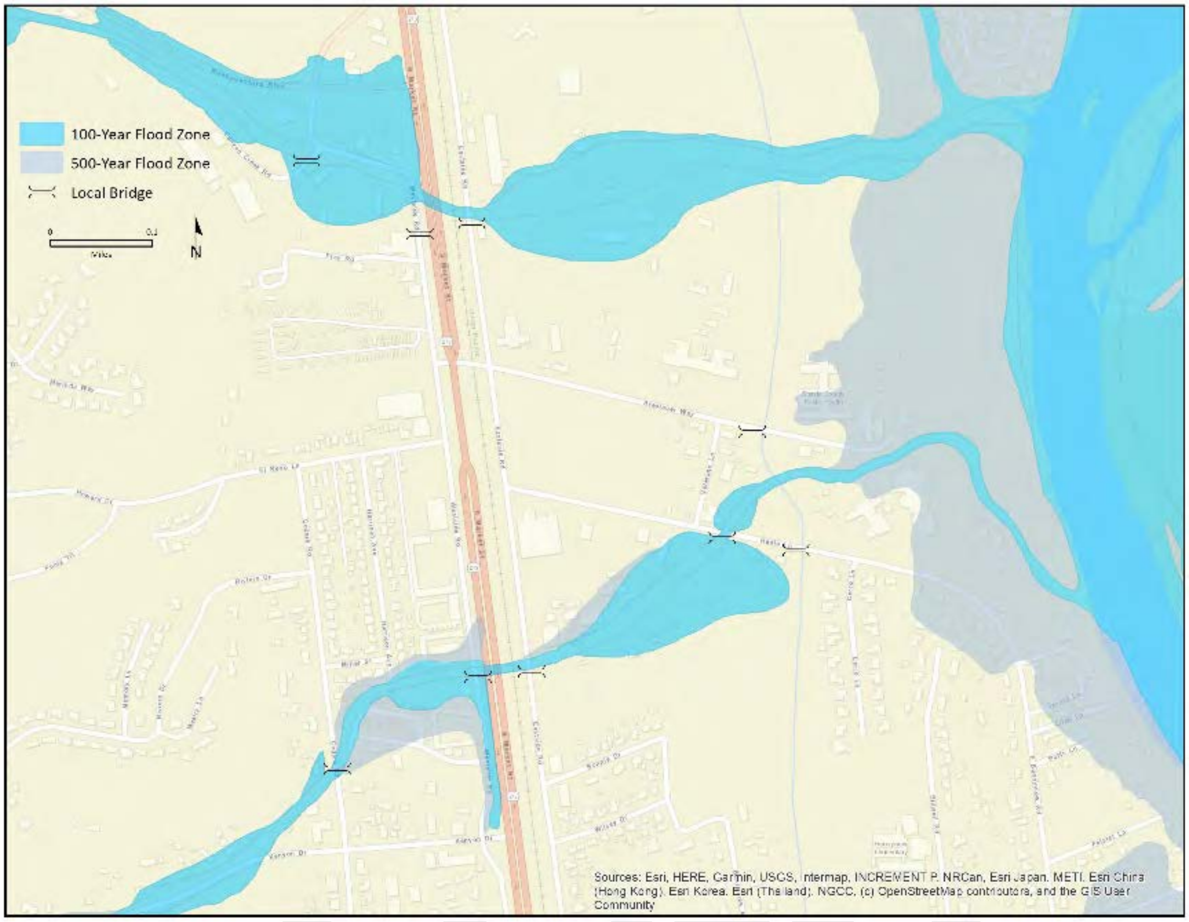

Figure 62. Flooding exposure in along Highway 273, south of Redding..

Further south in the Redding-Anderson corridor, the 100-year and 500-year floodplains are more extensive, with flood hazards mapped for tributary streams. In Girvan, Olney Creek and Clear Creek flow under local bridges beneath Highway 273 from the west and Churn Creek feeds the river from the east. Figure 63**,** Figure 64**,** and Figure 65 show the flood hazard exposure in this area of the watershed. The crossing at Olney Creek shows the potential for insufficient channel capacity to lead to overtopping of Highway 273. From Anderson north to the South Bonnyview Road exit, much of I-5 is in the 500-year floodplain, with small sections transiting the 100-year floodplain.

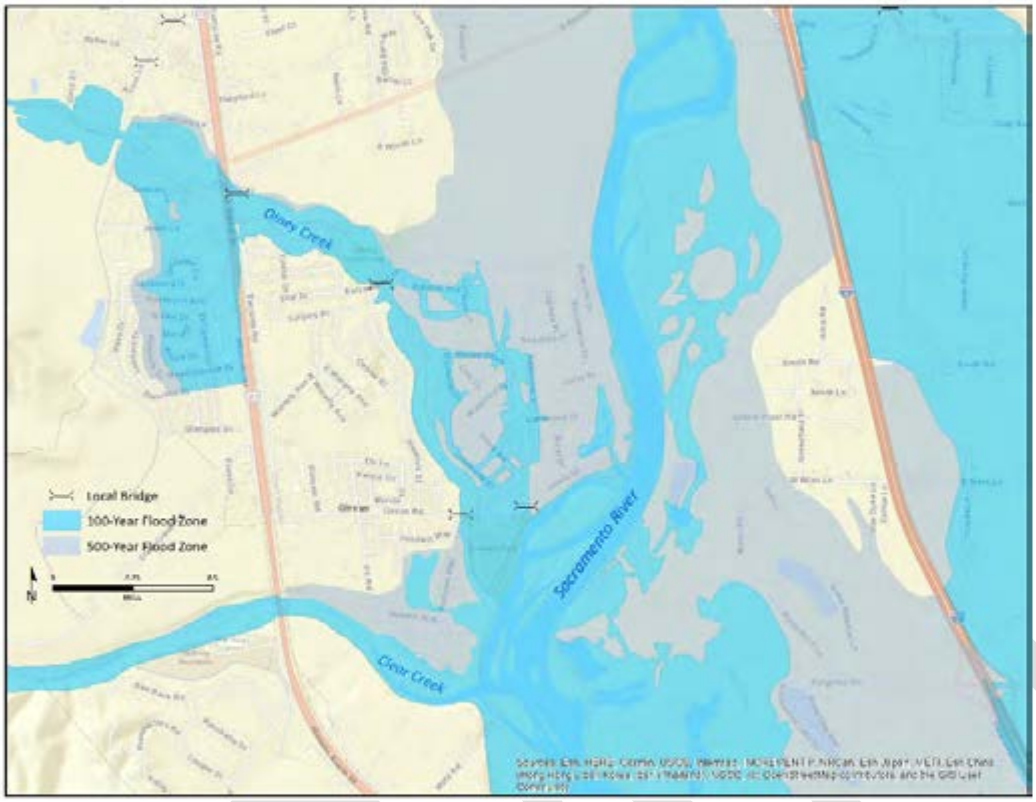

Figure 63. Flooding exposure in along Highway 273, Girvan.

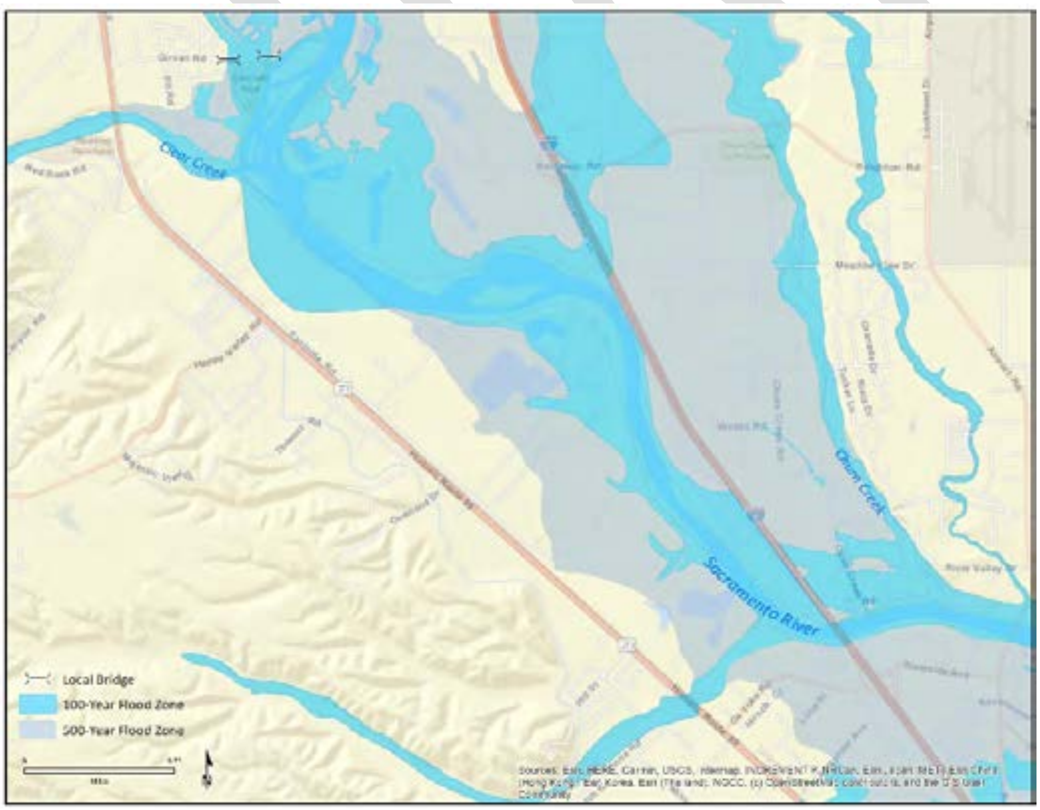

Figure 64. Flooding exposure in along Highway 273, north of Anderson.

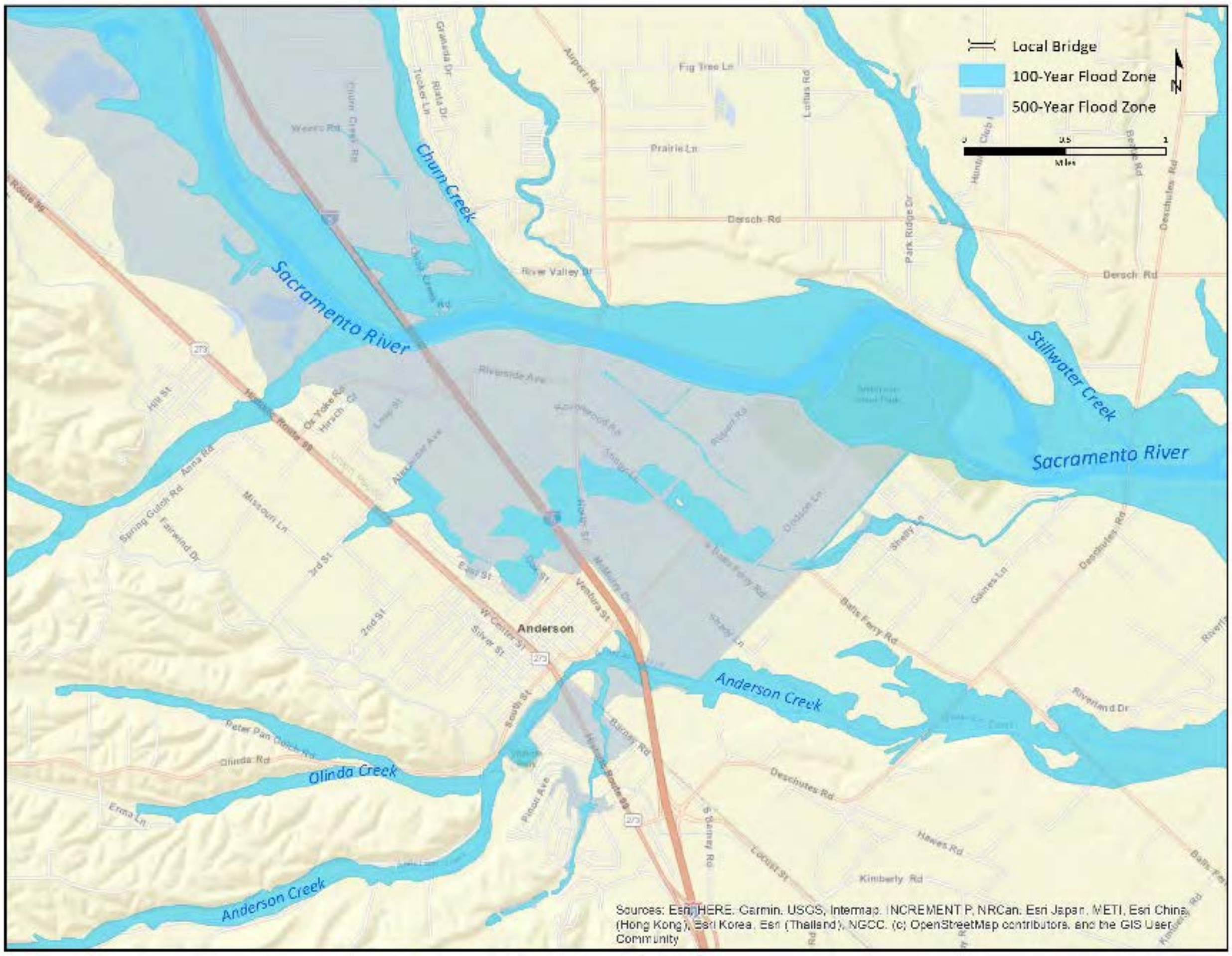

Figure 65. Flooding exposure in Anderson.

In the city of Shasta Lake to the north, flood hazards are primarily associated with tributary streams that form in the mountains north of town and flow south along the I-5 corridor on the east side of Redding. These (usually dry) streambeds converge in Churn Creek and Salt Creek, which flow south before meeting the Sacramento River near Anderson. Flood zones in Shasta Lake threaten surface street transportation along key corridors like Shasta Dam Boulevard, Pine Grove Avenue, and Lake Boulevard (Figure 66). I-5 transits a section of flood hazard near Autumn Harvest Way. Oasis Road is also subject to several potential flood zones near its junction with I-5.

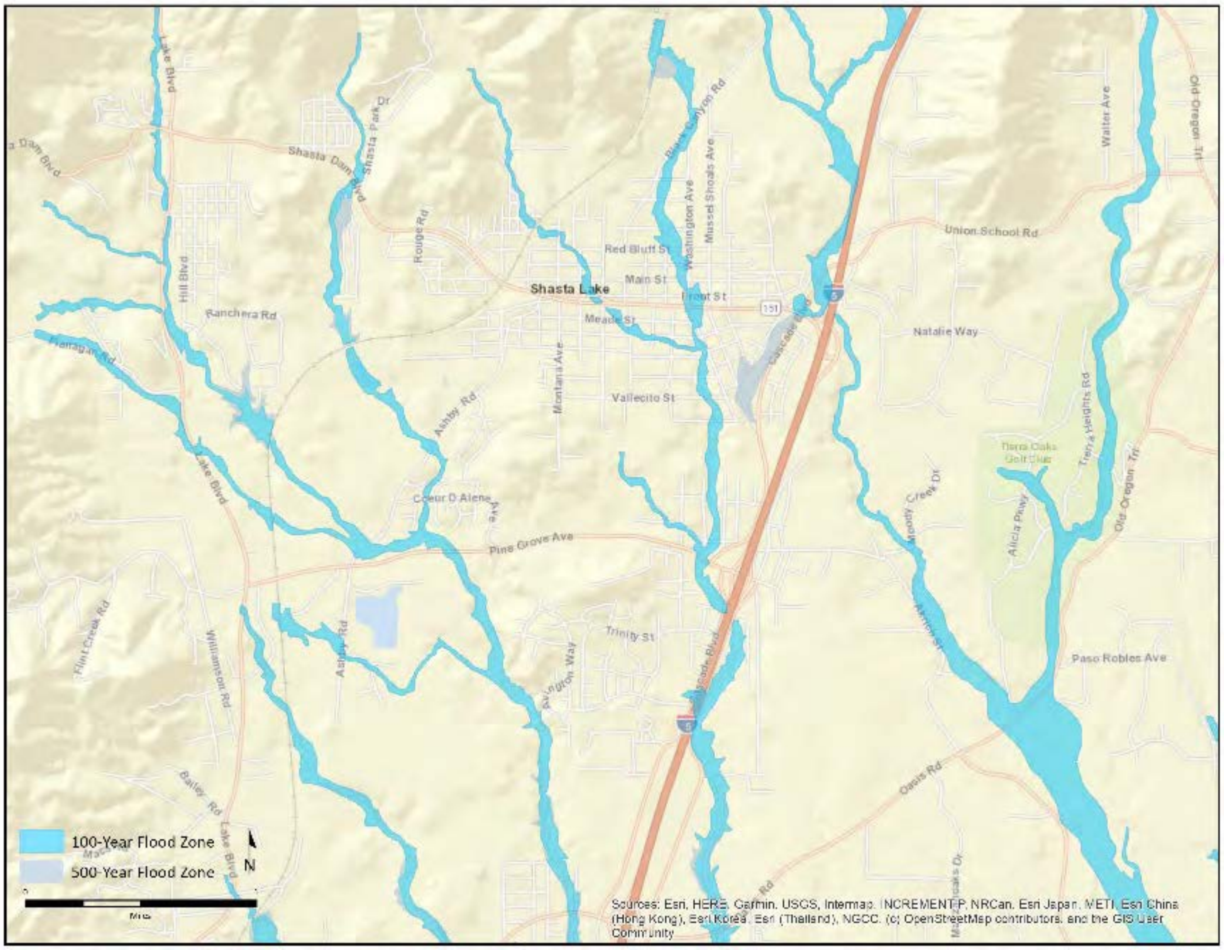

Figure 66. Tributaries and flooding exposure in the City of Shasta Lake.

In Bella Vista, Churn Creek and Stillwater Creek flow beneath small local bridges to cross under Highway 299. North of Highway 299, the 100-year floodplain of Churn Creek is relatively narrow and mostly confined to an area close to the stream bed, while the floodplain of Stillwater Creek is broader. In both cases, the flood hazard for transportation systems is constrained to smaller roads. South of Highway 299, the floodplains of both streams remain narrow with flooding exposure limited to a small number of residential neighborhoods and local roads. Slightly further south, Churn Creek and Stillwater Creek are fed by Cow Creek from the east in an area with wider flood hazard exposure north of Highway 44, particularly along Old Alturas Road. Figure 67 and Figure 68 show the flood hazard exposure in these areas.

Figure 67. Tributaries and flooding exposure in Bella Vista.

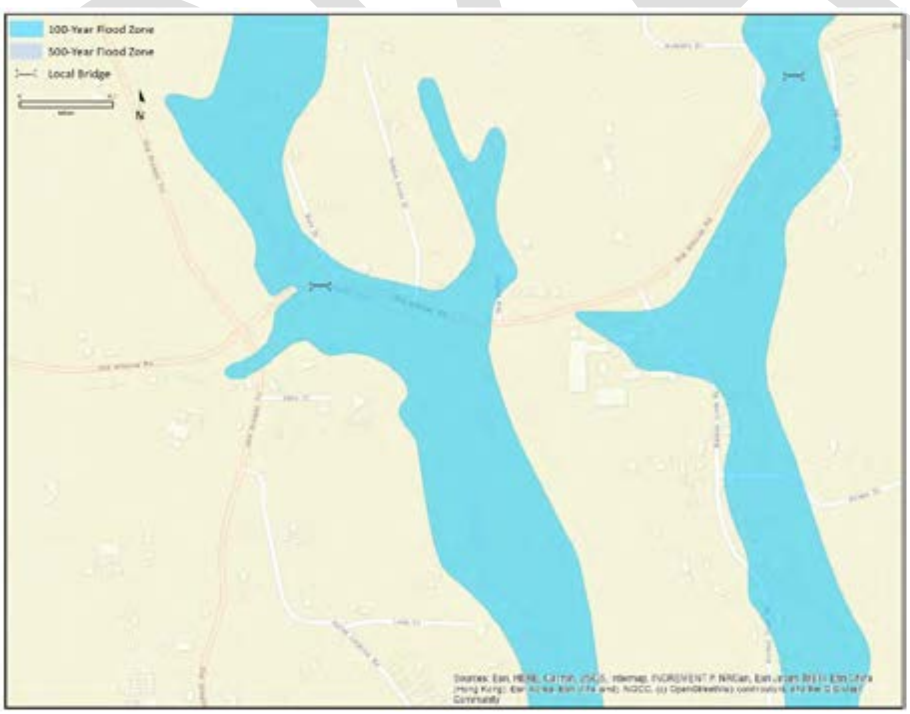

Figure 68. Tributaries and flooding exposure along Old Arturas Road.

Cow Creek is the primary drainage in Palo Cedro and Millville. Development density in this part of the Region is low and, therefore, flooding exposure is primarily related to local roads. The most significant area of concern is along Highway 44, east of the junction with Deschutes Road. Figure 69 and Figure 70 show the flood hazard exposure in this part of the Shasta Region.

Figure 69. Floodplains in Palo Cedro.

Figure 70. Floodplains in Millville.

Sacramento River Canyon

North of Shasta Lake, the Sacramento River Valley features steep slopes above the river, with I-5 and the Union Pacific railroad occupying substantial portions of the banks. Numerous small communities follow the river and these infrastructure corridors north to the boundary with Siskiyou County. In this narrow basin, flood hazards have been mapped for the Sacramento River floodplain, as well as some of its larger tributaries.

Figure 71. Flooding exposure of the Union Pacific Railroad in the Sacramento River Canyon, near Lamoine.

Based on historical 100-year flood events, the Sacramento River threatens the Union Pacific railroad at multiple locations throughout the upper valley. Small areas of exposure are located at Vollmers, between Vollmers and Lamoine, north of Lamoine (Figure 71), in Pollard Flat (Figure 72), Gibson, and Fisher.

From Gibson to Sweetbriar, multiple areas of flood hazard intersect with the railroad as well as with smaller roads in the valley. Along Hazel Creek, Hazel Creek Road is subject to inundation in a 100-year flood. At Castella, flood hazards threaten Castella Loop, Shade Avenue, and the Castella Loop bridge, as well as the railroad. Flooding along Castle Creek also threatens Castle Creek Road, and flooding in Dirigo threatens Riverside Road.

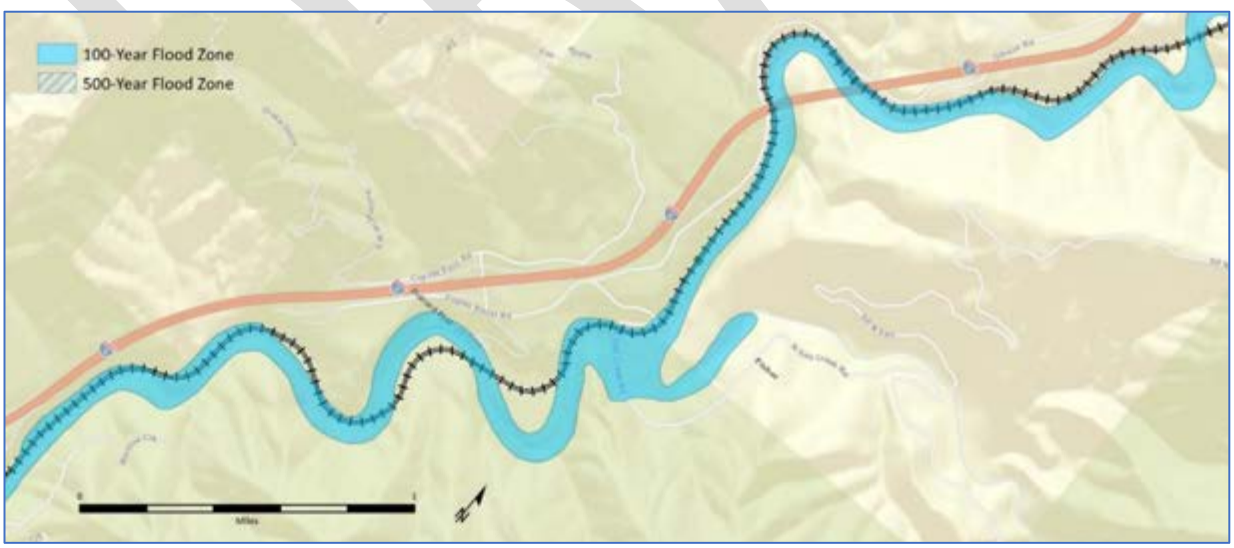

Figure 72. Flooding exposure of the Union Pacific Railroad in the Sacramento River Canyon, near Pollard Flat.

Near Castle Crag, flood hazards expose sections of the railroad to inundation during a 100-year flood (Figure 73). Additionally, portions of Soda Creek Road and the I-5 Frontage road are exposed here. The Soda Creek Road bridge comprises a link in the Pacific Crest Trail and is also within the 100-year floodplain.

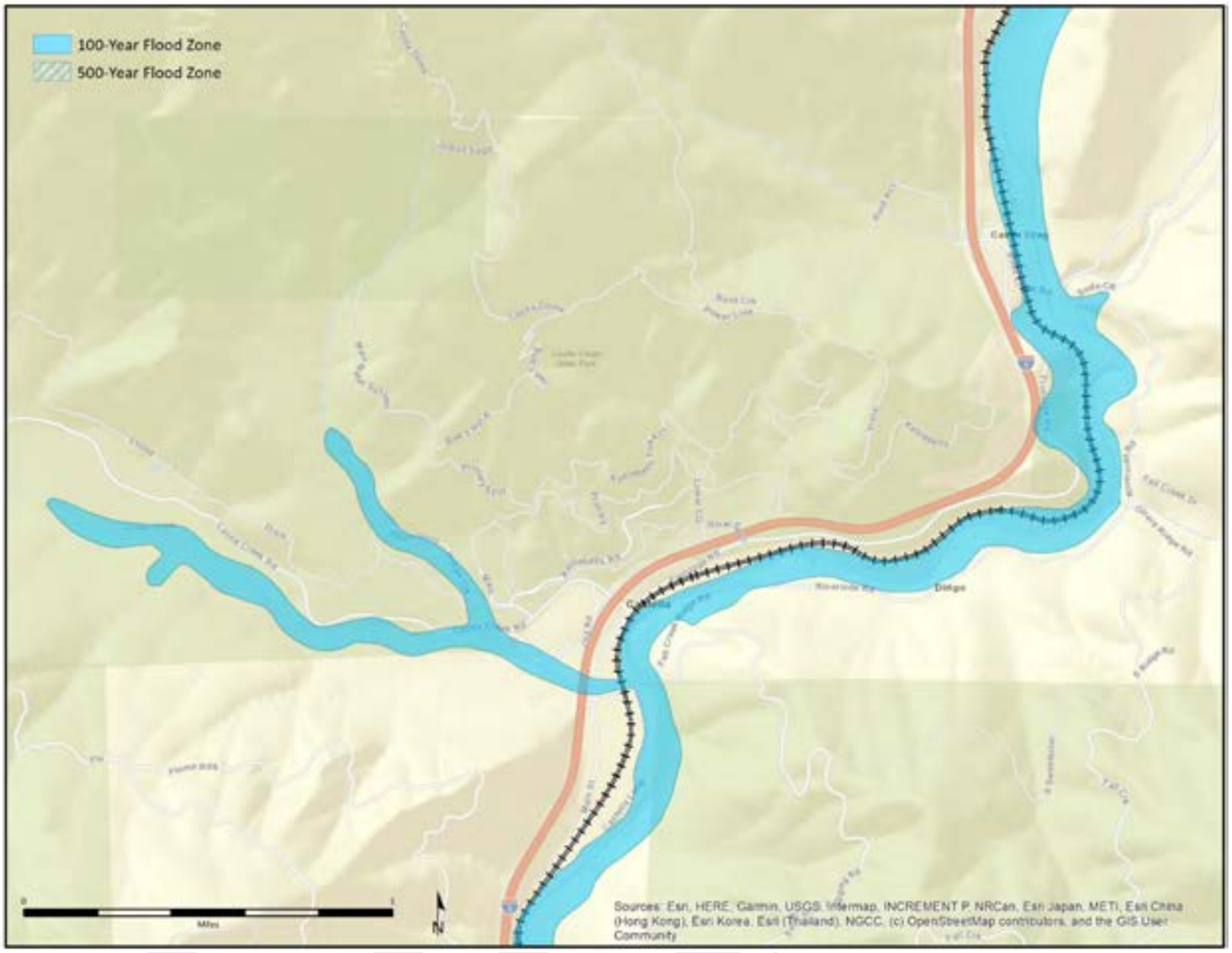

Figure 73. Flooding exposure of the Union Pacific Railroad in the Sacramento River Canyon, near Castle Crag State Park.

Whiskeytown Lake – Whiskeytown-Shasta-Trinity NRA

Whiskeytown Lake is fed by Clear Creek from the northwest, Grizzly Gulch and Whiskey Creek from the north, and Boulder Creek and Brandy Creek from the south. Additionally, the Clear Creek Tunnel diverts water from the Trinity River watershed into the lake. As a result, the watershed drains all of Whiskeytown National Recreation Area along with additional areas into the lake. Outflows from this drainage are controlled by the Whiskeytown Dam. Flood hazards are mapped around the lakeshore, as well as the Clear Creek drainage. A 100-year flood in Whiskeytown Lake would inundate sections of Highway 299 and South Shore Drive (Figure 74). Mapped flood hazards in Clear Creek do not threaten any transportation infrastructure.

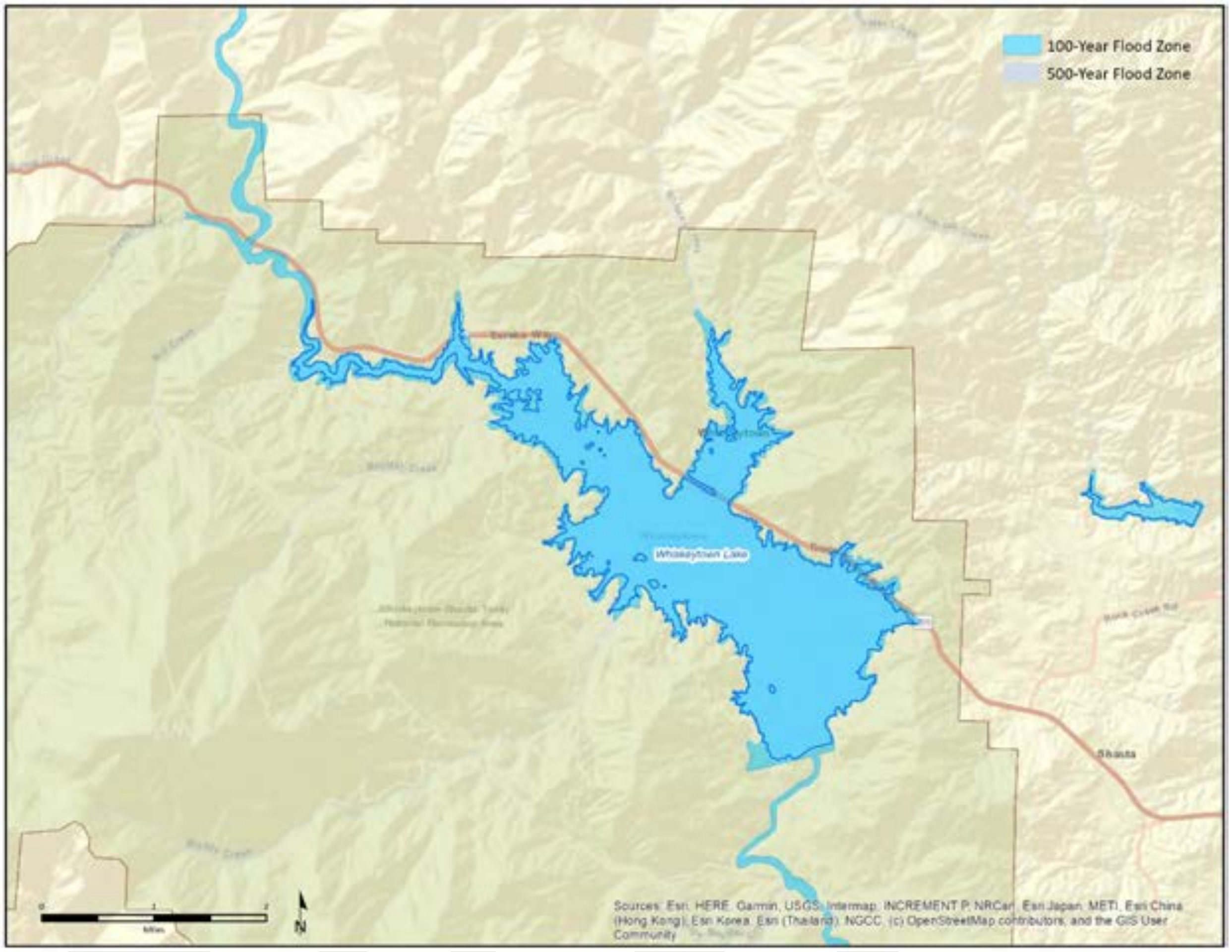

Figure 74. Flood hazard areas in and around Whiskeytown Lake.

Northeastern Shasta Region

The transportation network in the northeastern parts of the Shasta Region, from Fall River Mills in the far northeast to Burney and Old Station further south, centers around Highways 89 and 299, which are fed by a low to moderately dense network of local roads. The Pit River flows east to west through Fall River Mills where it is joined by the Fall River and Hat Creek as it into Lake Britton. In this area, the 100-year flood zones are mostly confined to the narrow river channels and impact is mostly limited to highway crossings (Figure 75). While widespread exposure is limited, the sparsely developed road network in this area exacerbates the impact in the event of a washout or road closure when detours can be lengthy.

