ResilientShasta

Extreme Climate Event Mobility and Adaptation Plan: Final Report

April 28, 2022

Project funded by a Caltrans Adaptation Planning Grant

SHASTA REGIONAL TRANSPORTATION AGENCY

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Resilient**Shasta** Extreme Climate Event Mobility and Adaptation Plan

Executive Summary

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.

This report focuses on the mobility infrastructure of the Shasta Region, including the cities of Shasta Lake, Redding, and Anderson, as well as Shasta County. It is the culmination of the Resilient**Shasta** effort undertaken by the Shasta Regional Transportation Agency (SRTA) 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 consists of two components: a Shasta Regional Mobility Vulnerability Assessment (vulnerability assessment) that comprehensively investigates, evaluates, and summarizes the Region's

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.

Figure ES-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.

key vulnerabilities to climate change and extreme weather, and the Shasta Regional Mobility Adaptation Plan that explores and recommends adaptation strategies that the Region's state and local agencies should consider to improve the region's resilience to climate impacts.

The vulnerability assessment addresses historical and projected future weather and climate conditions in the Shasta Region and identifies expected changes over the coming century. The vulnerability assessment also evaluates the exposure of the Region's transportation infrastructure and systems to climate and extreme weather hazards and assesses their vulnerability, identifying the Region's highest priority exposure to climate change. The adaptation plan follows the vulnerability assessment, outlining 25 strategies for municipal, county, and state agencies to address climate vulnerabilities. The strategies are designed to leverage existing processes where possible, expand on existing opportunities, and promote cooperation and communication among agencies that conduct similar programs.

Both the vulnerability assessment and the adaptation plan are informed by input from the region's governments and stakeholders, as well as through extensive public input gathered through two surveys and two public meetings.

Key Findings

The Shasta Region is extremely vulnerable to climate and extreme weather hazards, especially wildfires, threatening mobility

Exposure to extreme temperatures, extreme precipitation, and floods all threaten the mobility of Shasta residents, but wildfire poses the greatest challenge. The Shasta Region's forests are already experiencing weather conditions which threaten severe and dangerous fires every summer. Projected changes to weather in the region will intensify the threat, making fires both more likely and more severe. Likewise, projected changes to extreme temperatures and extreme precipitation threaten increased costs associated with faster road and vehicle degradation, flooding/ponding, erosion, and more frequent disruptions to road, bus, train, and active transportation services. Collectively the Region's exposure to these hazards severely threatens the mobility of Shasta residents.

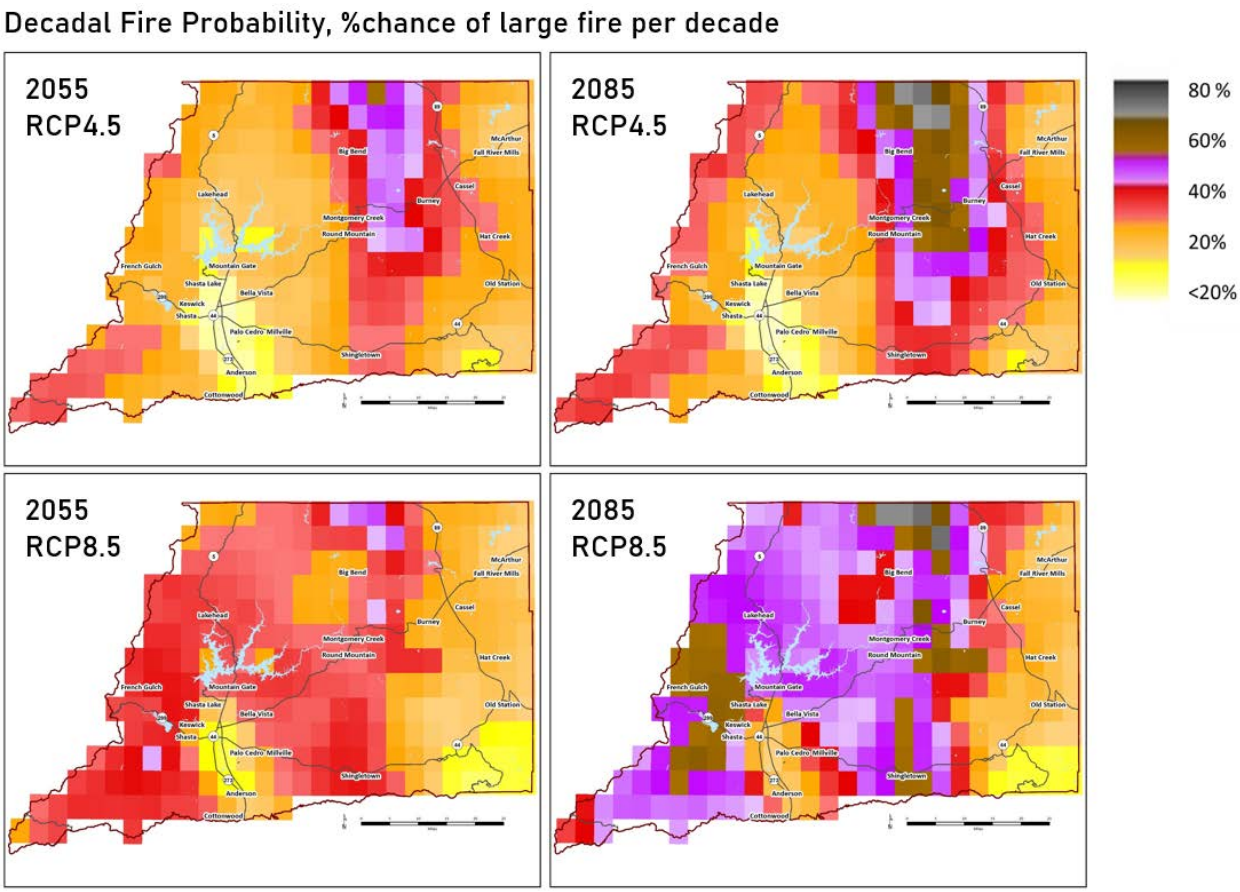
This study identified six key vulnerabilities, including:

- Projections show extreme increases in both **wildfire probability** and **severity** over the coming century, including in areas with key transportation infrastructure
- Evacuation planning (for all emergencies) should work to better address **key mobility gaps**, including those for **vulnerable populations**, and rural areas with limited transportation options
- Increases in extreme temperature are likely to accelerate wear & tear on roads and vehicles, impair use of pedestrian, cyclist, and transit systems
- Projected increases to **extreme precipitation** are likely to intensify current hazards related to **localized flooding** and **road delays/closures** due to snow
- **Flood hazards** are likely to increase with **extreme precipitation**, particularly on **uncontrolled streams**, and with **unknown implications for dams**
- Increases in extreme precipitation and wildfire hazards increase the risk of **landslide activity on burned slopes**, especially during **extreme precipitation events**

Mitigating emissions can reduce long-term impacts, but mid-century impacts are baked in

In most cases, the biggest differences between projected climate hazards in the 'best case' reduced emissions scenario (RCP4.5) and the 'worst case' unconstrained emissions scenario (RCP8.5) occur toward the end of the century in the 2085 projections. By comparison, mid-century (2055) projections show much smaller differences between reduced emissions and unconstrained emissions scenarios. Figure ES-2 shows how reduced global emissions may help the region avoid the worst projections for wildfire hazards.

Figure ES-2. Significant increases in wildfire probability are likely to occur by 2055, regardless of emissions scenario. But emissions reductions may reduce extreme hazards by the end of the century.



For Shasta residents and planners, the implication is clear: emissions mitigation actions are an important step to avoid the worst long-term effects of climate change, but will not be sufficient to avoid mid-century projections of climate hazards. Instead, the Shasta Region should plan to adapt its transportation systems to function under the climate and weather conditions projected in this report.

Managing extreme climate and weather hazards like fire is becoming essential to maintaining good condition transportation infrastructure

As the Shasta Region's climate becomes warmer and more extreme, design and maintenance of the region's built infrastructure must also adjust. Built infrastructure that was designed for past climates will likely face accelerated degradation as harsh operating conditions increase wear and tear. New infrastructure should be built with the climate of the future in mind. A paradigm shift towards addressing climate hazards is necessary as well: ensuring that roads are in good condition should include actions to prevent fires from igniting and spreading along roadsides, as well as protecting roads from fires. Similarly, maintaining vehicles, roads, and infrastructure for heat means maintaining them for extreme heat.

Evacuations are inevitable, so transportation investments should seek to make them faster, equitable, and more effective—all without compromising other mobility goals

While evacuation is not traditionally considered a core element of mobility, the fire hazards facing the Shasta Region compel public safety and transportation agencies to consider evacuations in all transportation planning. Evacuation should be considered from every perspective, including planning, design, infrastructure operations, and maintenance. Government, private, and non-profit stakeholders in the region should also work together to improve information sharing about mobility-challenged residents, accelerate evacuation warnings, and assign responsibilities for evacuations.

Changing conditions mean that new hazards are likely to emerge, including from co-dependent infrastructure systems

As transportation systems – along with other critical infrastructure systems like energy, telecommunications, and water – become more integrated and interdependent upon external services, mobility will be increasingly vulnerable to disruptions to interconnected systems. For example, electrification of vehicles exposes much of the Region's transportation infrastructure to vulnerabilities associated with extended power outages. Likewise, automation of signals and an increasing reliance on digital and connected systems to control transportation infrastructure leaves system operators reliant on power, internet, and cellular services. During emergencies, failures in energy or telecommunications systems can cascade, leading to disruptions in transportation services. Disruptions in transportation can likewise exacerbate emergencies or delay restoration of critical infrastructure systems – damaged or destroyed roads can prevent repair crews from reaching downed power lines or damaged communications equipment.

The risk of maladaptation can intensify existing vulnerabilities in the Shasta Region

Recognizing and adapting to climate threats is an important role that governments, intuitions, and private organizations at every level must engage in. But when adaptive approaches fail to address the full scale of a vulnerability or when they rely on inaccurate or overly optimistic projections, the risk is that the adaptive action not only wastes resources while providing deceptive protection, but also that it crowds out effective adaptive approaches. Maladaptation can happen when planners focus too narrowly on a single threat, an individual sector, or a specific location without fully integrating actions into a long-term, multi-sector, and intergovernmental adaptation strategy. Maladaptive approaches may result in inadequate investments in infrastructure solutions that consume resources and lock a region into a vulnerable infrastructure system, or it may result in duplicative work conducted by government agencies that fail to coordinate efforts.

In the Shasta Region, the risk of maladaptation may be increased by inconsistent and uncoordinated planning across the Region's governments, institutions, and system operators. This plan partially addresses the risks of maladaptation by seeking solutions that emphasize the formation of working groups, forums, and other spaces for the Region's policymakers to coordinate and collaborate on long-term, intersectoral adaptation planning. However, more work is needed to ensure the Shasta Region avoids maladaptive approaches to climate risks.

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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.

Fire Weather Watch

A Fire Weather Watch is a National Weather Service forecast indicating weather conditions associated with elevated fire hazard over the next 12 to 72 hours. Weather conditions contributing to a Fire Weather Watch may include warm temperatures, very low humidity, low fuel moisture content, and high winds.

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.

Maladaptation

Actions that may lead to increased risk of negative outcomes related to climate change, including actions that increase greenhouse gas emissions; increase, spread, or shift vulnerability to climate change; create or exacerbate inequitable outcomes; or which reduce welfare, now or in the future. Most often, maladaptation is an unintended consequence.

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.

Public Safety Power Shutoff (PSPS) Events

During dangerous weather conditions that could contribute to the ignition or spread of wildfire, utilities may proactively cut power to electrical lines to reduce the likelihood that their infrastructure could cause or contribute to a wildfire. While PSPS events are an emergency measure intended to reduce the risk of wildfire, cutting off power to entire communities can significantly impair the resilience and responsiveness of communities to wildfire.

Red Flag Warning

A Red Flag Warning is the National Weather Service's highest-level warning for weather conditions that contribute to fire hazards. A Red Flag Warning typically indicates that temperatures, humidity, fuel water content, and wind are ideal for the ignition and spread of wildfires. Red Flag Warnings extend up to 24 hours, and Fire Weather Watches may extend to 72 hours.

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. This scenario is considered very unlikely given current international emissions outlooks but serves as an illustrative 'minimum' in terms of projected 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. This scenario is considered a ‘worst case’ scenario, but one that reflects current global trends in emissions and assumes no change in trajectory.

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.

Introduction

Purpose and Background

This final report synthesizes the findings and recommendations of the Resilient**Shasta** project. Resilient**Shasta** is an effort conducted by the Shasta Regional Transportation Agency with the purpose of helping regional communities and leaders understand and adapt to climate and extreme weather threats to the mobility of the Shasta Region. This study has been funded through a Caltrans Adaptation Planning Grant secured by SRTA. Resilient**Shasta** seeks to advance three goals:

- Development of a mobility vulnerability assessment explaining extreme weather 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 effort leveraged data, modeling, and expertise from local, state, and federal agencies to evaluate the exposure of infrastructure systems and Shasta Region communities to climate and extreme weather hazards, including average and extreme temperatures, average and extreme precipitation, flooding, wildfire, and landslide potential. Following the methodology established in the California Department of Transportation (Caltrans) District 2 Climate Change Vulnerability Assessment, this study applied a similar analysis to the Shasta Region, including a detailed assessment of county and municipal infrastructure and operations vulnerabilities.[1] Based on this assessment, this effort produced the Draft Resilient**Shasta** Extreme Climate Event Transportation Vulnerability Assessment. SRTA staff and consultants conducted public outreach through two public meetings and two public surveys, and sought stakeholder input from Regional agencies to refine and improve the initial vulnerability assessment.

Using the findings of the vulnerability assessment, the Resilient**Shasta** Transportation Adaptation Plan identifies 25 individual adaptation strategies that can address the Region's most pressing mobility vulnerabilities, especially those related to wildfire and evacuations. These recommendations seek to ensure the Shasta Region's transportation systems and operations are prepared for, protected from, and able to recover from climate disruptions, while also preparing the Region's agencies for inevitable evacuations. As for the vulnerability assessment SRTA staff and consultants conducted public and stakeholder outreach, using surveys, meetings and workshops to elicit feedback and input.

[1] Caltrans 2018a

Why Extreme Weather and Climate Change?

Wildfires—including 2018's Carr Fire, 2020's Zogg Fire, and 2021's Dixie, Salt, and Fawn Fires—are a present and growing danger in the Shasta Region. These fires, and the climate conditions that enable them, are growing more dangerous every year. 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 Carr Fire, like 2021's Salt Fire, was initially ignited by vehicle sparks igniting dry roadside vegetation, and quickly grew to consume 230,000 acres and over a thousand homes, with eight lives lost in its wake.[2] 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.[3] By the time the fire had burned through Igo and Ono, four people were killed and over 200 buildings damaged.[4] 2021 brought the Dixie Fire, which burned almost one million acres in five counties, including over 1300 structures and one death—with a total estimated cost of over $1 billion dollars.[5]

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. Table 1 shows example mobility impacts related to each kind of hazard evaluated in this study.

Table 1. Types of climate hazards and example mobility impacts.

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

[2] Estrada 2019
[3] Brannon 2021
[4] Arthur 2020
[5] Kasler 2021

Shasta Regional Mobility Vulnerability Assessment

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 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 2 lists many of the various ways that rising temperatures can affect the region's transportation systems.

Table 2. 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 1 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.

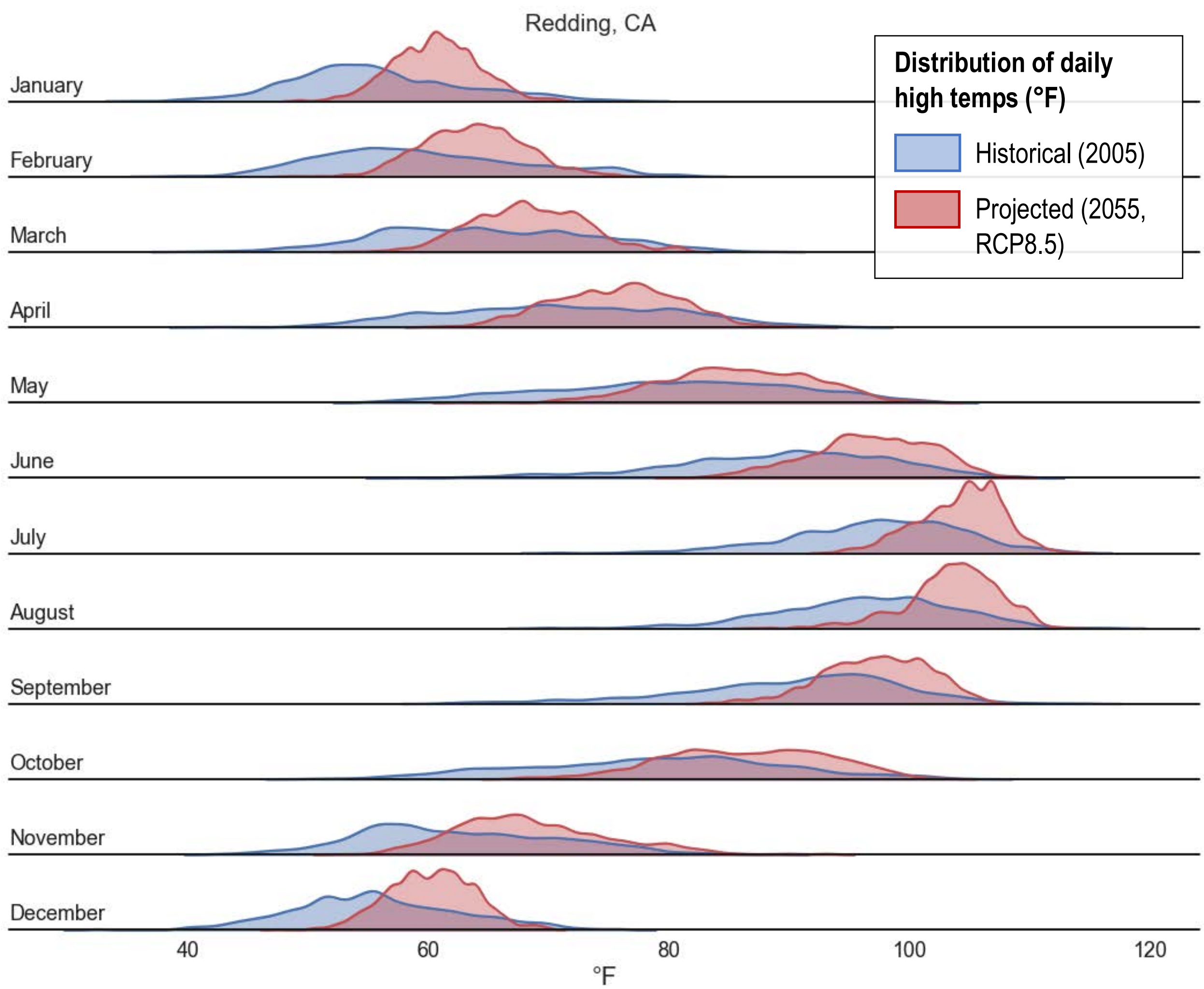

Figure 1. Projected changes to the distribution of daily high temperatures in Redding, CA.

Similar trends are visible in other parts of the Shasta Region. Figure 2, Figure 3, and Figure 4 show the distribution of temperatures in Shingletown, Burney, and at Lake Helen in the Lassen National Volcanic Park.