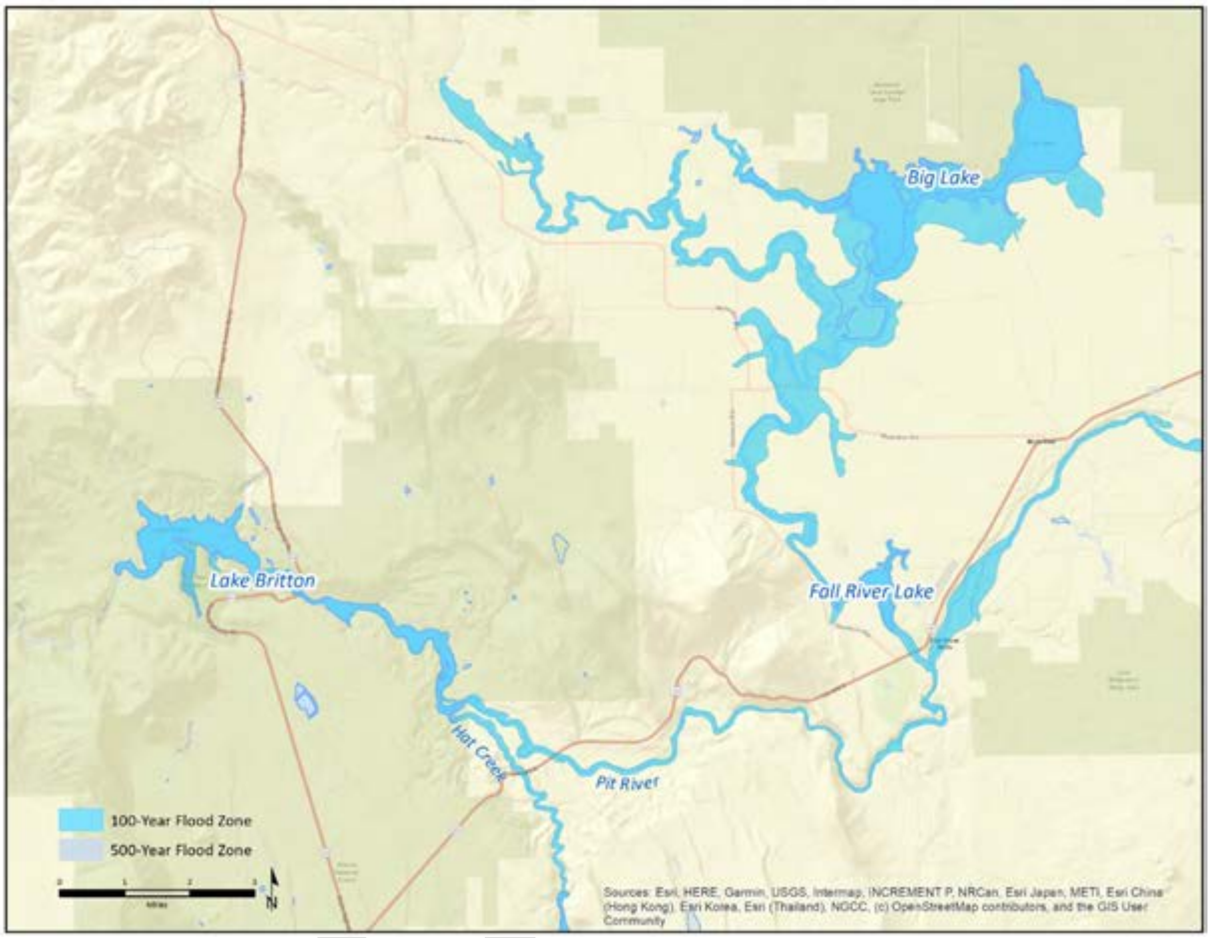

Figure 75. Flood hazard areas in northeastern Shasta Region.

In and around Burney, the 100-year floodplain extends eastward from Burney Creek to an irrigation canal (Figure 76). The area within this floodplain is largely grazing land, however the flood zone includes Main Street (Highway 299) and multiple surface streets on the north side of town. The extended 500-year floodplain further includes surface streets on the south side of town. Much of Burney is located in one of these two floodplains, including Pit River Tribal lands and the Pit River Casino. A 100-year flood of Burney Creek would disrupt traffic on Highway 299 between communities to the east and west.

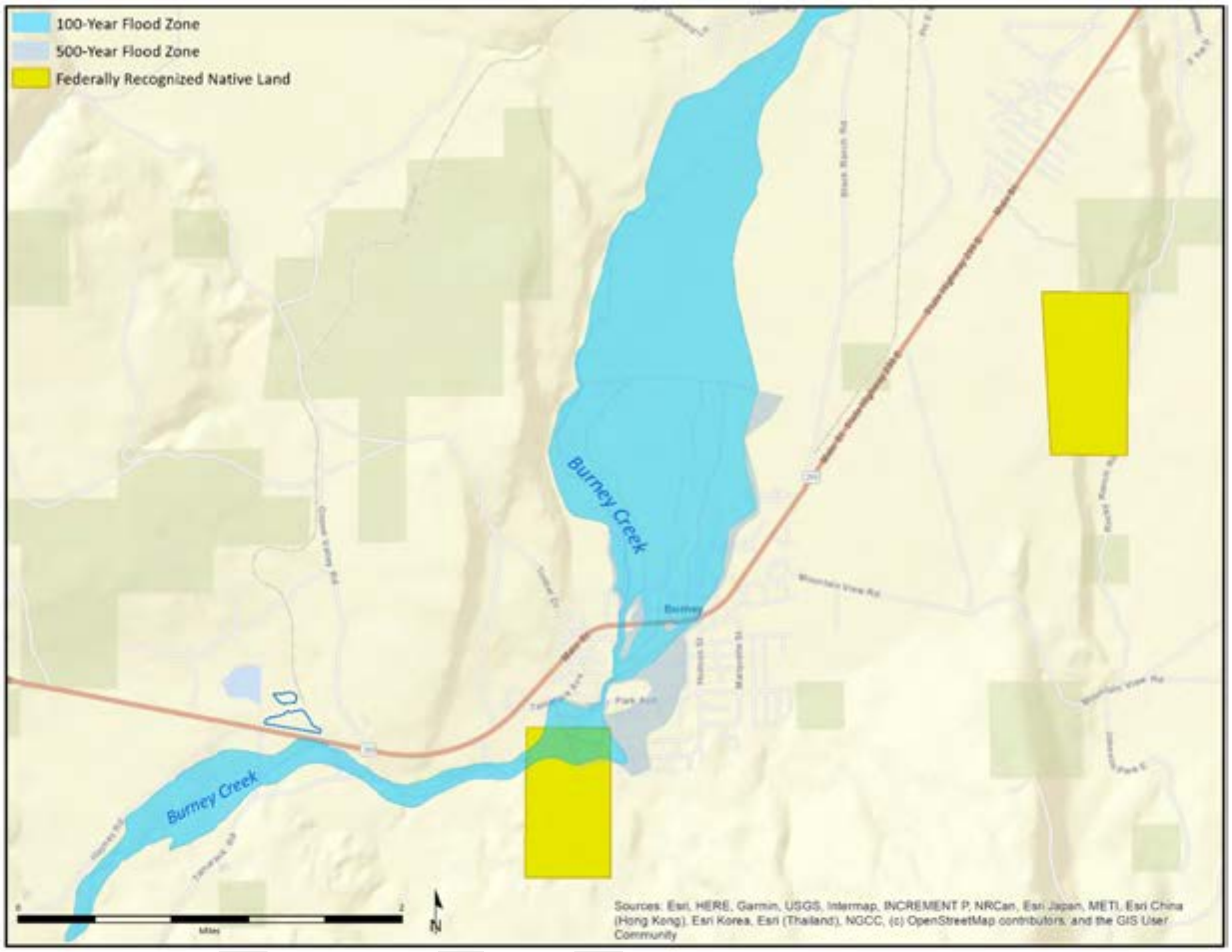

Figure 76. Flood hazard areas in and around Burney.

To the east, Hat Creek flows north from its headwaters in Lassen Volcanic National Park, through the communities of Old Station, Hat Creek, and Cassel before joining the Pit River (Figure 77, Figure 78, and Figure 79). While the 100-year flood zone is constrained by the topography, there are several areas with the potential for localized flooding along stretches of Highways 89 and 299. Additionally, several local roads and structures are exposed to potential flooding.

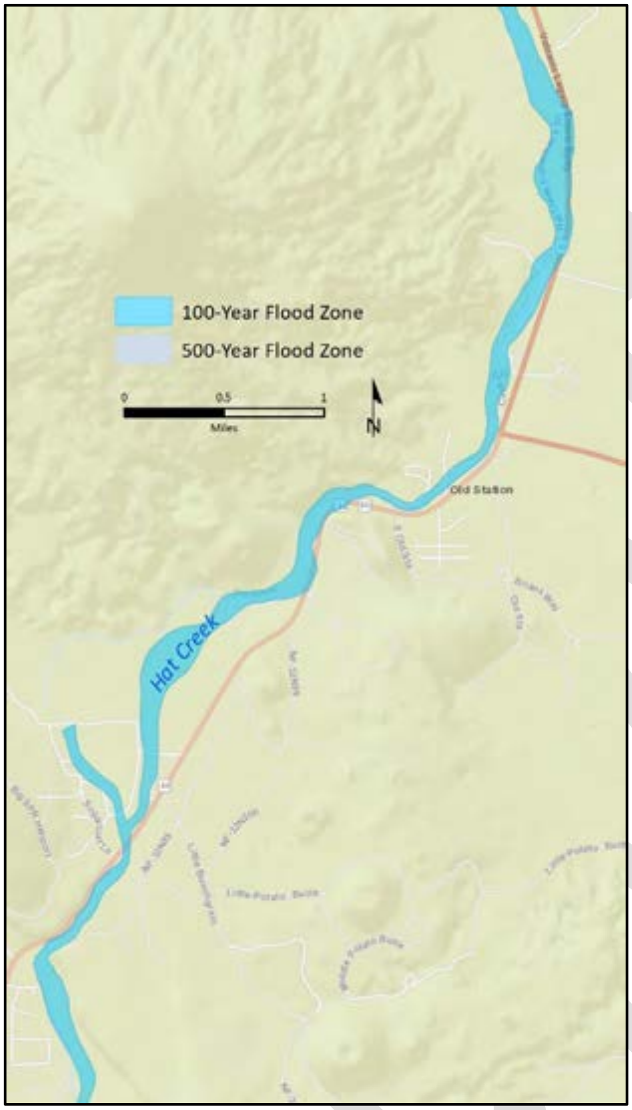

Figure 78. Flooding hazards associated with Hat Creek near Old Station.

Figure 77. Flooding hazards associated with Hat Creek in the community of Hat Creek.

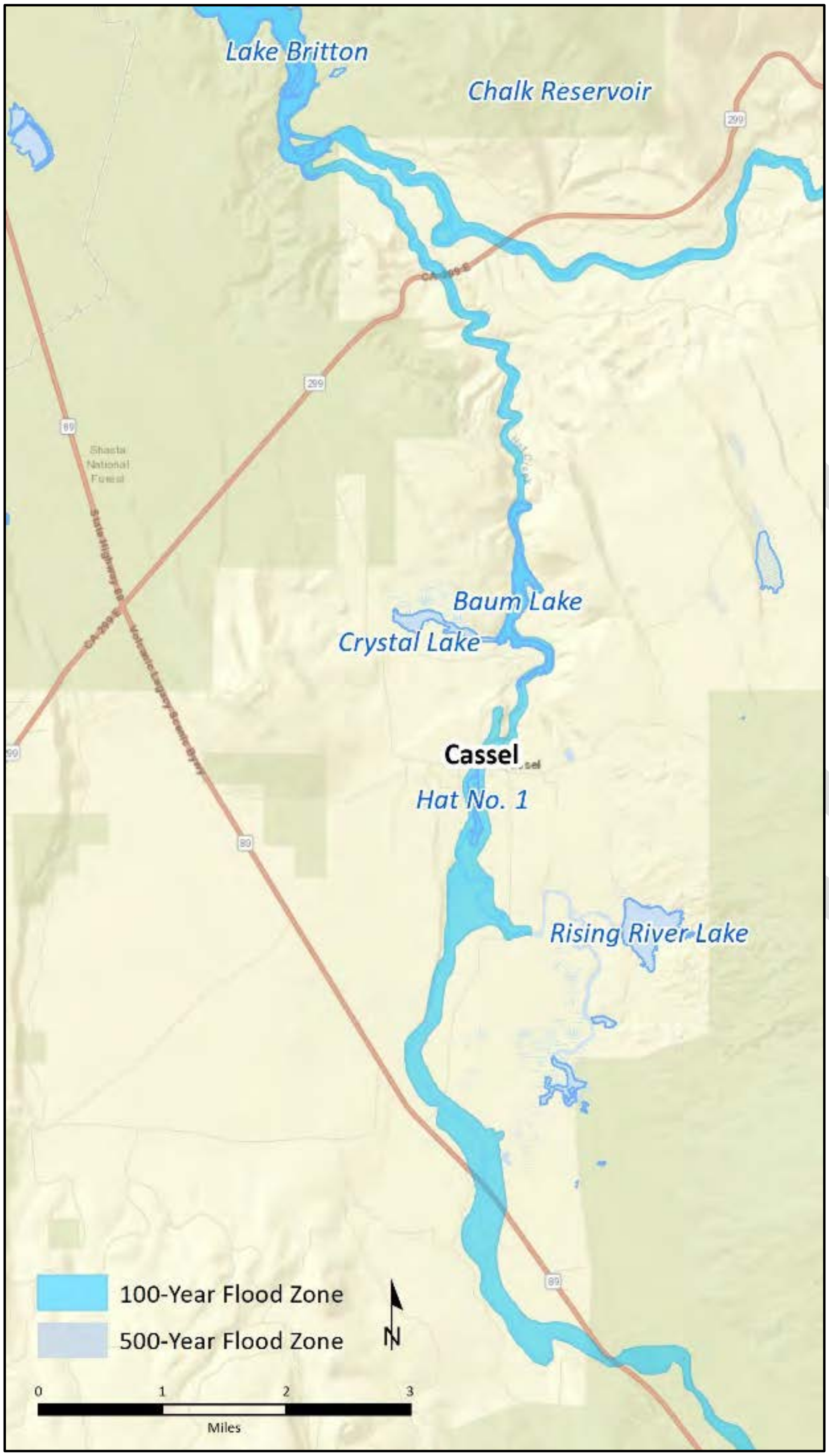

Figure 79. Flooding hazards associated with Hat Creek threaten Highways 89 and 299 near Cassel.

McCloud River

Along the Shasta Region's northern border, the McCloud River is impounded at Lake McCloud by McCloud Dam. During a 100-year streamflow event, the roads along the lake's shores may be exposed to flooding, particularly along the northern shores of the lake (Figure 80). This is a low priority hazard.

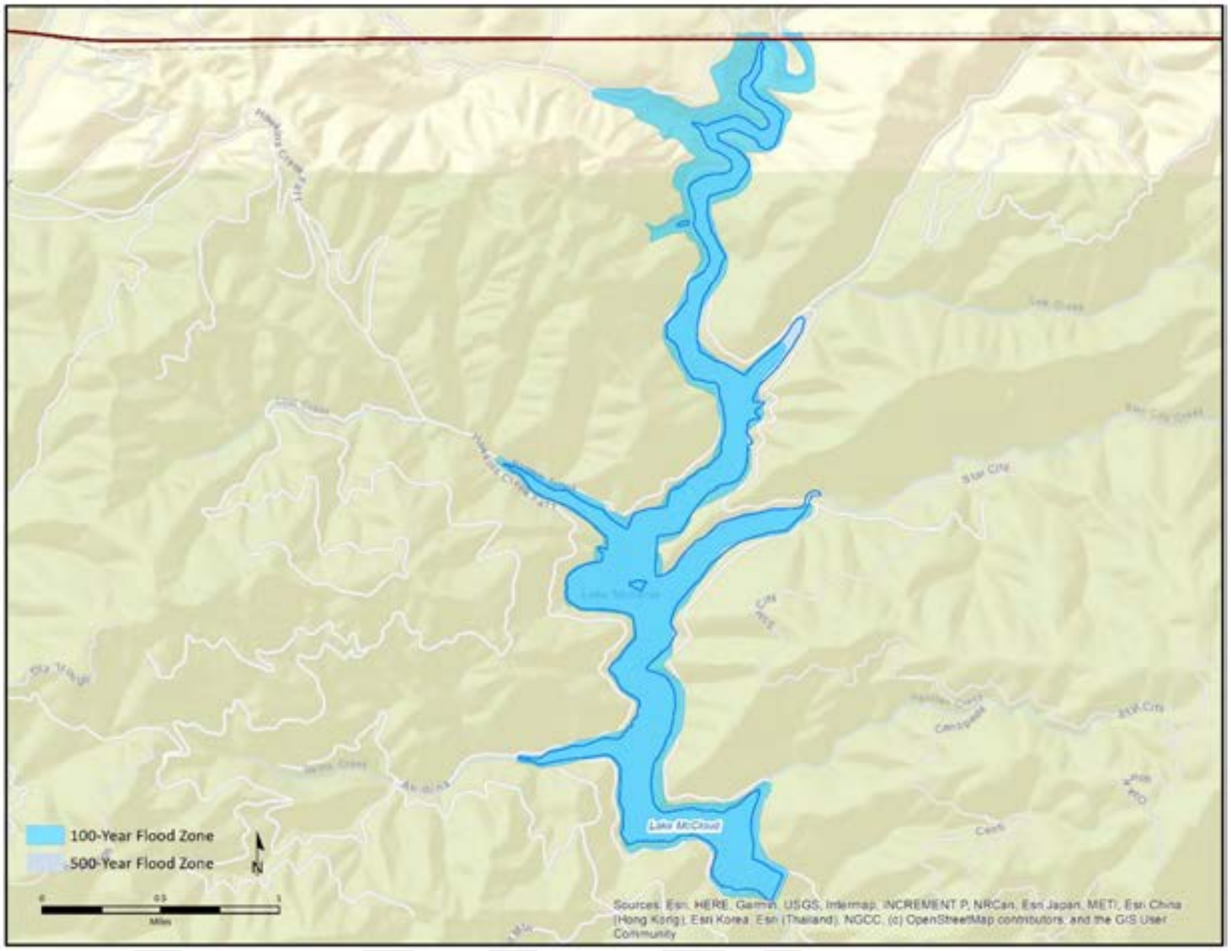

Figure 80. Flood hazards around Lake McCloud.

Landslide Impacts and Vulnerabilities

Landslides include a variety of different types of ground movement, including mudslides or debris flows, deep failure of slopes, and rockfall. Landslides can be small enough to block only a lane of traffic, or large enough to sweep entire segments of road down a hillside. Although gravity is always the primary cause of a landslide, there are additional contributing factors are important considerations for evaluating slope stability, especially in regions with high risk of wildfire, extreme precipitation, or seismic activity. One of the major concerns with projected changes to the climate across California is that rising temperatures and drier summers are increasing the likelihood of wildfires that are intense enough to destroy hillside vegetation, including root systems crucial to retaining hillside soils. Additionally, more intense extreme precipitation events are projected to lead to the types of runoff that can quickly erode burn-scarred hillsides. Where these projections come together (as in the Shasta Region), historical experiences with landslides may not provide sufficient guidance for landslide hazards going forward.

Landslides, including rockfall, mudslides, debris flows, and large bulk landslides are all serious hazards for mobility systems, particularly where rural highways provide essential transportation links through mountainous regions. Table 15 lists many of the specific impacts that landslides can have on different transportation systems.

Table 15. Example table of sector-specific impacts for landslide hazards

	Landslides
Roads & Bridges	• Temporary road closures due to blockages • Clogging of drainage systems from debris flows leading to localized flooding hazards • Hazard to drivers from falling rocks and debris • Destruction of road surfaces and roadbeds due to large landslides
Rails	• Closure of rail corridor due to blockages • Destruction of rails, rail infrastructure, or railbeds due to large landslides
Transit Systems	• Route disruptions related to road closures
Airports	• Delays due to transportation network delays (e.g., passenger/staff late arrivals)
Pedestrians & Bicycles	• Closures of sidewalks, bicycle lanes • Recreational access closures and delayed reopening on backcountry routes

In the Shasta Region, landslide hazard has not been comprehensively evaluated by qualified geologists, and the Shasta County Hazard Mitigation Plan excludes landslide hazards.[13] The Hazard Mitigation Plan notes that "landslides are more prevalent in the eastern and northern portions of Shasta County and are commonly related to the sedimentary and volcanic rocks in these vicinities."

Because climate-related factors that contribute to landsliding are changing in complex ways, this screening analysis focuses instead on the geomorphology of the Shasta Region's hillsides in order to identify a "potential landslide hazard slope zone." The landslide hazard screening analysis does not identify specific landslide hazards, but rather identifies areas with slopes similar to areas where landslides have been triggered in the past. Using the California Geological Survey's inventory of

[13] Shasta County 2017

landslide hazard assessments, we have selected mapped landslide hazards within the American River Valley as the likely point of comparison for landslides in the Shasta Region.[14] Landslide initiation zones in this inventory include hillsides with an average slope of 24.7°, and with a standard deviation of 12.6°, thus all slopes in the range of 18.4° to 31.0° are considered "potentially hazardous."

Regionwide Projections

Areas of potentially hazardous slope are widespread in the Shasta Region, with the highest concentrations in the Klamath Mountains, and more limited distribution in the Cascades. Despite the large number of potentially hazardous slopes, only three general areas of potential hazard occur in proximity to key highways in the Shasta Region. These are the I-5 corridor in the Sacramento River Canyon, Highway 299 along and west of Whiskeytown Lake, and Highway 299 between Bella Vista and Round Mountain. Figure 81 shows the Region-wide distribution of potentially hazardous slopes, as well as the areas of particular concern.

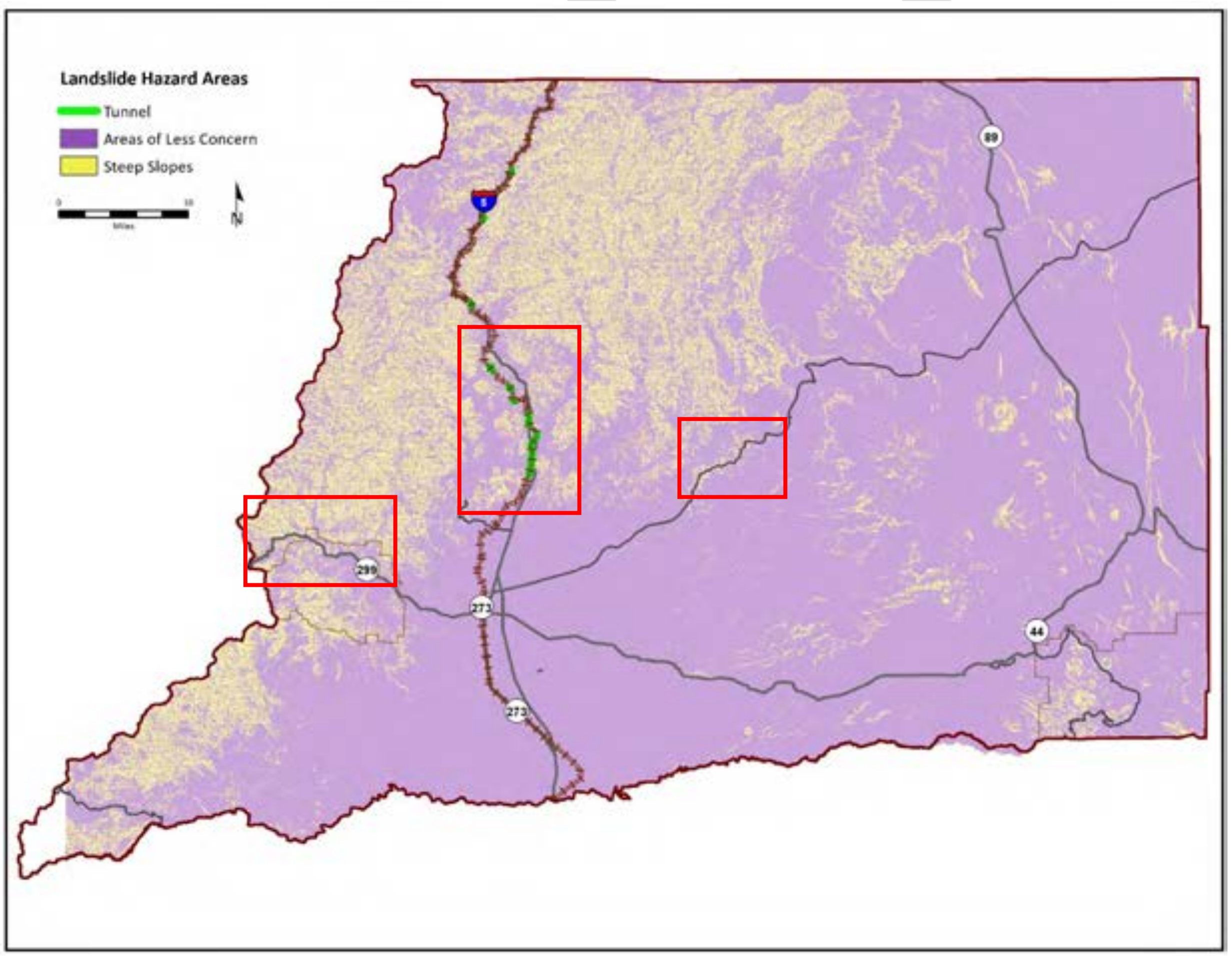

Figure 81. Potentially hazardous landslide slope zones in the Shasta Region. Areas where large numbers of potentially hazardous slopes exist above important transportation systems are identified.

[14] California Dept. of Conservation 1997

Infrastructure Vulnerabilities

The most pressing area of landslide concern is the northern portion of the I-5 corridor in the Sacramento River Canyon. Extensive tunneling and bridging of rail and highway infrastructure in the corridor has a mitigating effect on landslide hazard, however multiple locations of potential hazard still exist. Figure 82 shows the areas within the Region where steep slopes could create landslide hazards, as well as locations where rail infrastructure in the I-5 corridor is protected by tunnels.

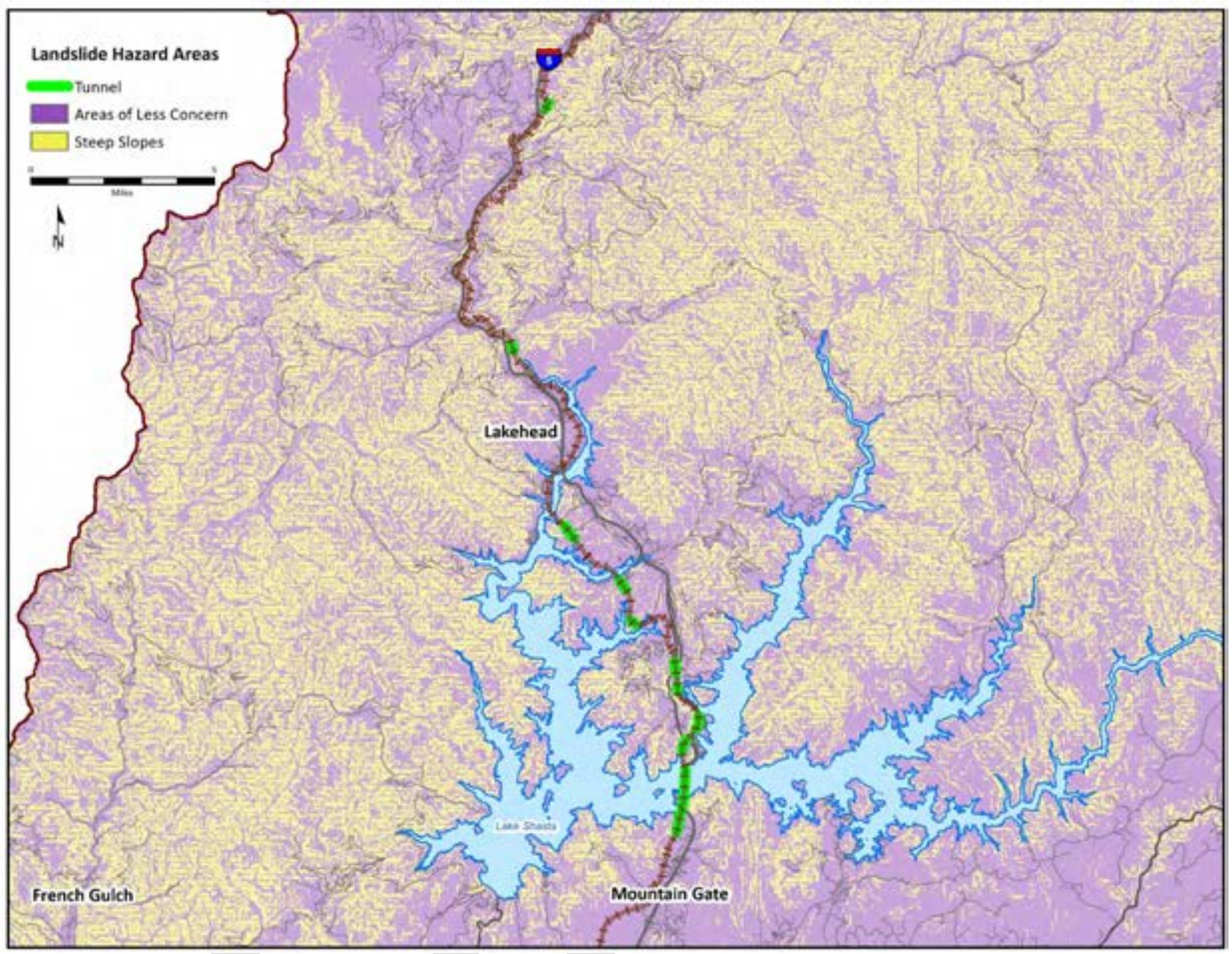

Figure 82. Areas of potentially hazardous landslide slope zones in the Sacramento River Canyon.

West of Whiskeytown Lake, Highway 299 follows the north side of Willow Creek to Buckhorn Summit at the border of Trinity County. Along much of this route, the northern slopes pose many large areas of potentially hazardous landslide slope zones. If large fires in this area destroy the roots of hillside vegetation, landsliding here could create serious challenges to road operations. Highway 299 is protected from potential landsliding along southern slopes due to the Willow Creek drainage. Figure 83 shows the potential landslide hazards along Highway 299.

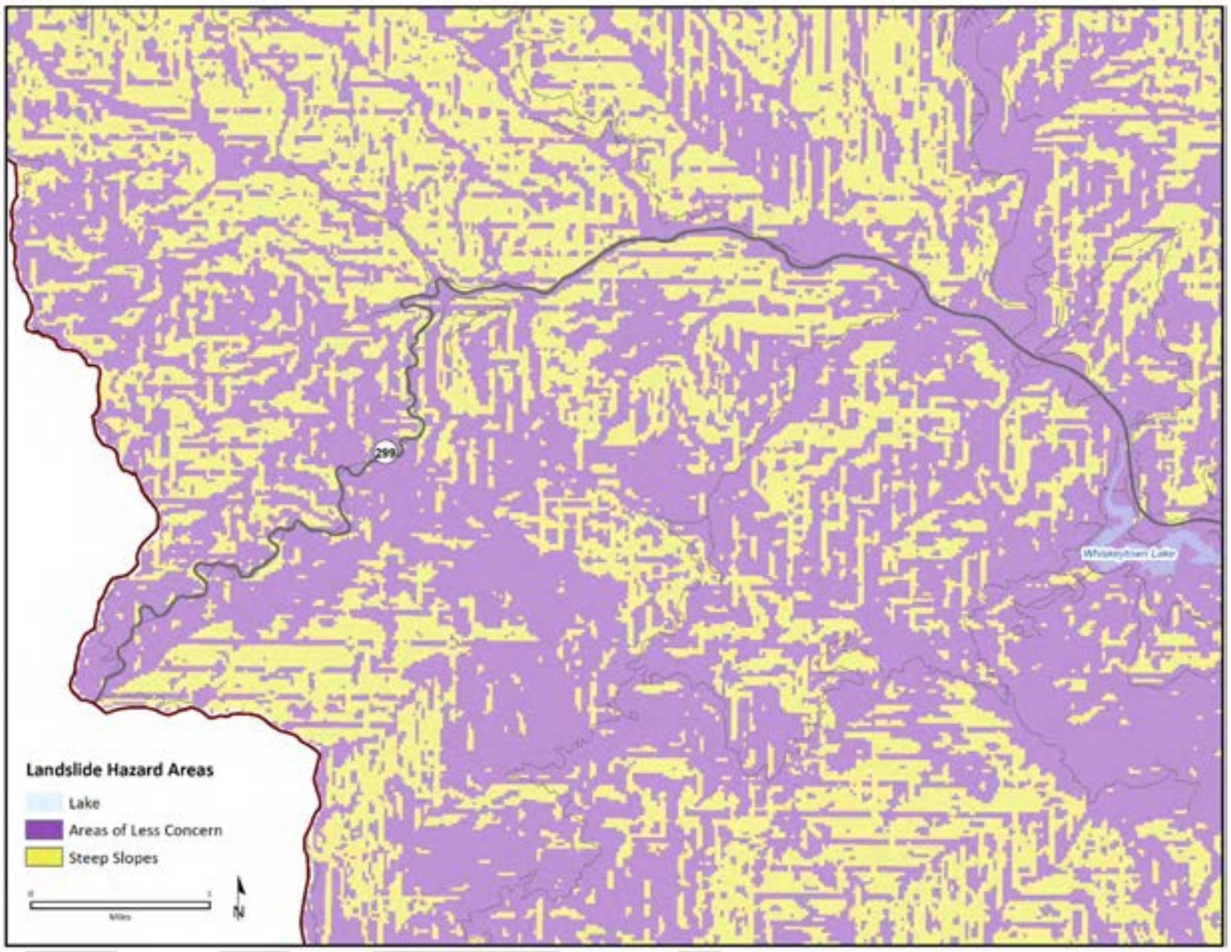

Figure 83. Potentially hazardous landslide slope zones along Highway 299 west of Whiskeytown Lake.

Highway 299 enters another area with high densities of potentially hazardous landslide slope zones east of Bella Vista and west of Round Mountain. Here Highway 299 follows the northern banks of Cedar Creek and Little Cow Creek, and transits multiple areas of high-density steep slopes. As with the Whiskeytown Lake area, a landslide here would isolate a number of eastern Shasta communities from the Redding area. The highway is largely protected from potential landsliding on the southern banks. However projected changes to both wildfire hazard and extreme precipitation put this area at elevated risk of future landslide hazards. Figure 84 shows the distribution of potentially hazardous landslide slope zones in this area.

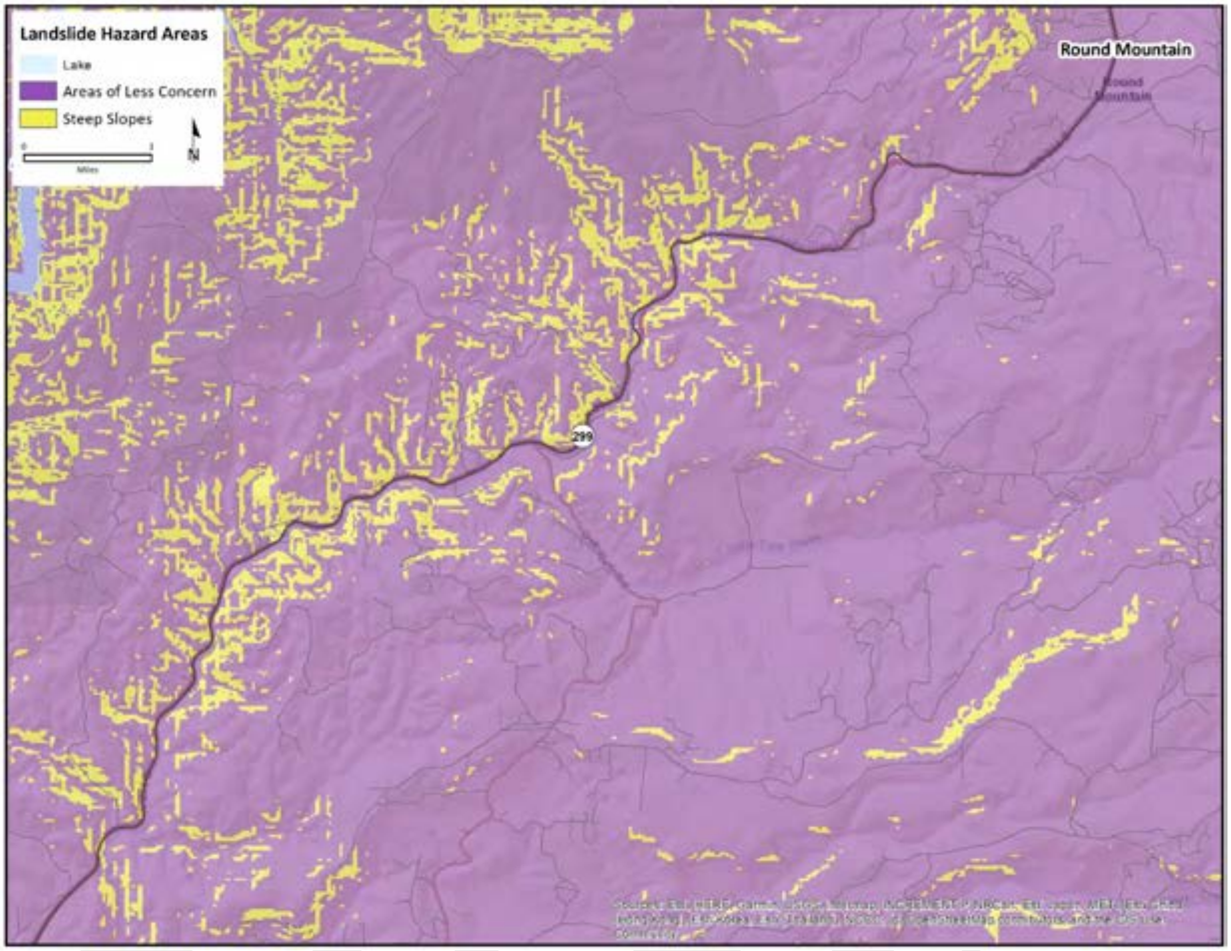

Figure 84. Potentially hazardous landslide slope zones around Highway 299 between Bella Vista and Round Mountain.