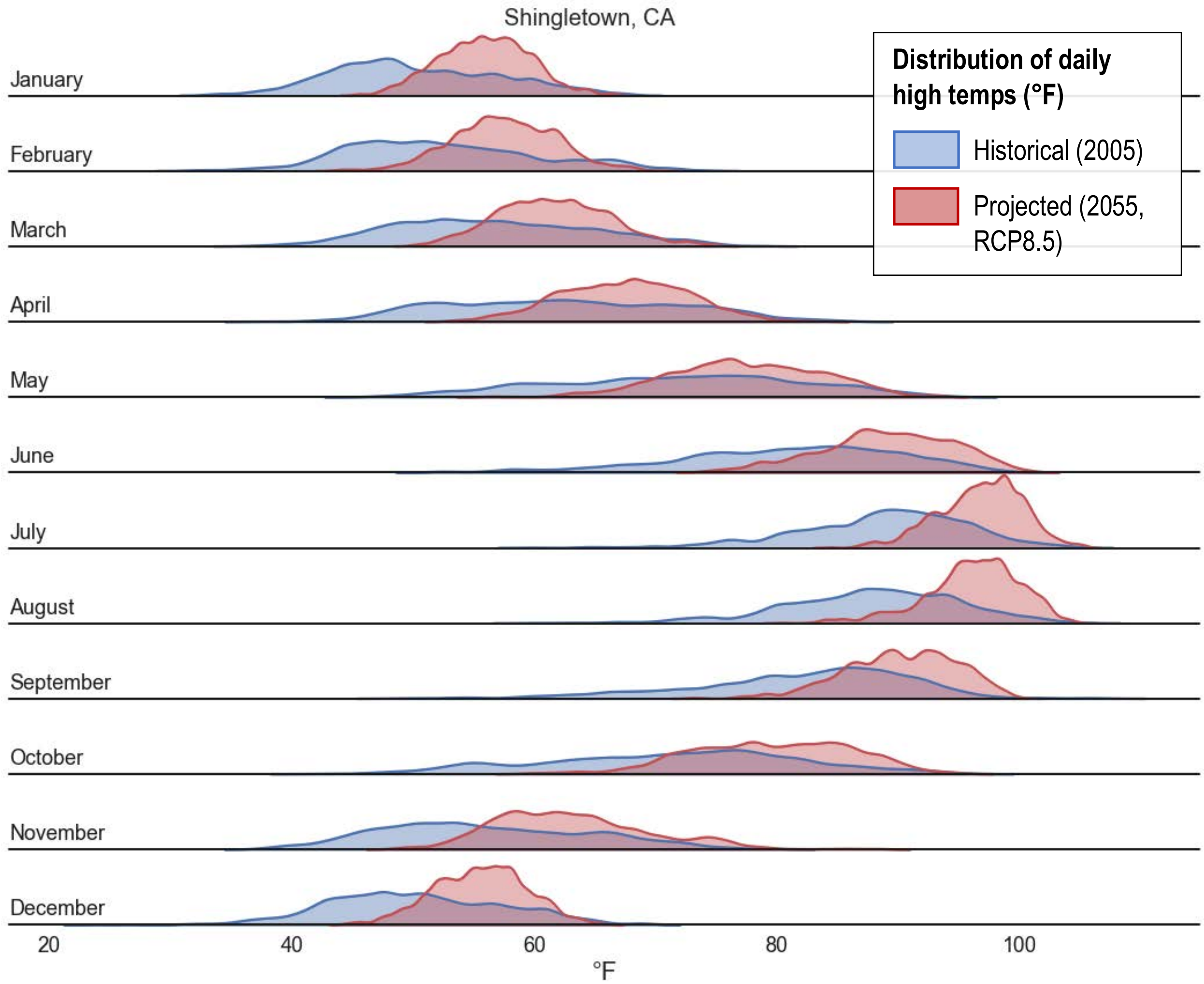

Figure 2. Projected changes to the distribution of daily high temperatures in Shingletown, CA.

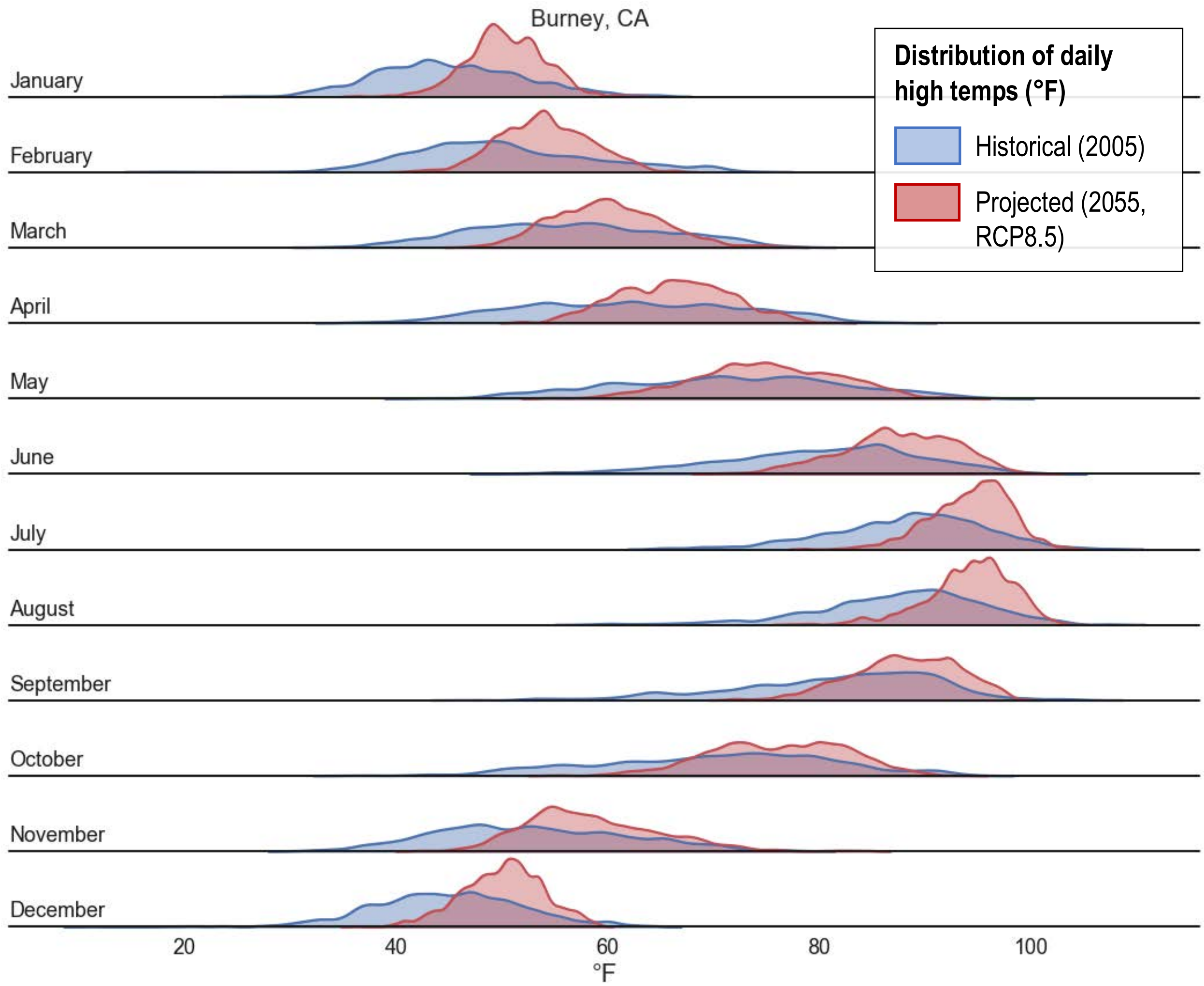

Figure 3. Projected changes to the distribution of daily high temperatures in Burney, CA.

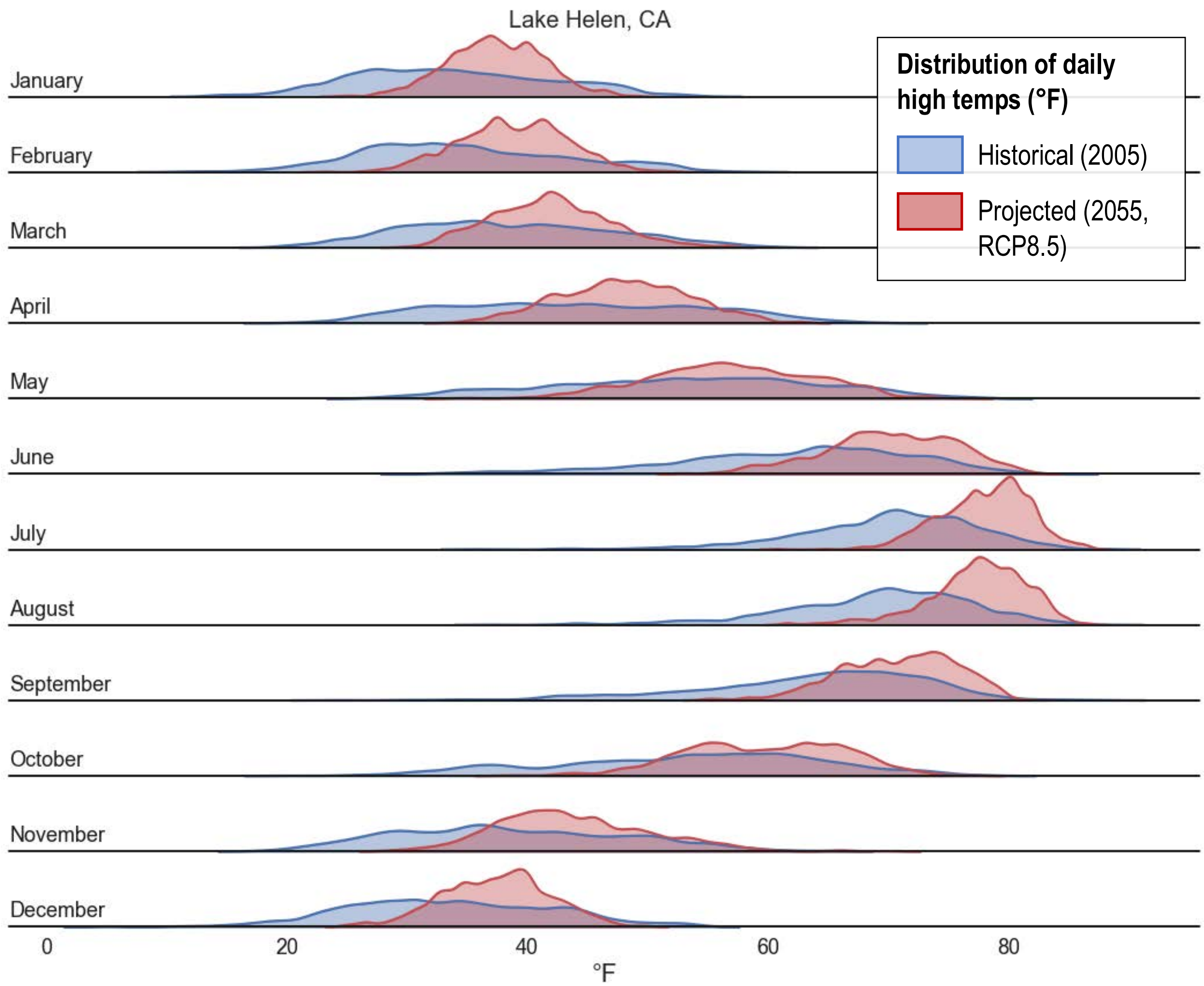

Figure 4. Projected changes to the distribution of daily high temperatures at Helen Lake.

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 3 shows the projected average annual high temperatures across the Shasta Region.

Table 3. 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 5 shows the historical and projected increases in average annual high temperatures in the unconstrained emissions scenario. Additional figures can be found in Appendix C.

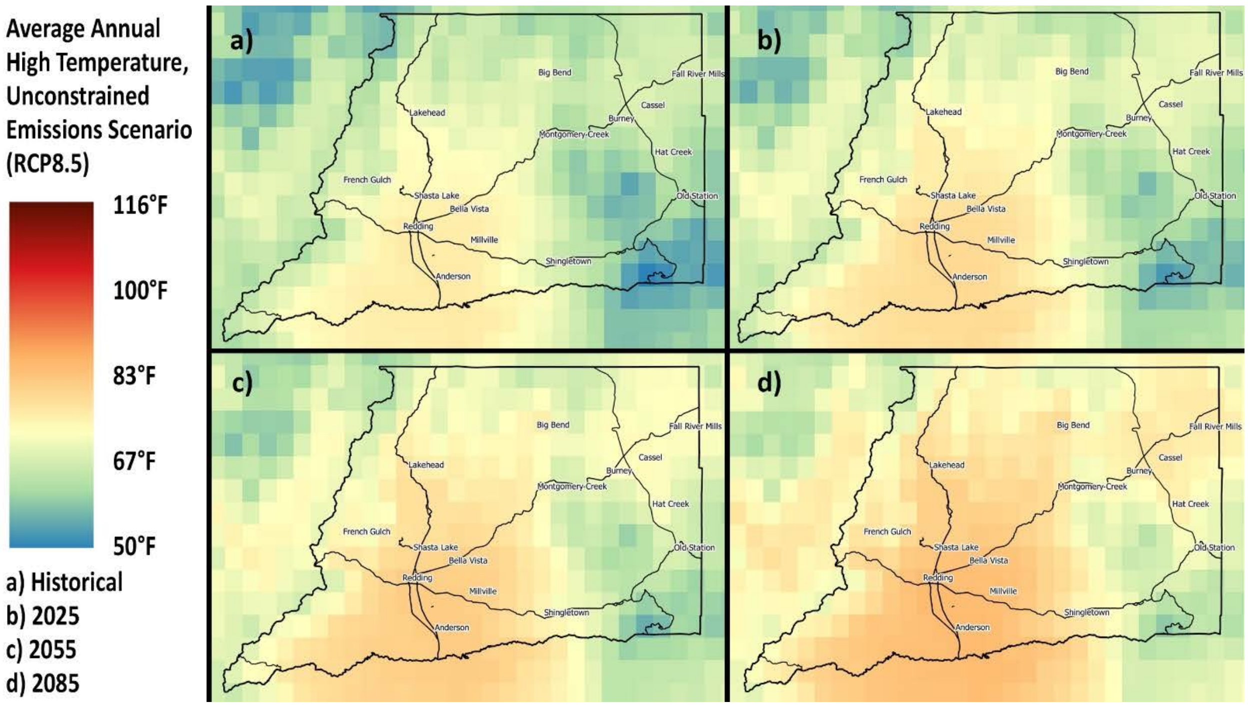

Figure 5. Projected changes to annual average high temperature over the course of the 21st century in an unconstrained emissions scenario. The upper Sacramento River Valley bears the brunt of increasing temperatures, but all parts of the Shasta Region see higher annual temperatures.

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 4 shows projected changes to average summer high temperatures in select locations across the Shasta Region.

Table 4. 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 6 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 C.

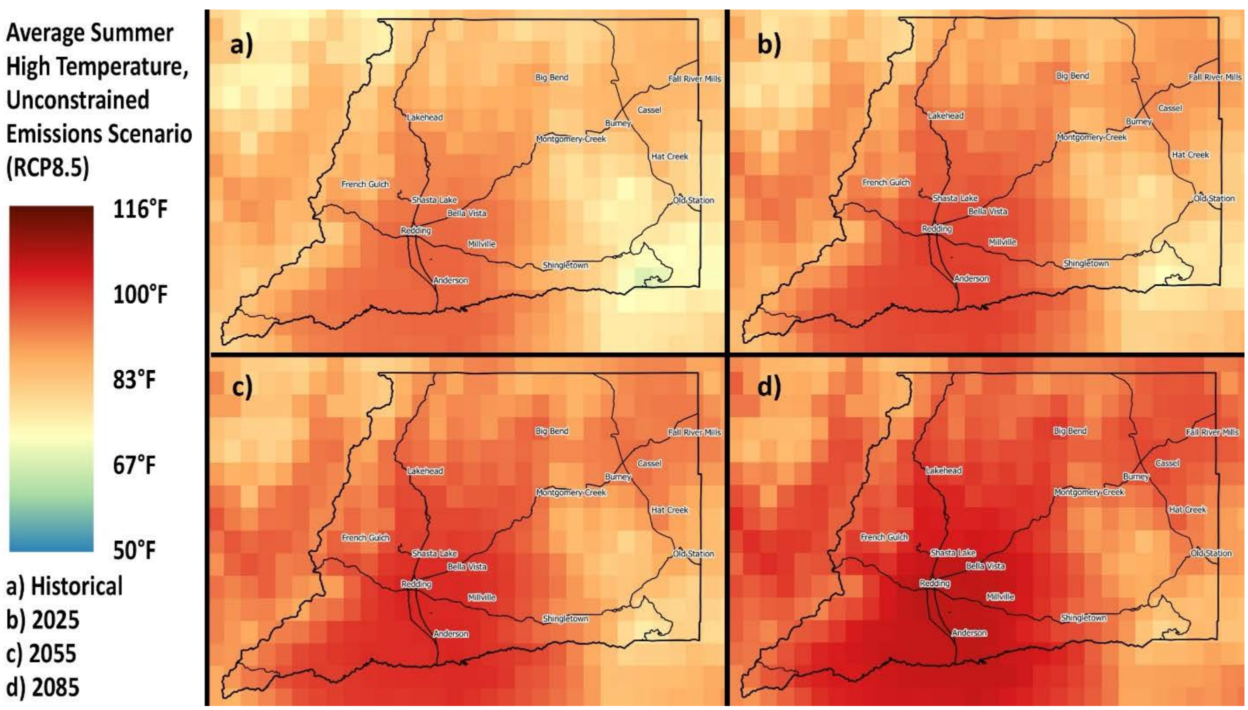

Figure 6. Projected changes to average summer high temperatures over the course of the 21st century in an unconstrained emissions scenario. Average summer temperatures in Redding and the upper Sacramento River Valley are projected to exceed 100°F by midcentury in both the unconstrained and reduced emissions 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 107 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.**

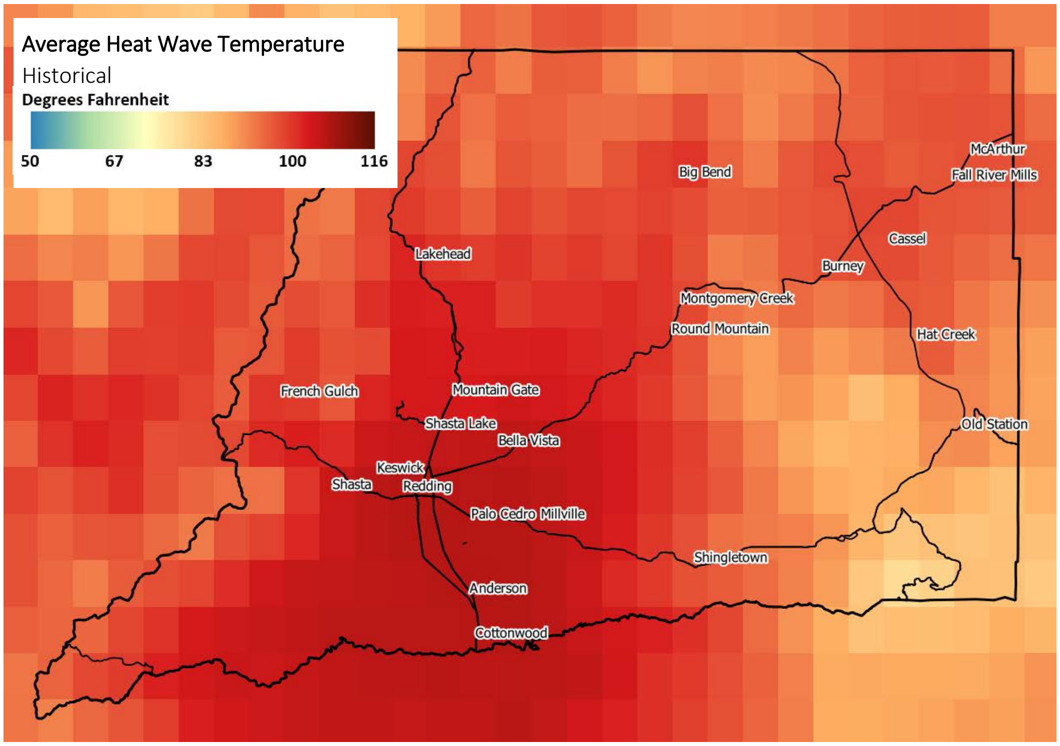

Figure 7. Average heat wave high temperatures in the Shasta region under historical conditions (1975 - 2004).

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 5 and Figure 8 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 C.

Table 5. 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

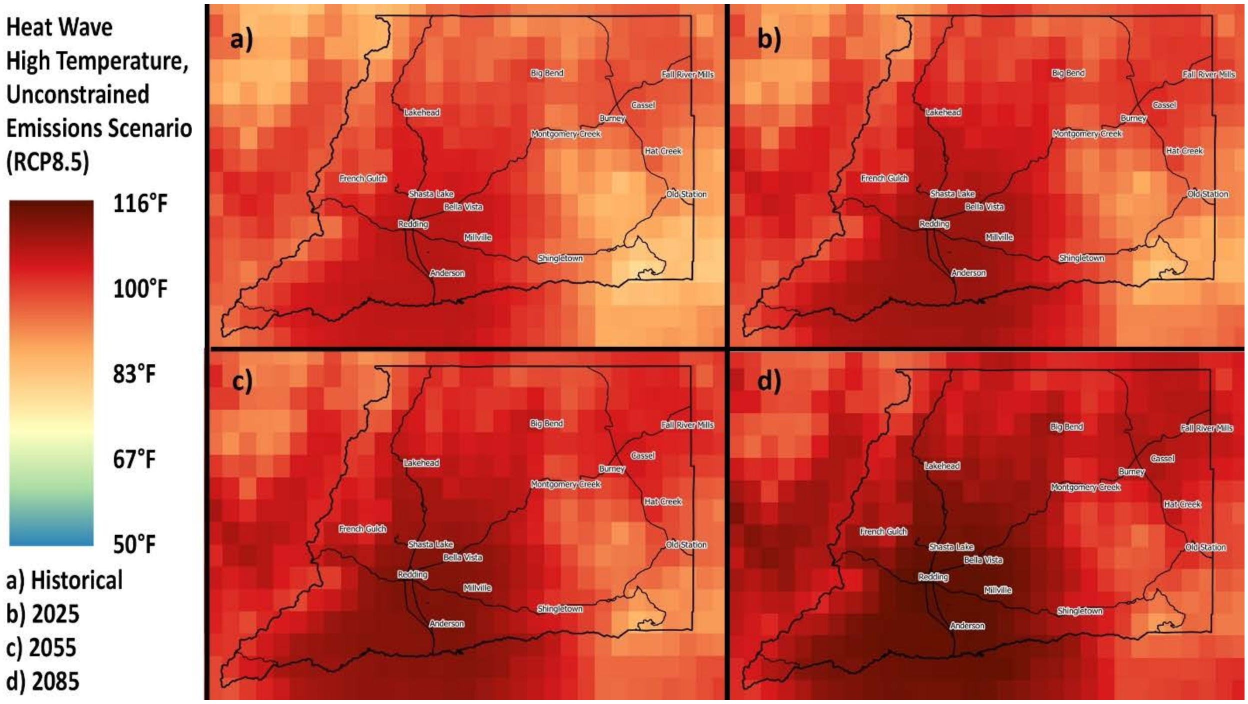

Figure 8. Historical and projected heat wave temperatures in the Shasta Region in an unconstrained emissions scenario (RCP8.5).

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 6 shows the historical and projected numbers of freeze thaw cycles at select locations across the Shasta Region. Figure 9 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 6. 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

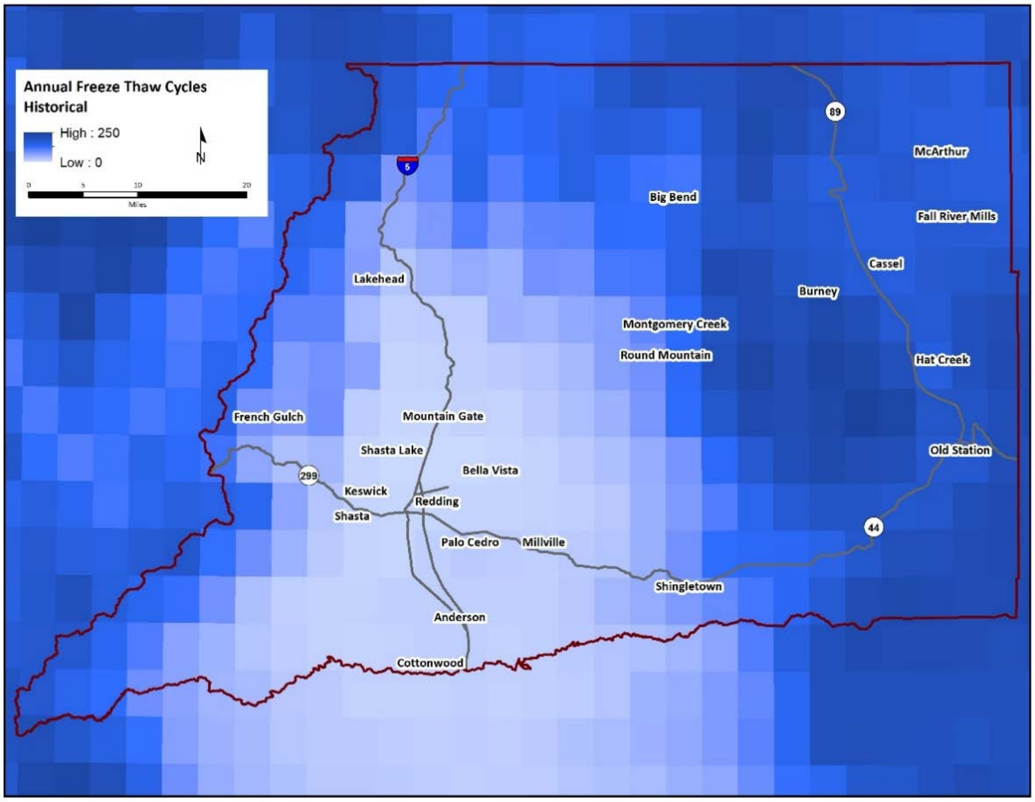

Figure 9. Annual average number of freeze-thaw cycles per year, historical average (2005).

Figure 10 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).

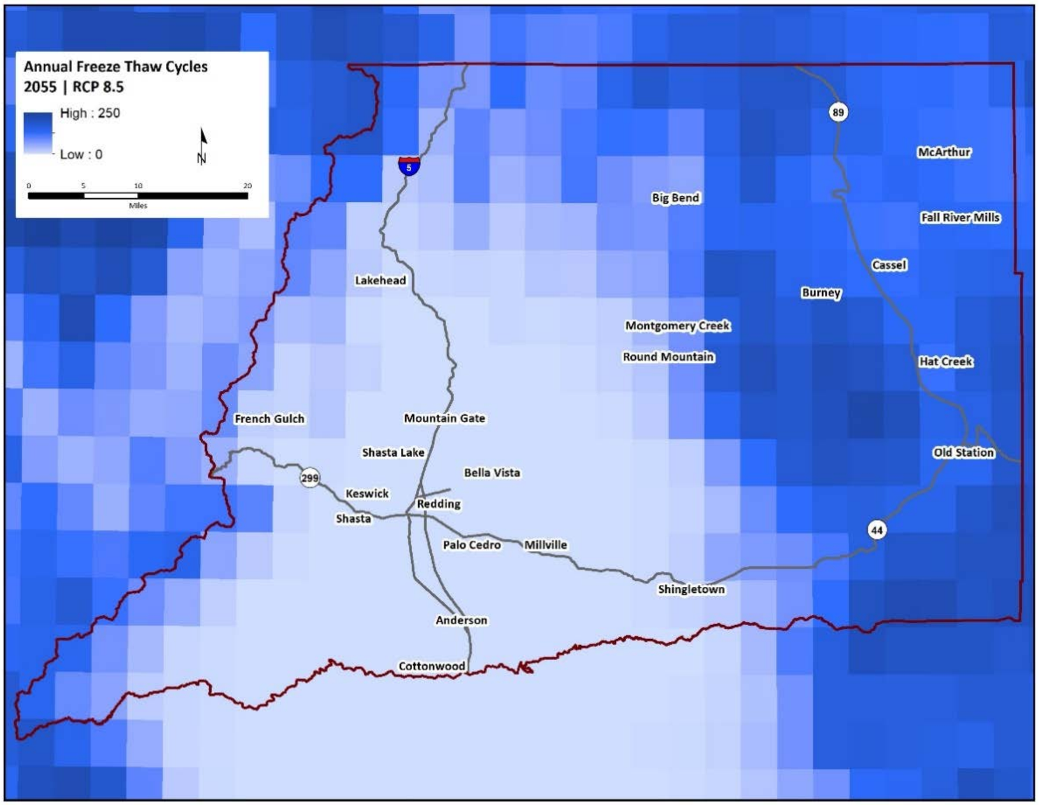

Figure 10. Annual average number of freeze-thaw cycles per year, projected (2055, RCP8.5).

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 7 provides examples of the ways that these impacts affect the region's mobility and transportation systems.

Table 7. 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 11 shows the average historical precipitation across the Shasta Region.

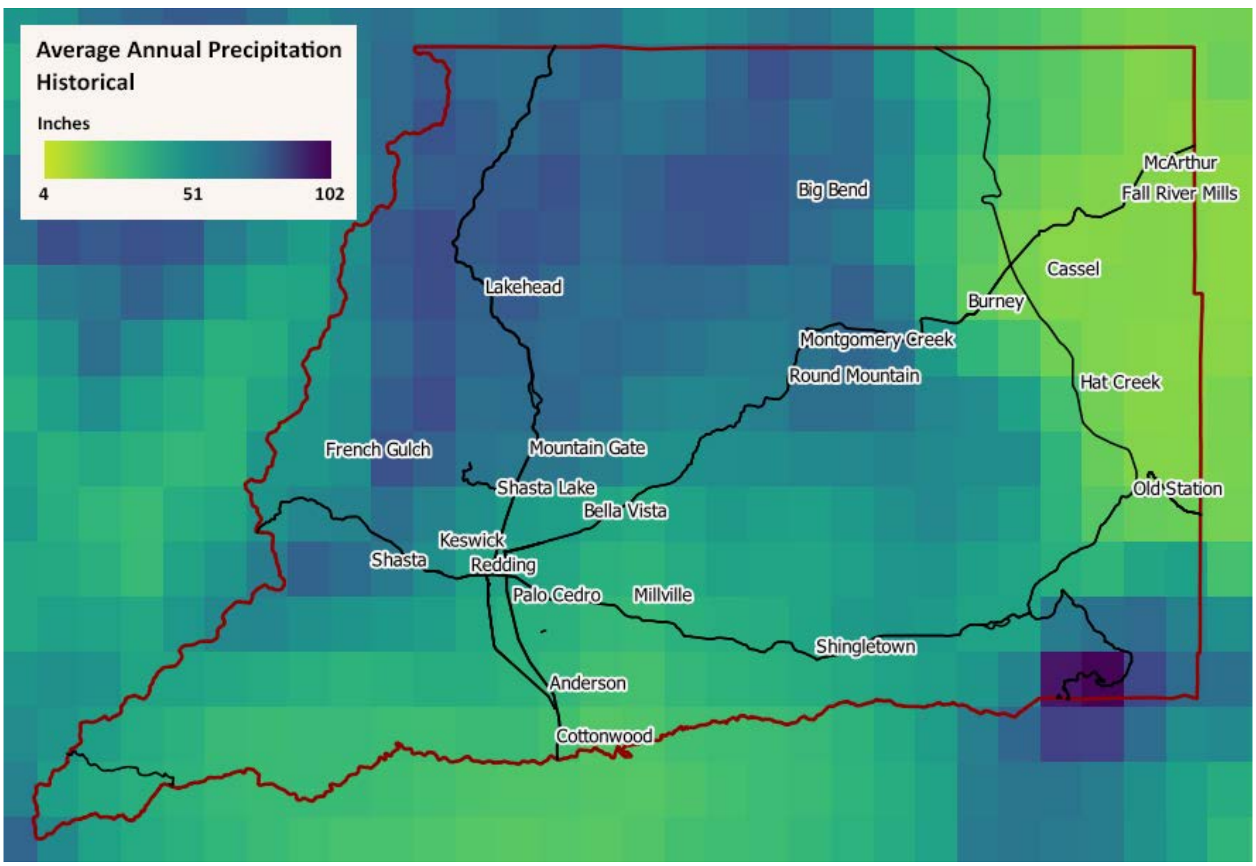

Figure 11. Historical annual average precipitation across the Shasta Region.

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 12 shows the historical average pattern of precipitation across the Shasta Region during the wet season.

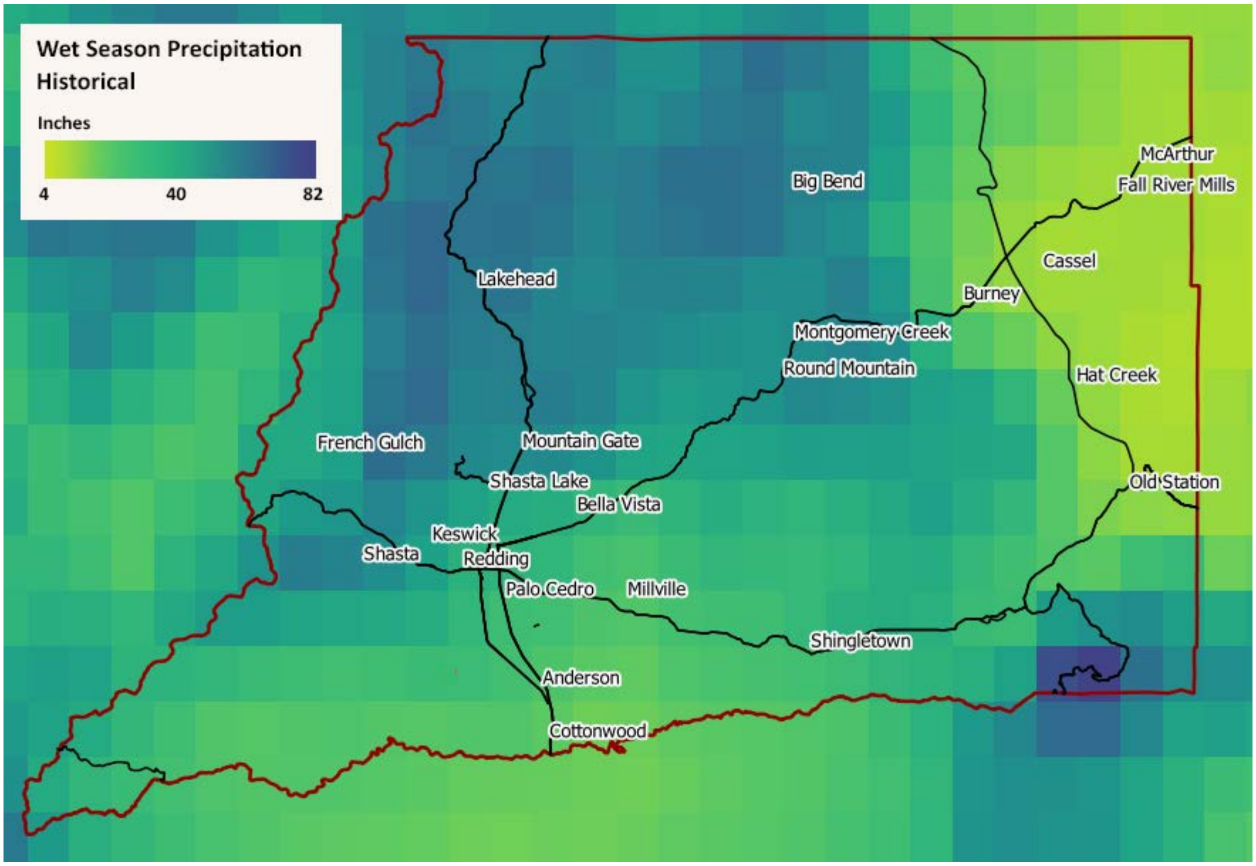

Figure 12. Historical average wet season precipitation in the Shasta Region.

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 13 shows the historical average dry season precipitation in the Shasta Region.

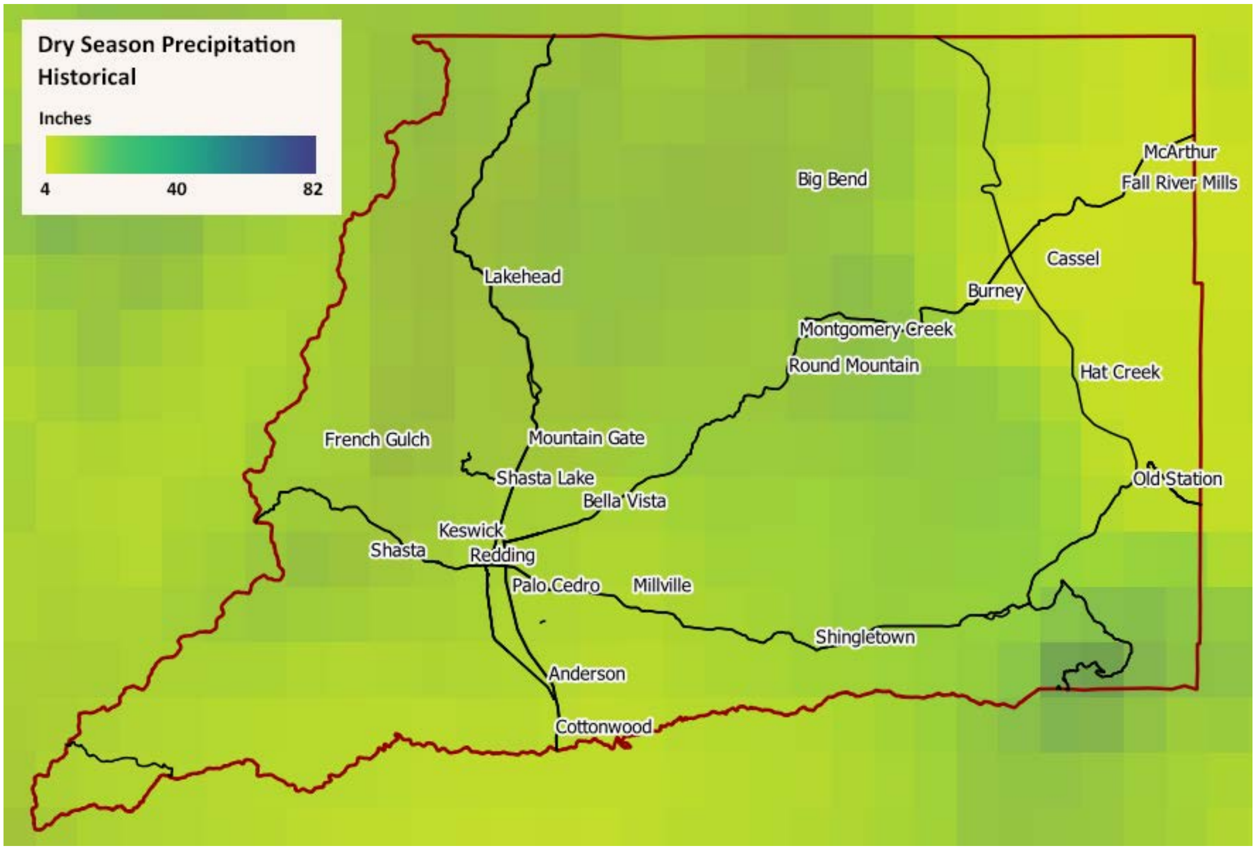

Figure 13. Historical average dry-season precipitation across the Shasta Region.

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 8). 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 C.

Table 8. 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 14). 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.

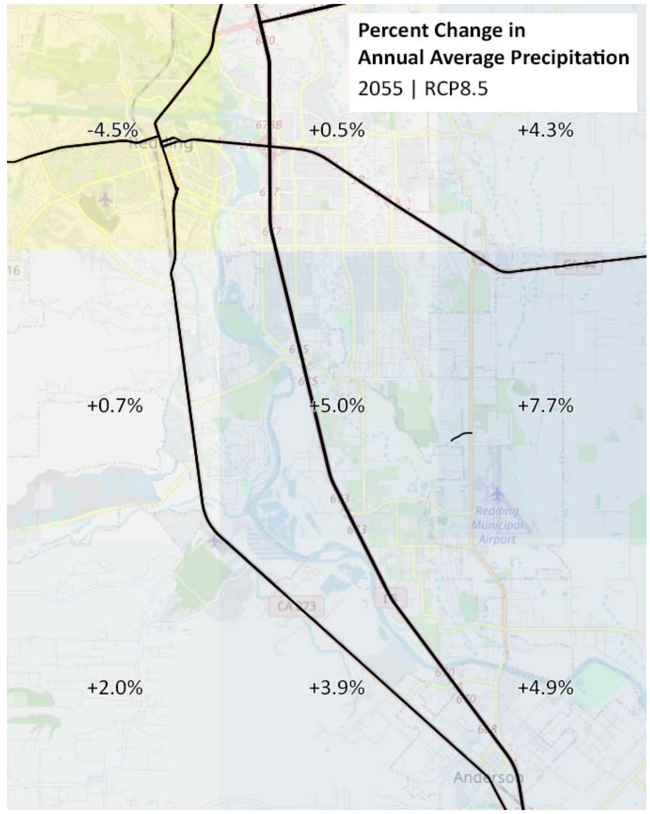

Figure 14. Detail of projected change in annual average precipitation in the Redding - Anderson area. 2055, RCP8.5.

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 9.

Table 9.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 15). 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.