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Appendix A: Complete Projection Figures

This appendix includes a complete set of figures for all projected climate parameters.

Temperature Projections

Temperature projections include annual average high temperature, seasonal average high temperature, and heat wave temperature.

Average Annual High Temperature Projections

Historical Conditions

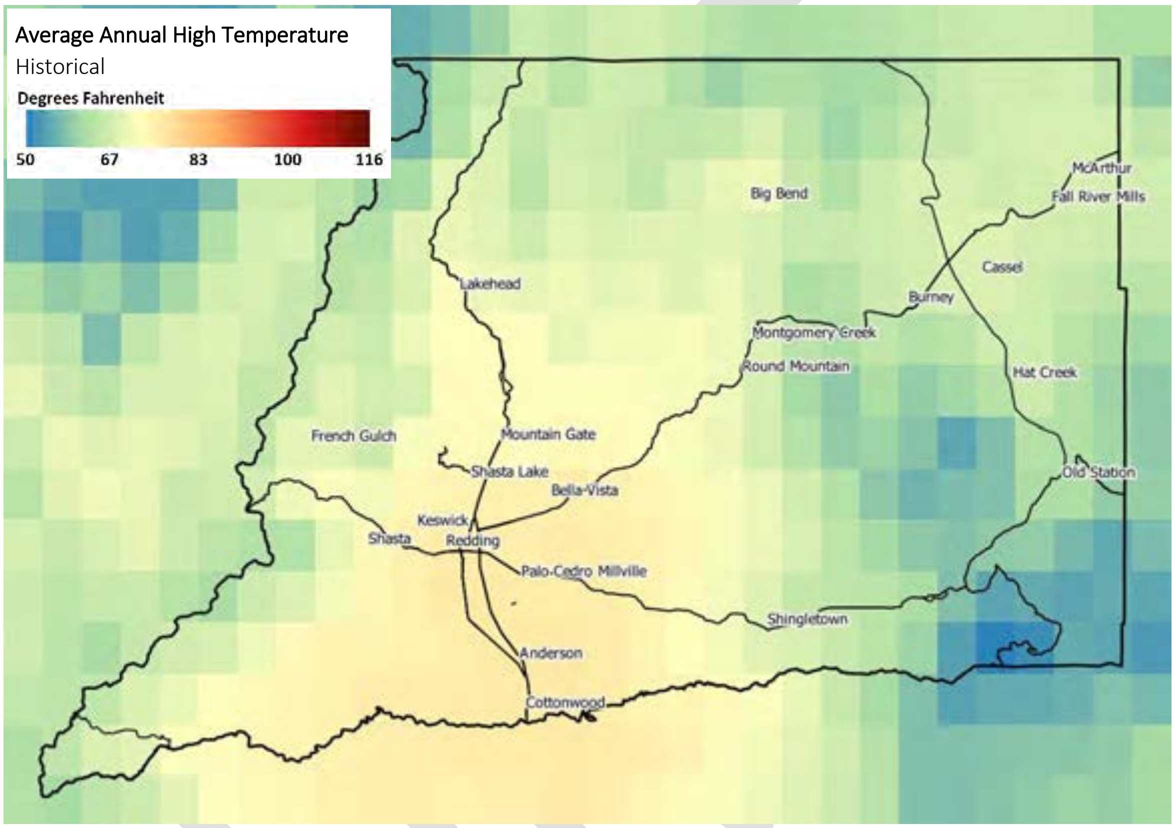

Figure 85. Historical average annual high temperatures.

Reduced Emissions Scenario (RCP4.5)

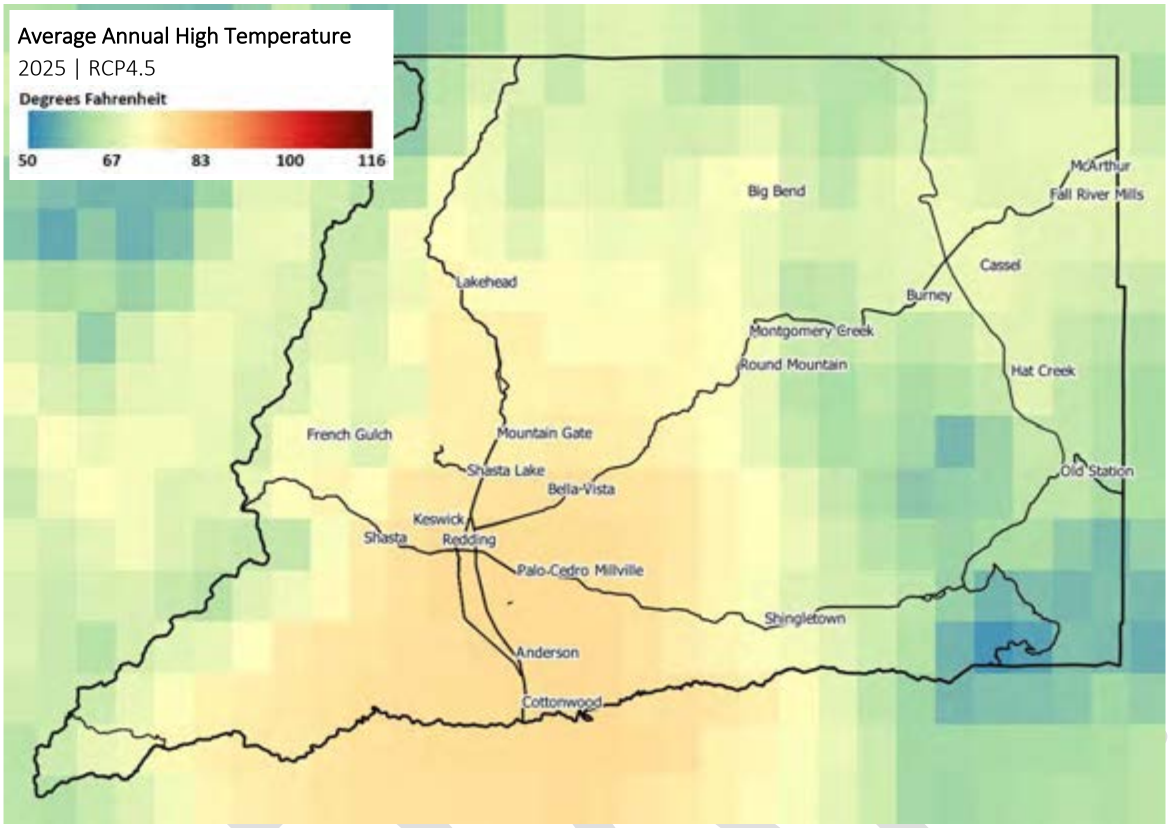

Figure 86. Average annual high temperatures in 2025, RCP4.5.

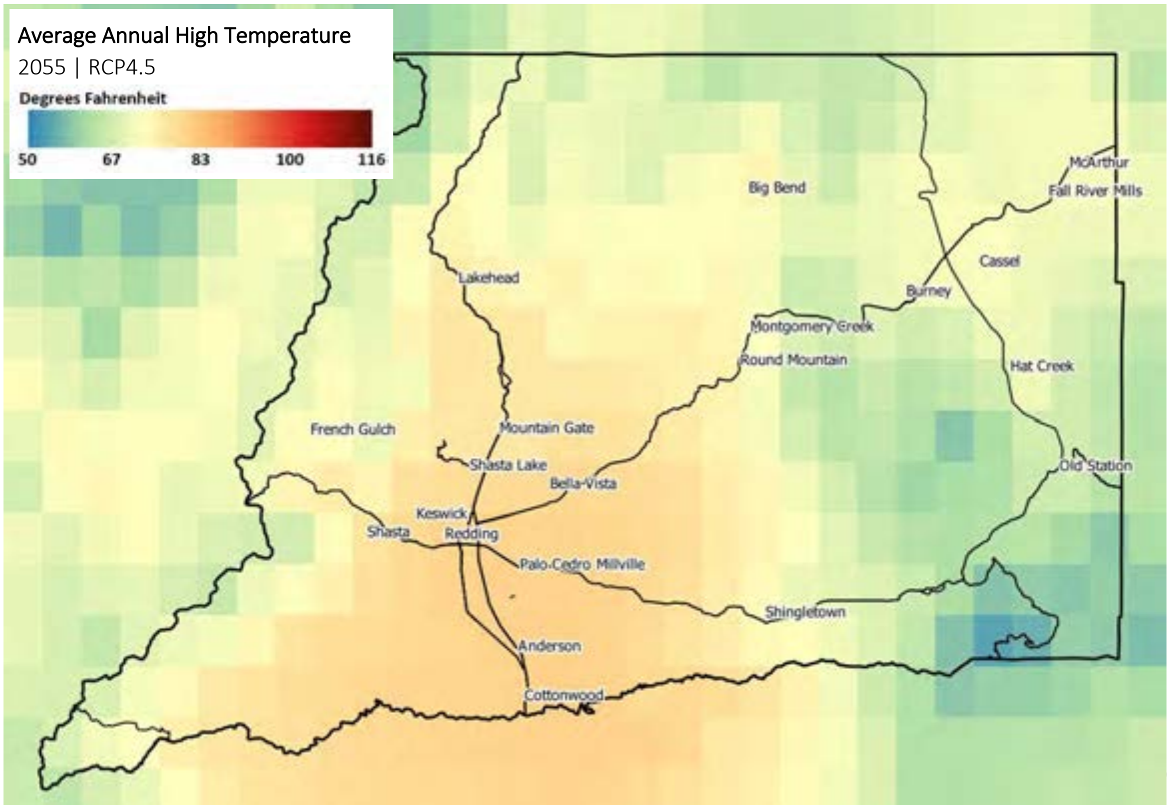

Figure 87. Average annual high temperatures in 2055, RCP4.5.

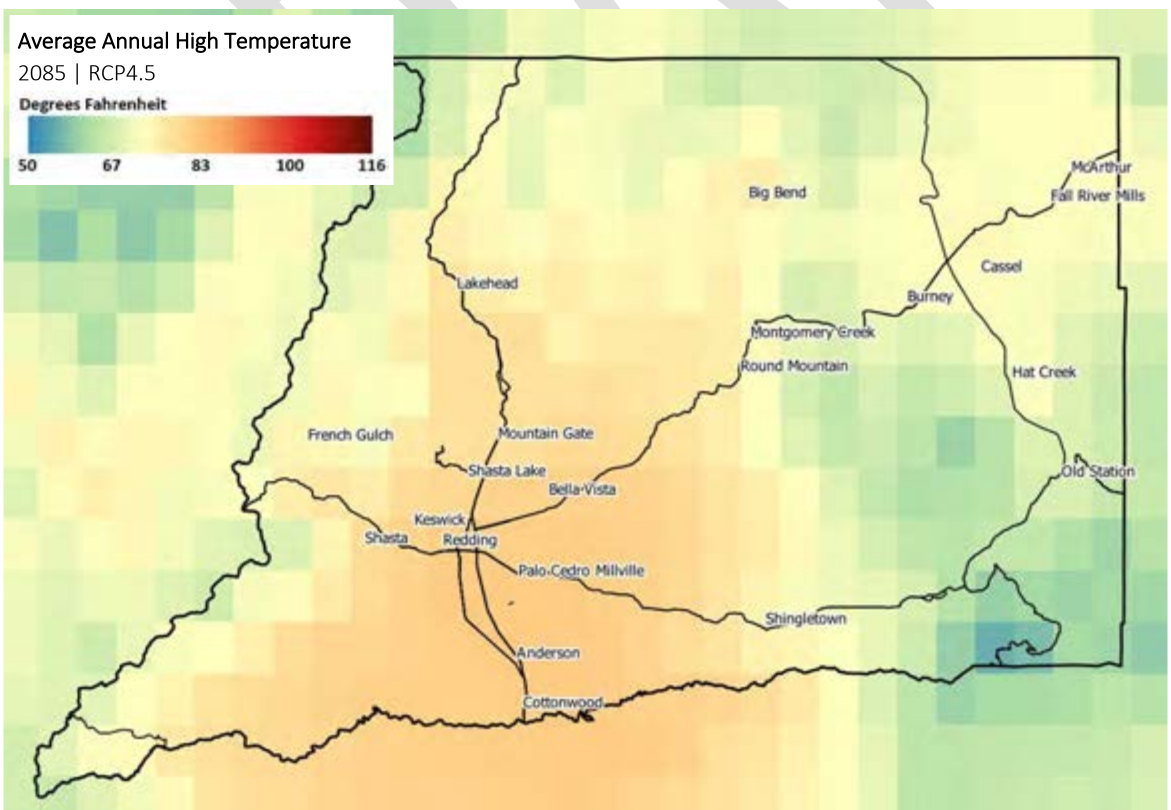

Figure 88. Average annual high temperatures in 2085, RCP4.5.

Unconstrained Emissions Scenario (RCP8.5)

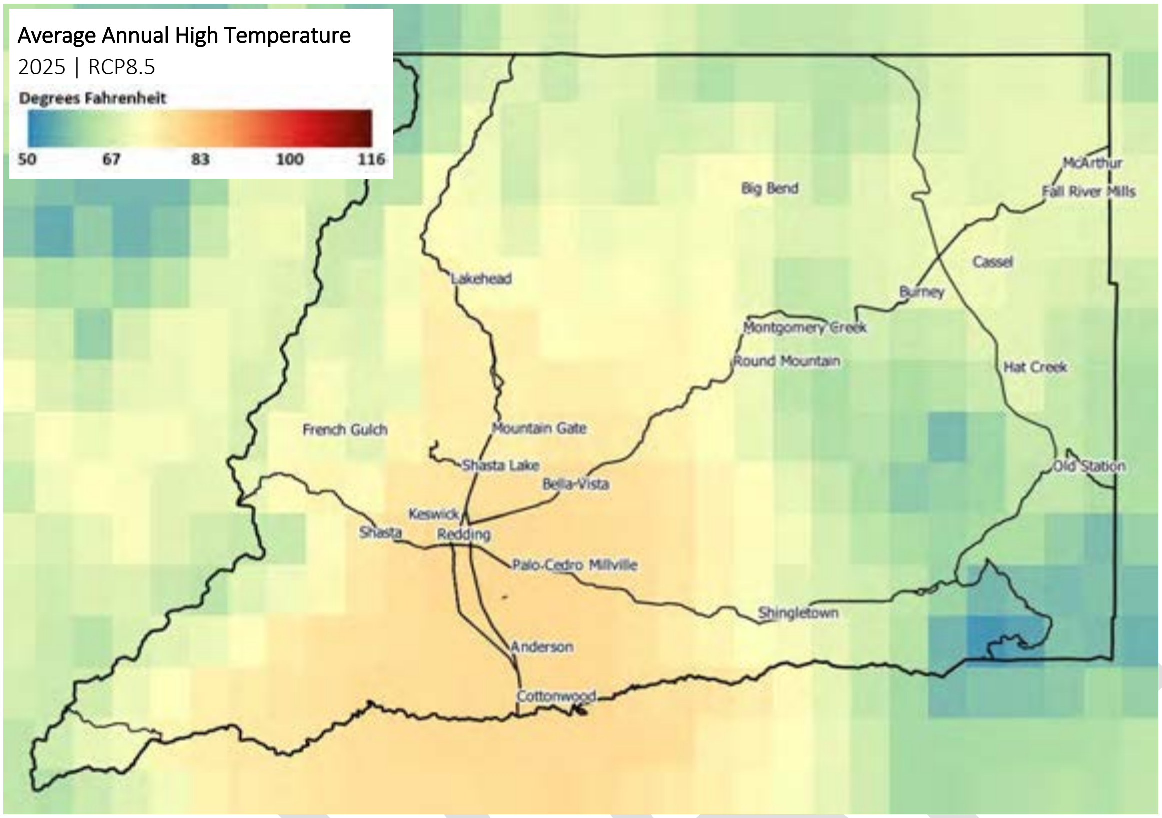

Figure 89. Average annual high temperatures in 2025, RCP8.5.

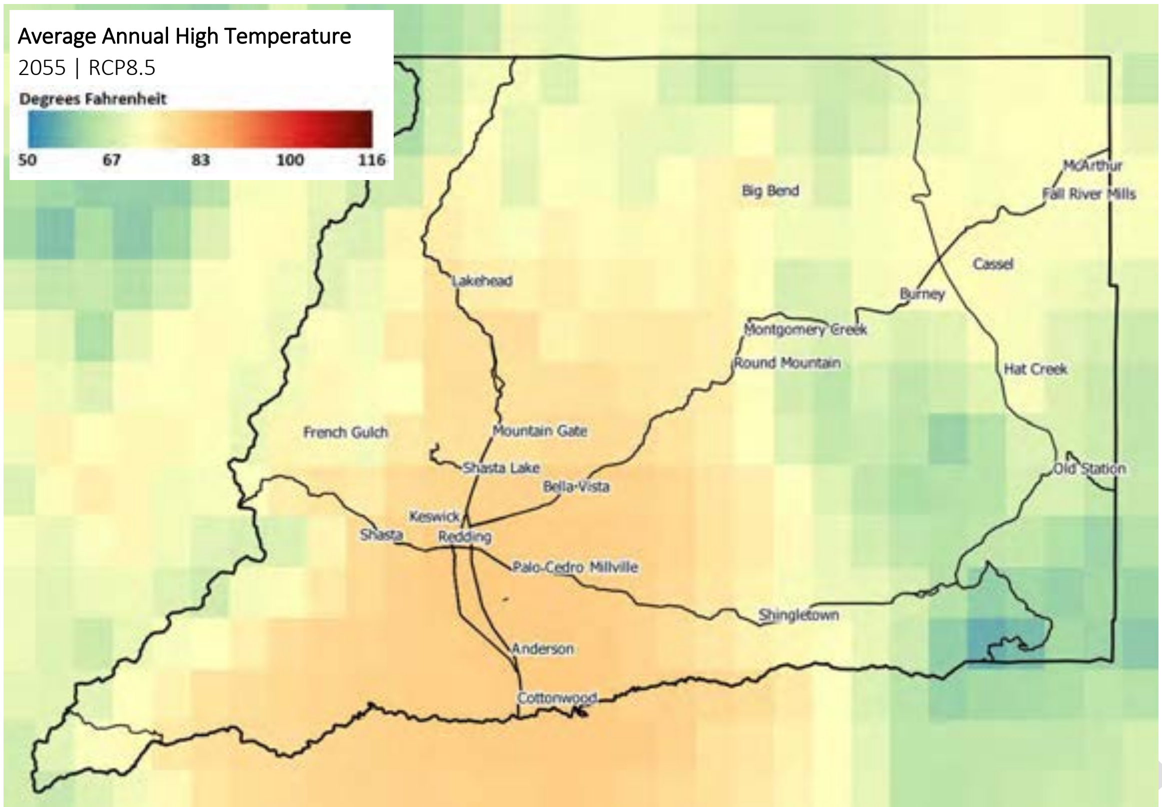

Figure 90. Average annual high temperatures in 2055, RCP8.5.

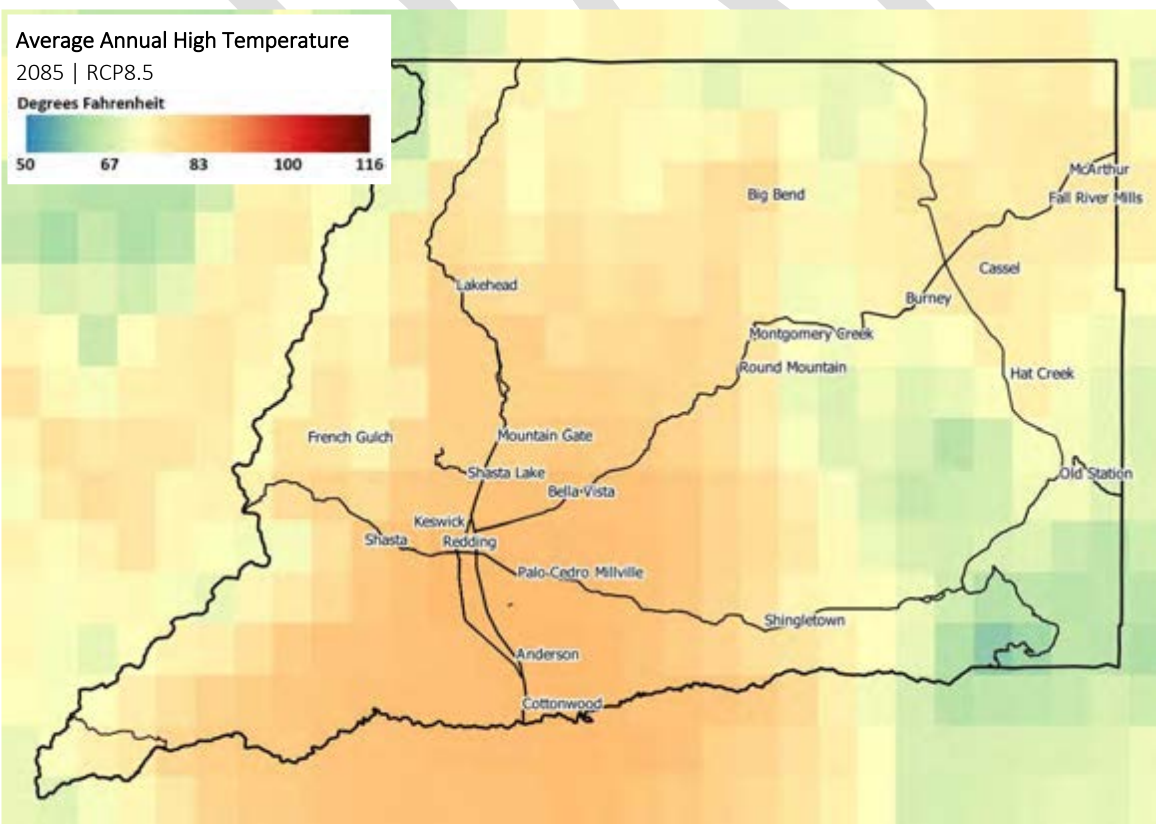

Figure 91. Average annual high temperatures in 2085, RCP8.5.

Average Summer High Temperature Projections

The average summer high temperature reflects the average daily high temperature in each grid cell for the months of June, July, and August.

Historical Conditions

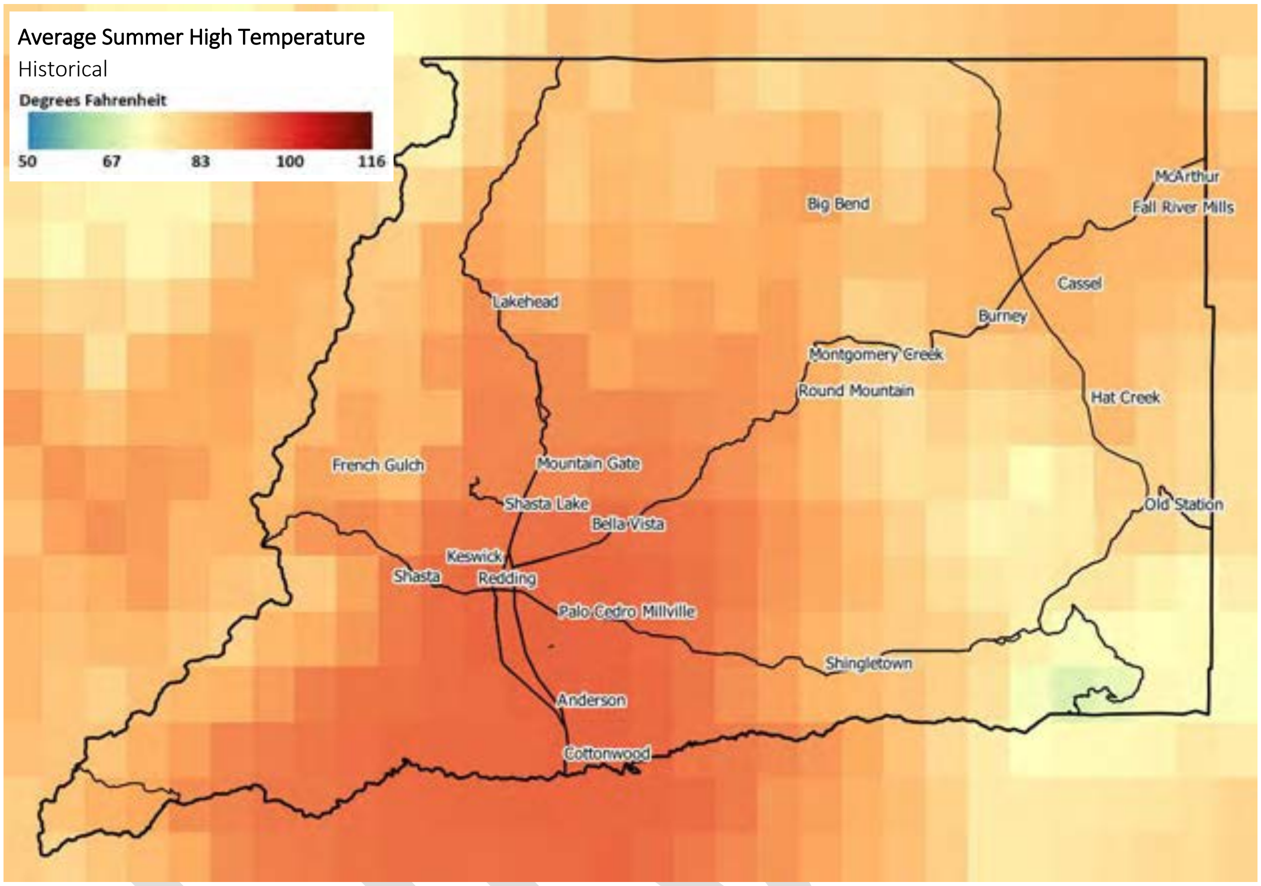

Figure 92. Historical average summer high temperatures.

Reduced Emissions Scenario (RCP4.5)

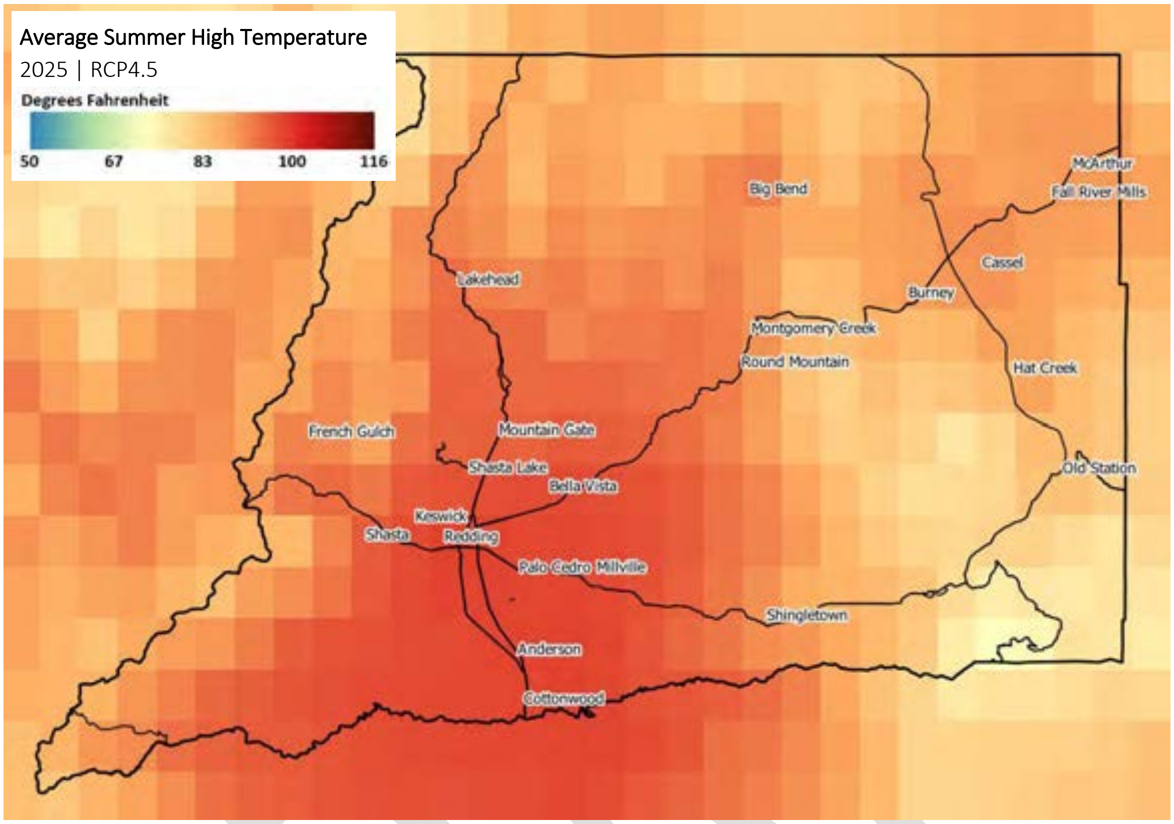

Figure 93. Average summer high temperatures, 2025, RCP4.5.

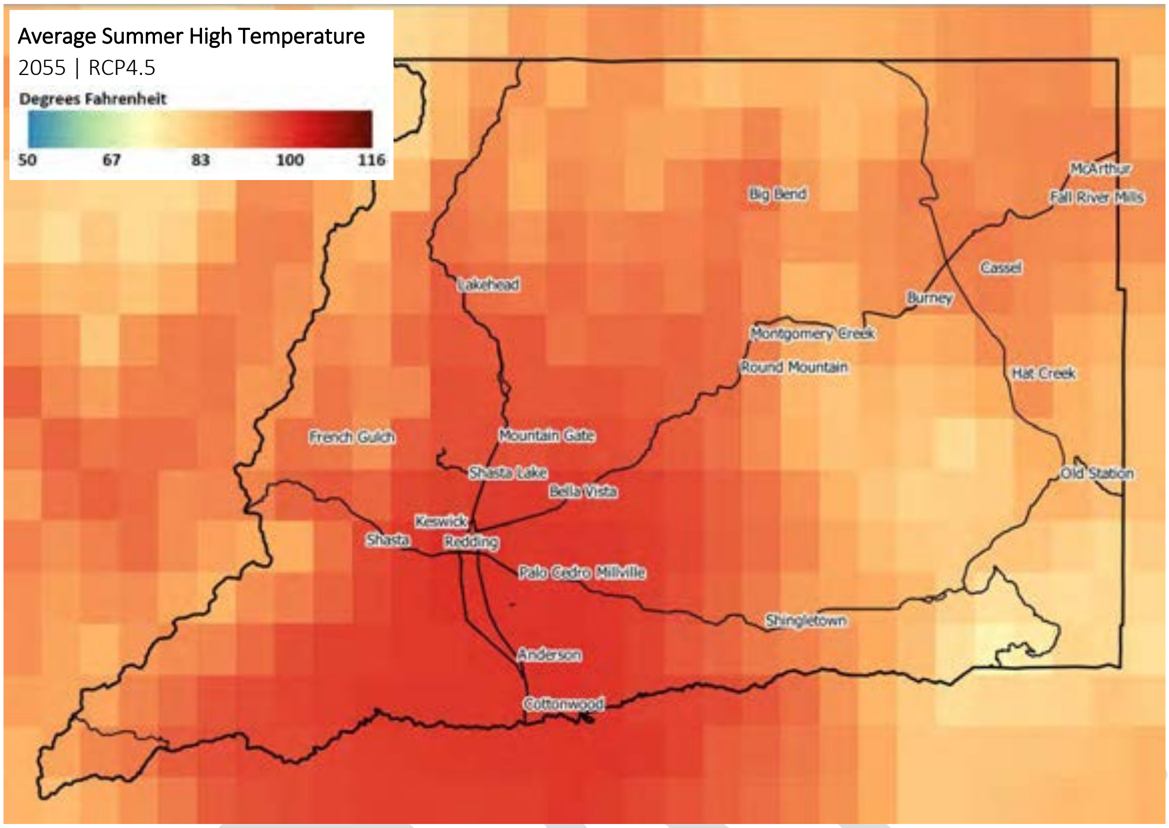

Figure 94. Average summer high temperatures, 2055, RCP4.5.

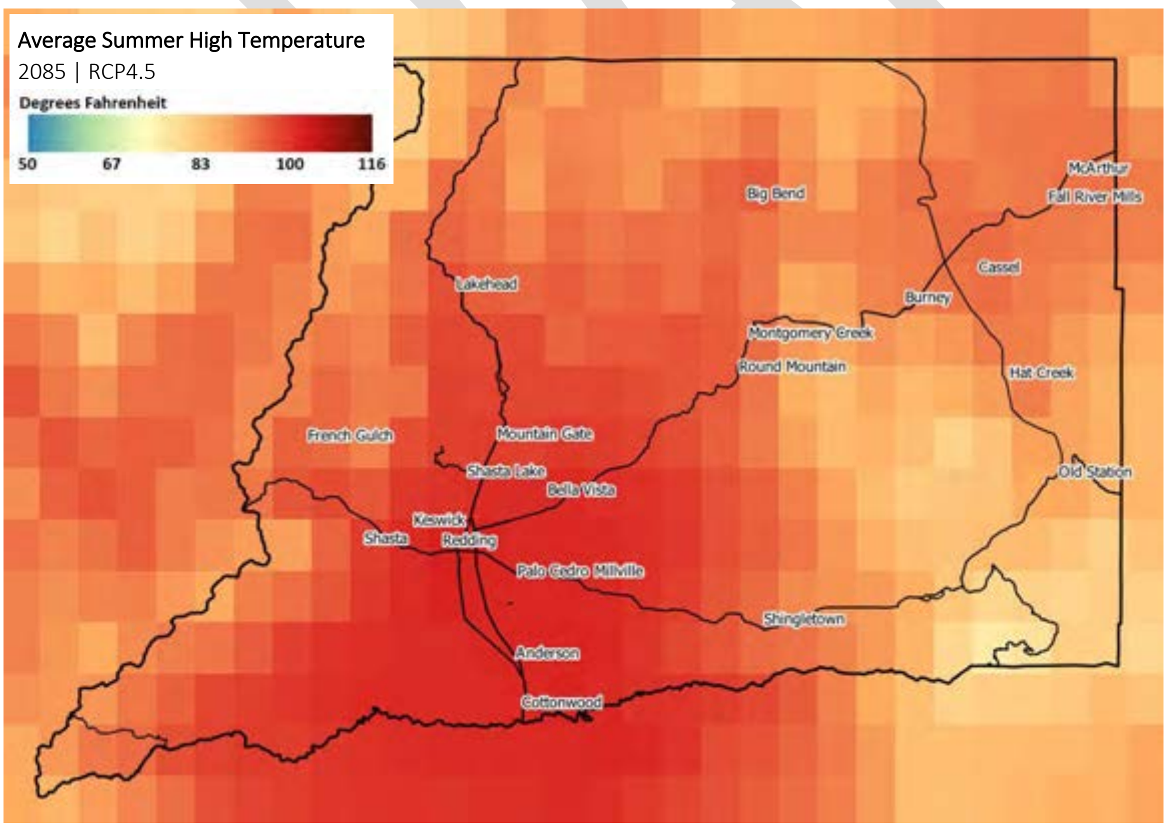

Figure 95. Average summer high temperatures, 2085, RCP4.5.