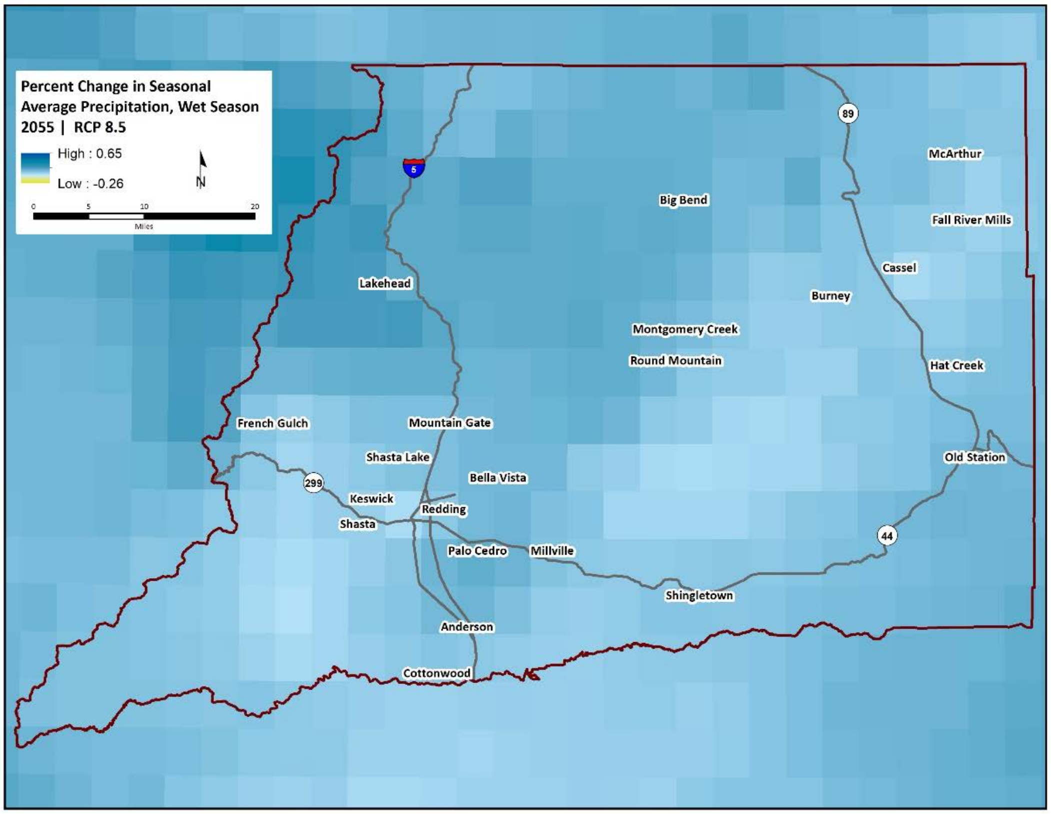

Figure 15. Projected change in average wet season precipitation in the Shasta Region. 2055, RCP8.5 scenario.

By 2085, every part of the Shasta Region is projected to see increased wet-season precipitation, with most increases significant (Figure 16). 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 C.

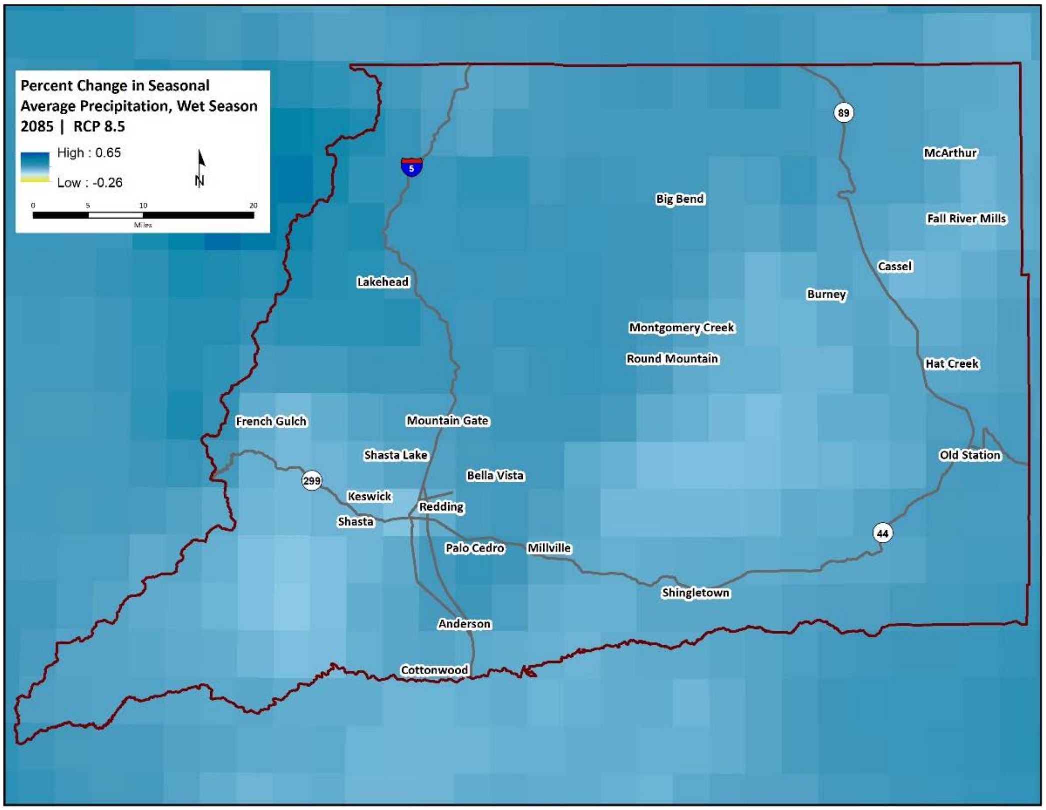

Figure 16. Projected change in average wet season precipitation in the Shasta Region. 2085, RCP8.5 scenario.

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

[6] Shasta County 2017

Table 10. 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 17). 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 10. 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%

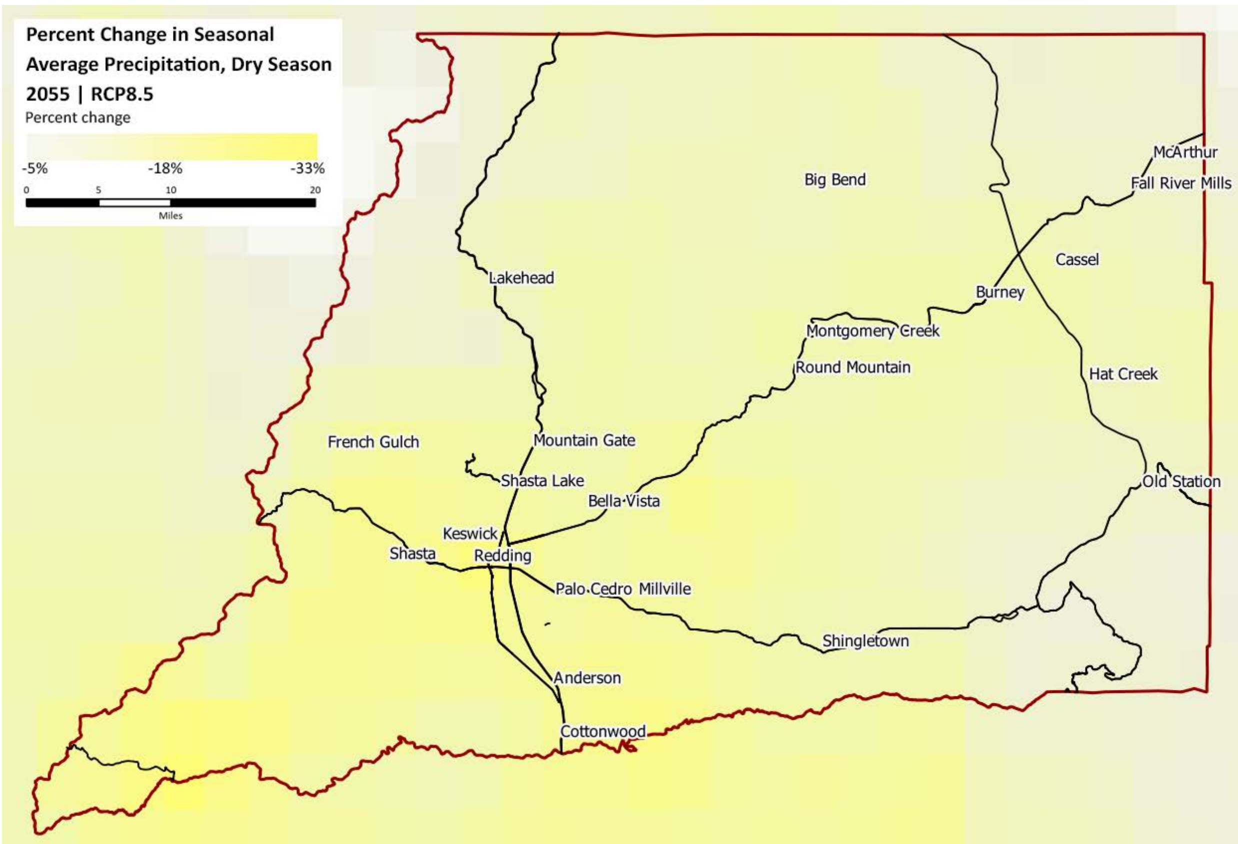

Figure 17. Percent change in dry season precipitation, 2055 RCP8.5.

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 18). 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.

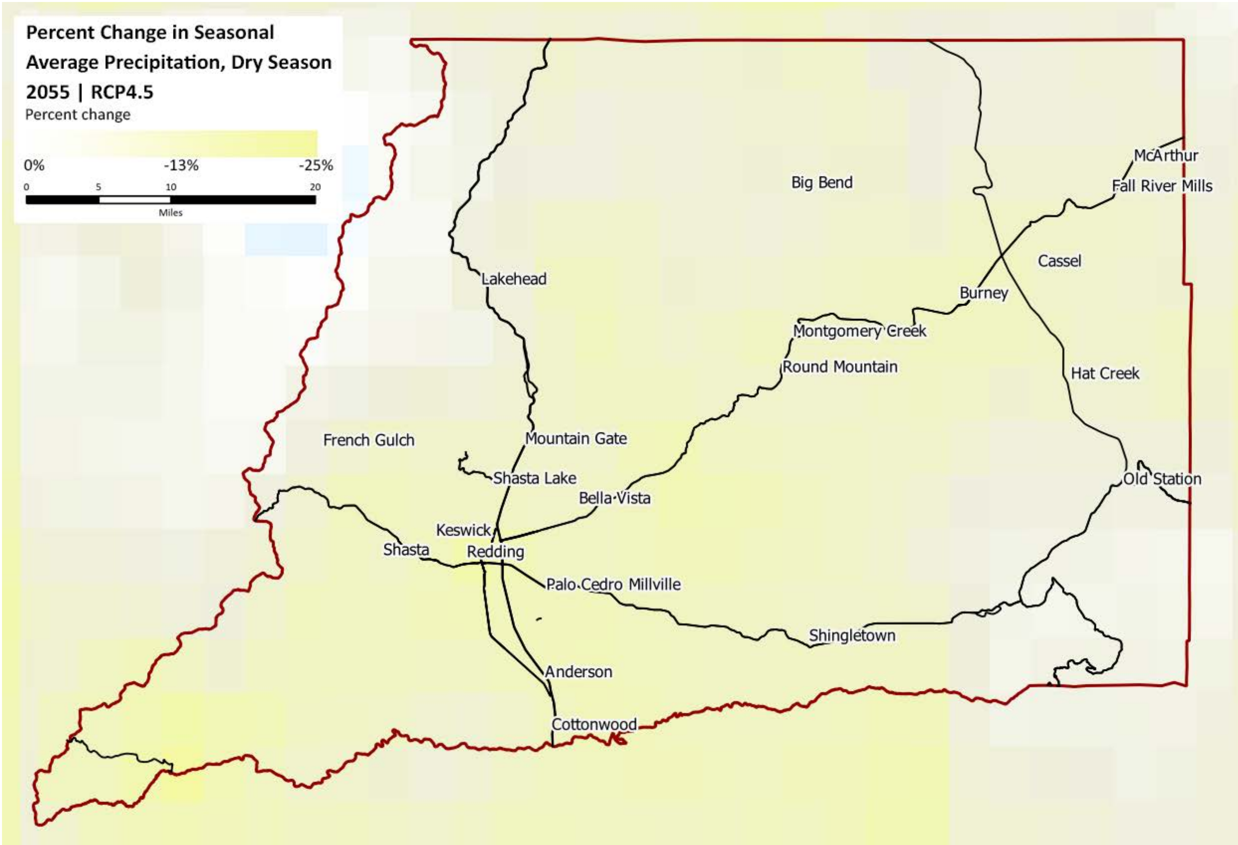

Figure 18. Percent change in dry season precipitation, 2055 RCP4.5.

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 11 shows the projected changes to extreme precipitation events in 2055 in both the reduced and unconstrained emissions scenarios. Figure 19 and Figure 20 show the projected change in 100-year and 25-year extreme precipitation events by 2055 in an unconstrained emissions scenario. Figure 21 and Figure 22 show the same projections for the 2025 time period.

Table 11. 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%

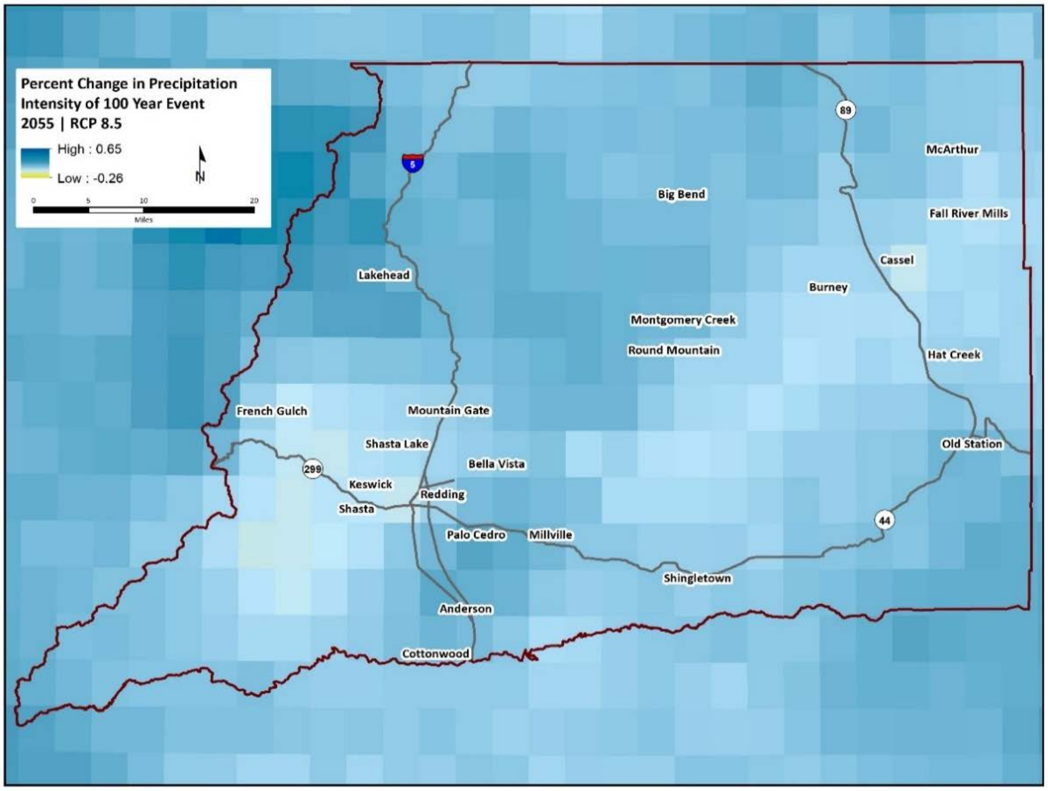

Figure 19. Projected percent change in intensity of 100-year extreme precipitation event. 2055, RCP8.5.

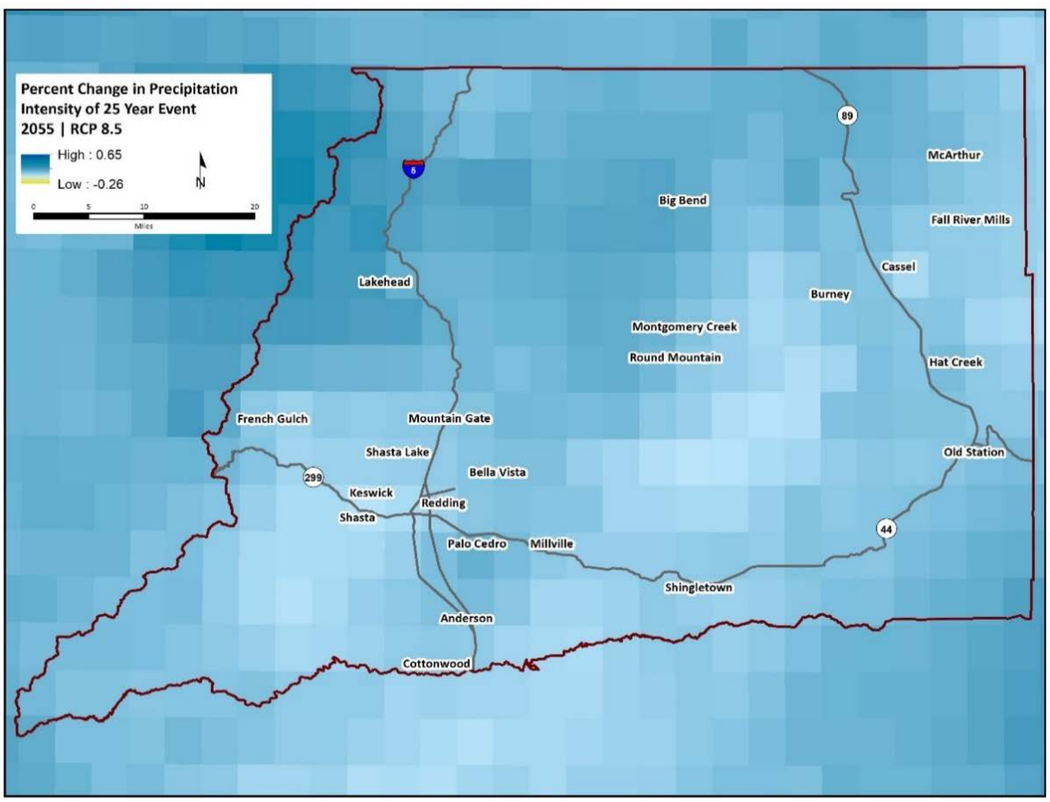

Figure 20. Projected percent change in intensity of 25-year extreme precipitation event. 2055, RCP8.5.

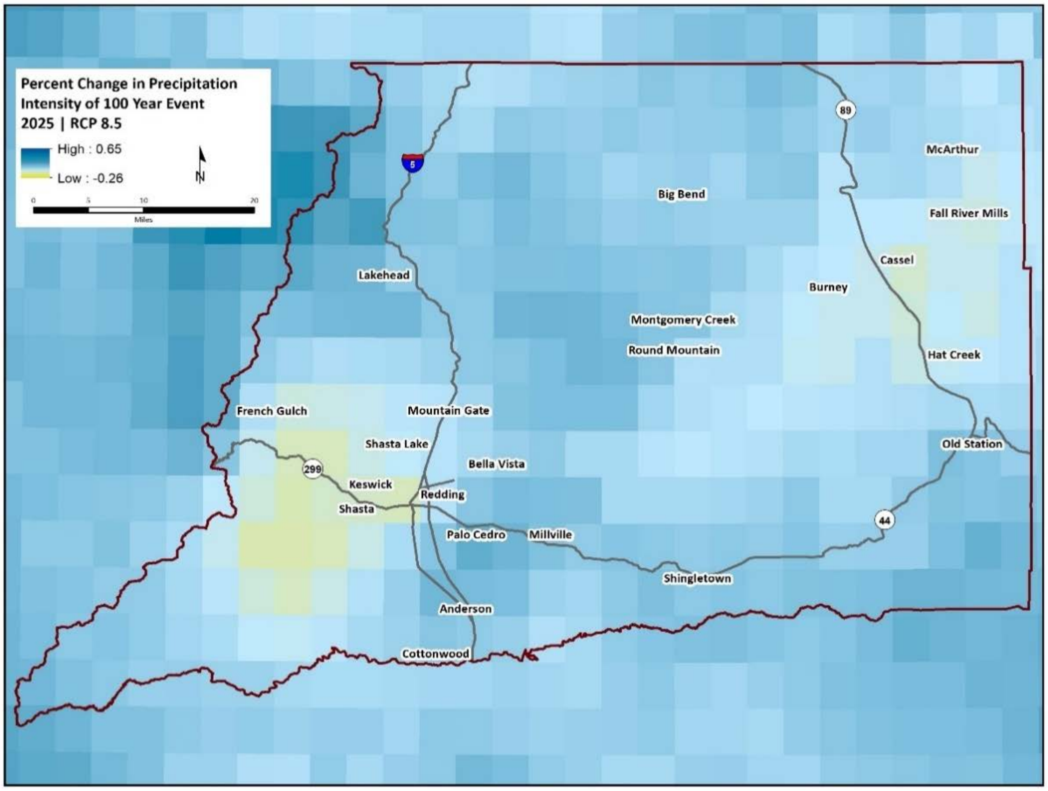

Figure 21. Projected percent change in intensity of 100-year extreme precipitation event. 2025, RCP8.5.

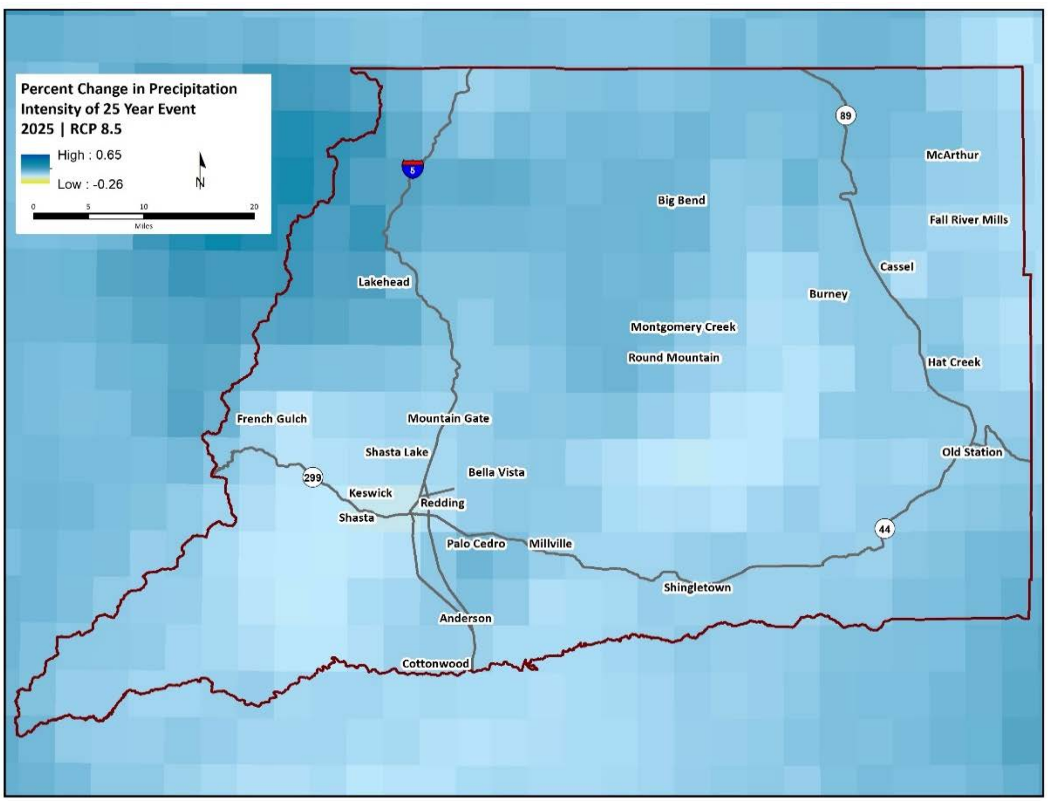

Figure 22. Projected percent change in intensity of 25-year extreme precipitation event. 2025, RCP8.5.

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 23 shows the projected change for the 500-year extreme precipitation event by 2055 in an unconstrained emissions scenario; Figure 24 shows the same in 2025.

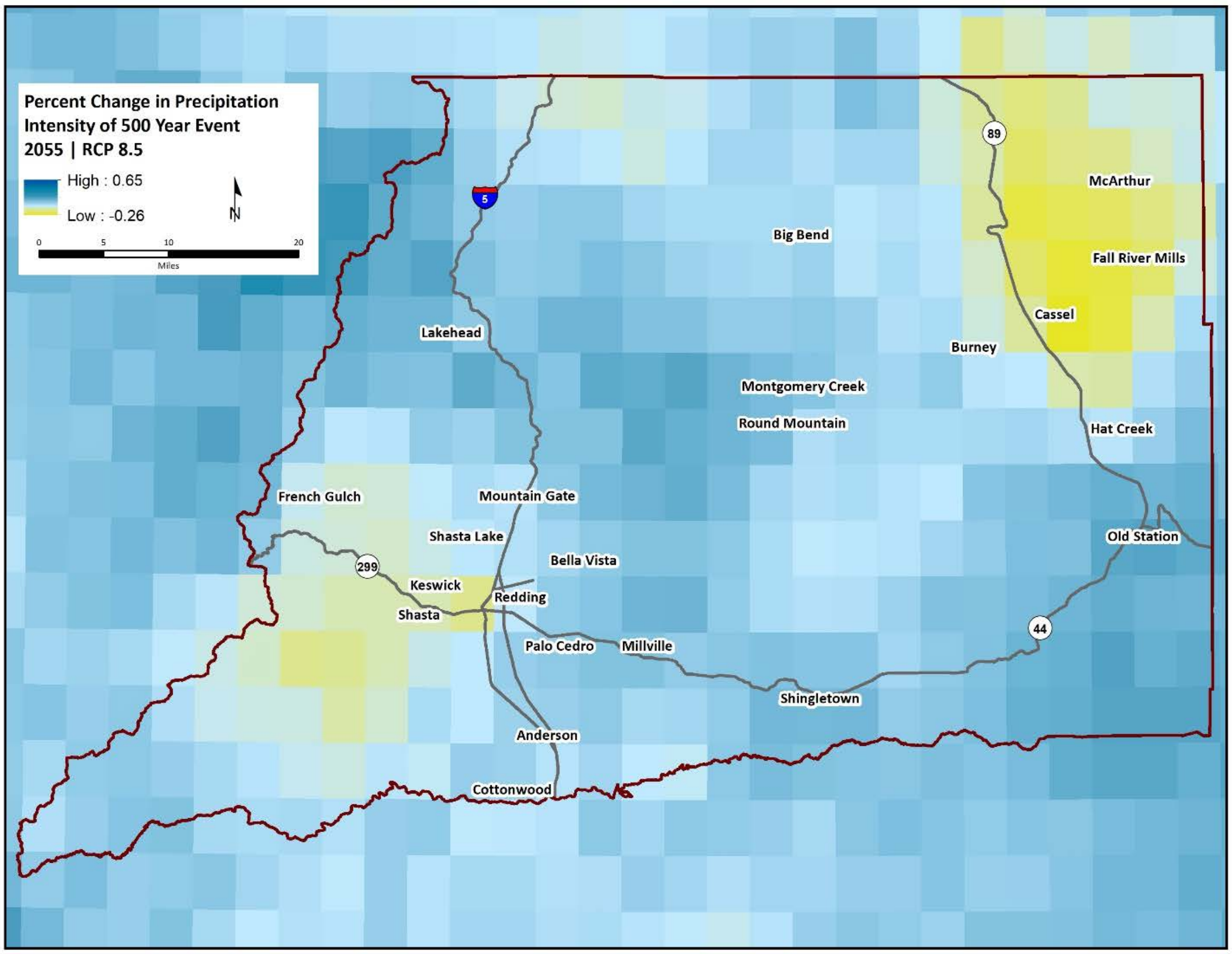

Figure 23. Projected percent change in intensity of 500-year extreme precipitation event. 2055, RCP8.5.

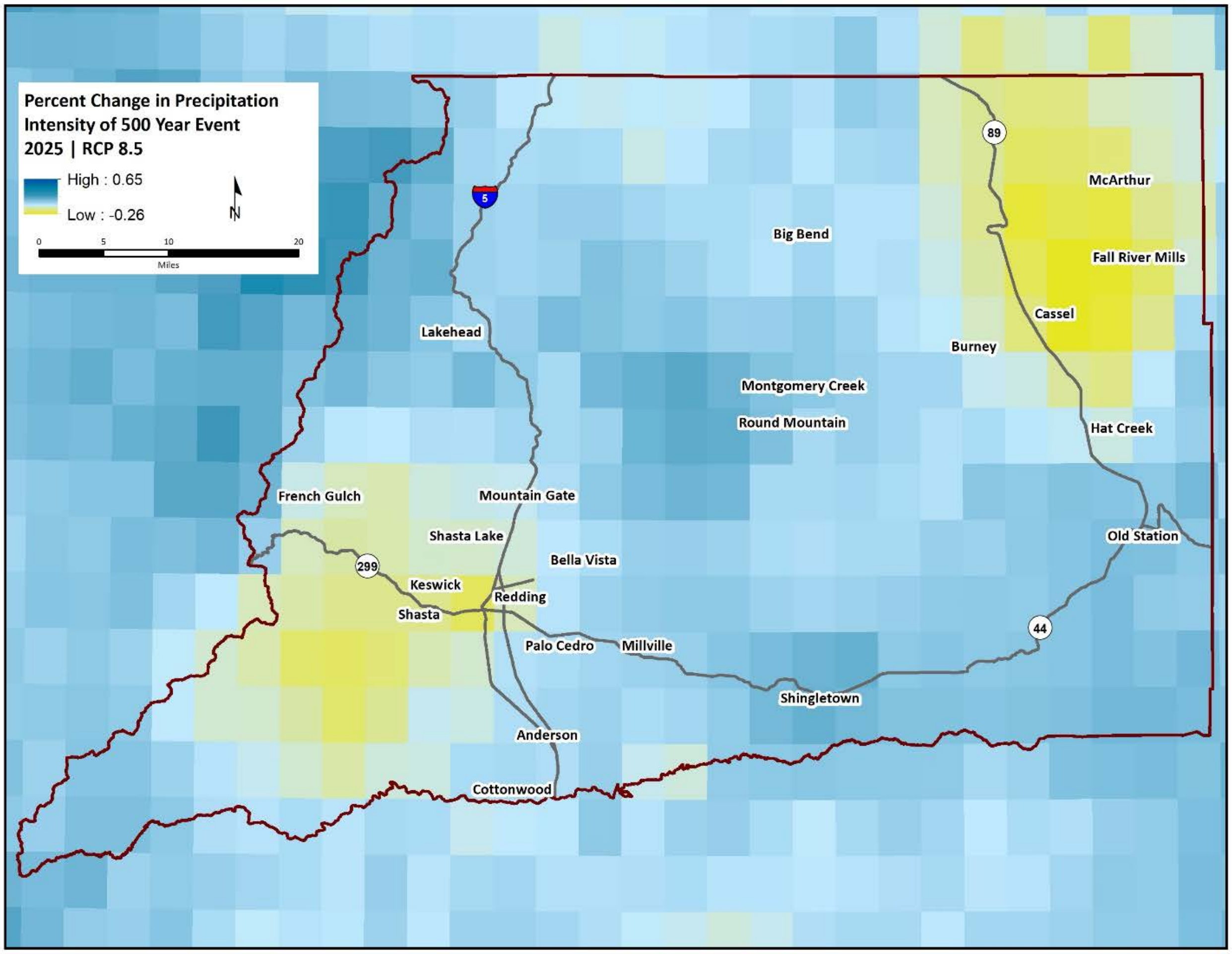

Figure 24. Projected percent change in intensity of 500-year extreme precipitation event. 2025, RCP8.5.

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 25, Figure 26, and Figure 27 show the projected change for the 25-, 100-, and 500-year extreme precipitation events in 2085 in an unconstrained emissions scenario, respectively.

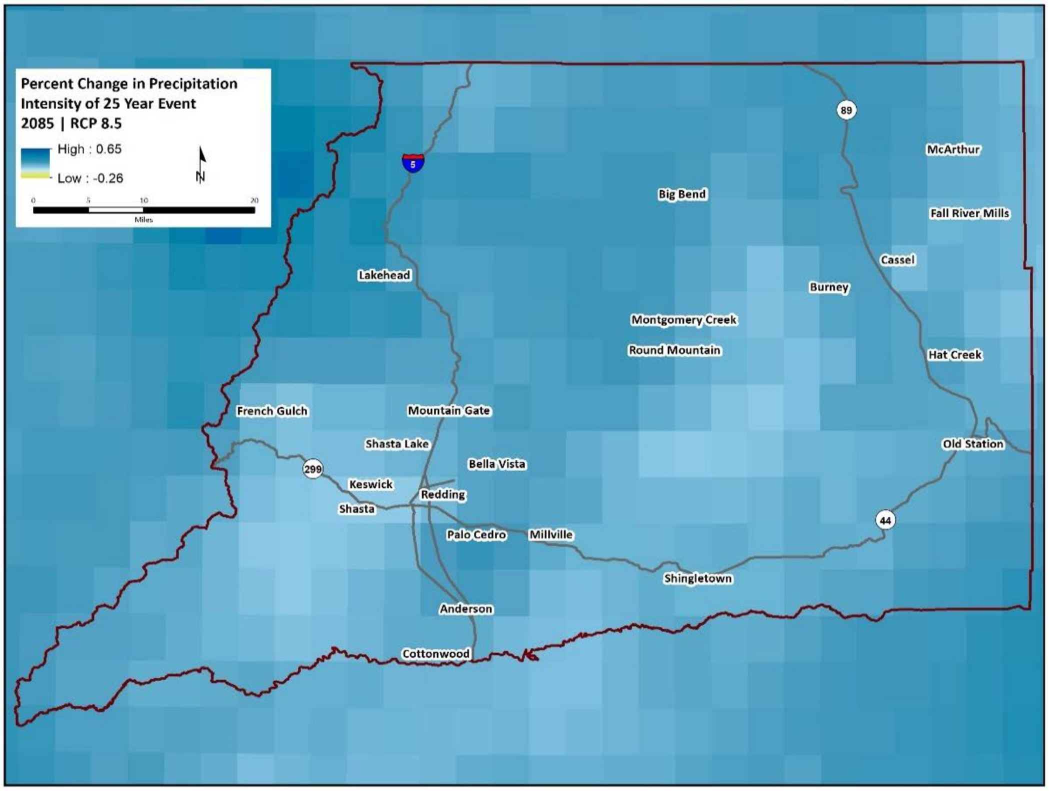

Figure 25. Projected percent change in intensity of 25-year extreme precipitation event. 2085, RCP8.5.

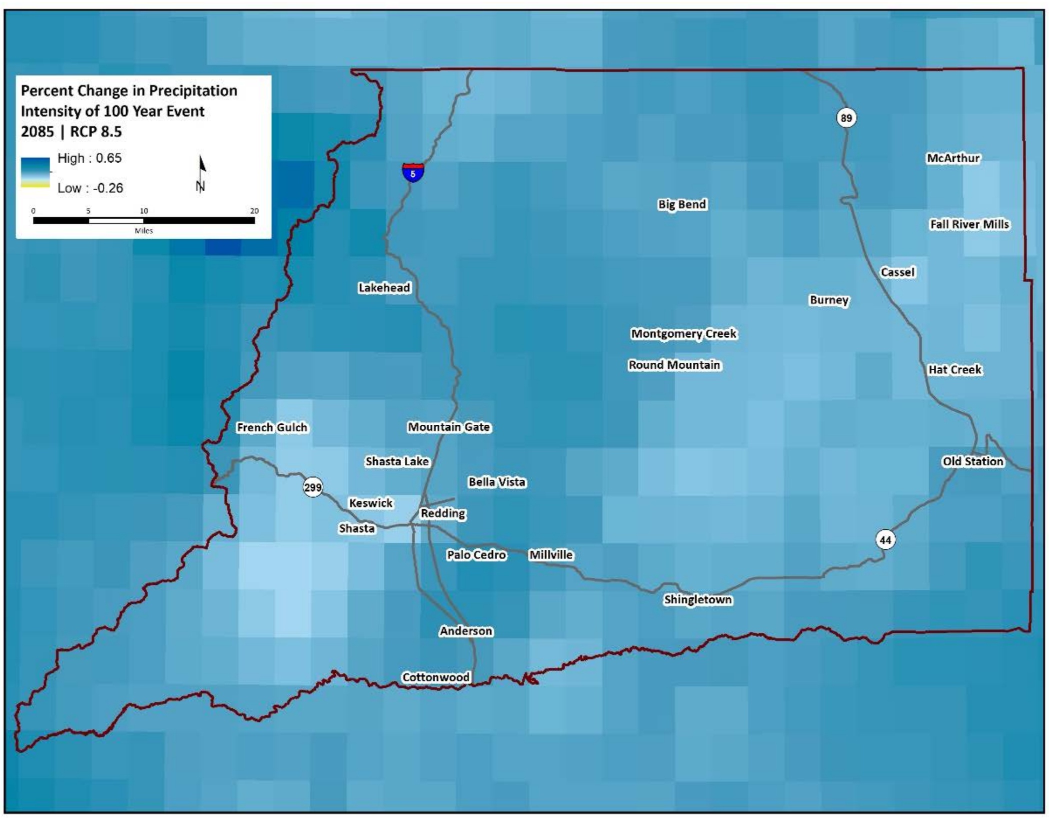

Figure 26. Projected percent change in intensity of 100-year extreme precipitation event. 2085, RCP8.5.

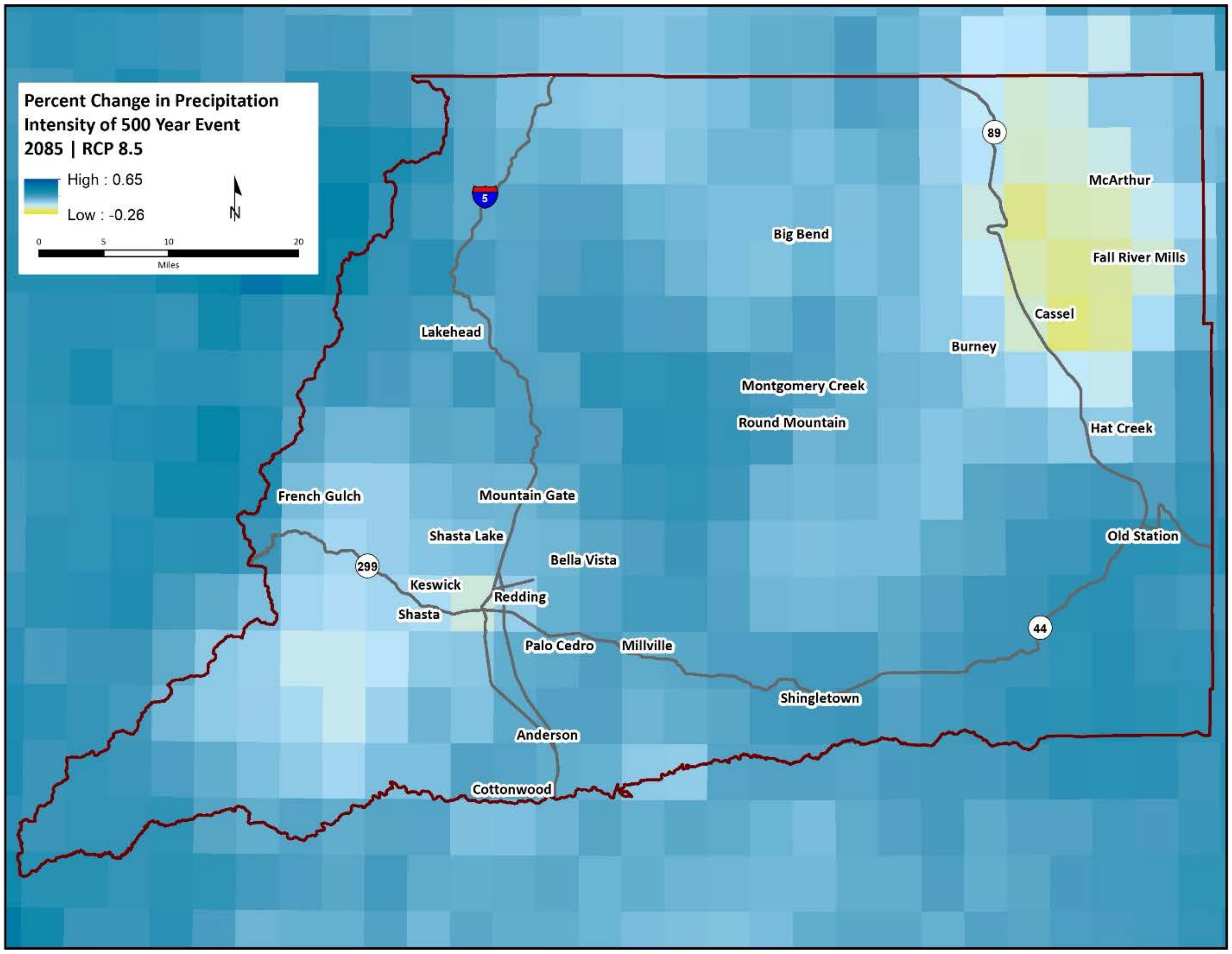

Figure 27. Projected percent change in intensity of 500-year extreme precipitation event. 2085, RCP8.5.