Unconstrained Emissions Scenario (RCP8.5)

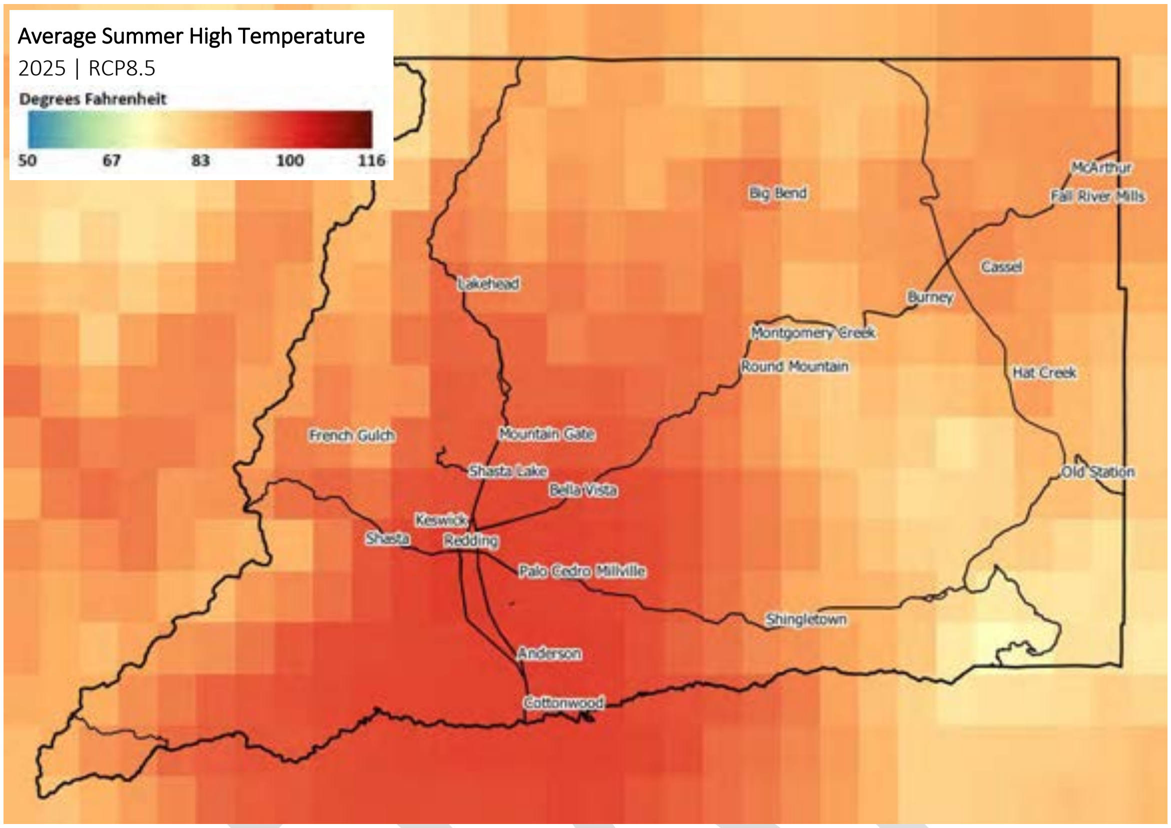

Figure 96. Average summer high temperatures, 2025, RCP8.5.

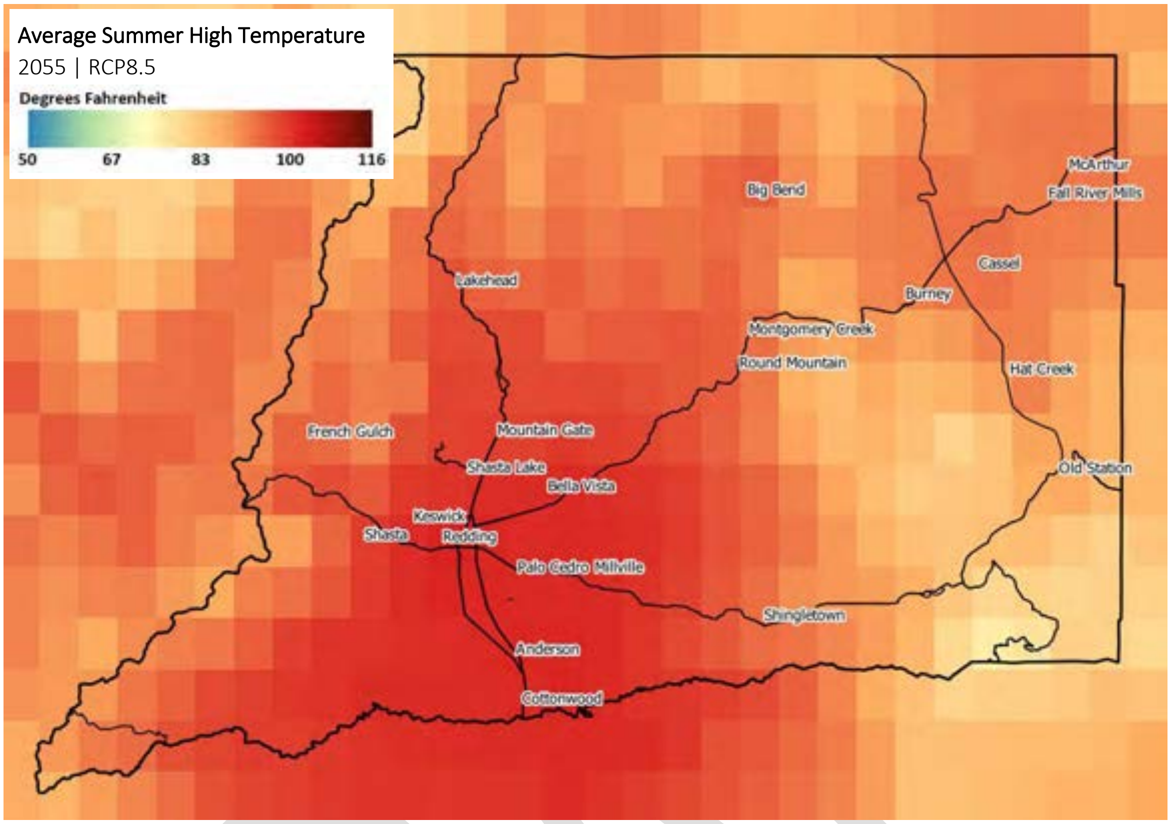

Figure 97. Average summer high temperatures, 2055, RCP8.5.

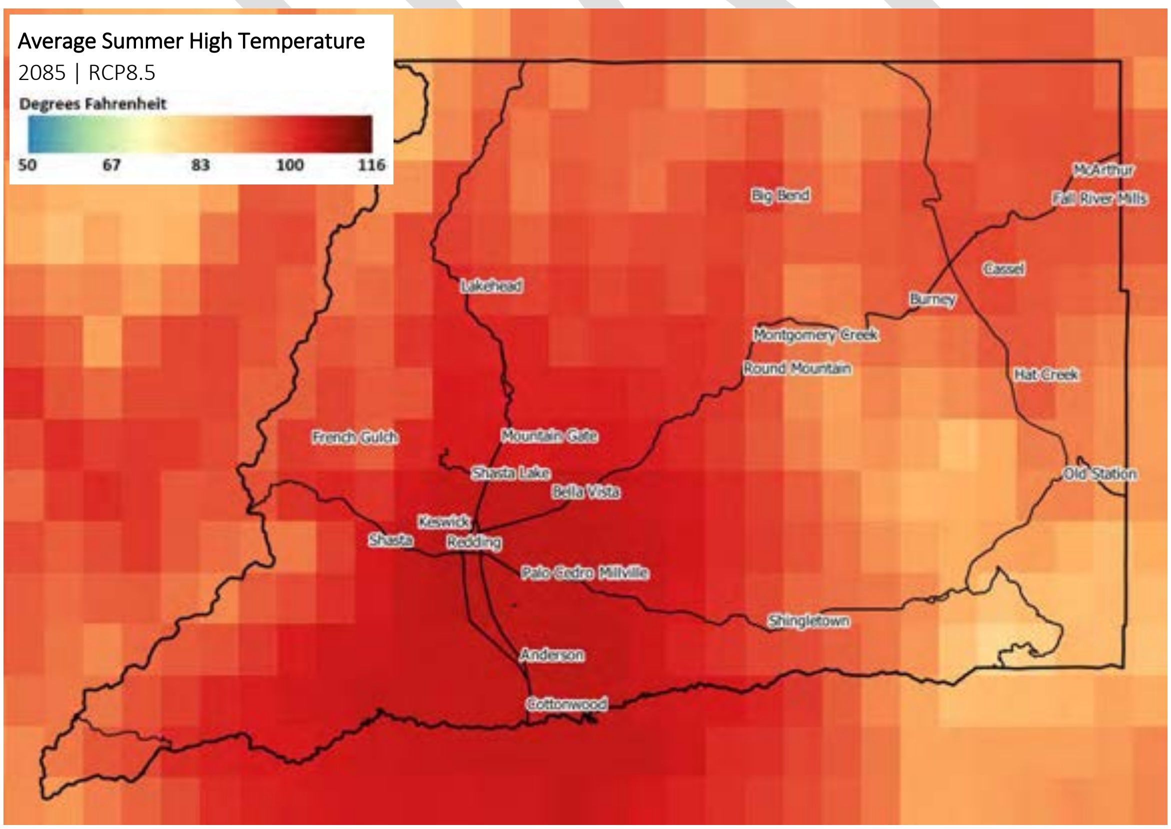

Figure 98. Average summer high temperatures in 2085, RCP8.5.

Average Heat Wave Temperature Projections

Historical Conditions

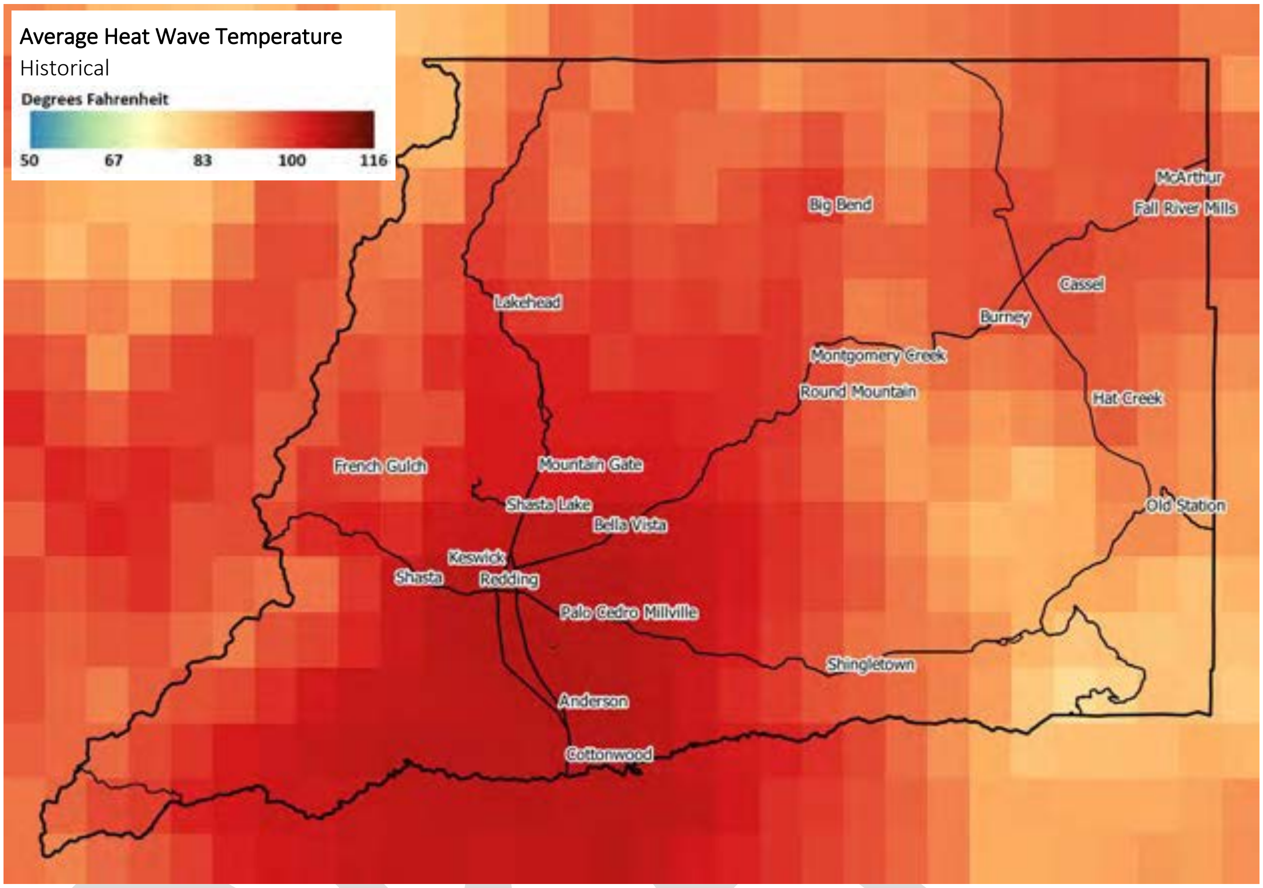

Figure 99. Average heat wave high temperatures in the Shasta region under historical conditions (1975 - 2004).

Reduced Emissions Scenario (RCP4.5)

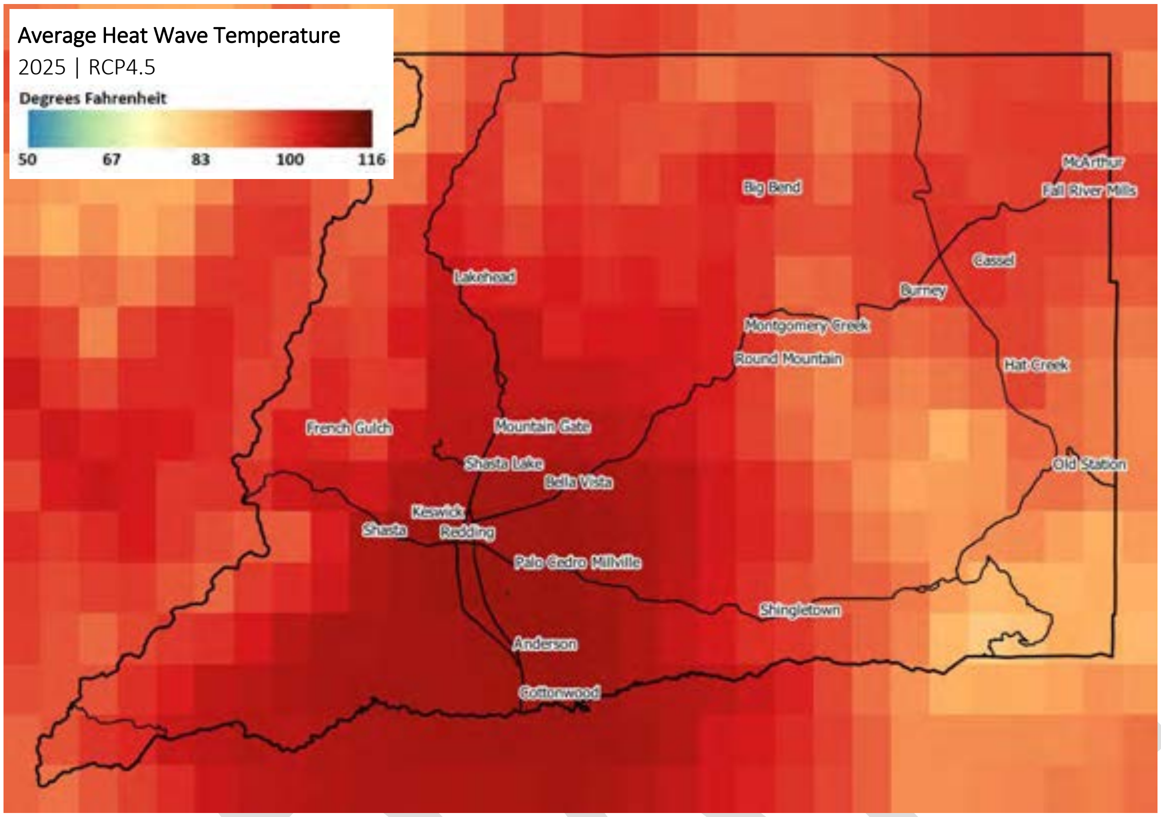

Figure 100. Average heat wave high temperatures, 2025, RCP4.5.

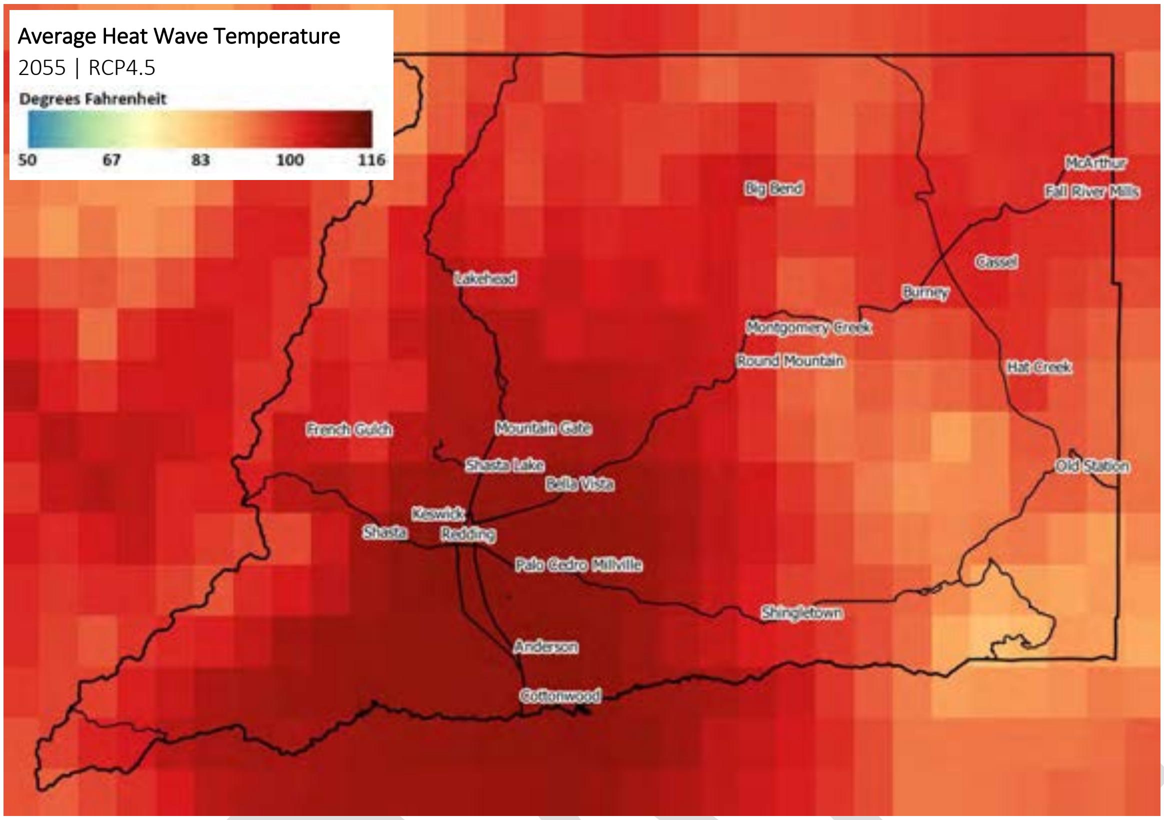

Figure 101. Average heat wave high temperatures, 2055, RCP4.5.

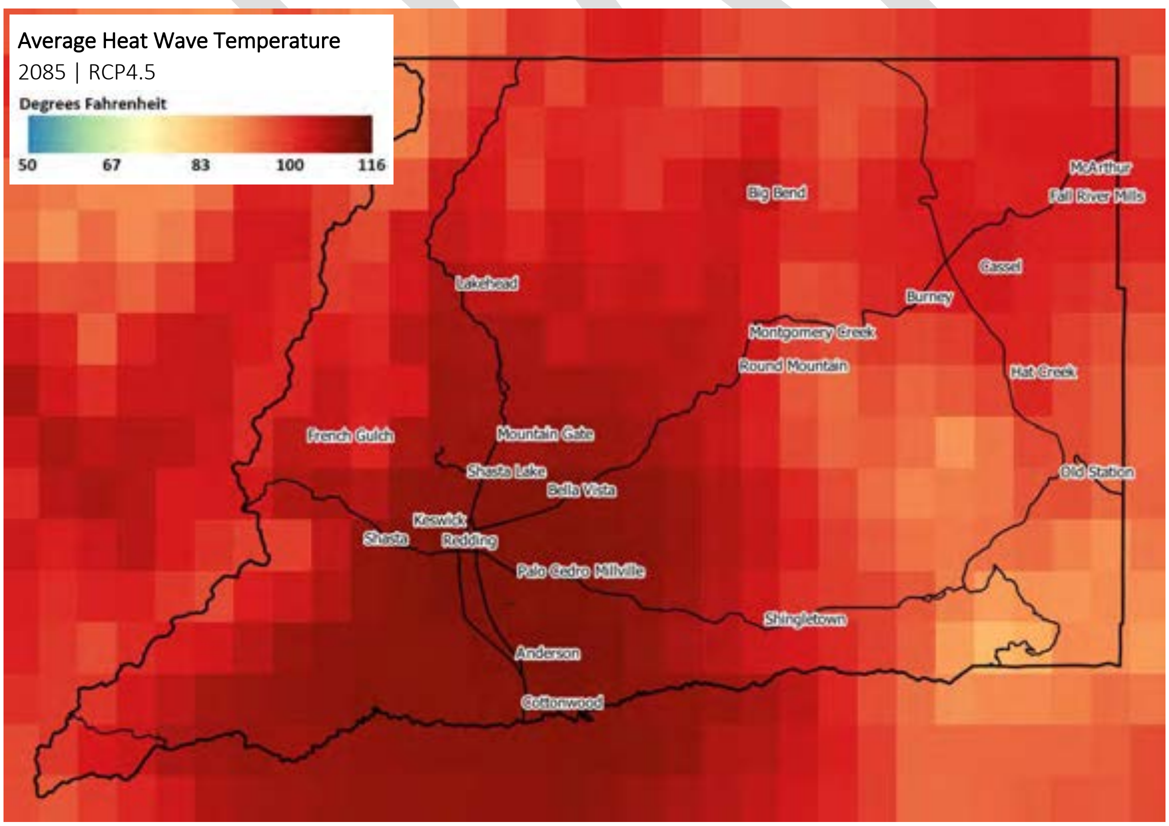

Figure 102. Average heat wave high temperatures, 2085, RCP4.5.

Unconstrained Emissions Scenario (RCP8.5)

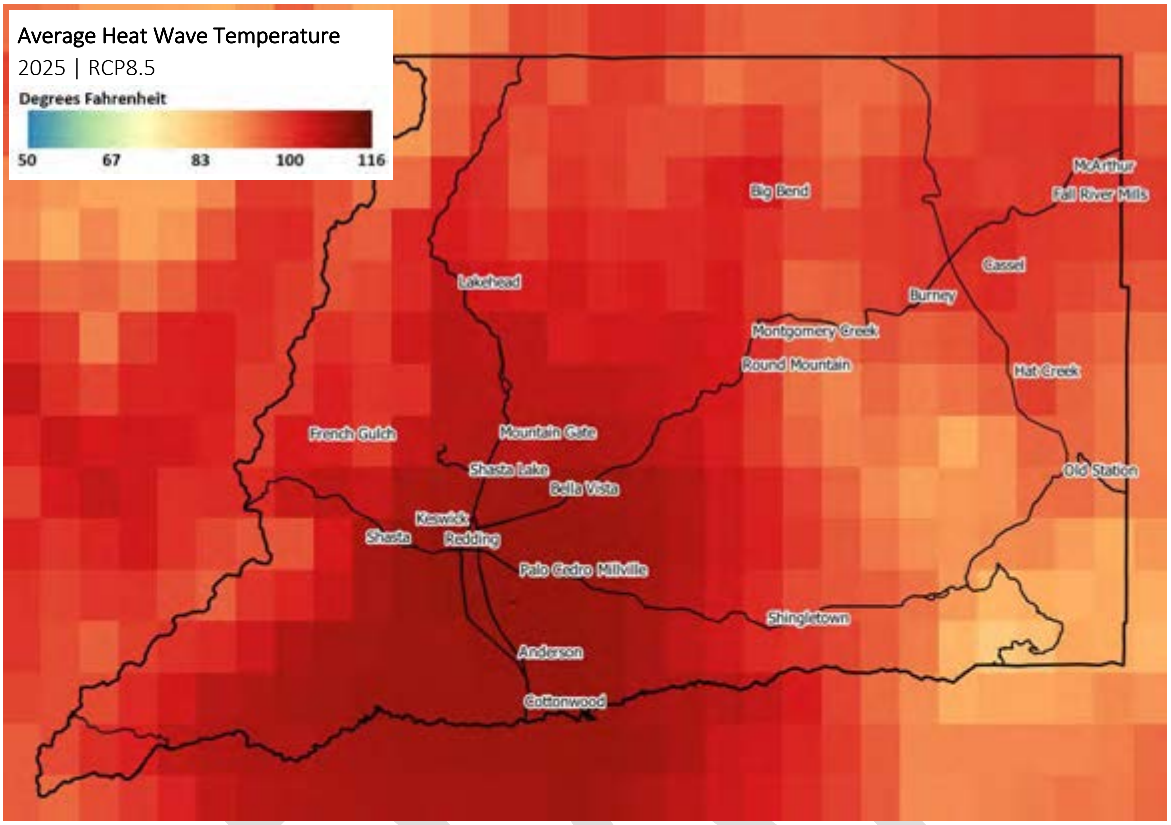

Figure 103. Average heat wave high temperatures, 2025, RCP8.5.

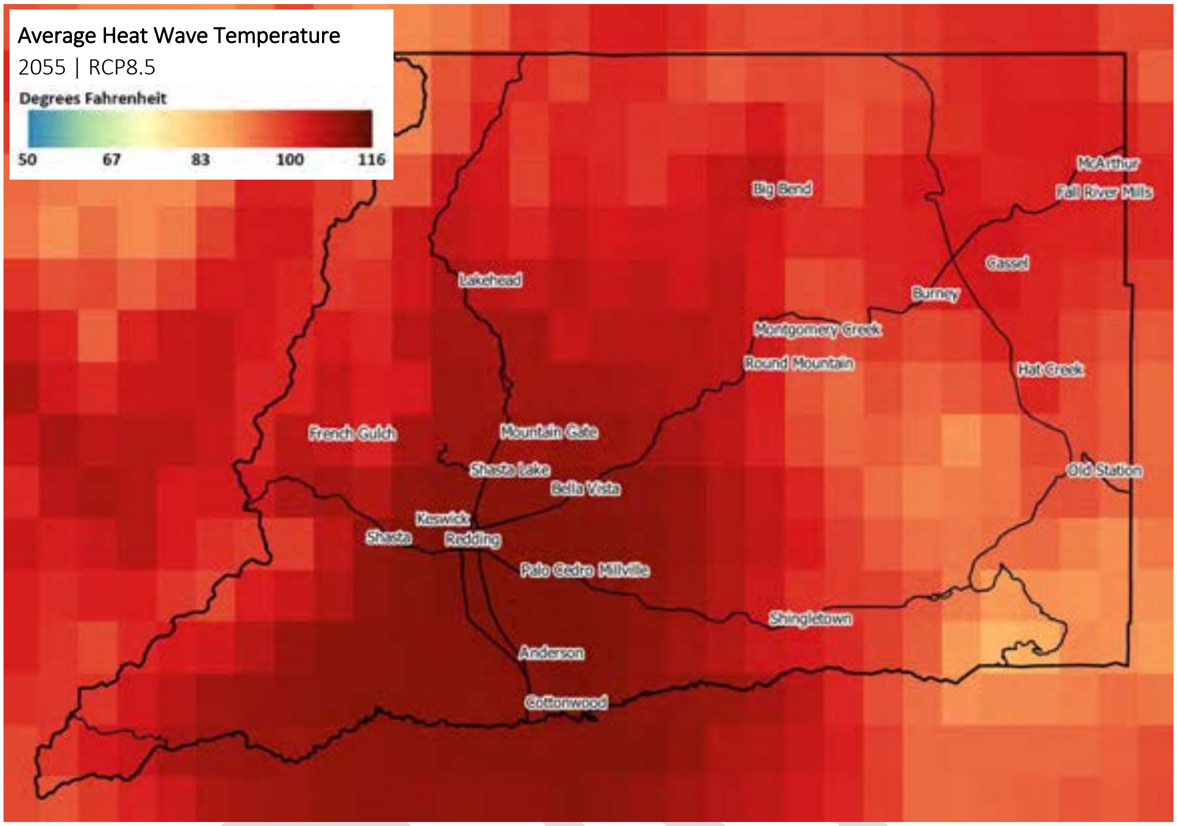

Figure 104. Average heat wave high temperatures, 2055, RCP8.5.

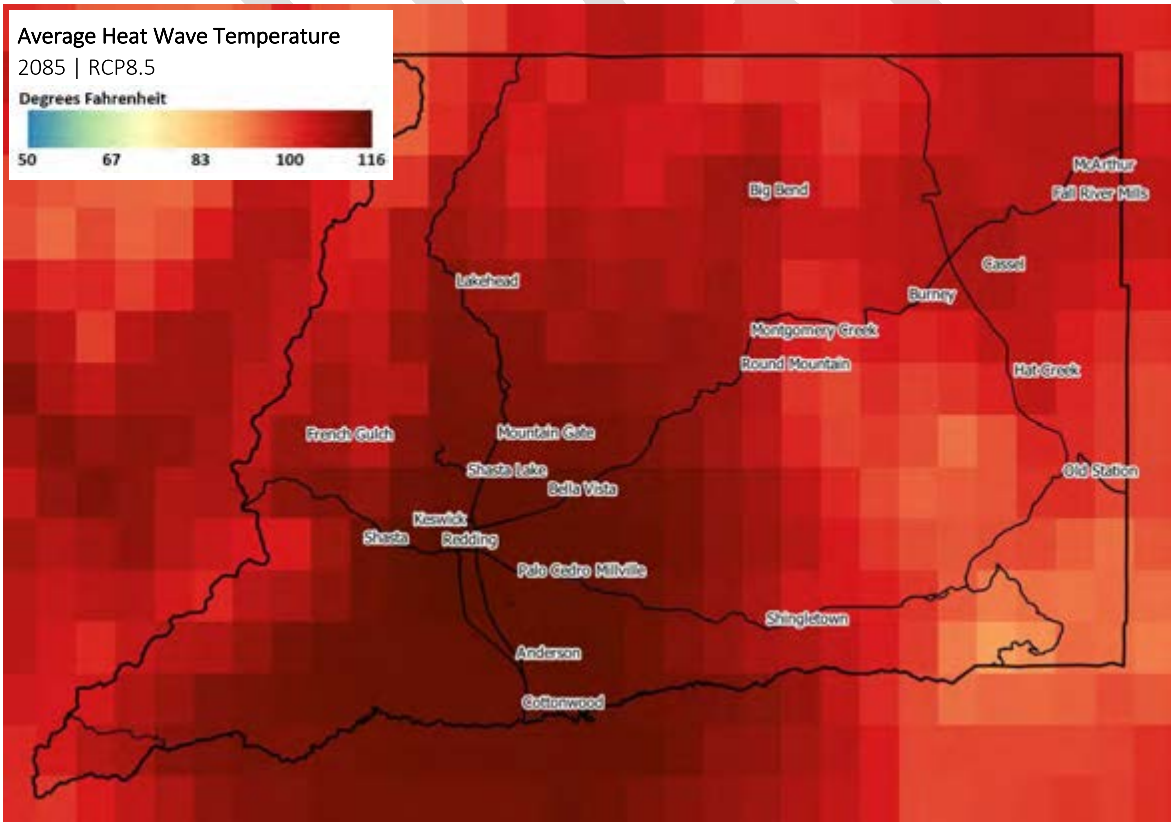

Figure 105. Average heat wave high temperatures, 2085, RCP8.5.

Precipitation Projections

Precipitation projections include projected changes to average annual precipitation, seasonal average precipitation, and extreme precipitation.

Percent Change in Average Annual Precipitation

The following figures show projected change in annual average precipitation, compared to the historical period.

Reduced Emissions Scenario (RCP4.5)

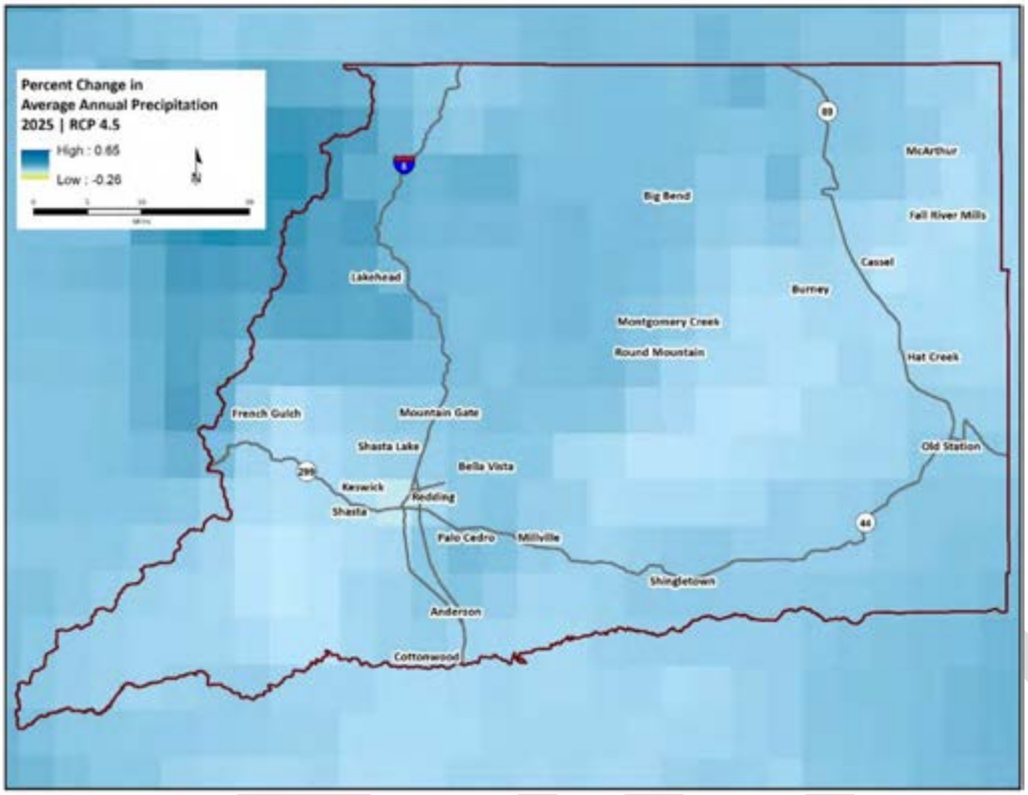

Figure 106. Projected change in average annual precipitation in the Shasta Region. 2025, RCP4.5 scenario.