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 28, Figure 29, and Figure 30 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 C.

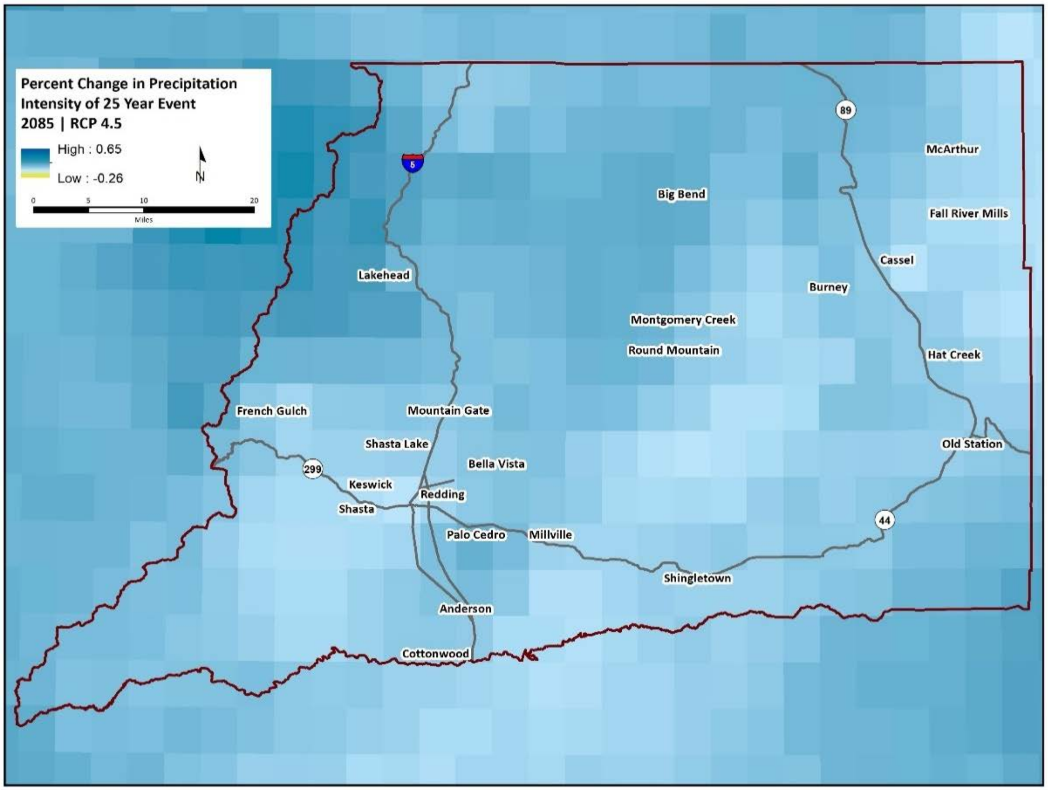

Figure 28. Projected percent change in intensity of 25-year extreme precipitation event. 2085, RCP4.5.

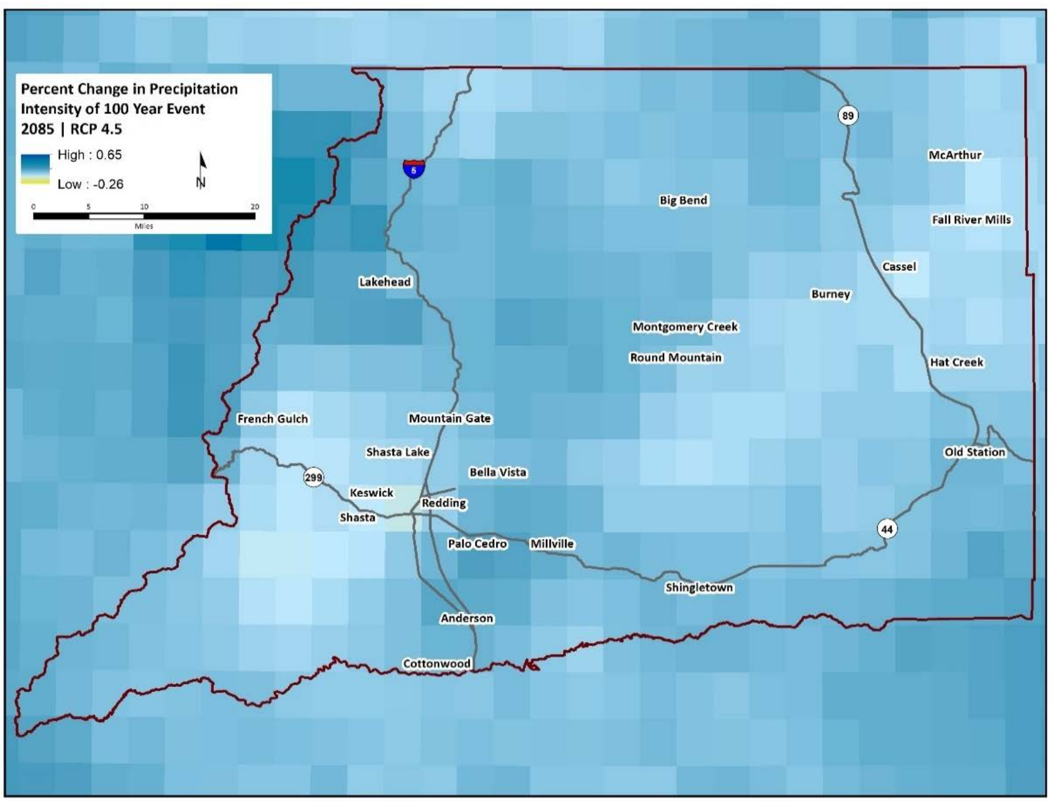

Figure 29. Projected percent change in intensity of 100-year extreme precipitation event. 2085, RCP4.5.

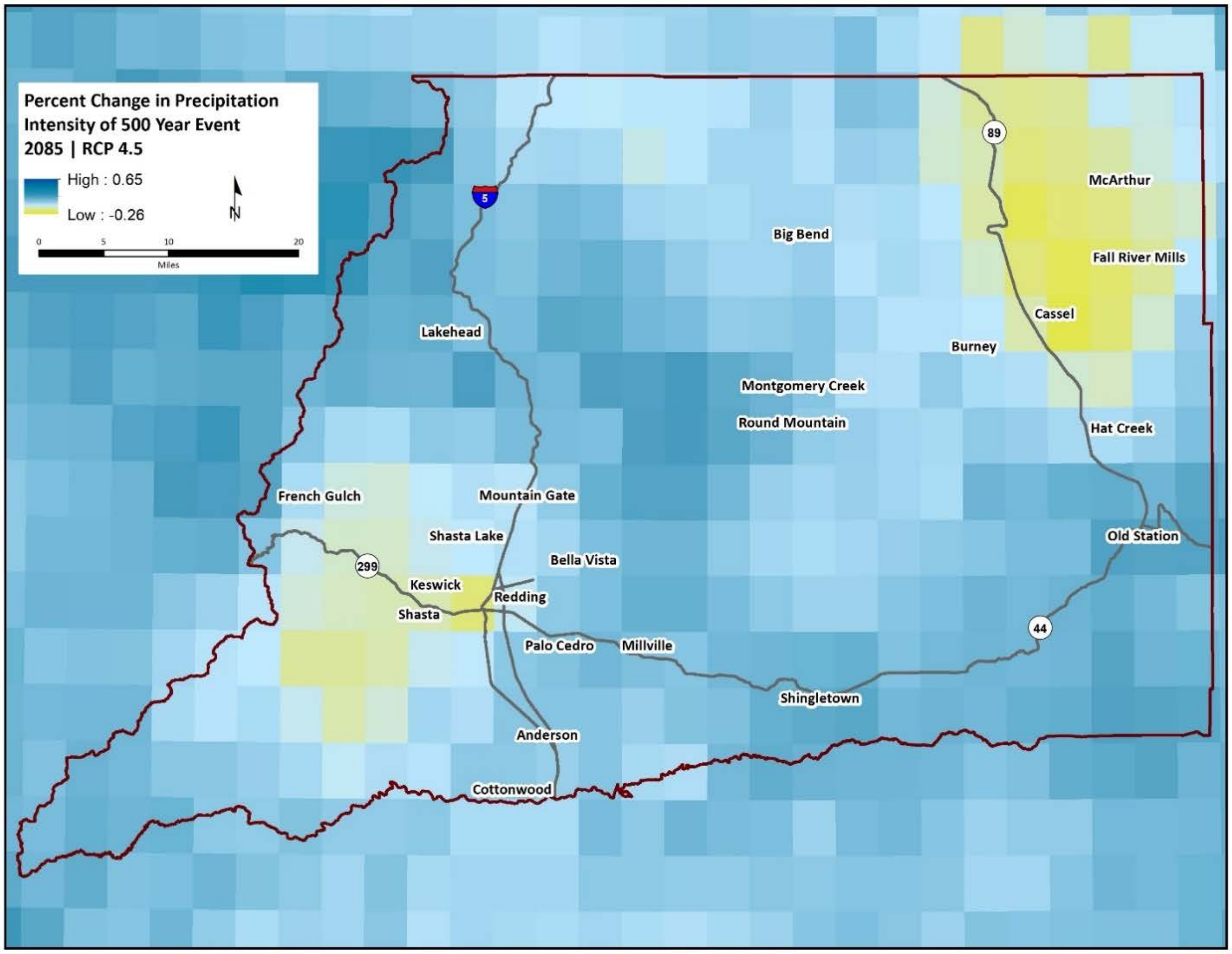

Figure 30. Projected percent change in intensity of 500-year extreme precipitation event. 2085, RCP4.5.

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 31. 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 12 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 12. 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 32.

> Projections show extreme increases in both **wildfire probability** and **severity** over the coming century, including in areas with key transportation infrastructure

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 13.

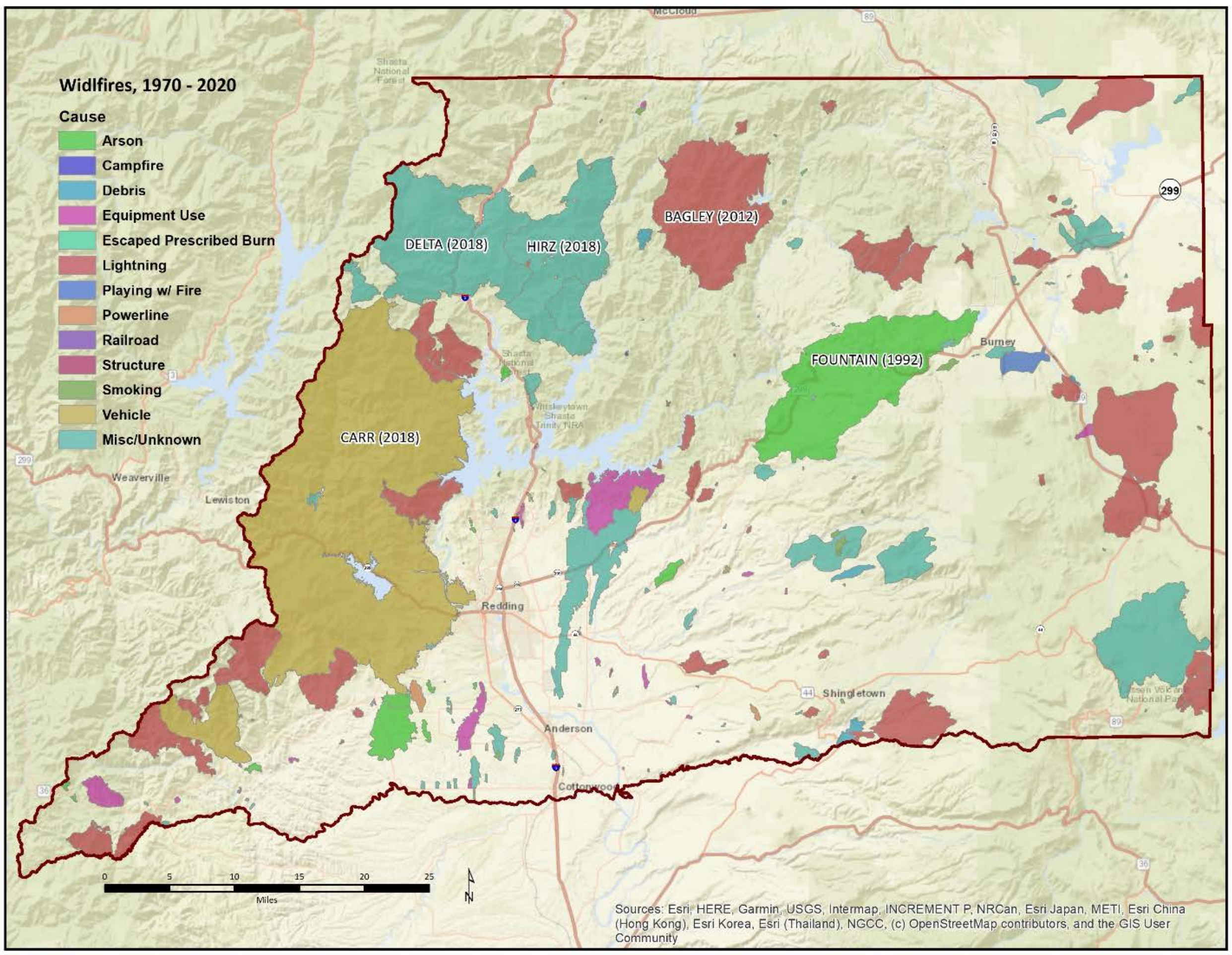

Figure 32. Wildfires in the Shasta region, 1970 – 2020.

Table 13. 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 33).

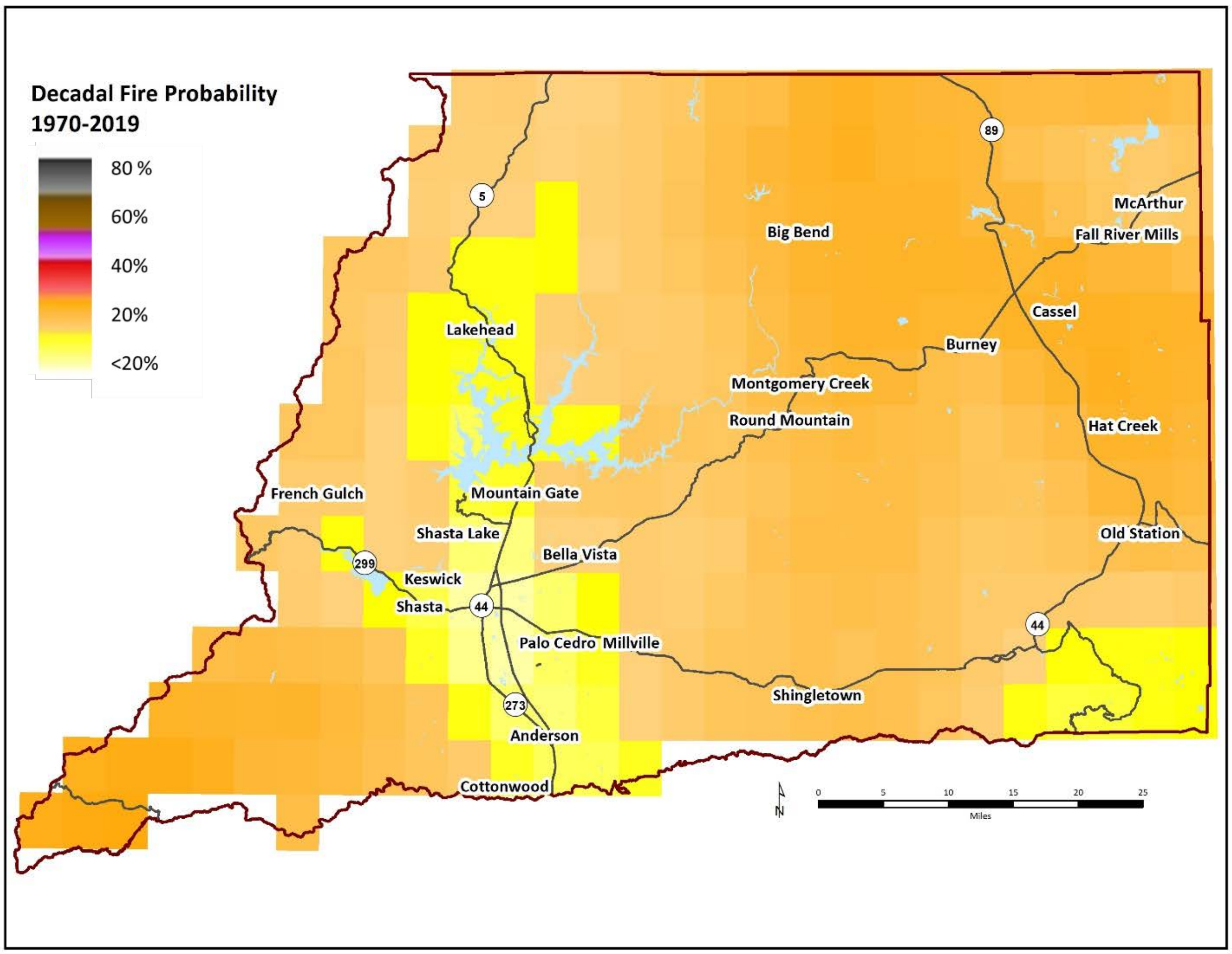

Figure 33. Average decadal Fire Probability in the historical period (1970 - 2019).

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 34, Figure 35, and Figure 36 show the expected changes in decadal wildfire probability across the Shasta Region in the unconstrained emissions scenario.

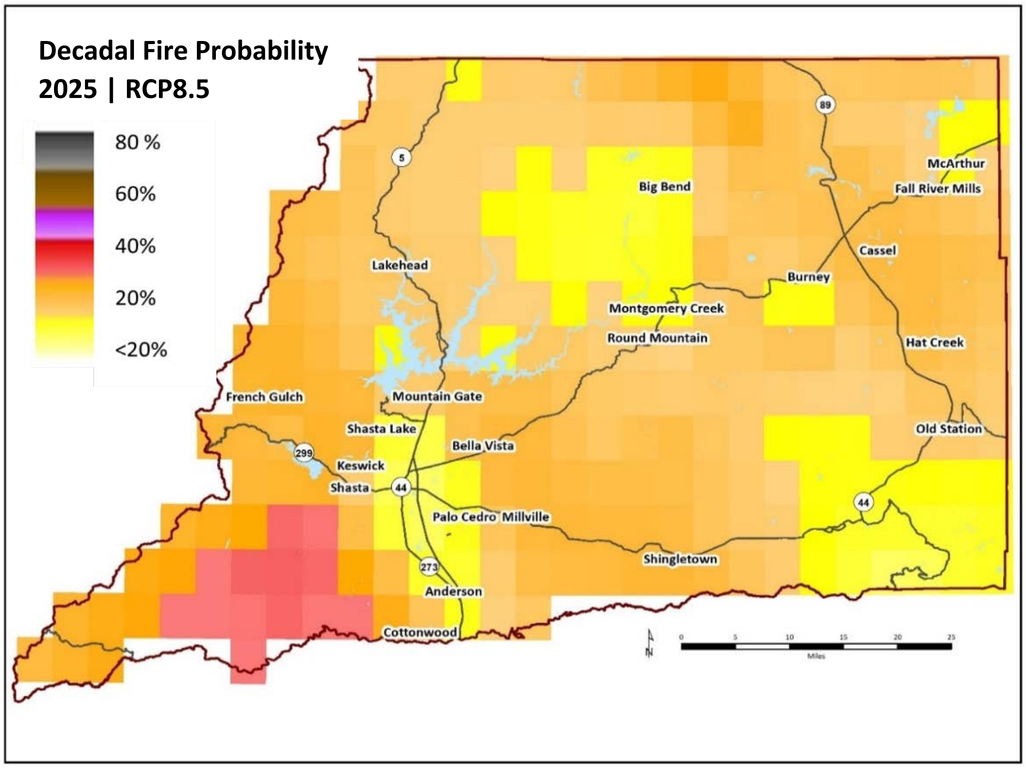

Figure 34. Decadal Fire Probability in 2025, RCP8.5.