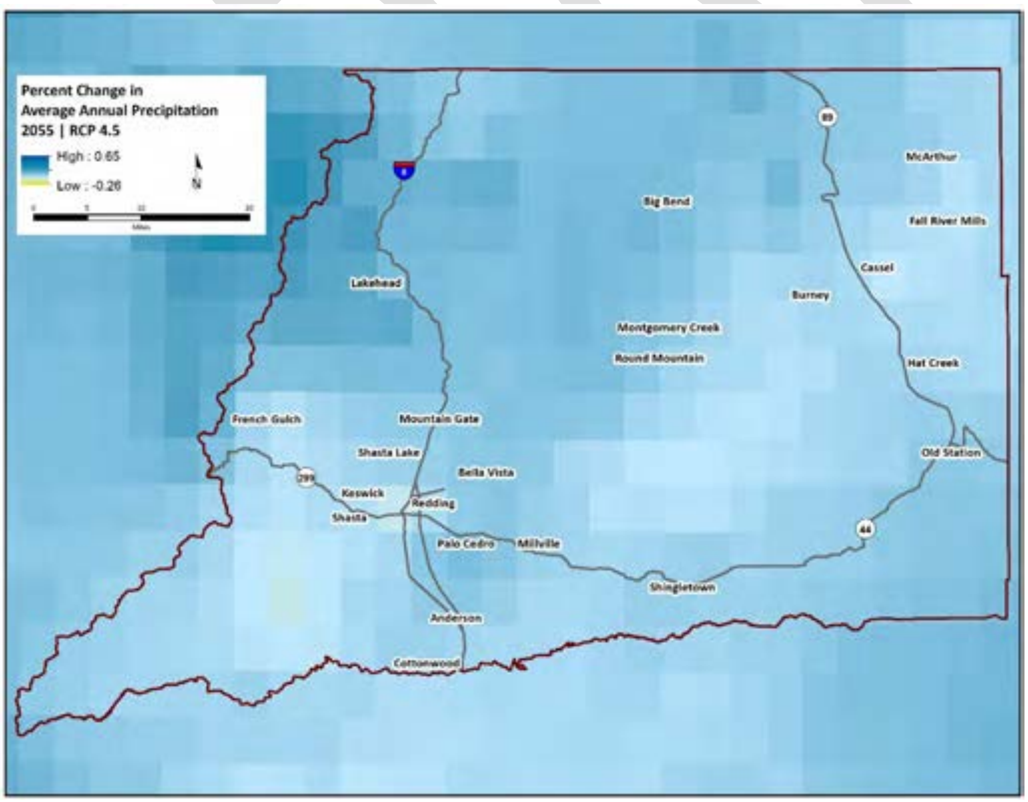

Figure 107. Projected change in average annual precipitation in the Shasta Region. 2055, RCP4.5 scenario.

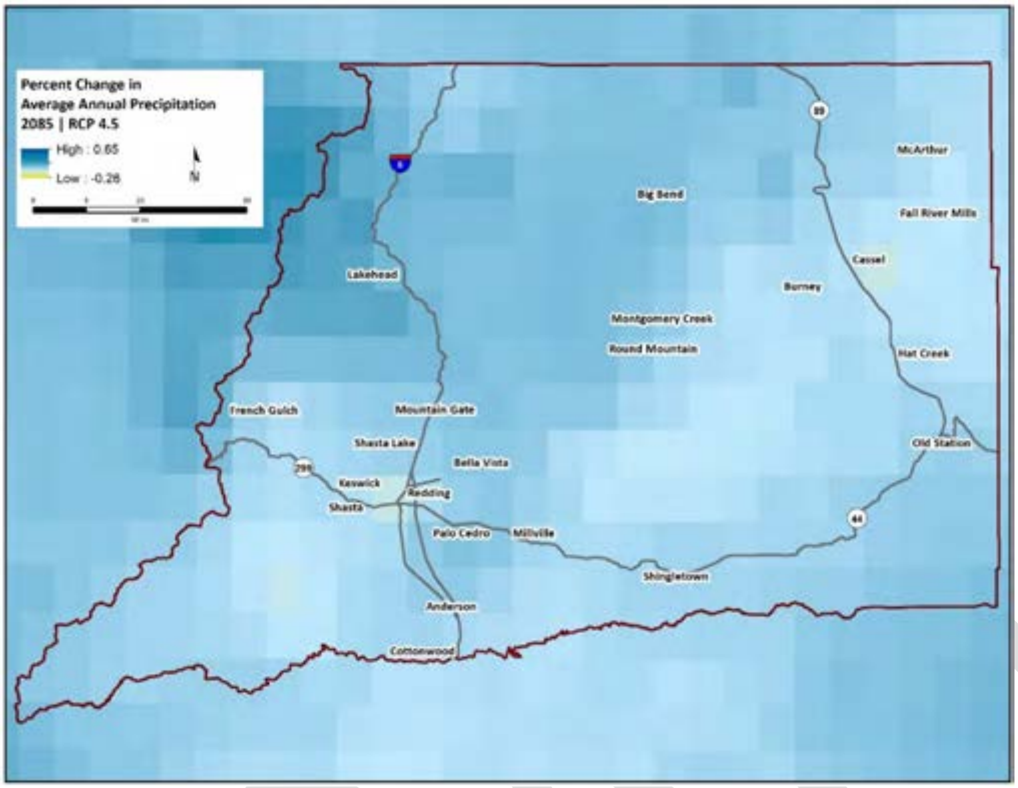

Figure 108. Projected change in average annual precipitation in the Shasta Region. 2085, RCP4.5 scenario.

Unconstrained Emissions Scenario (RCP8.5)

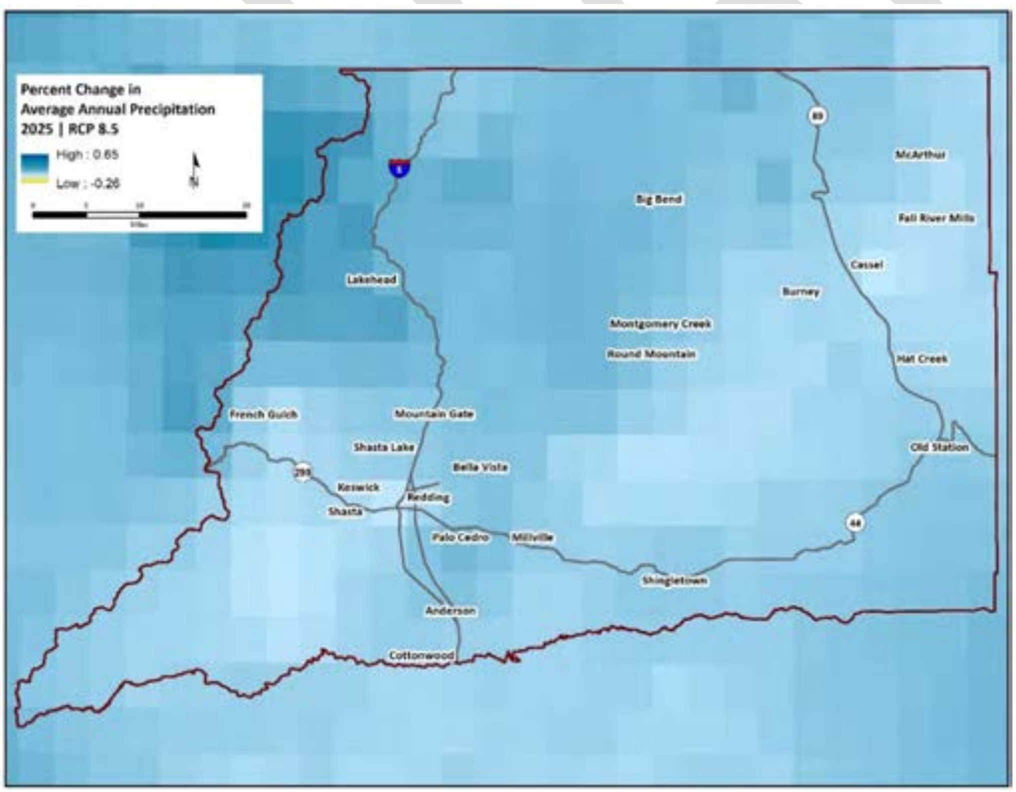

Figure 109. Projected change in average annual precipitation in the Shasta Region. 2025, RCP8.5 scenario.

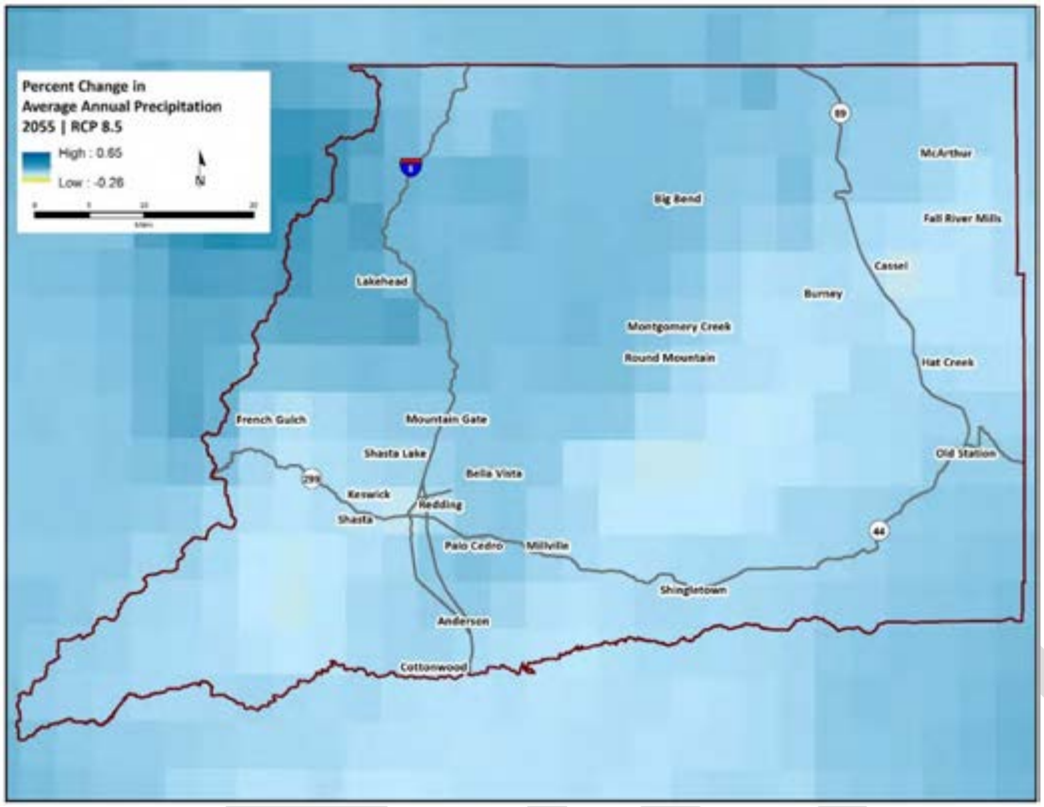

Figure 110. Projected change in average annual precipitation in the Shasta Region. 2055, RCP8.5 scenario.

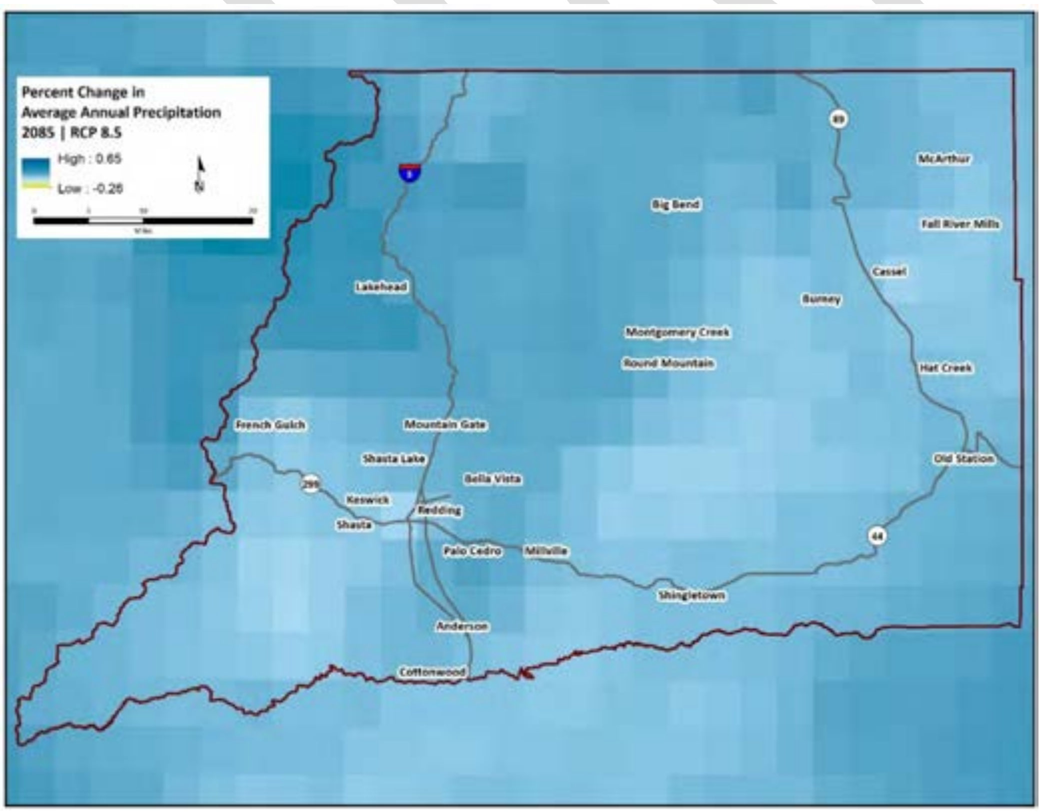

Figure 111. Projected change in average annual precipitation in the Shasta Region. 2085, RCP8.5 scenario.

Percent Change in Dry Season Average Precipitation

Dry season precipitation projections are only shown for 2055.

Reduced Emissions Scenario (RCP4.5)

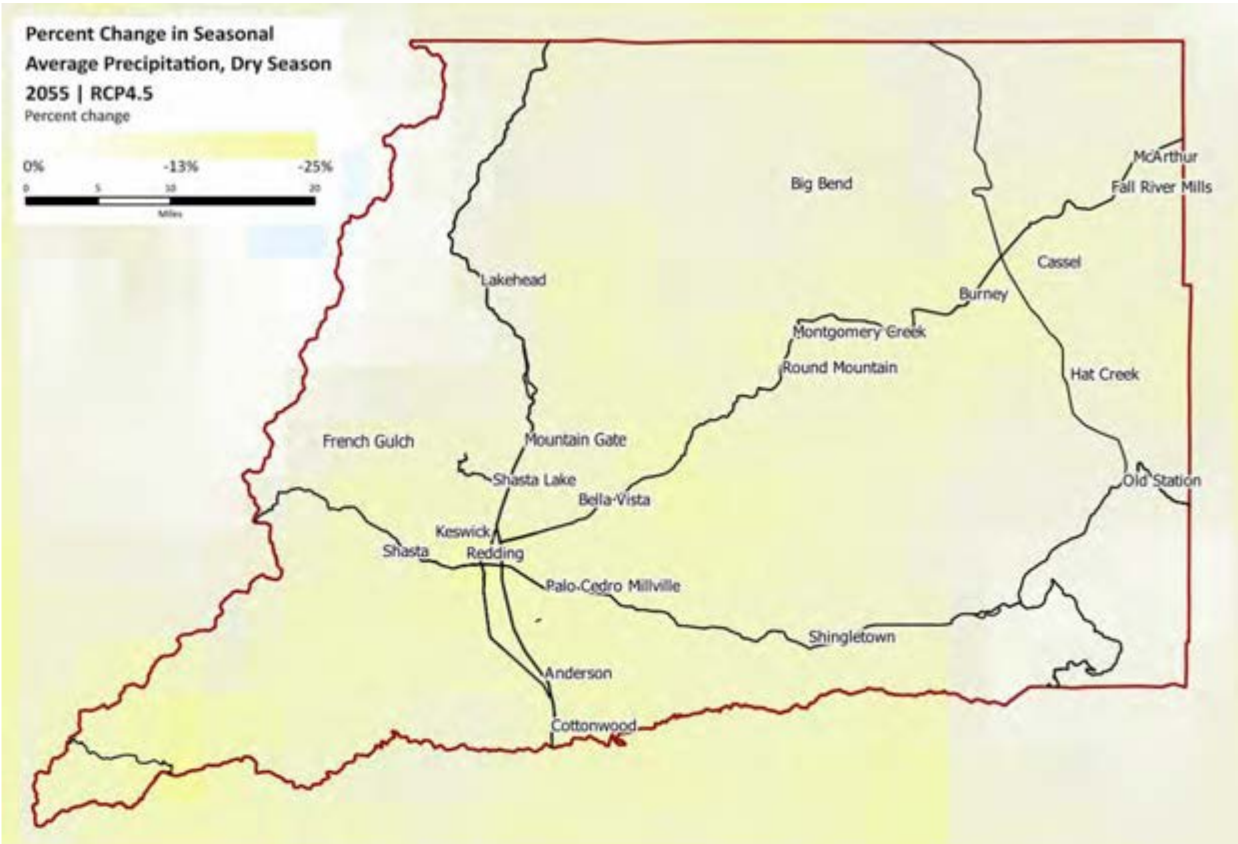

Figure 112. Percent change in dry season precipitation, 2055 RCP4.5.

Unconstrained Emissions Scenario (RCP8.5)

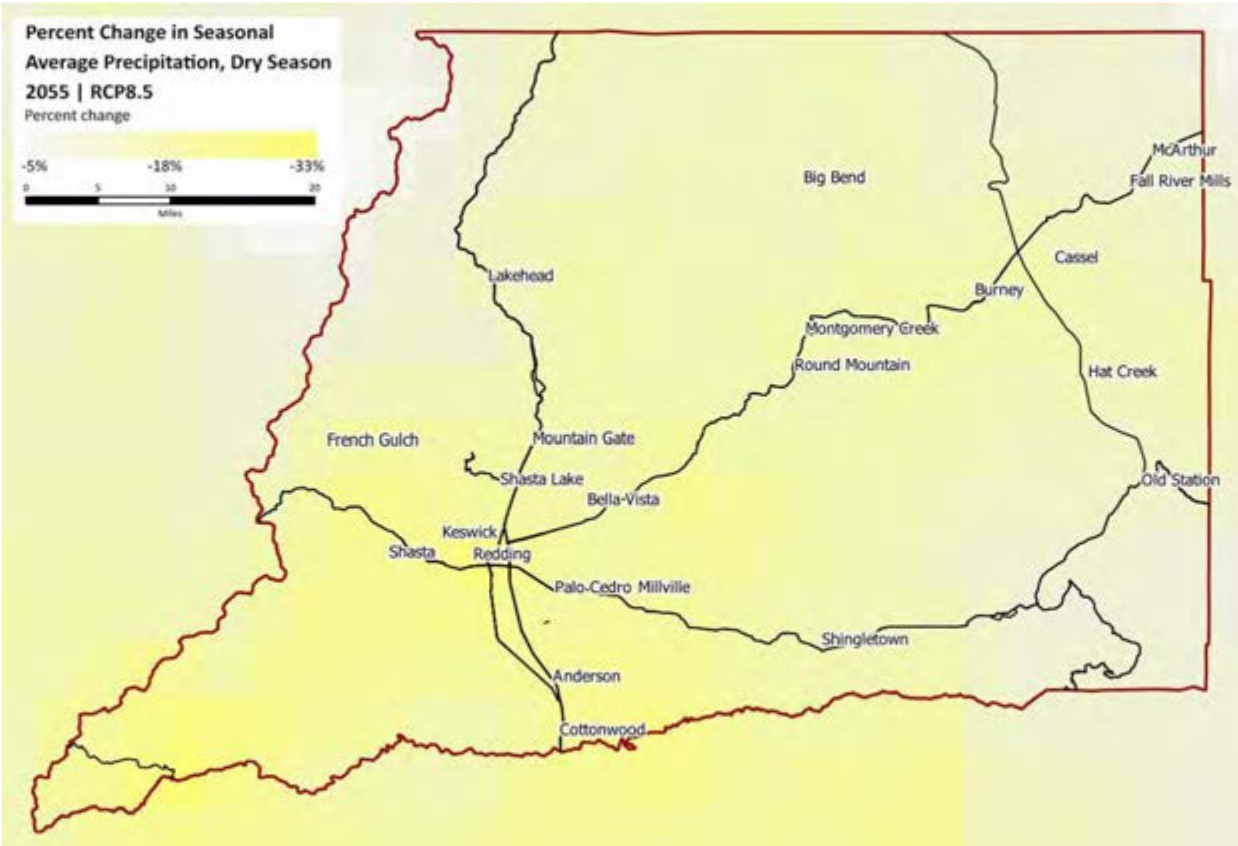

Figure 113. Percent change in dry season precipitation, 2055 RCP8.5.

Percent Change in Wet Season Average Precipitation

Reduced Emissions Scenario (RCP4.5)

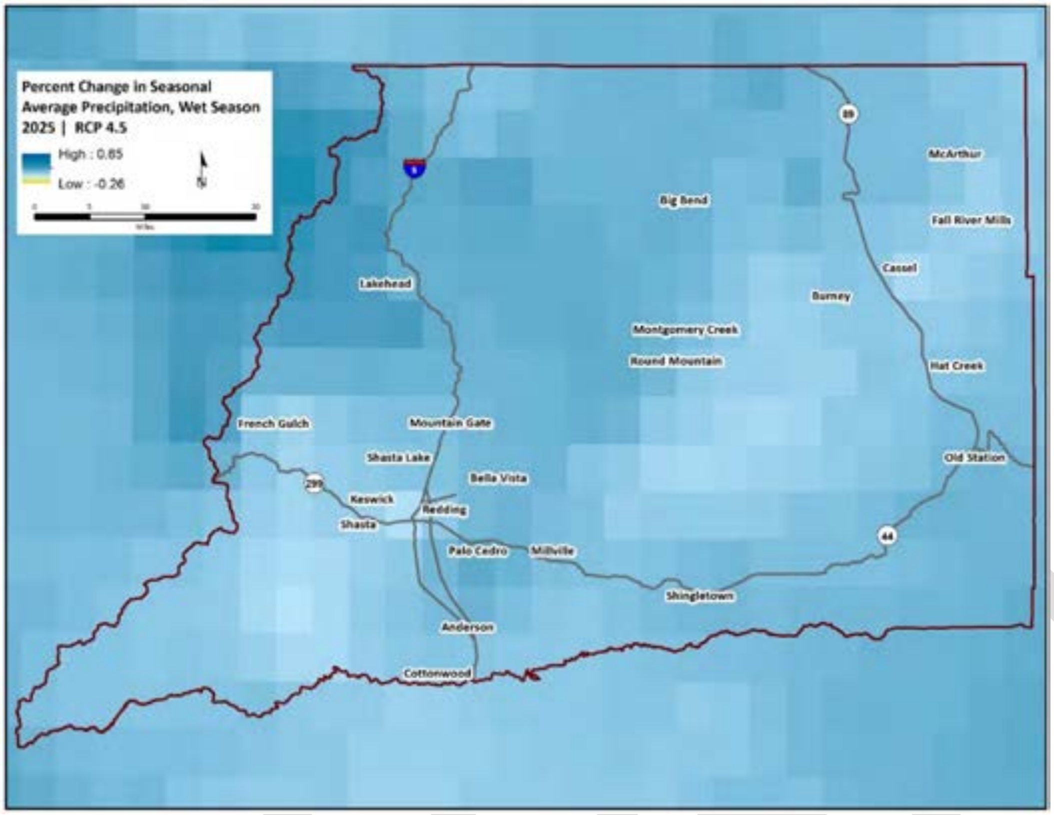

Figure 114. Projected change in average wet season precipitation in the Shasta Region. 2025, RCP4.5 scenario.

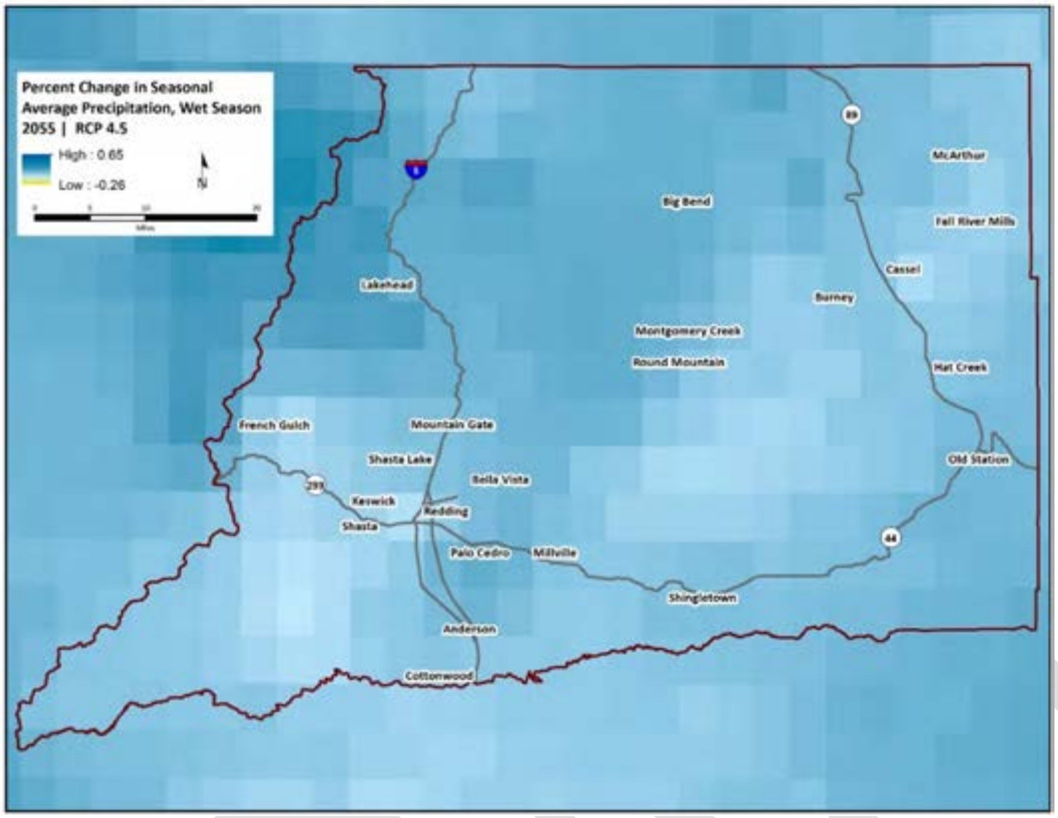

Figure 115. Projected change in average wet season precipitation in the Shasta Region. 2055, RCP4.5 scenario.

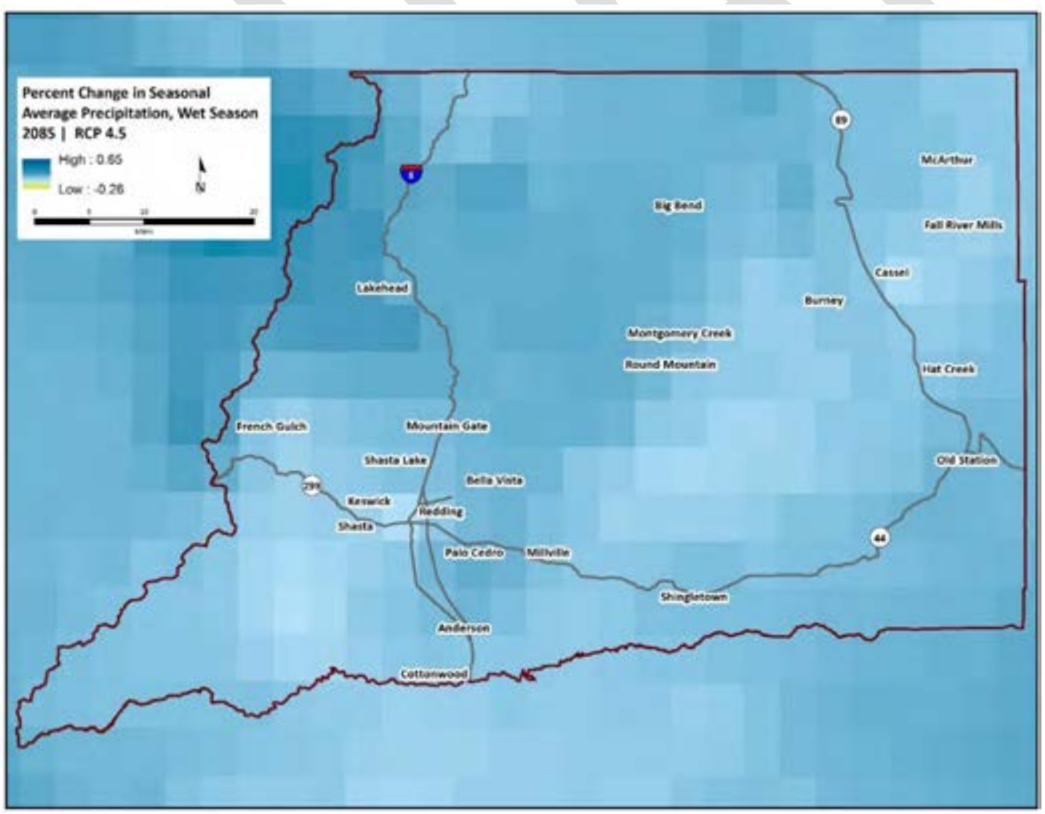

Figure 116.Projected change in average wet season precipitation in the Shasta Region. 2085, RCP4.5 scenario.

Unconstrained Emissions Scenario (RCP8.5)

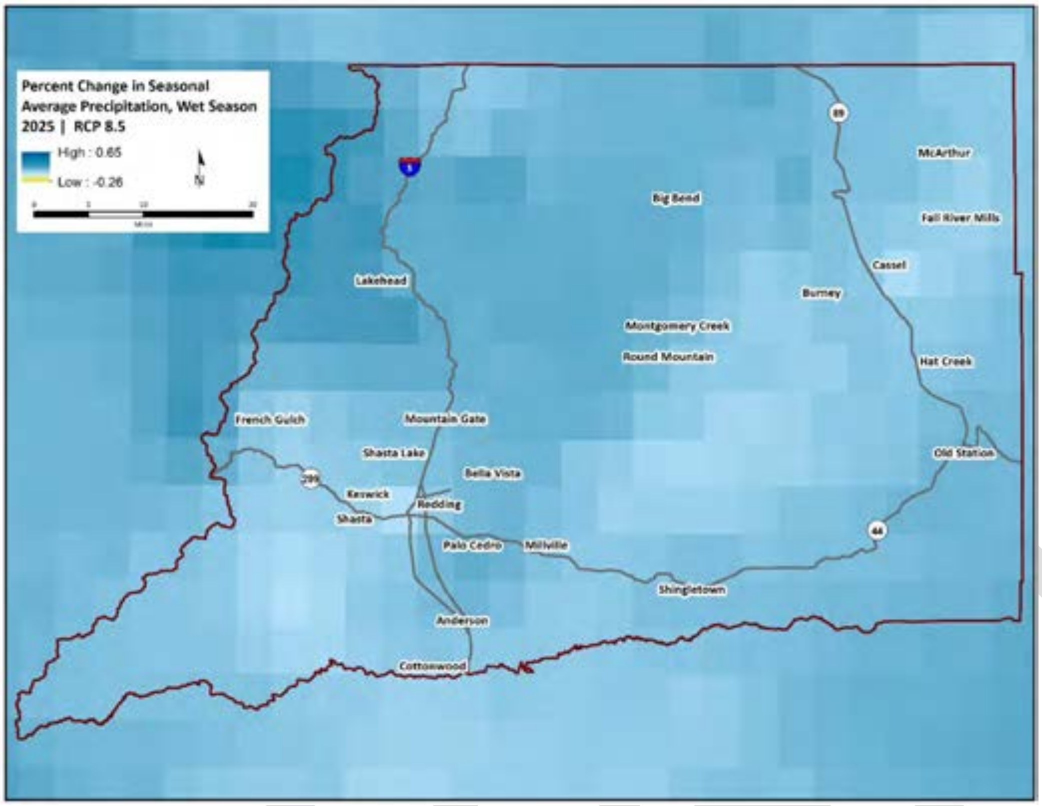

Figure 117.Projected change in average wet season precipitation in the Shasta Region. 2025, RCP8.5 scenario.

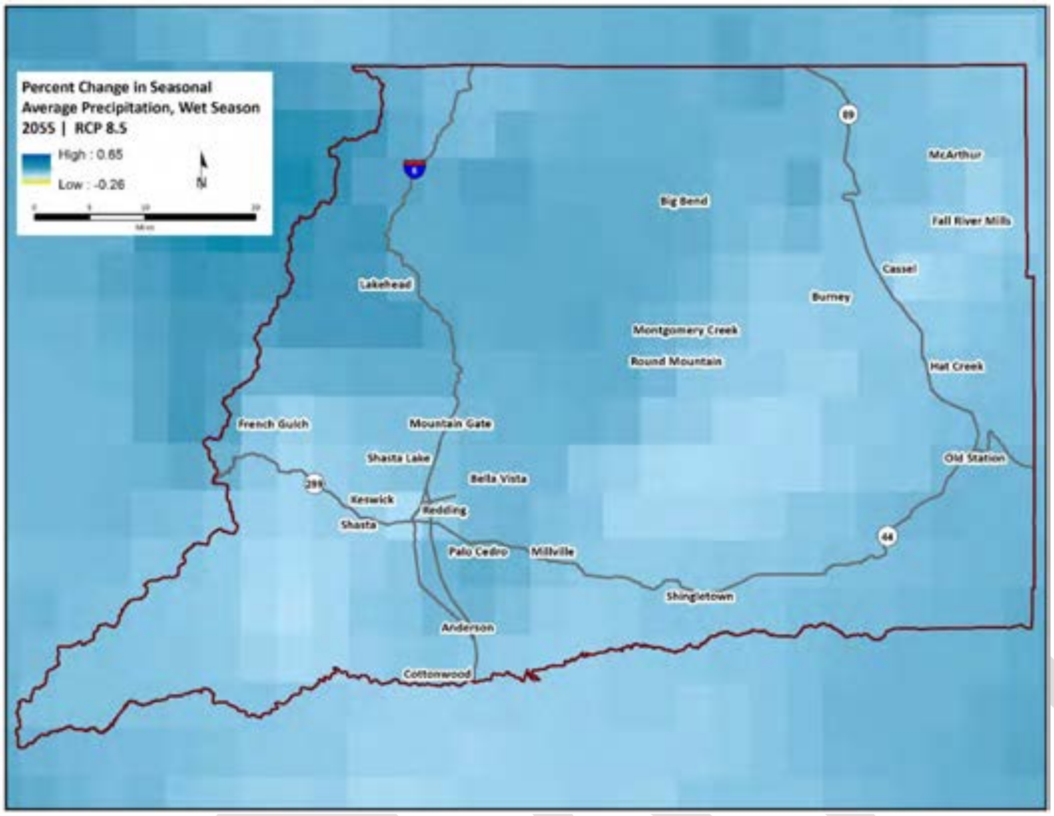

Figure 118. Projected change in average wet season precipitation in the Shasta Region. 2055, RCP8.5 scenario.