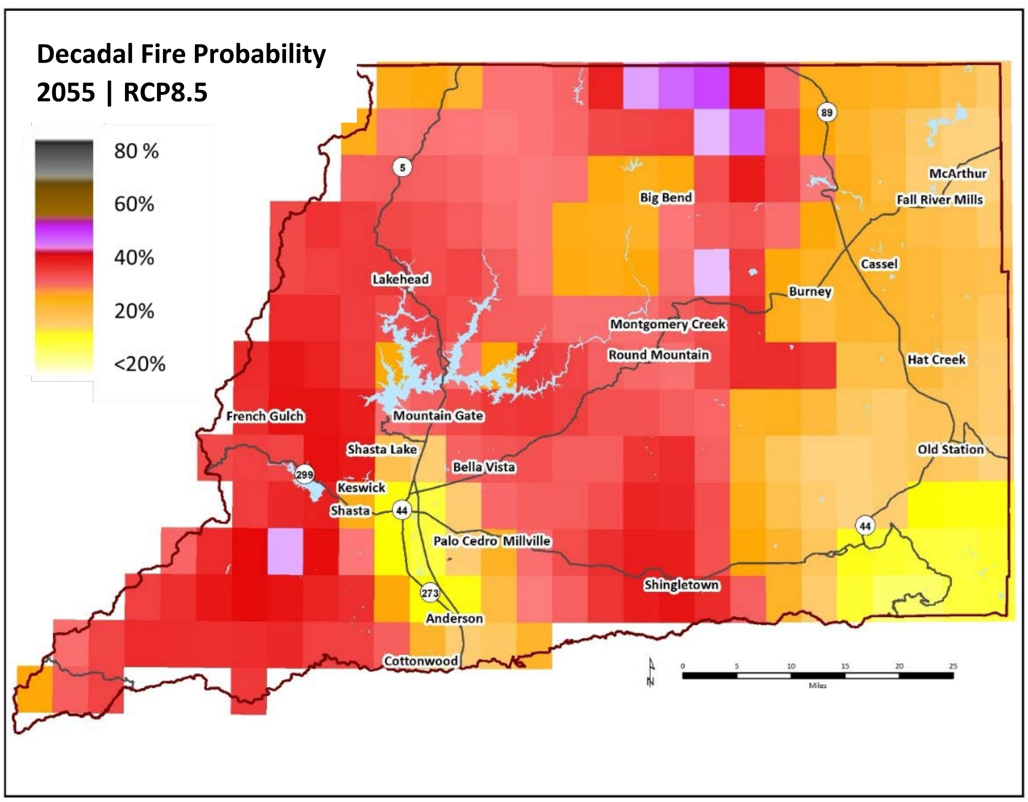

Figure 35. Decadal Fire Probability in 2055, RCP8.5.

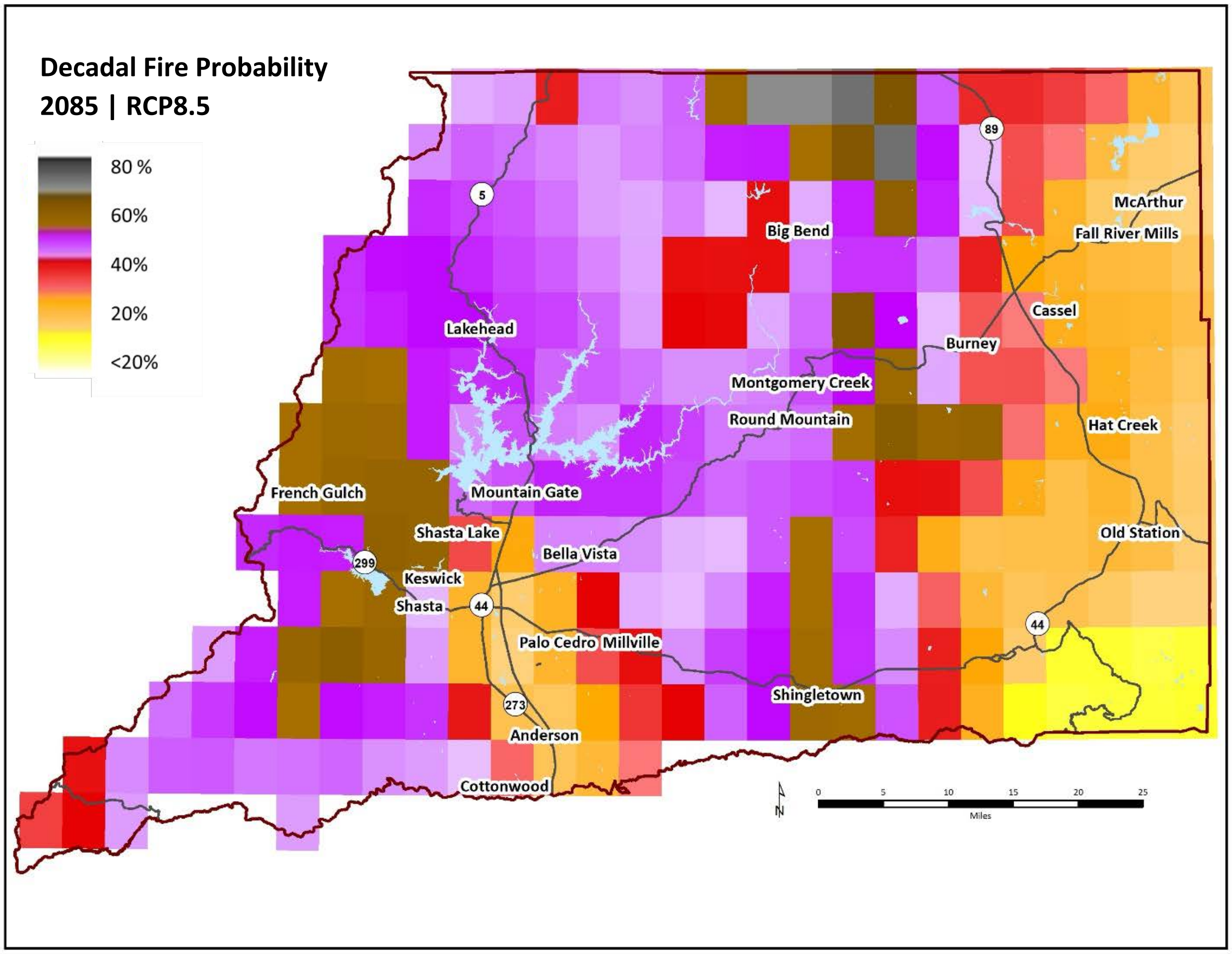

Figure 36. Decadal Fire Probability in 2085, RCP8.5.

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 38, Figure 37, and Figure 39 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.

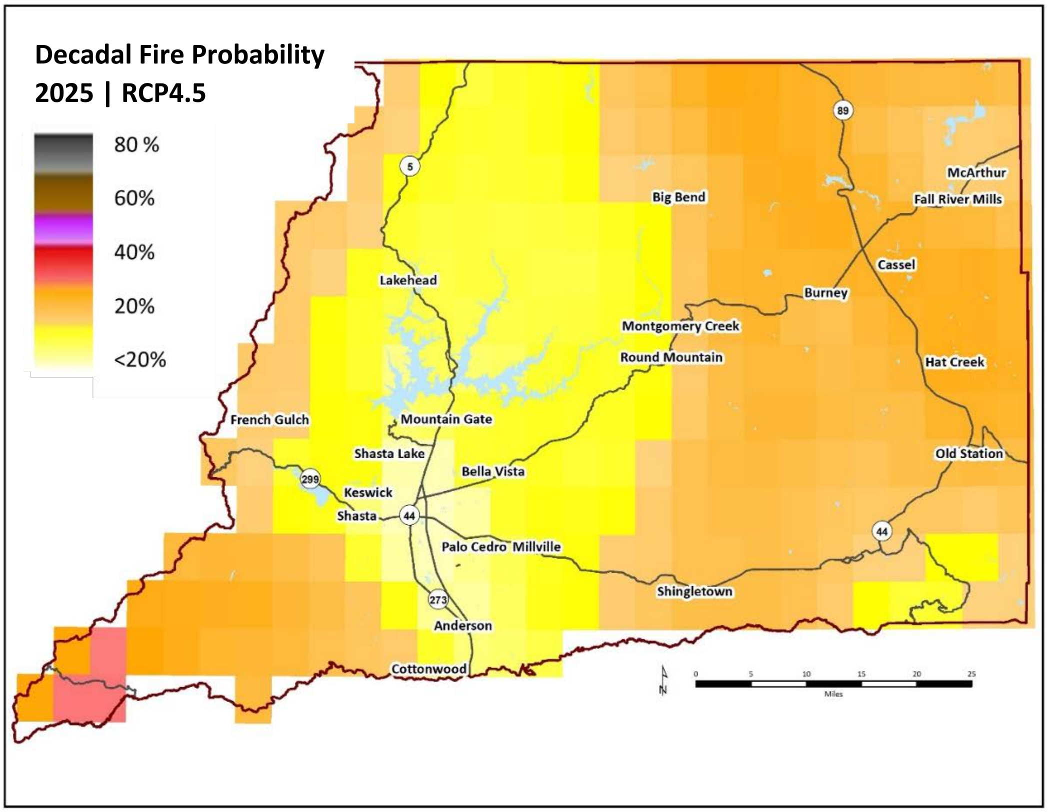

Figure 38. Decadal Fire Probability in 2025, RCP4.5.

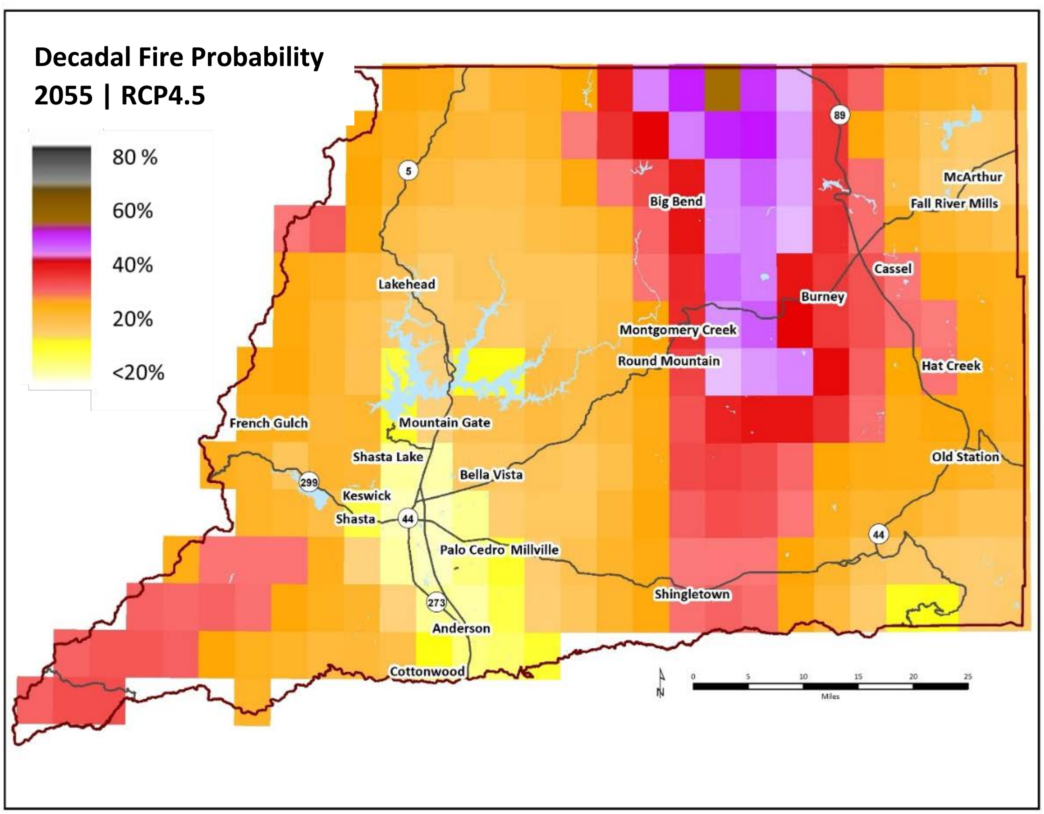

Figure 37. Decadal Fire Probability in 2055, RCP4.5.

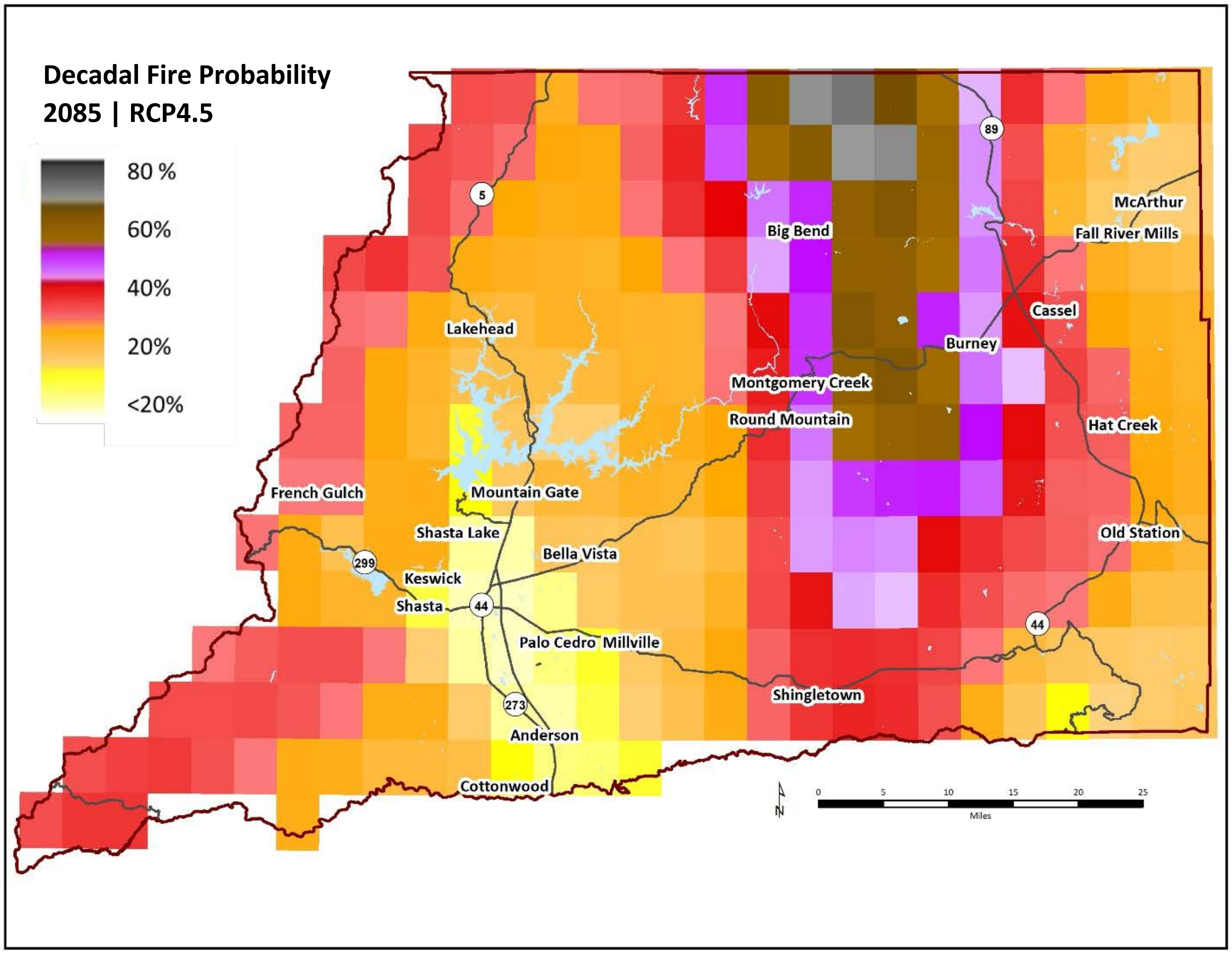

Figure 39. Decadal Fire Probability in 2085, RCP4.5.

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 40 shows the historical average area burned in the Shasta Region.

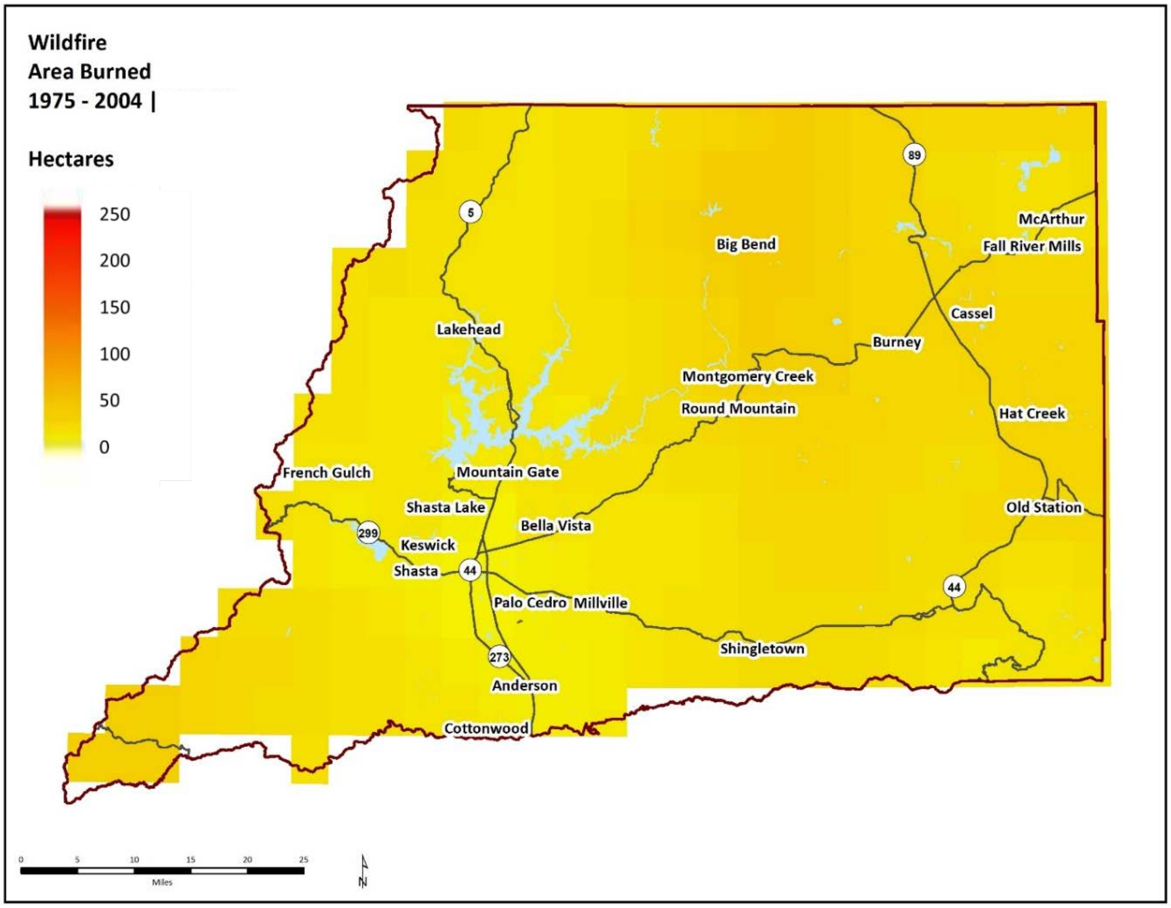

Figure 40. Average annual area burned in the historical period (1975 - 2004).

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 41, Figure 42, and Figure 43 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.