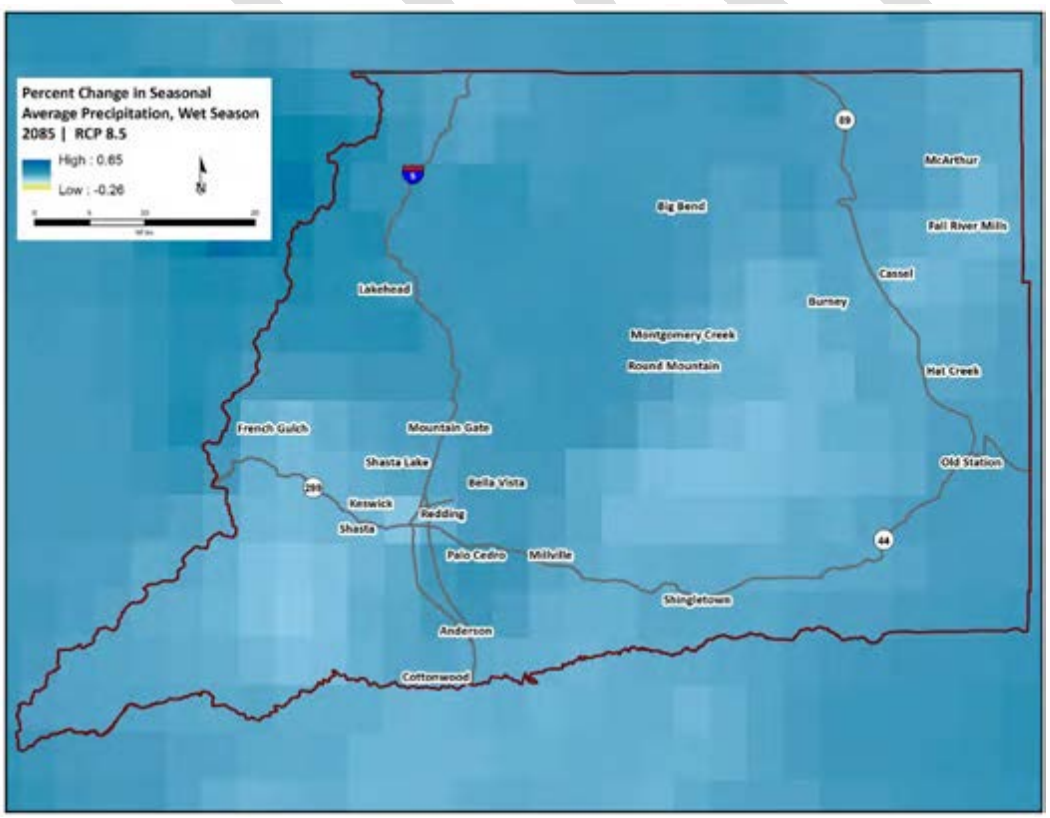

Figure 119. Projected change in average wet season precipitation in the Shasta Region. 2085, RCP8.5 scenario.

Percent Change in Extreme Precipitation Event Intensity

25-year Event

Reduced Emissions Scenario (RCP4.5)

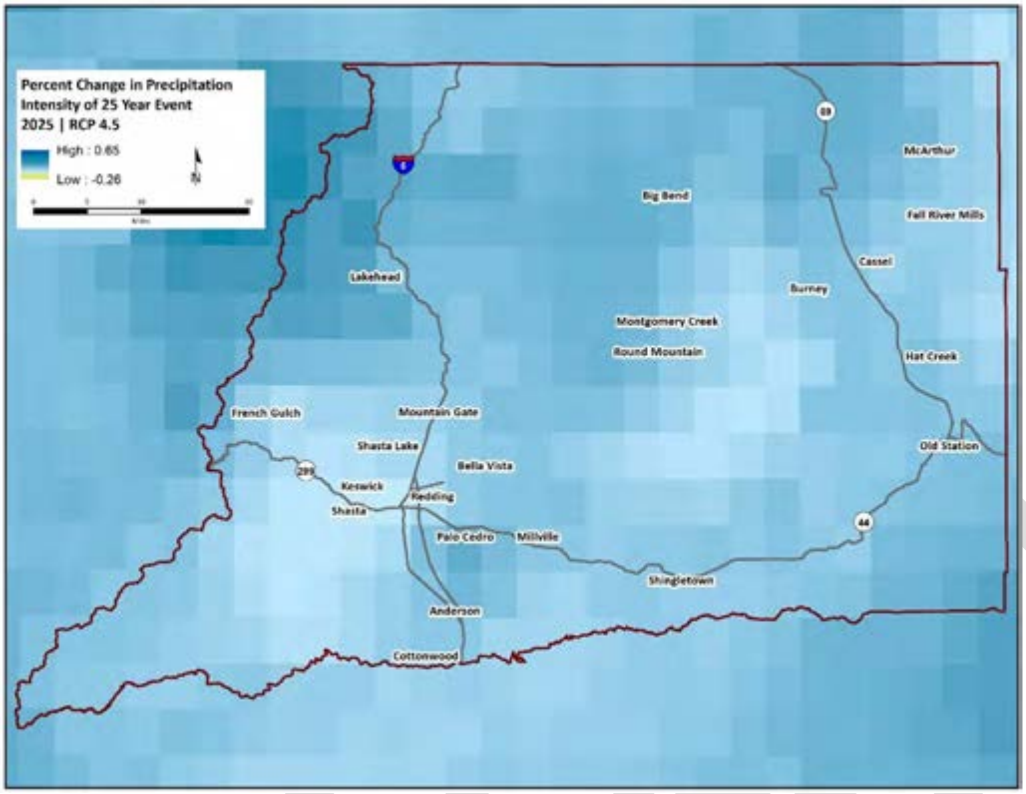

Figure 120. Projected percent change in intensity of 25-year extreme precipitation event. 2025, RCP4.5.

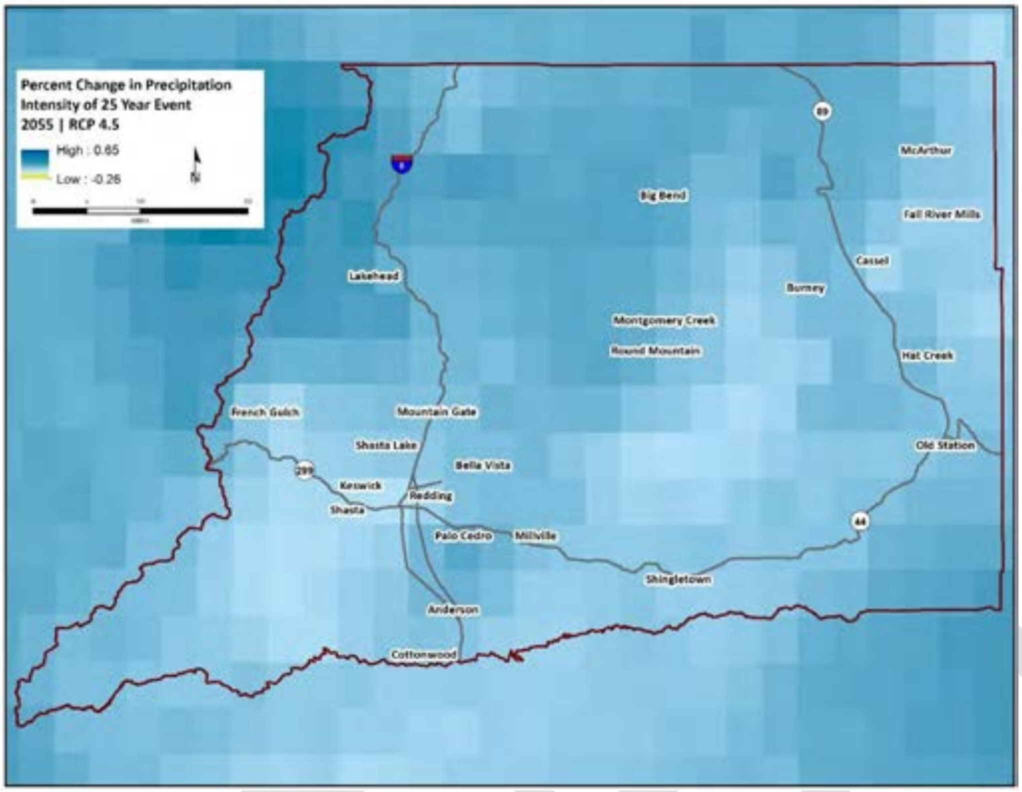

Figure 121. Projected percent change in intensity of 25-year extreme precipitation event. 2055, RCP4.5.

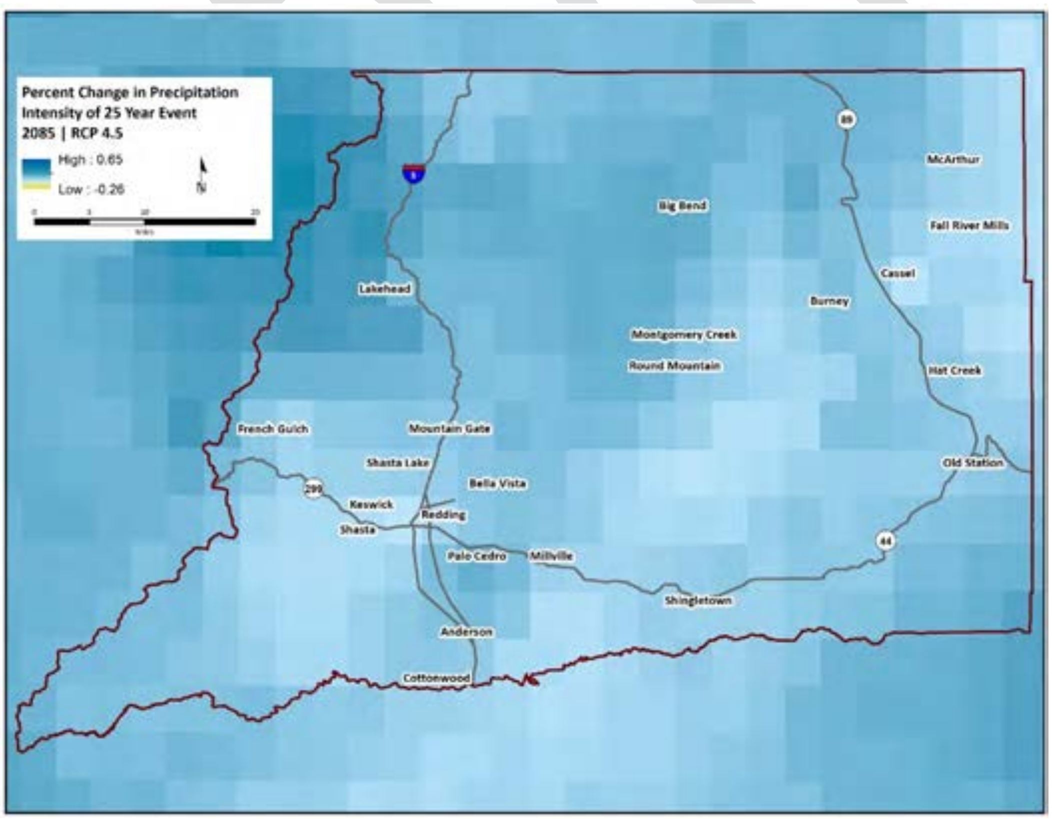

Figure 122. Projected percent change in intensity of 25-year extreme precipitation event. 2085, RCP4.5.

Unconstrained Emissions Scenario (RCP8.5)

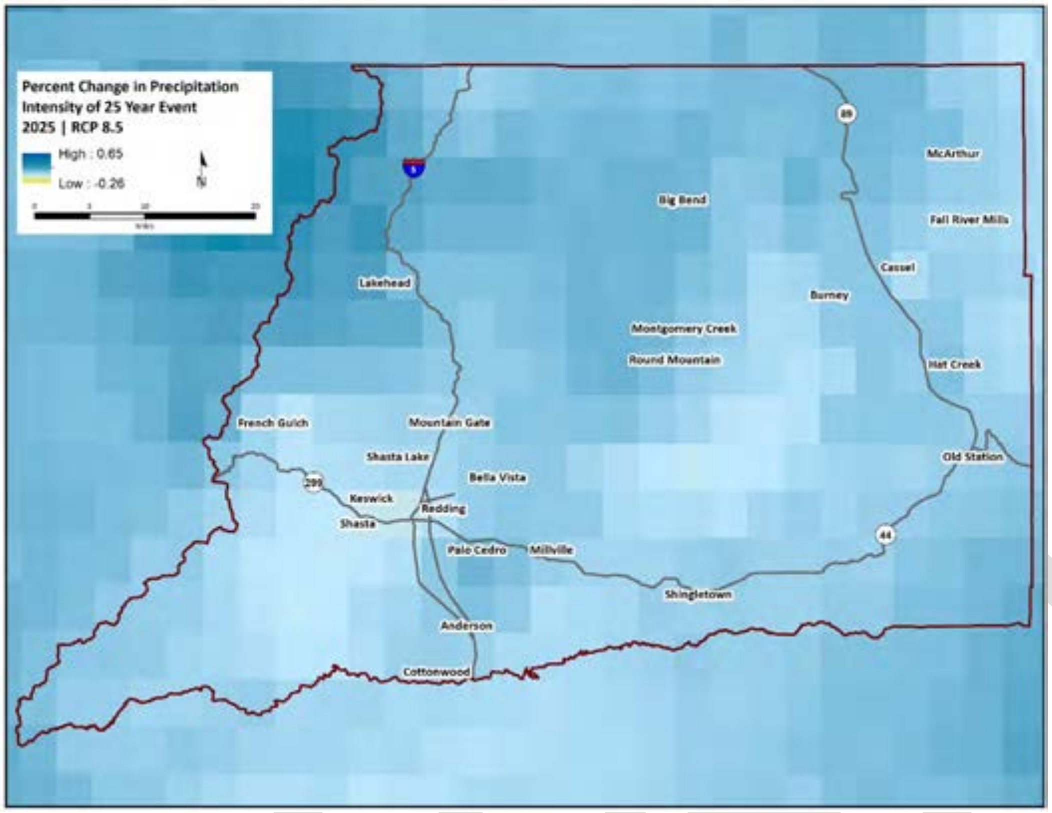

Figure 123. Projected percent change in intensity of 25-year extreme precipitation event. 2025, RCP8.5.

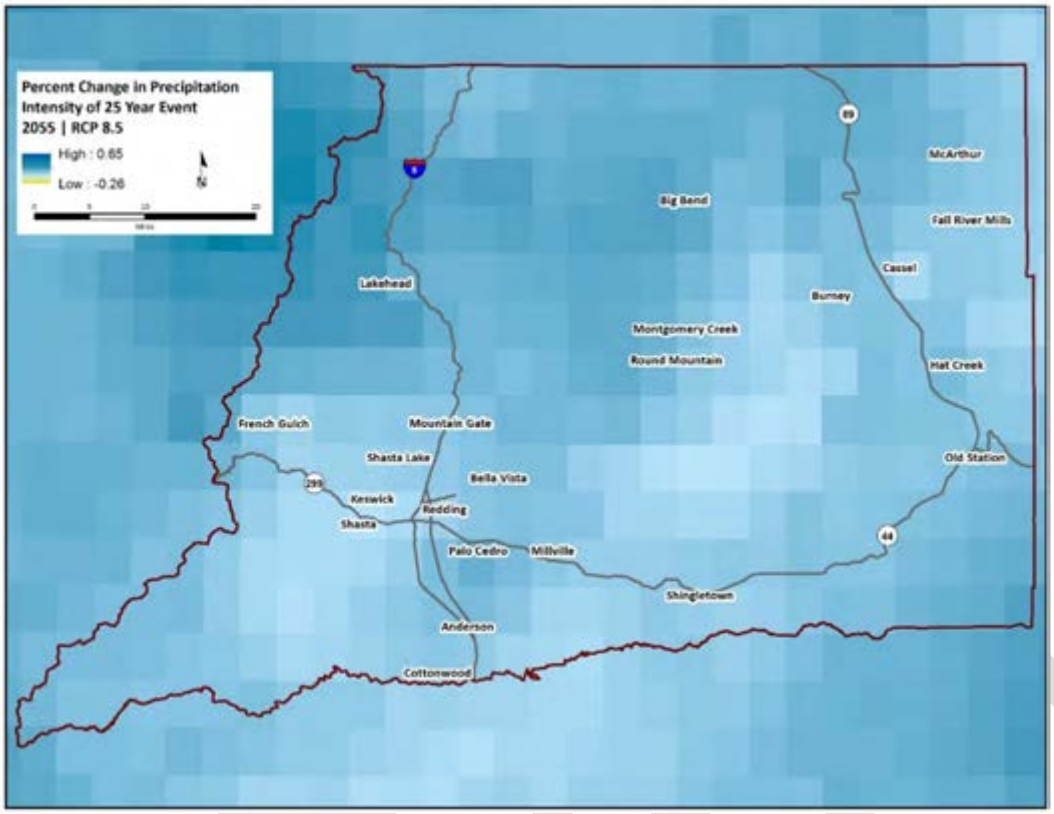

Figure 124. Projected percent change in intensity of 25-year extreme precipitation event. 2055, RCP8.5.

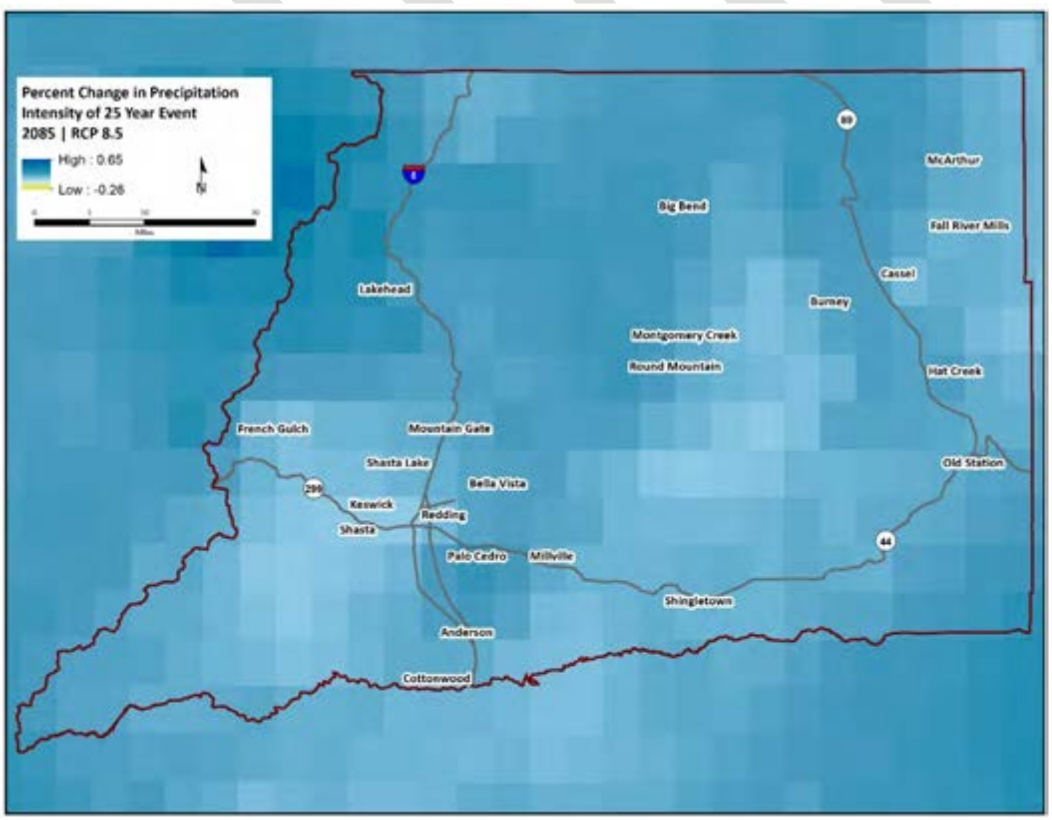

Figure 125. Projected percent change in intensity of 25-year extreme precipitation event. 2085, RCP8.5.

100-year Event

Reduced Emissions Scenario (RCP4.5)

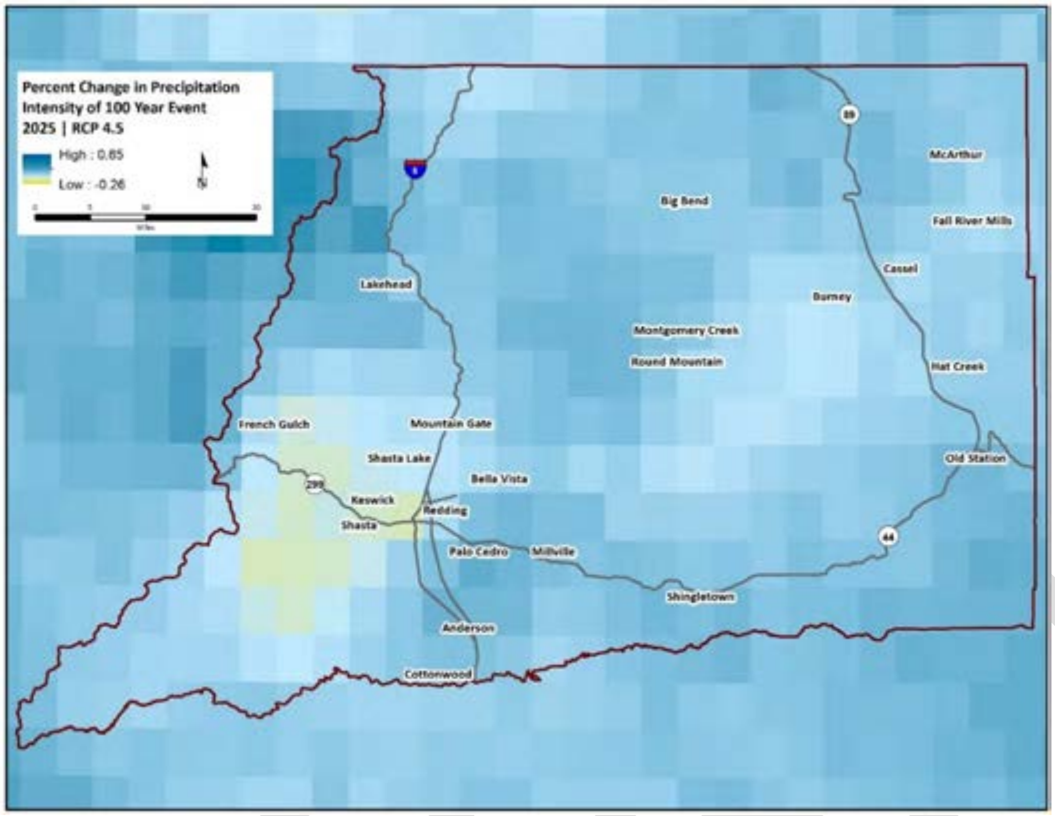

Figure 126. Projected percent change in intensity of 100-year extreme precipitation event. 2025, RCP4.5.

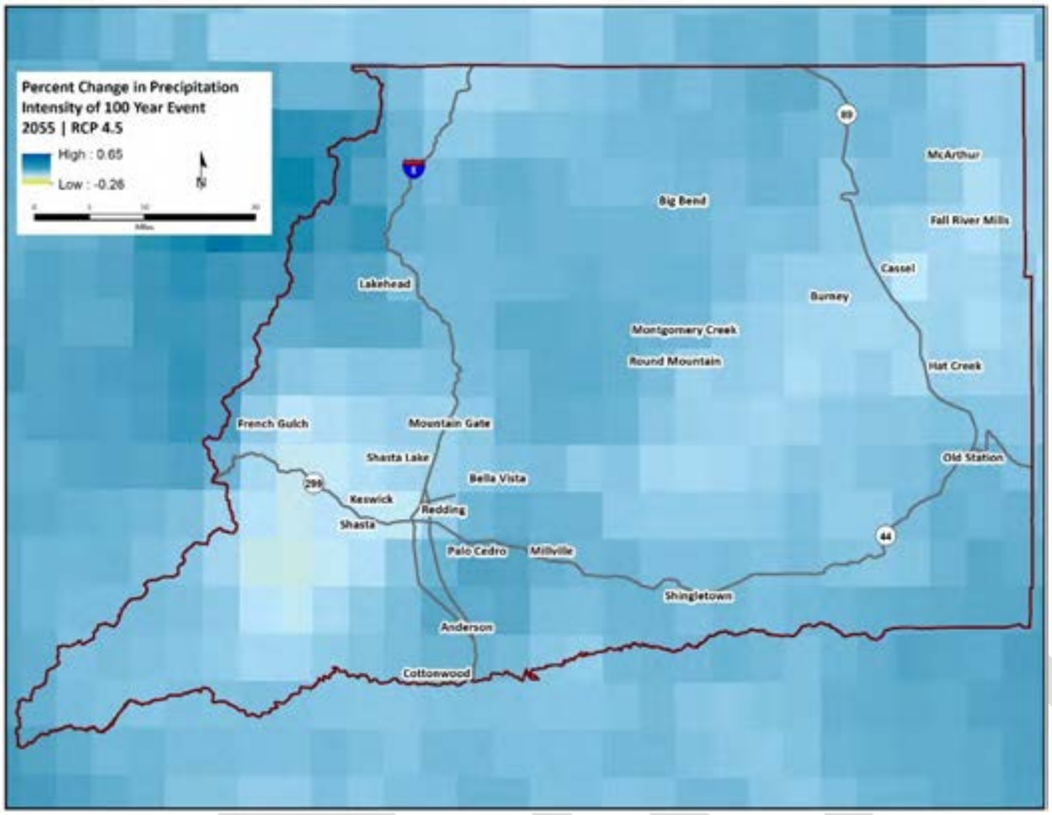

Figure 127. Projected percent change in intensity of 100-year extreme precipitation event. 2055, RCP4.5.

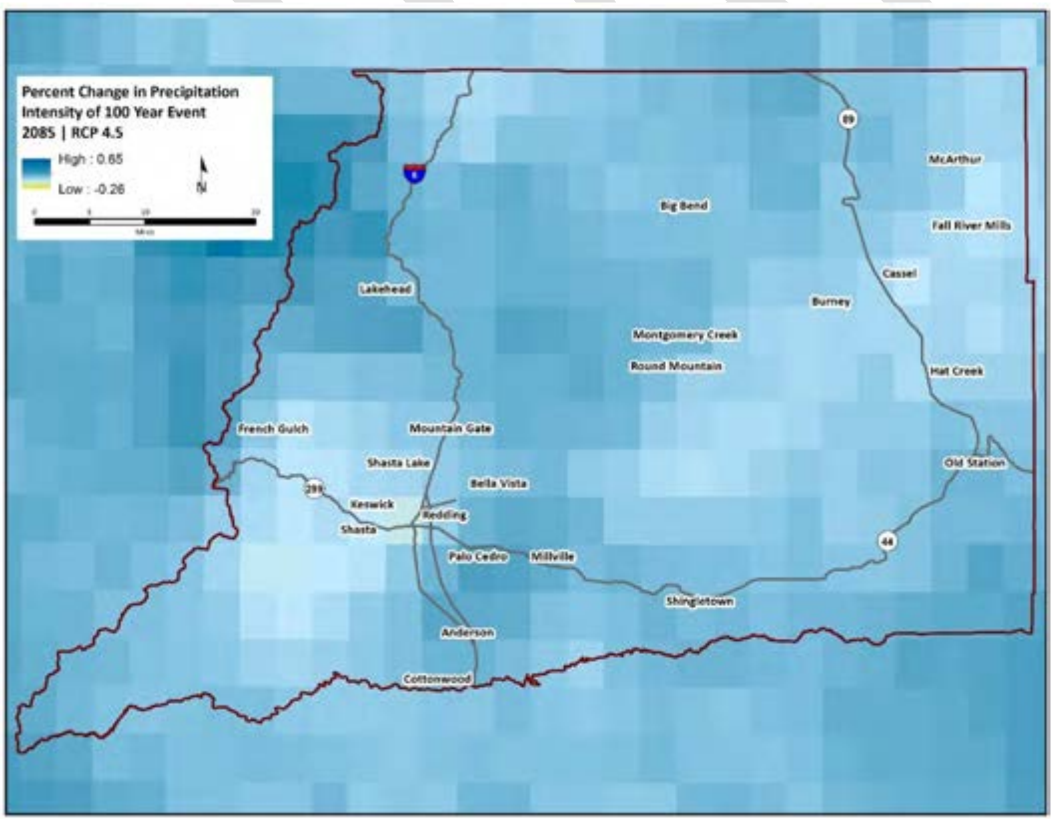

Figure 128. Projected percent change in intensity of 100-year extreme precipitation event. 2085, RCP4.5.

Unconstrained Emissions Scenario (RCP8.5)

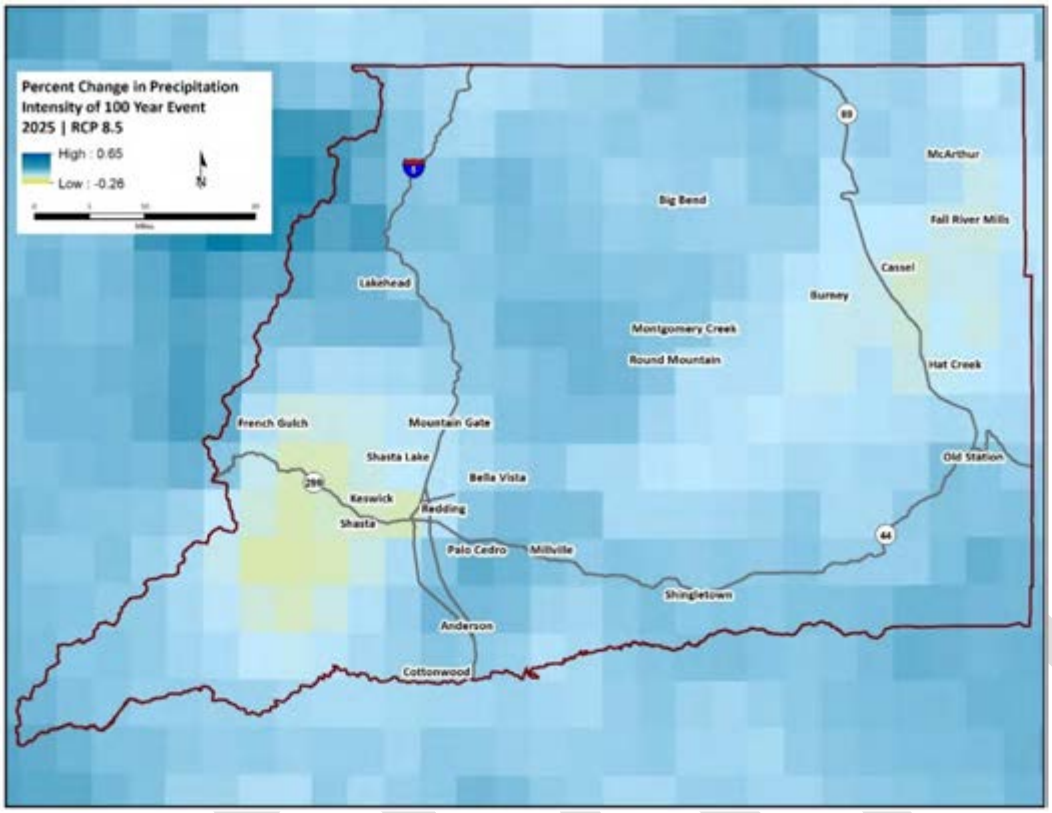

Figure 129. Projected percent change in intensity of 100-year extreme precipitation event. 2025, RCP8.5.

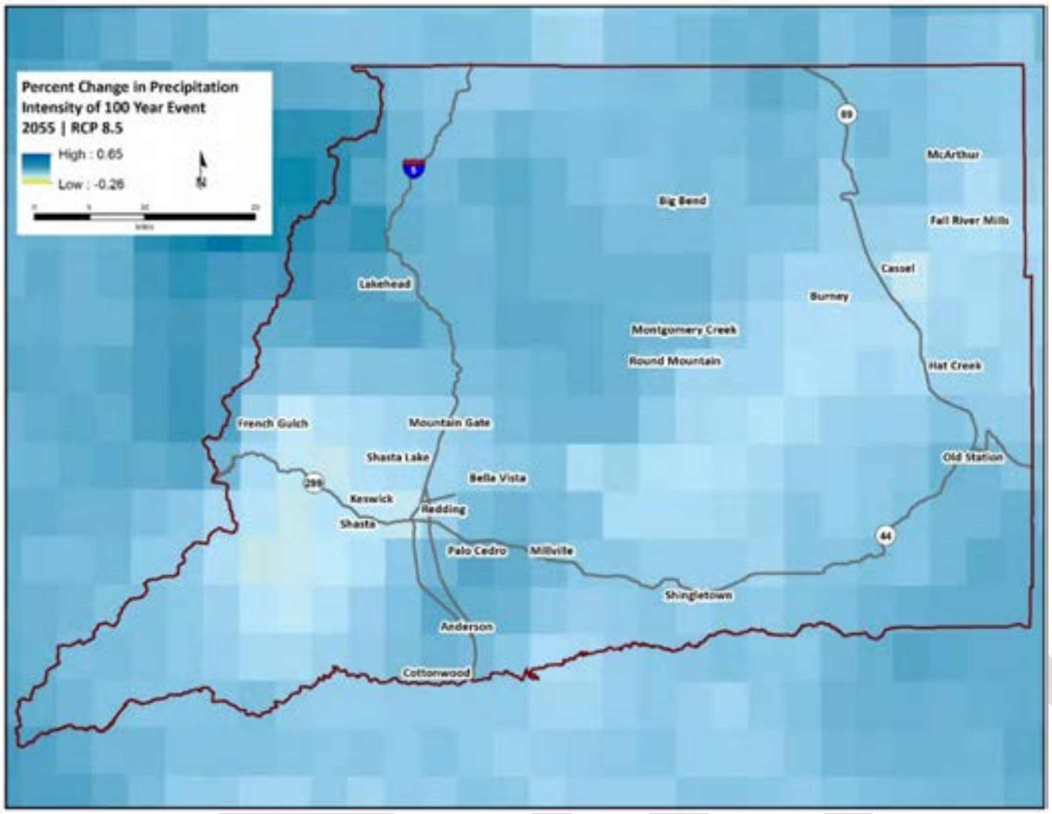

Figure 130. Projected percent change in intensity of 100-year extreme precipitation event. 2055, RCP8.5.

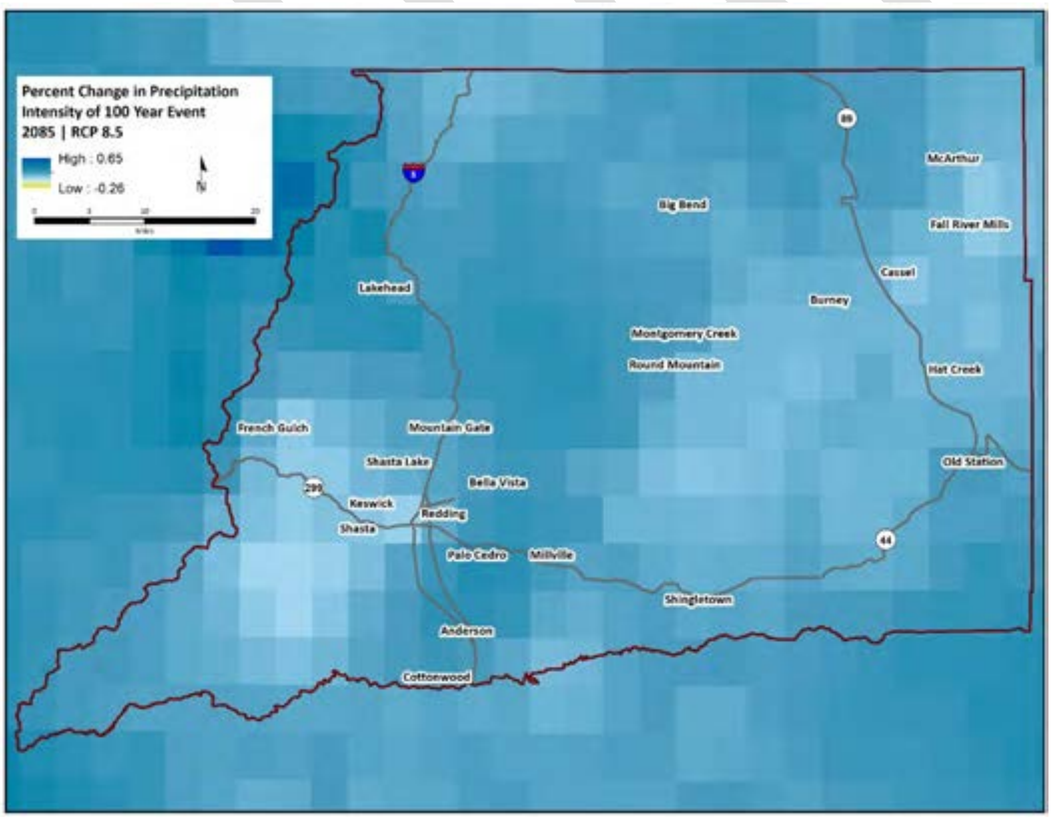

Figure 131. Projected percent change in intensity of 100-year extreme precipitation event. 2085, RCP8.5.

500-year Event

Reduced Emissions Scenario (RCP4.5)

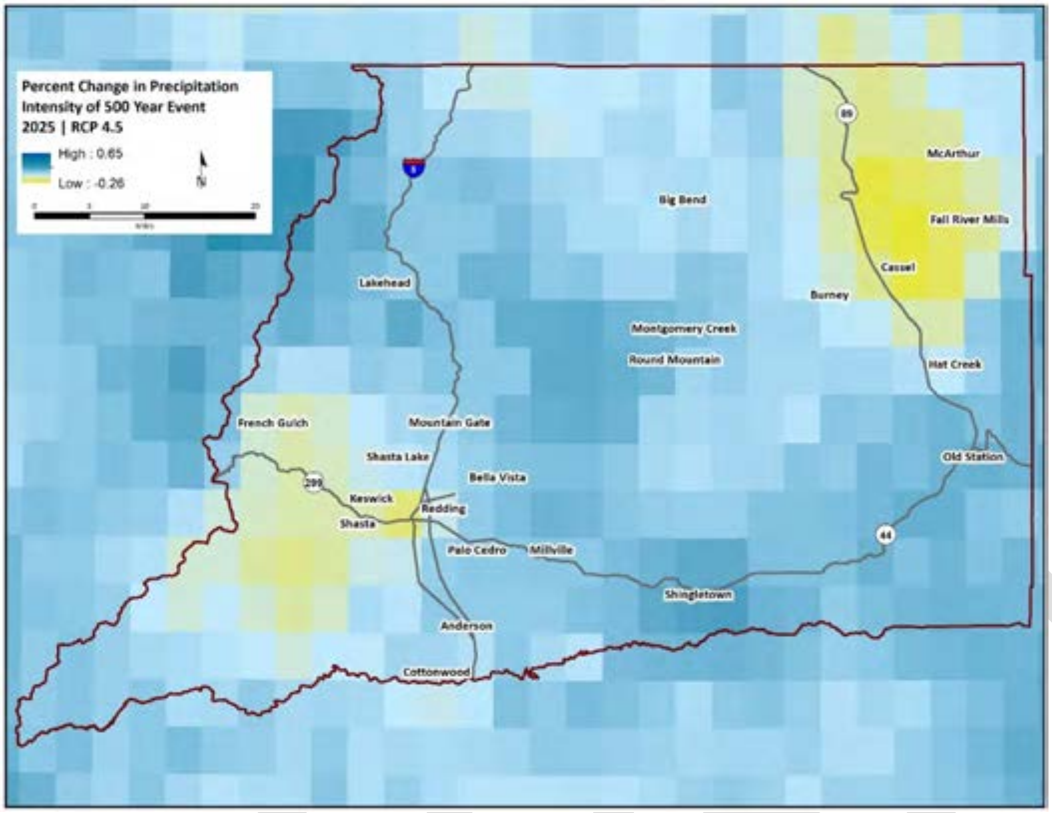

Figure 132. Projected percent change in intensity of 500-year extreme precipitation event. 2025, RCP4.5.

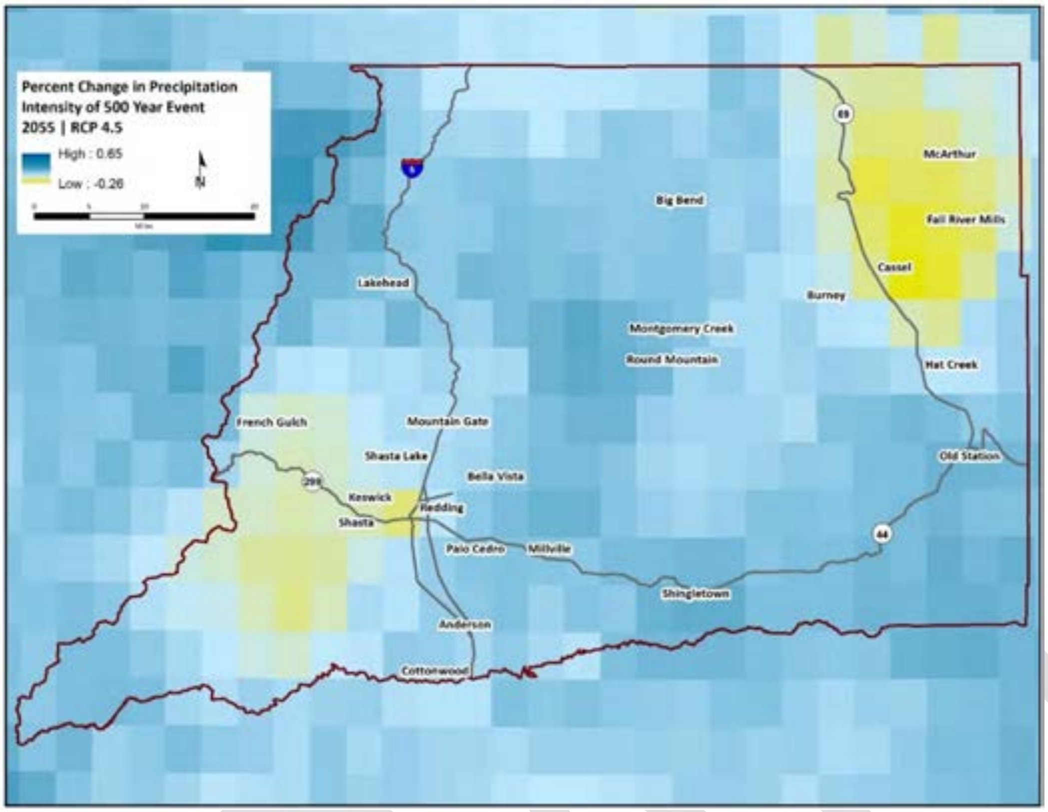

Figure 133. Projected percent change in intensity of 500-year extreme precipitation event. 2055, RCP4.5.

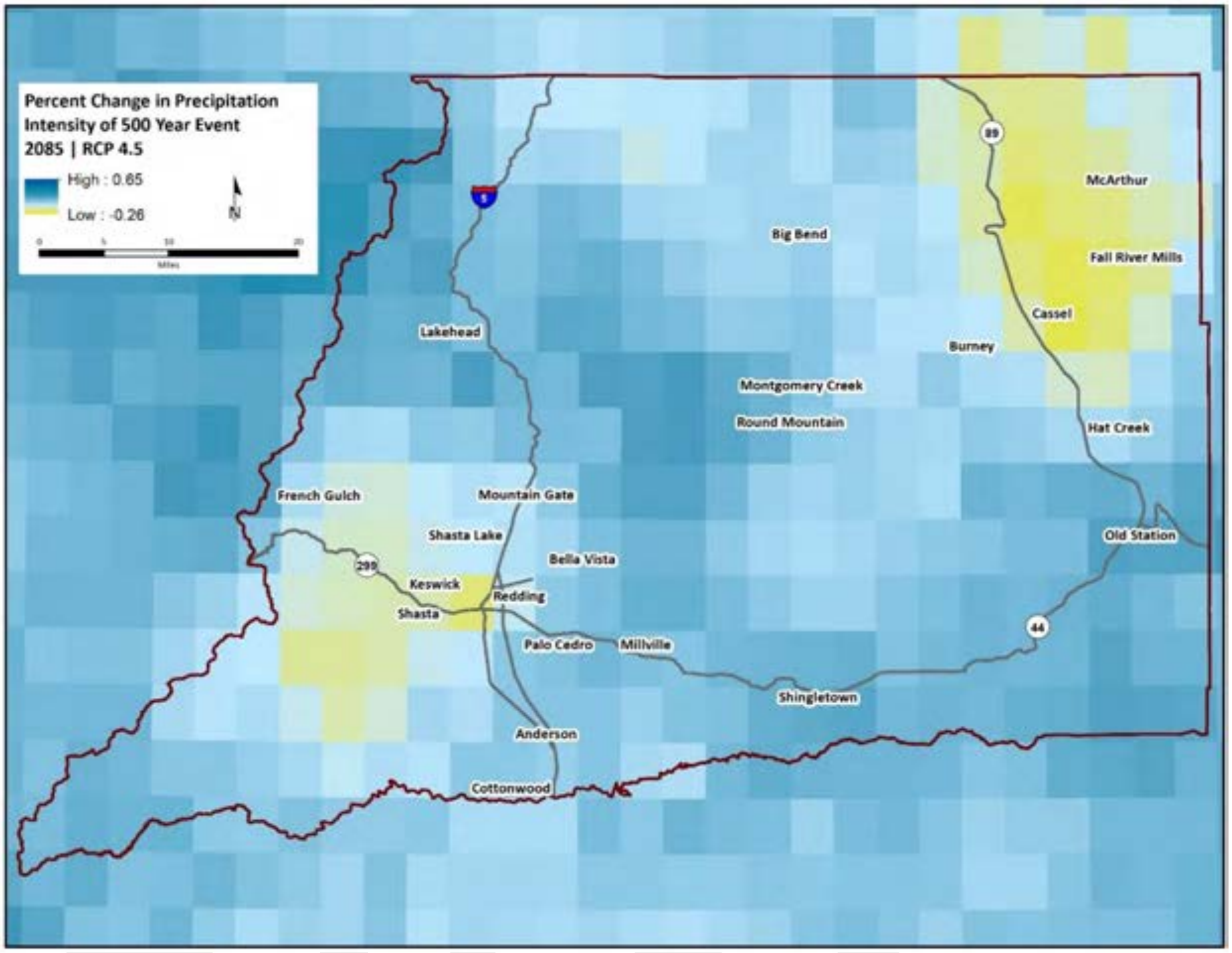

Figure 134. Projected percent change in intensity of 500-year extreme precipitation event. 2085, RCP4.5.

Unconstrained Emissions Scenario (RCP8.5)

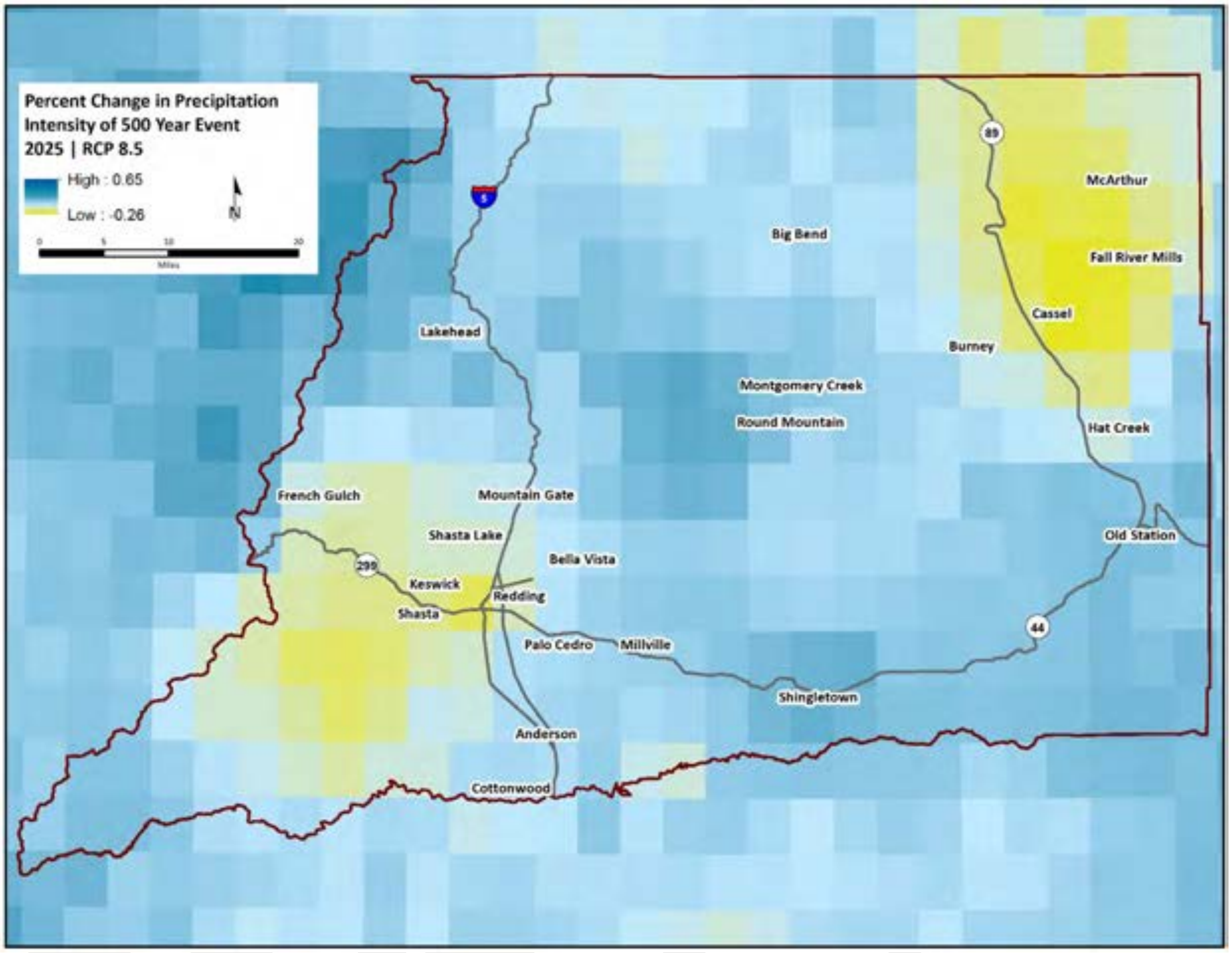

Figure 135. Projected percent change in intensity of 500-year extreme precipitation event. 2025, RCP8.5.

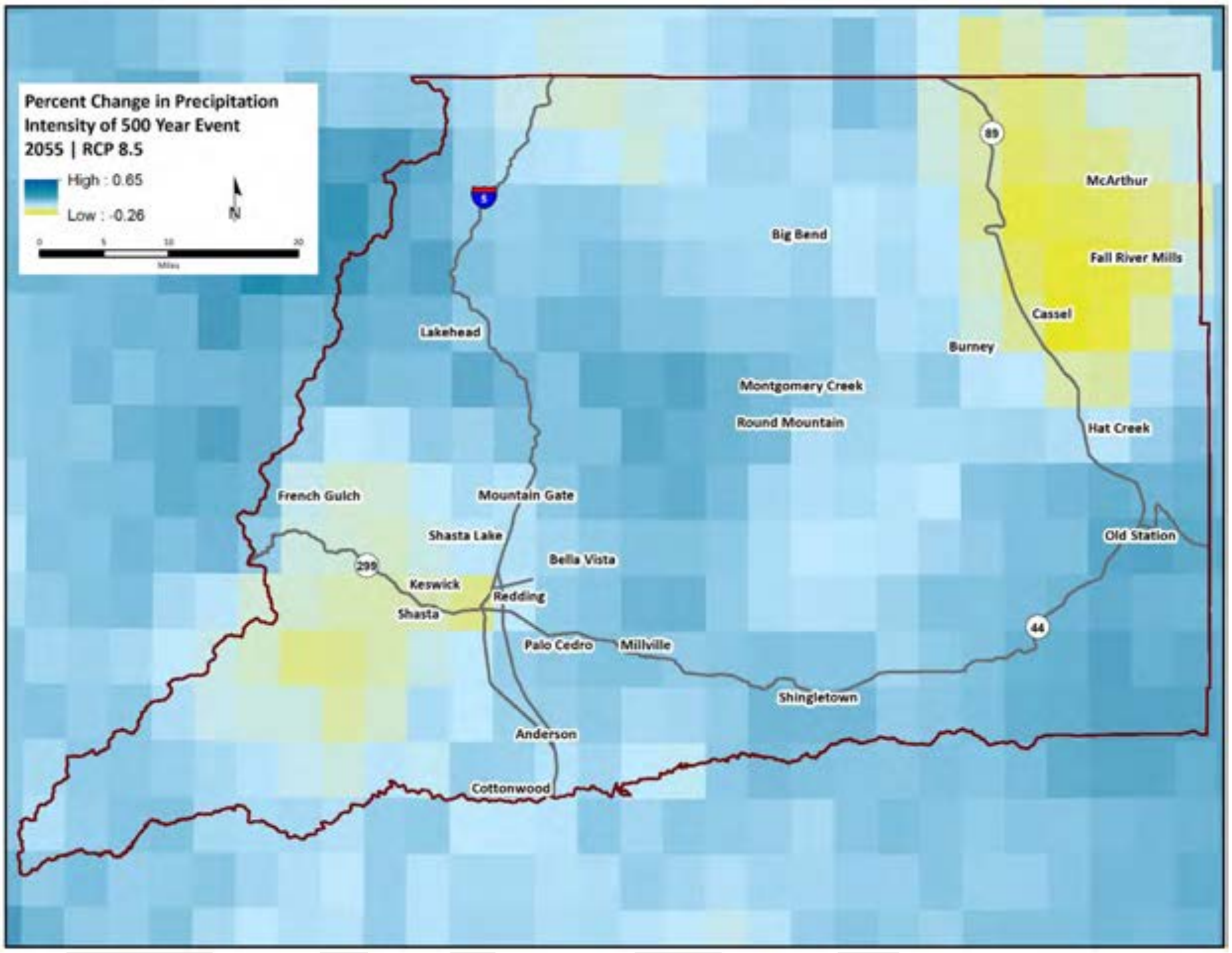

Figure 136. Projected percent change in intensity of 500-year extreme precipitation event. 2055, RCP8.5.

Wildfire Projections

Decadal Wildfire Probability

Historical

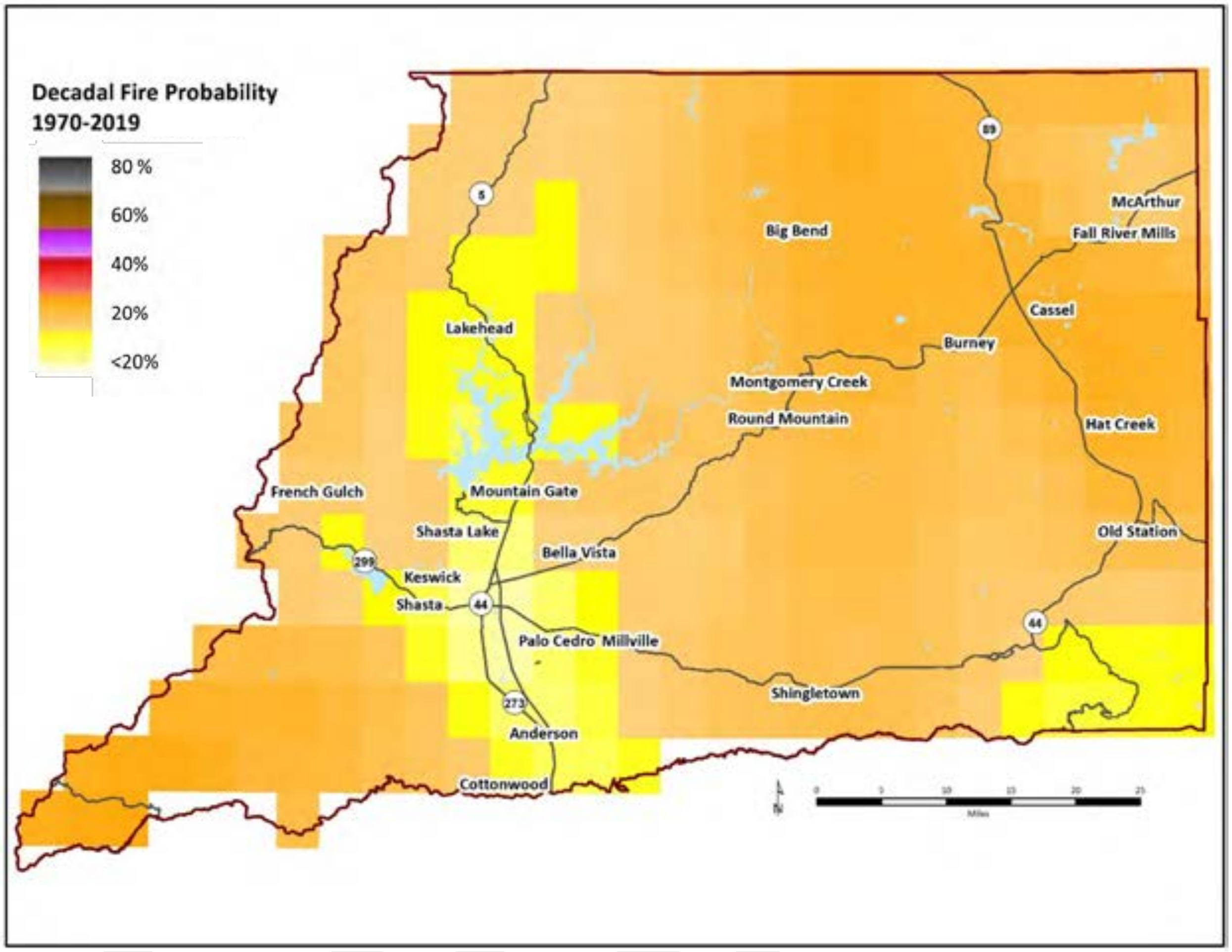

Figure 137. Average decadal Fire Probability in the historical period (1970 - 2019).

Reduced Emissions Scenario (RCP4.5)

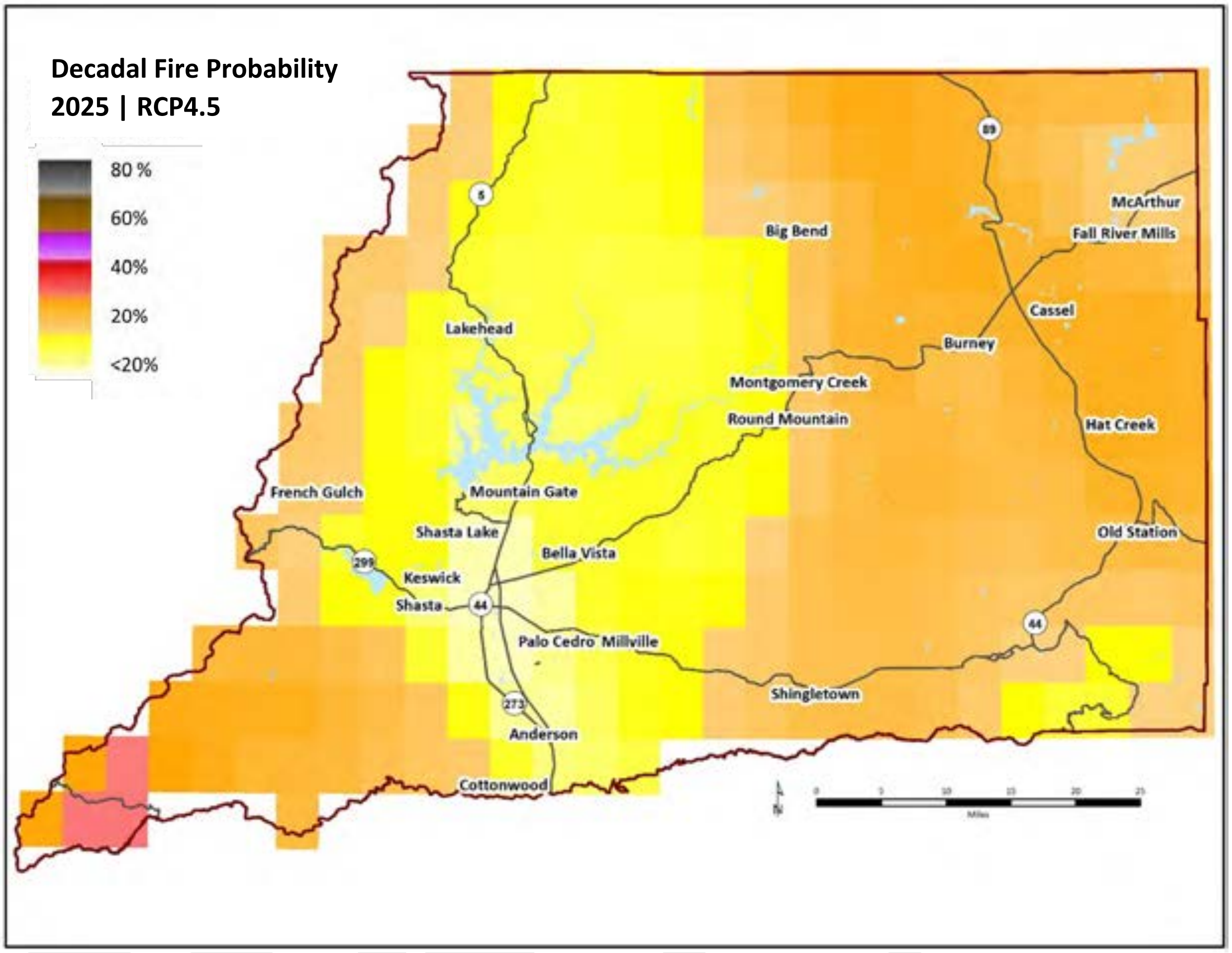

Figure 138. Decadal Fire Probability in 2025, RCP4.5.

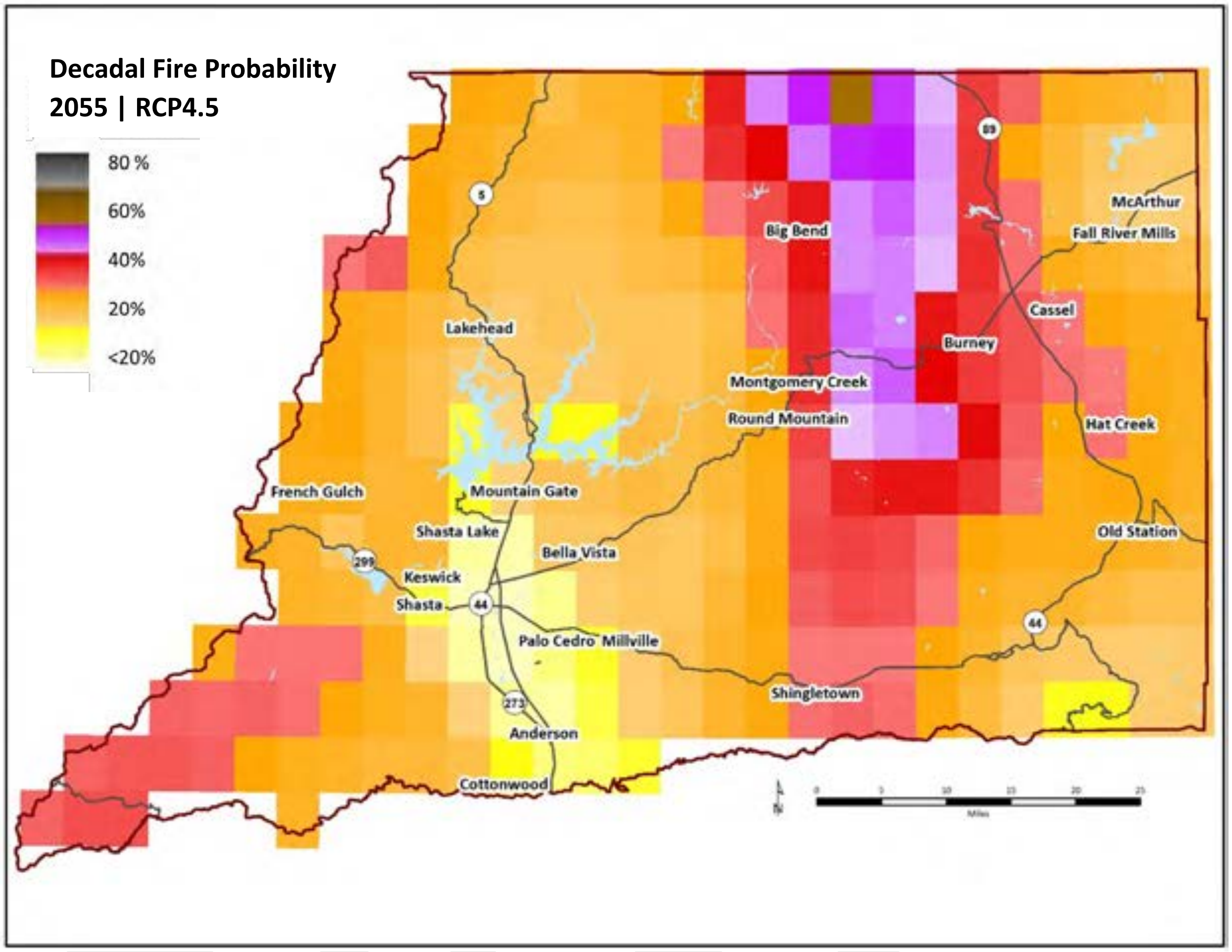

Figure 139. Decadal Fire Probability in 2055, RCP4.5.

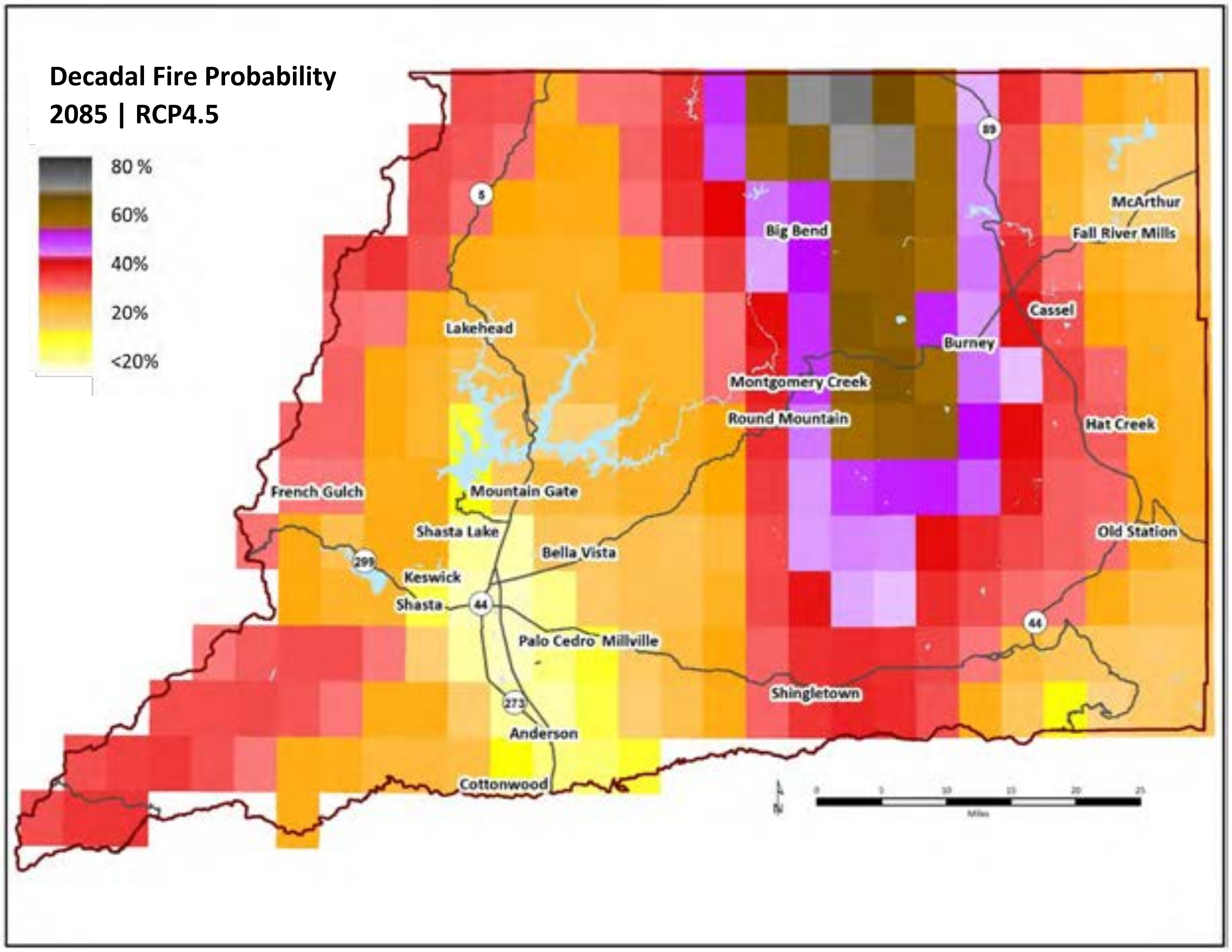

Figure 140. Decadal Fire Probability in 2085, RCP4.5.

Unconstrained Emissions Scenario (RCP8.5)

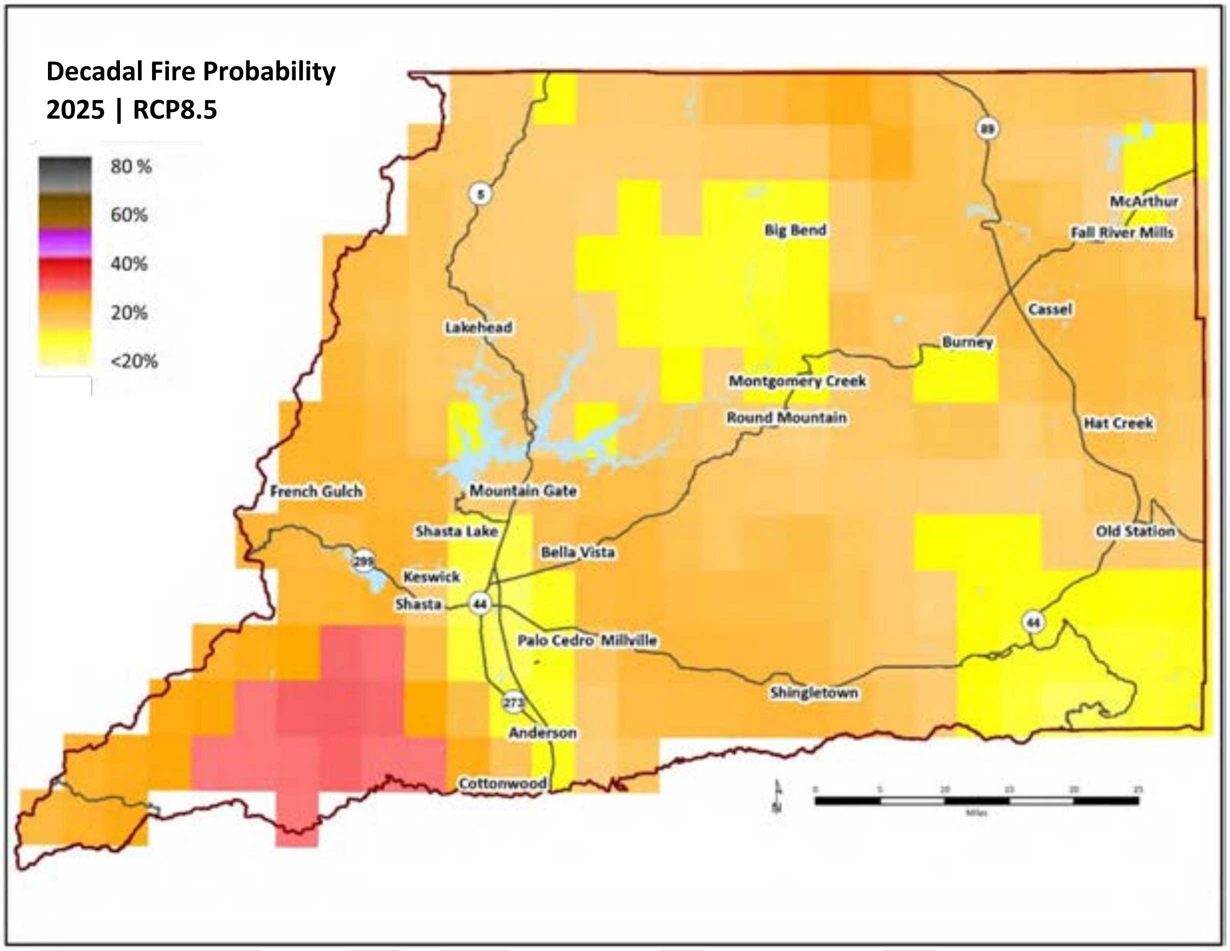

Figure 141. Decadal Fire Probability in 2025, RCP8.5.

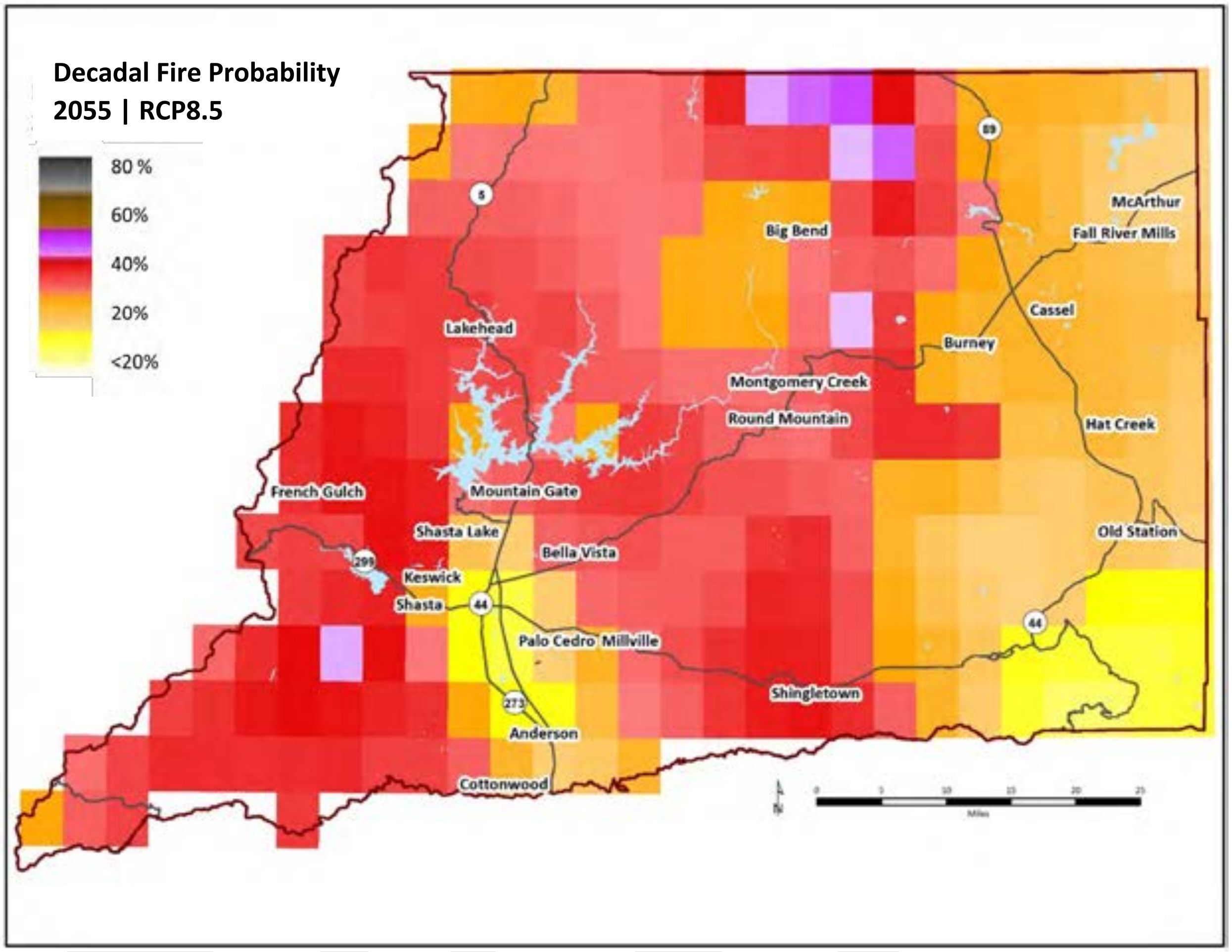

Figure 142. Decadal Fire Probability in 2055, RCP8.5.

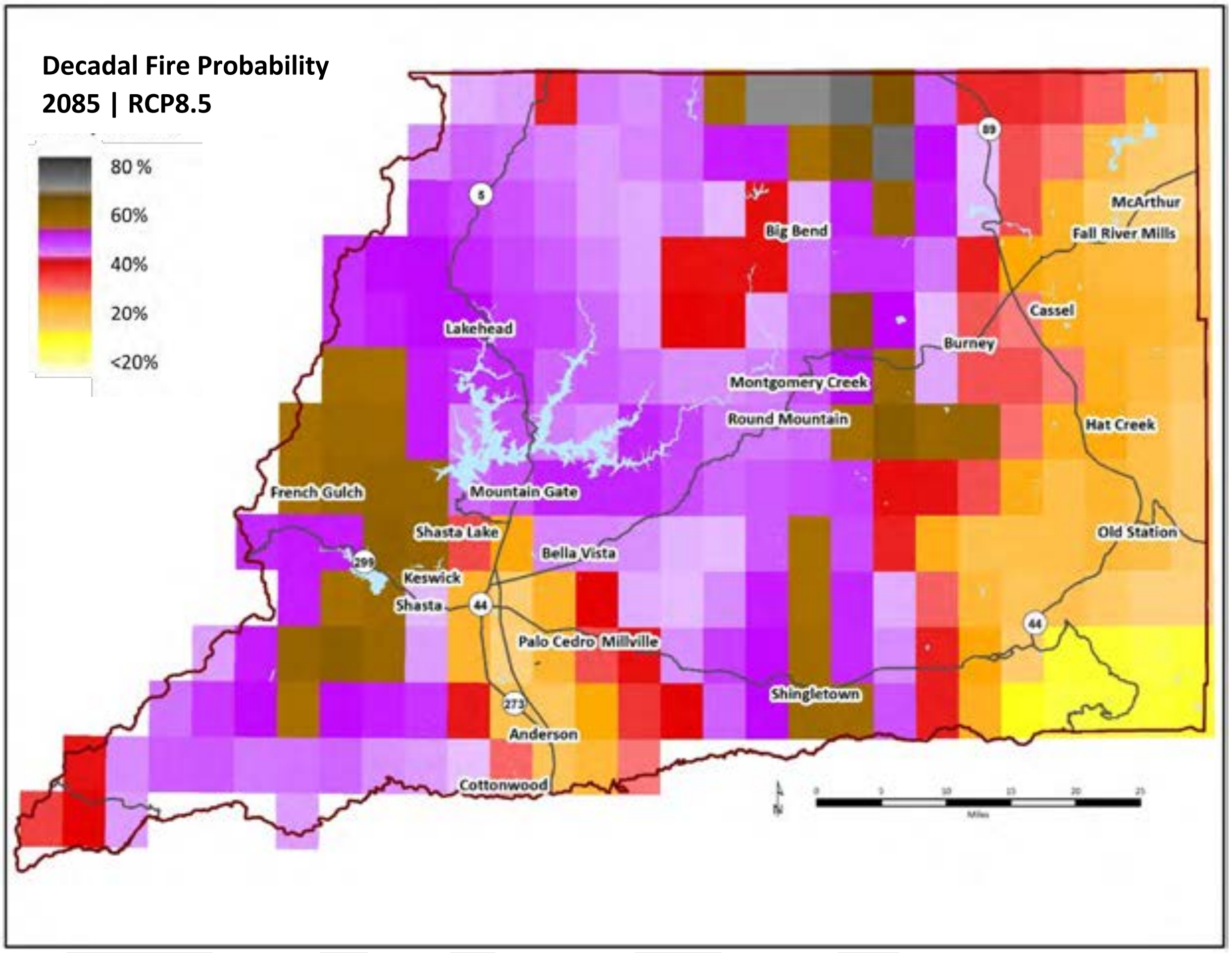

Figure 143. Decadal Fire Probability in 2085, RCP8.5.

Wildfire Area Burned

Historical

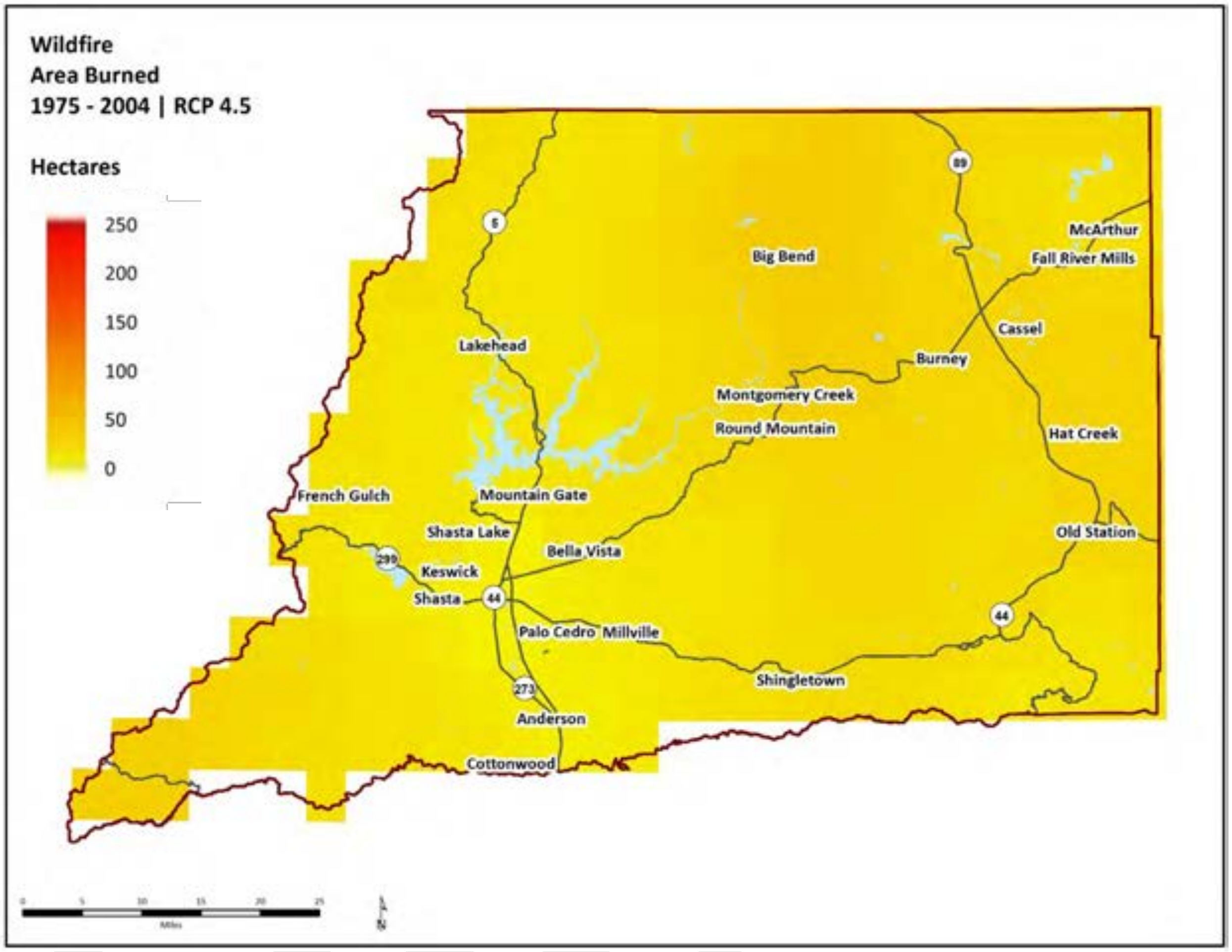

Figure 144. Average annual area burned in the historical period (1975 - 2004).

Reduced Emissions Scenario (RCP4.5)

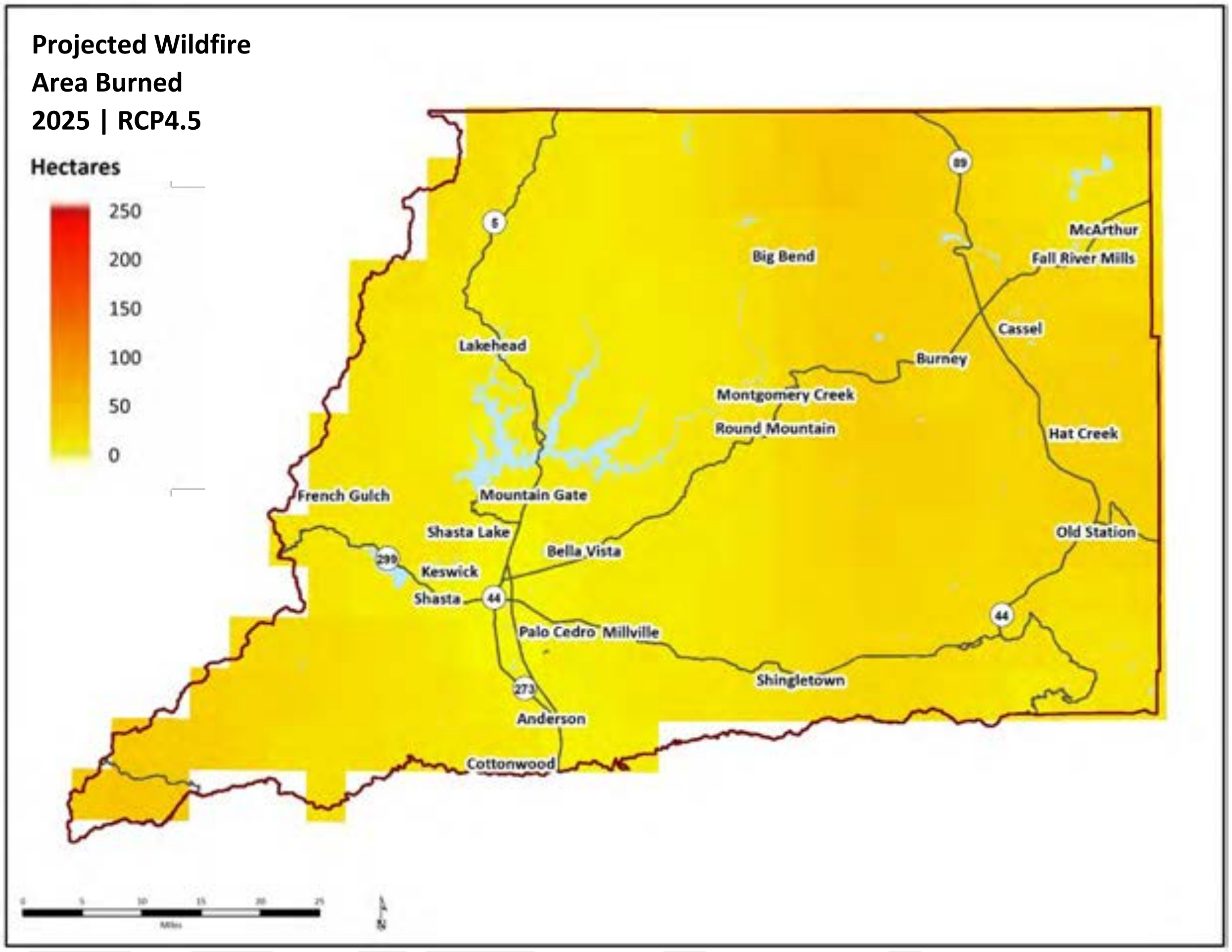

Figure 145. Average annual area burned in 2025, RCP4.5.

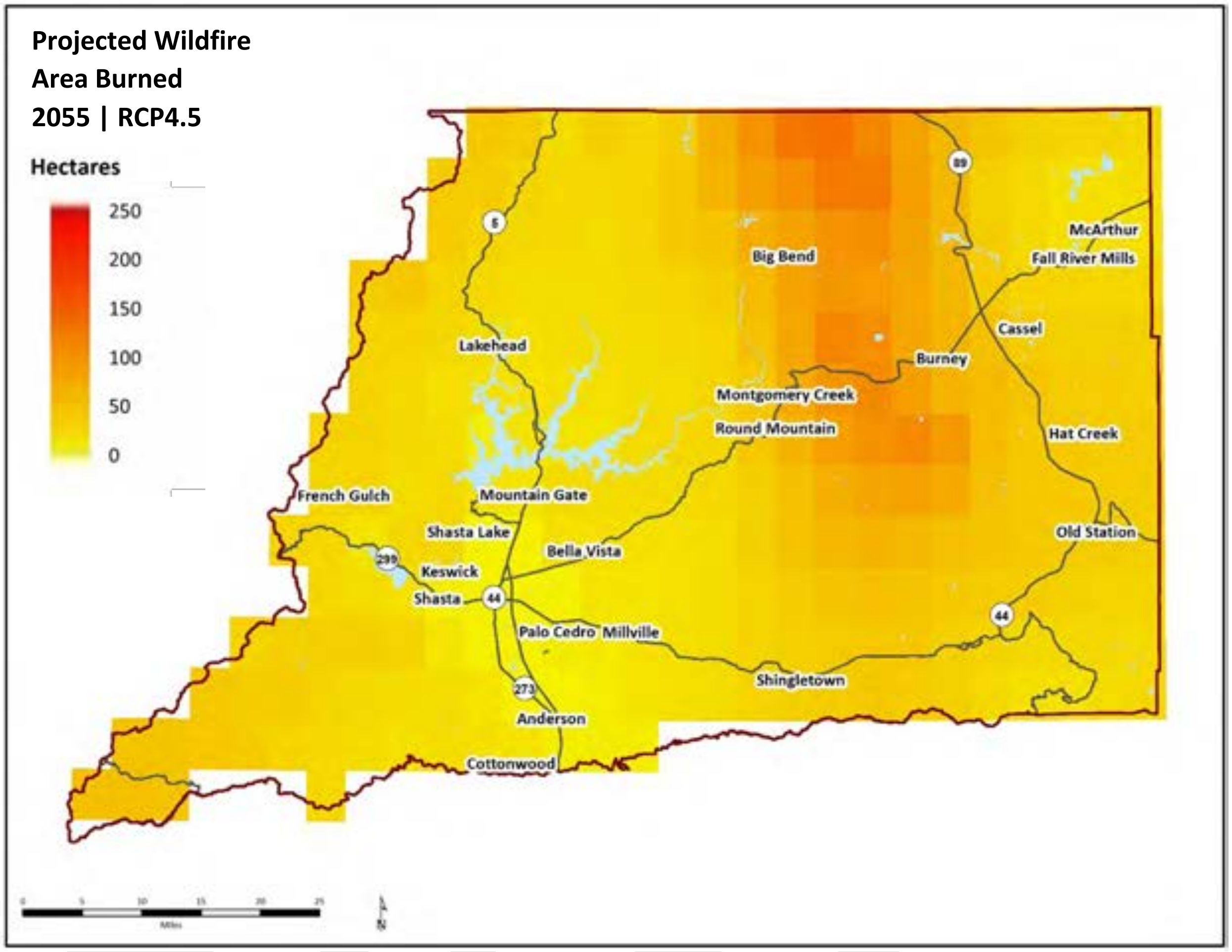

Figure 146. Average annual area burned in 2055, RCP4.5.

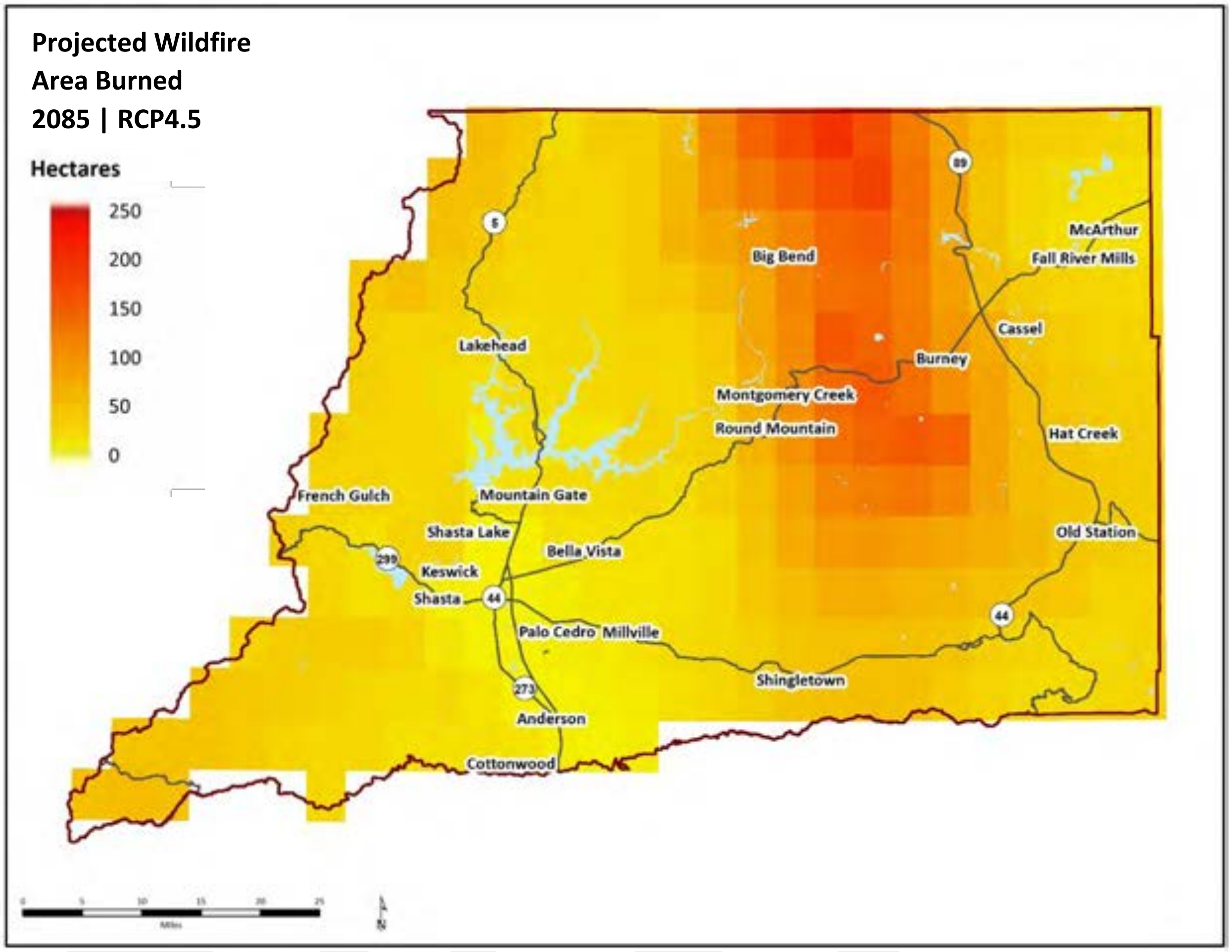

Figure 147. Average annual area burned in 2085, RCP4.5.

Unconstrained Emissions Scenario (RCP8.5)

Appendix B: Methodology

This appendix describes the sources and methodologies for the ResilientShasta Extreme Climate Event Mobility and Adaptation Plan: Transportation Vulnerability Assessment.

Scenario Definitions

Describing future outcomes requires some assumptions about the future. By using well-documented scenarios considered to be the industry standard, the projections in this study can be compared with similar efforts such as the Caltrans District 2 vulnerability assessment.[15]

Emissions scenarios

Scenarios used in this study are based on the Intergovernmental Panel on Climate Change's (IPCC) scenarios for the Fifth Assessment Report (AR5).[16] The two scenarios used in this study are the "reduced emissions scenario" (RCP4.5) and the "unconstrained emissions scenario (RCP8.5). These scenarios address the uncertainty of climate change outcomes associated with the amount of greenhouse gas emissions added to the atmosphere between now and the end of the 21st century by human activities. The reduced emissions scenario assumes that global greenhouse gas emissions peak in 2040 and decline afterwards, resulting in an elevated but stable amount of warming by 2100. By contrast the unconstrained emissions scenario corresponds to a world where global greenhouse gas emissions continue to rise throughout the century, leading to rapid and escalating warming by 2100. While neither scenario portrays a future that is the most likely path for human emissions, together these two scenarios 'bookend' the range of outcomes considered most likely.

Time Periods

Climate parameters such as temperature and precipitation can vary year to year, so descriptions of historical or projected future conditions are described in terms of 30-year climate averages. This study uses the same period definitions as the Caltrans District 2 Vulnerability Assessment.[17] For each period, the central year is used to describe the overall period.

Historical:

- 1990 (1975 – 2004)[18]

Projections:

- 2025 (2010 – 2039)[19]
- 2055 (2040 – 2069)
- 2085 (2070 – 2099)

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[15] Caltrans 2018
[16] IPCC 2014
[17] Caltrans 2018
[18] Historical wildfire probability metrics differ from others, as wildfire probability is only defined by decade. Historical wildfire probability metrics are given for the period 1970 – 2019.
[19] 2025 projection period includes data for the period 2010 – 2020; because the projections were completed in 2015, these projections cover years which have already happened; for purposes of methodological consistency, we use the historical period within the projection file, although the difference between these 'historical projections' and real historical data is very small

Hazard Projections

Climate Change Projections

Future climate projections (including temperature and precipitation) are sourced from the Scripps Institute's Local constructed-analogs (LOCA) downscaled global climate model (GCM) data,[20] which uses global-scale climate change projections from the Climate Model Intercomparison Project 5 (CMIP5) and enhances the resolution of these projections using localized geography and weather data. These are the same downscaled climate projections used by the California climate change assessments, and by Caltrans in its district vulnerability assessments.

The CMIP5 project includes over 30 different GCMs, however only four are used in this analysis. This analysis uses the same four models identified by California's Climate Action Team for California's Fourth Climate Change Assessment.[21] These are:

- HadGEM2-ES, producing a warm/dry simulation
- CNRM-CM5, producing a cooler/wetter simulation
- CanESM2, producing an average simulation, and
- MIROC5, the model simulation that is most unlike the first three for the best coverage of different possibilities[22]

Temperature

Temperature projections in the LOCA downscaled GCM data are used to generate several temperature metrics.

Average annual high temperature

The annual average high temperature is calculated by first by averaging together the daily high temperature (tasmax) for every day in the 30-year climate period, and then by averaging together the temperatures of all four models.

Average seasonal high temperature

Because summer temperatures are more indicative of heat stress, a similar average high temperature metric is generated for just the months of June, July, and August. The daily temperature for every day in the three-month period is averaged together across all 30-years and across the four GCMs.

Heat Wave Temperature

The heat wave temperature is generated by first calculating the rolling seven-day average high temperature, and then identifying the hottest seven-day period in each year. Each annual heat wave temperature is then averaged across all 30 years and all four models.

Freeze-Thaw Cycles

Diurnal freeze-thaw cycles are defined as the number of days in which the daily high temperature is above 32°F, and daily low temperature (tasmin) is equal-to or lower-than 32°F. The number of FTCs is calculated for each year in each model, and then the annual number of FTCs is averaged across all 30 years and all four models.

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[20] Bracken et al. 2016
[21] Pierce et al. 2018
[22] Cal Adapt 2021a

Precipitation

Precipitation projections in the LOCA downscaled GCM data are used to generate several precipitation metrics.

Average annual precipitation

The annual average precipitation is calculated using the precipitation metric (pr), and averaging the daily precipitation for every day in the 30-year period and across all four models. Percent changes in precipitation are generated by comparing the projected seasonal precipitation to the same metric calculated using historical data.

Average seasonal precipitation

Because the projected changes to precipitation diverge seasonally, precipitation projections are generated for both the wet season (November – April) and the dry season (May – October). These are generated in the same way as annual averages, but only for the relevant six-month period. Daily precipitation totals (pr) are averaged across each day in the six-month period, over the 30-year timeframe, and across four models.

Percent changes in precipitation are generated by comparing the projected seasonal precipitation to the same metric calculated using historical data.

Extreme precipitation

Extreme precipitation metrics are generated by using the projected daily precipitation totals, and generating three-day rolling totals. Each three-day total shows the total precipitation of the preceding three days. Within each 30-year period and across four models, the top 4%, 1%, and 0.2% of rolling precipitation totals are identified. The lowest value at the threshold of the top 4%, 1%, and 0.2% of values is considered the exceedance threshold for the 25, 100, or 500-year extreme precipitation events, respectively. Comparison of the projected exceedance thresholds to the historical period gives the percent change in exceedance threshold for each type of extreme precipitation event.

Wildfire

Wildfire projections rely on hazard analyses conducted with specialized models for evaluating the effects of climate on wildfire conditions. Two wildfire projections are used, as well as one high-resolution model of current wildfire hazard conditions.

Wildfire Area Burned

The area burned by wildfires has been modeled by Dr. LeRoy Westerling at the University of California, Merced.[23] The UC Merced model evaluated historical wildfires to identify relationships between key climate parameters and wildfire severity. Future wildfire severity was modeled for each grid cell using projected future climate conditions, resulting in an “area burned” metric for large wildfires that corresponds to the intensity of resulting fires. Area burned is measured in hectares per grid cell. Importantly the model is restricted only to “large wildfires” (i.e., fires greater than 1,000 acres in size), so these findings should not be interpreted to include the cumulative area burned of many small fires.

[23] Westerling 2018

Wildfire area burned projections are hosted on Cal Adapt, and this study uses only the central growth scenario.[24]

Decadal Wildfire Probability

Wildfire probability is also modeled using the UC Merced model, but adapted with a unique methodology described in Dale et al. 2018.[25] This approach produces a percent likelihood of the occurrence of a large wildfire within an individual grid cell over the course of a decade (as opposed to an annual probability). One consequence of using decadal probabilities is that the historical period is expanded to include 1970 – 2019 (as opposed to the 1975 – 2004 historical period used in other comparisons). Similar to area burned, the model results only address large wildfires, although the size of "large" wildfires differs from the area burned metric, with fires over 400 acres in size included.

Decadal wildfire probability projections are hosted on Cal Adapt, and this study uses only the central growth scenario.[26]

Fire Threat Index

Both projections of wildfire intensity and probability are limited in resolution to the 1/16th degree grid cells used by the LOCA downscaled climate projection data. In order to provide high-resolution characterization of fire hazards near and along critical transportation infrastructure, the West-wide Wildfire Assessment Fire Threat Index is used.[27] FTI provides a high-resolution (30m x 30m grid cell) characterization of the combustibility of biomass at the surface, given historical weather conditions. Rankings in the FTI are relative, and serve to provide an indication of the specific locations where fire probability and severity could be highest, near the wildland urban interface.

Flooding

Flood hazards are mapped exclusively using FEMA FIRMs from the National Flood Hazard Layer (NFHL). FEMA FIRMs provide a combined source for modeled flood hazards, although the flood hazards are only retrospective. FIRMs provide both a 100-year floodplain (showing areas of flooding and base flood elevation for flooding associated with streamflow with a 1% annual chance of occurring), and in some areas a 500-year floodplain (associated with streamflow with a 0.2% annual chance of occurring). Because FIRM floodplains are based on historical flood conditions, these probabilistic characterizations of flood hazard are likely underestimates. FIRMs are not mapped comprehensively throughout the Shasta Region, so the absence of flood hazard layers should not be interpreted as an absence of flood hazards.

FIRMs are hosted on the FEMA NFHL Viewer.[28]

Flood Zones

FEMA designates flood zones based on the probability of experiencing a flood, as well as characteristics about flooding, should it occur. In general, zones designated as or starting with "A" are expected to

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[24] Cal Adapt 2021b
[25] Dale et al. 2018
[26] Cal Adapt 2021b
[27] Oregon Department of Forestry 2013
[28] FEMA 2021

experience flooding during a 100-year flood event (based on historical data). Zones A, AE, AH, AO, and AR are considered 100-year floodplains. Zone X is considered the 500-year floodplain.

Landslides

No comprehensive or detailed landslide hazard assessments have been conducted in the Shasta Region, so this study relies on a multi-step process to identify one key component of potential landslide hazard: slope angles. The approach used in this assessment is based on evaluation of similar nearby landslide inventories, and application of similar slope characteristics to slopes in the Shasta Region. In this case, the 1997 inventory of landslides in the American River Valley was selected, and analysis of the landslide starting areas identified an average start zone slope of 24.7° with a standard deviation of 12.6°.[29] Slopes in the range 18.4° – 31.0° are considered "potentially hazardous."

Areas of potentially hazardous landslide slope zone are mapped across the entire Shasta Region, and detailed attention is paid to areas with large potential hazard transited by major roads and highways. These potentially hazardous slope zones are cataloged in the landslide section of this report.

Finally, a visual inspection satellite imagery was conducted to identify any historical landslide scars on potentially hazardous slopes above major roads and highways. This survey did not locate any large landslide scars, corroborating the Shasta County Hazard Mitigation Plan's exclusion of landslides.[30]

[29] California Dept. of Conservation 1997
[30] Shasta County 2017