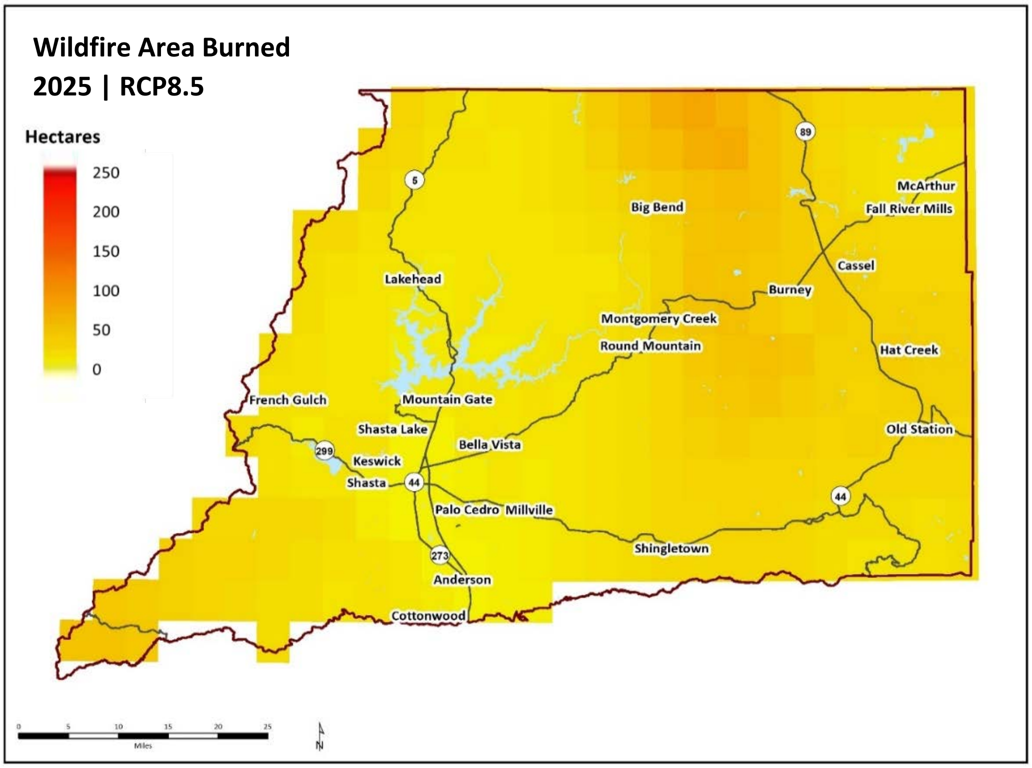

Figure 41. Average annual area burned in 2025, RCP8.5.

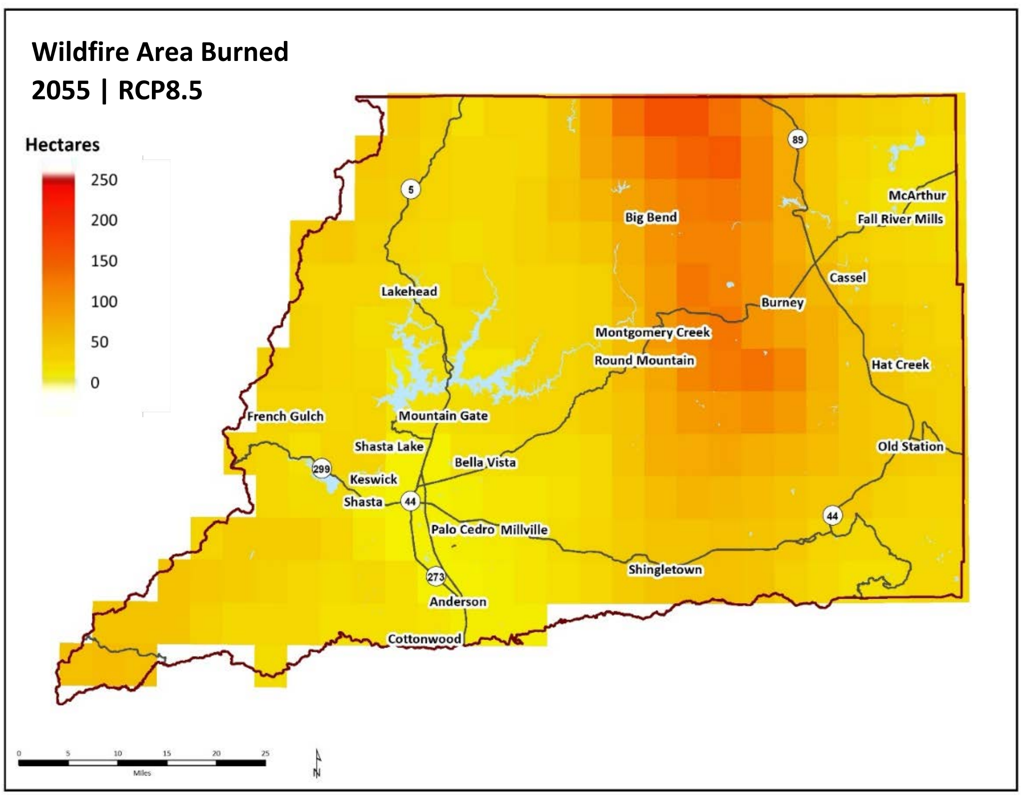

Figure 42. Average annual area burned in 2055, RCP8.5.

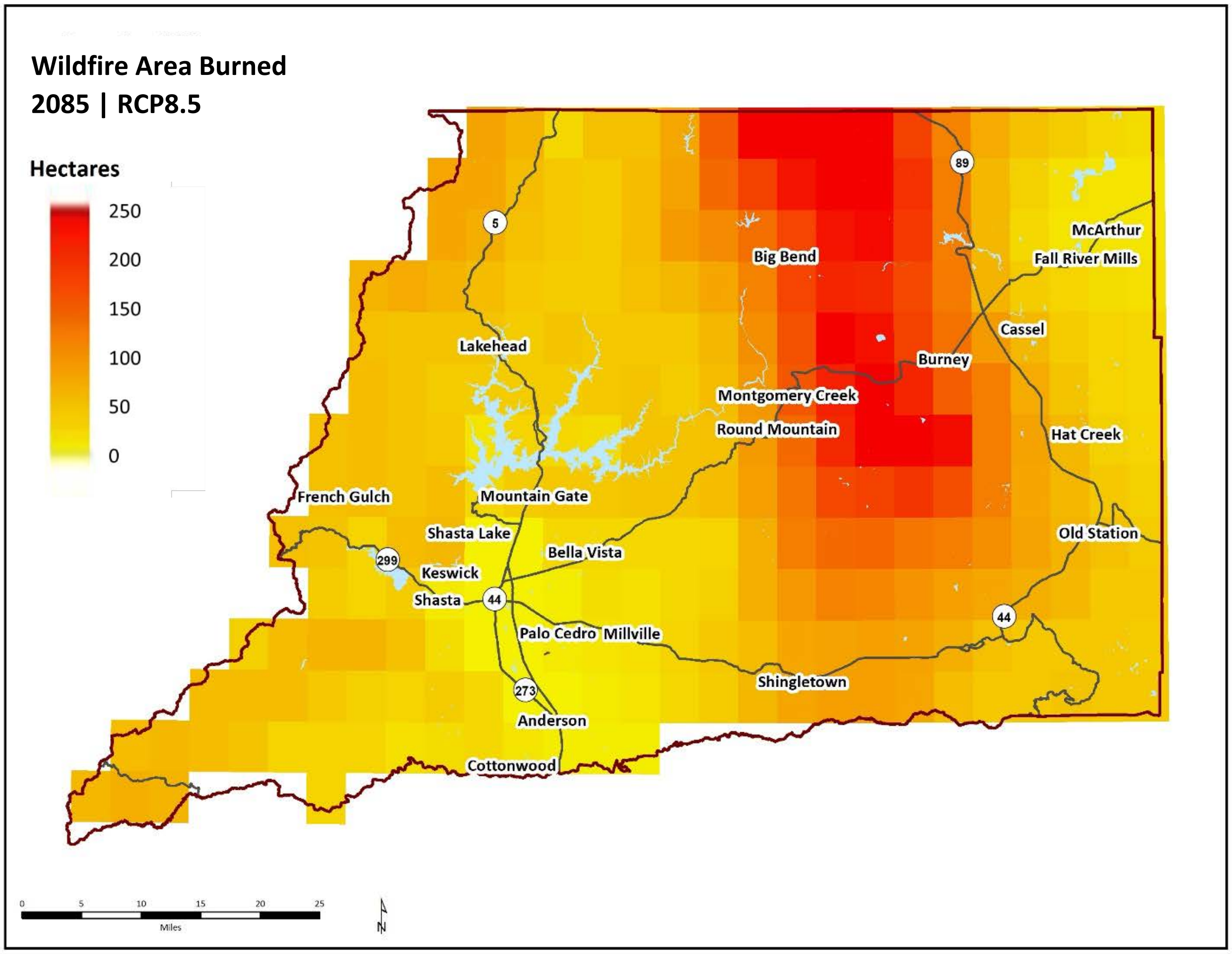

Figure 43. Average annual area burned in 2085, RCP8.5.

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 44, Figure 45, and Figure 46 show projected changes to wildfire intensity across the Shasta Region in a reduced emissionss scenario.

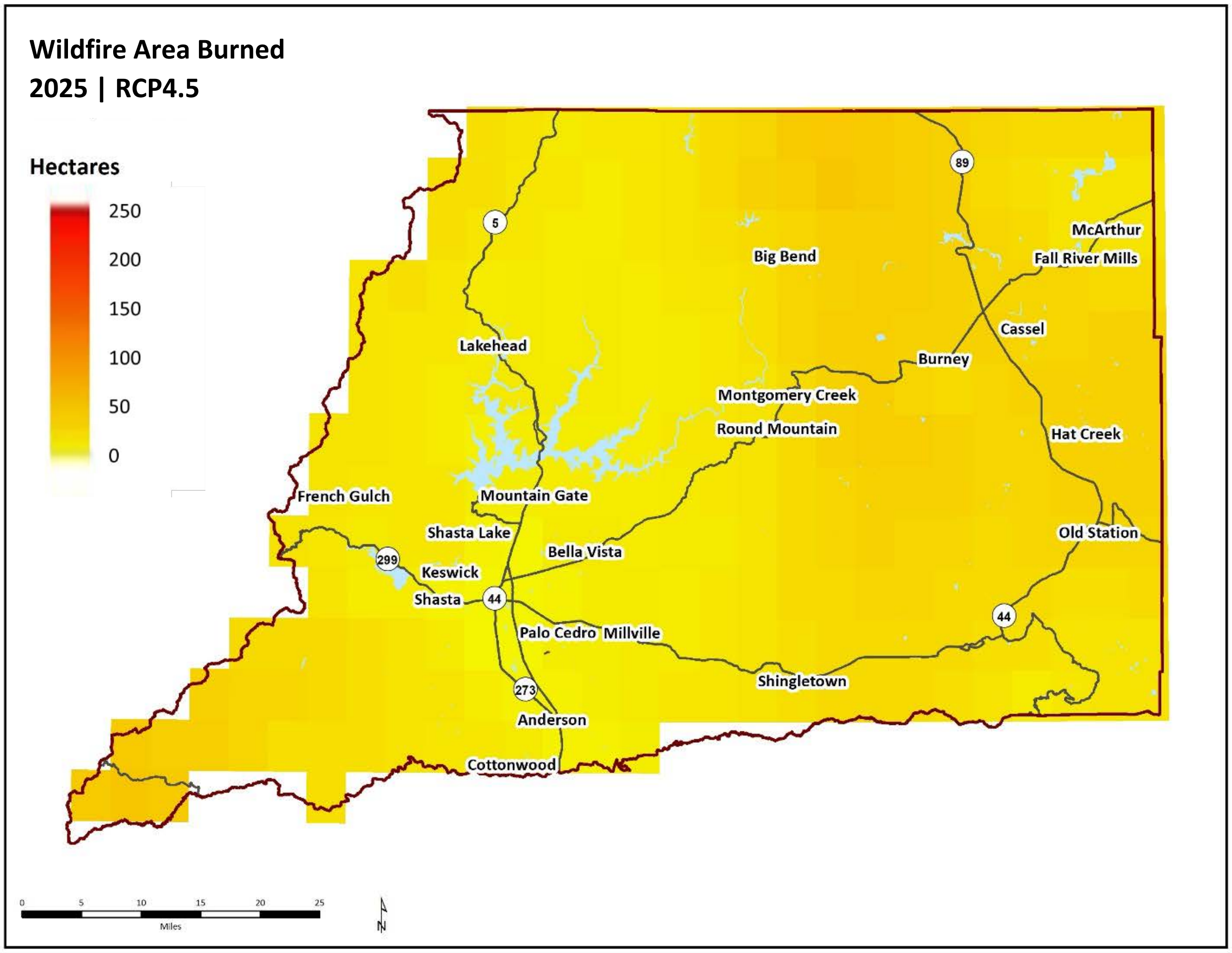

Figure 44. Average annual area burned in 2025, RCP4.5.

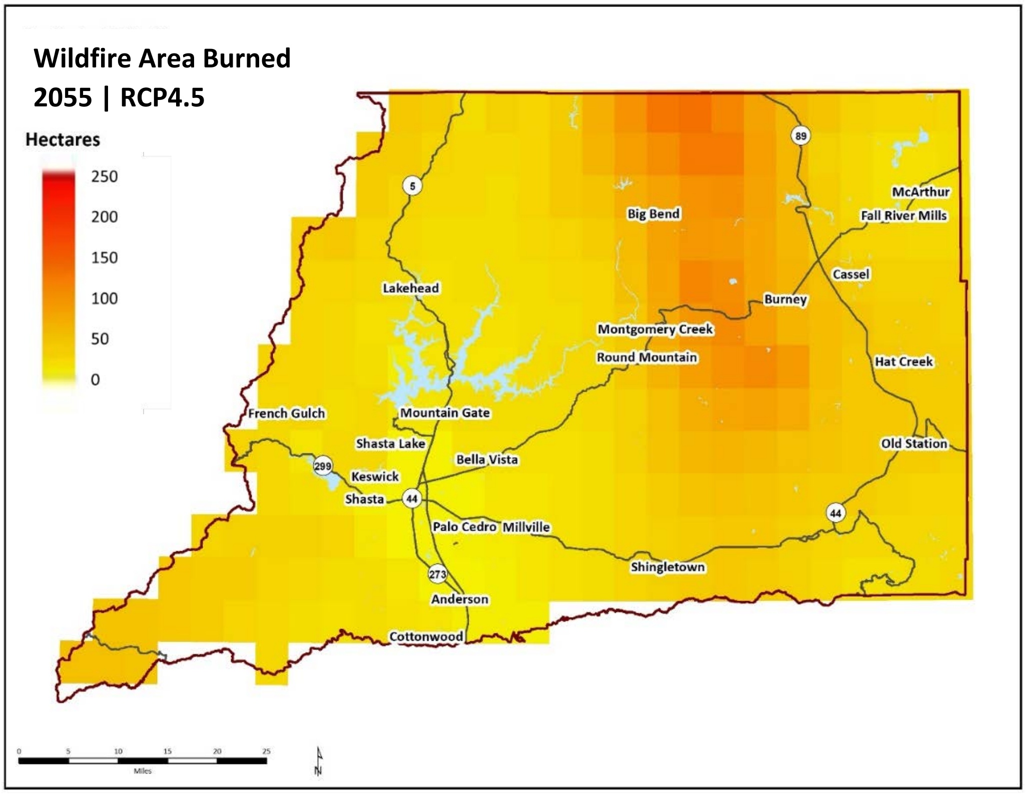

Figure 45. Average annual area burned in 2055, RCP4.5.

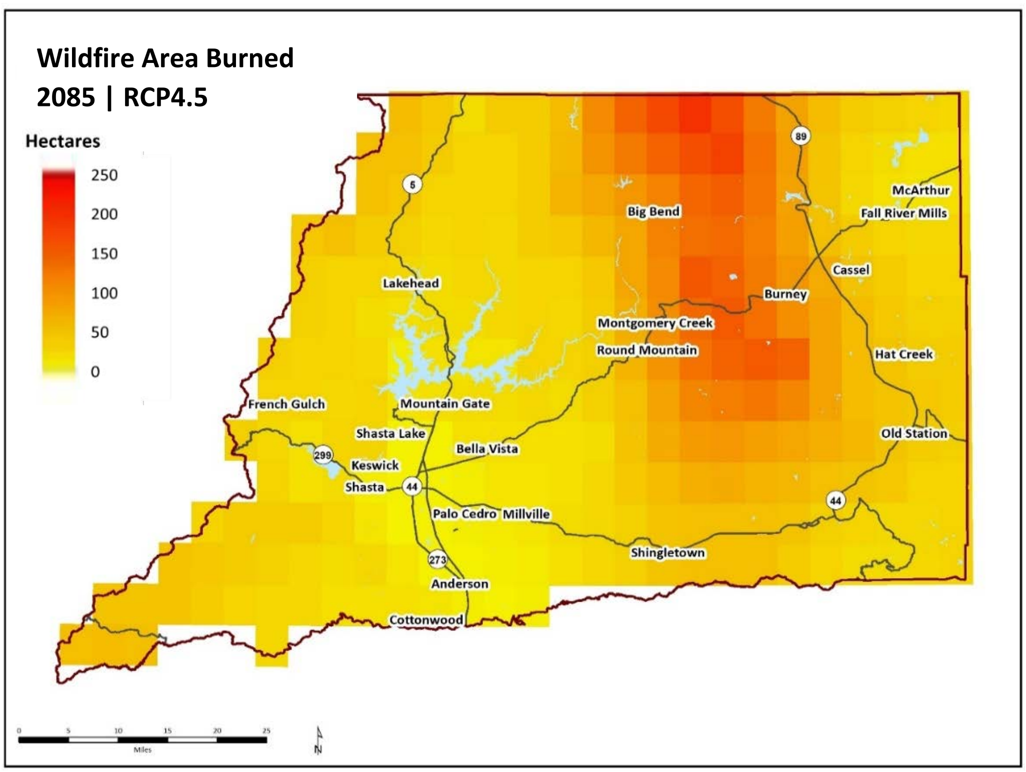

Figure 46. Average annual area burned in 2085, RCP4.5.

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 47 shows the current-conditions FTI across the Shasta Region.

Table 14. 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

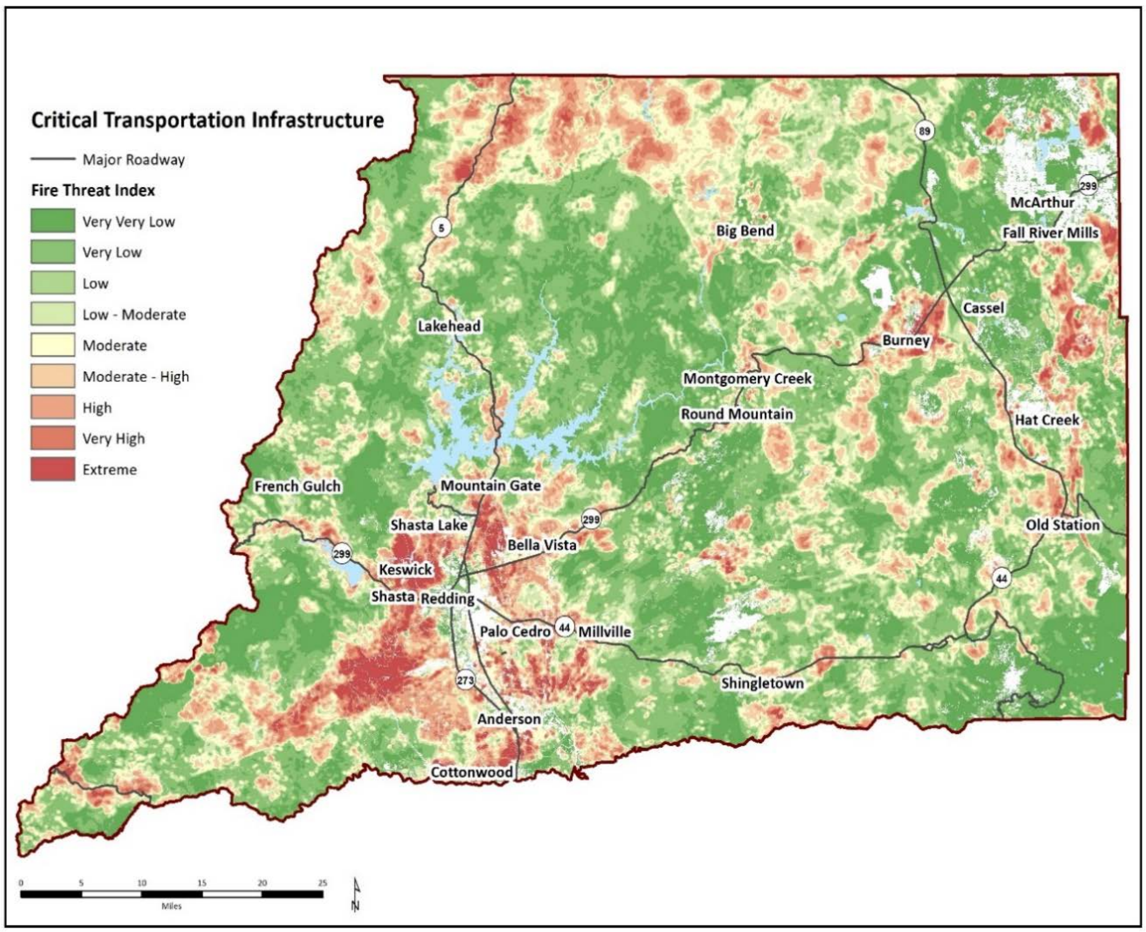

Figure 47. Current Regionwide Fire Threat Index.

[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 48). 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.

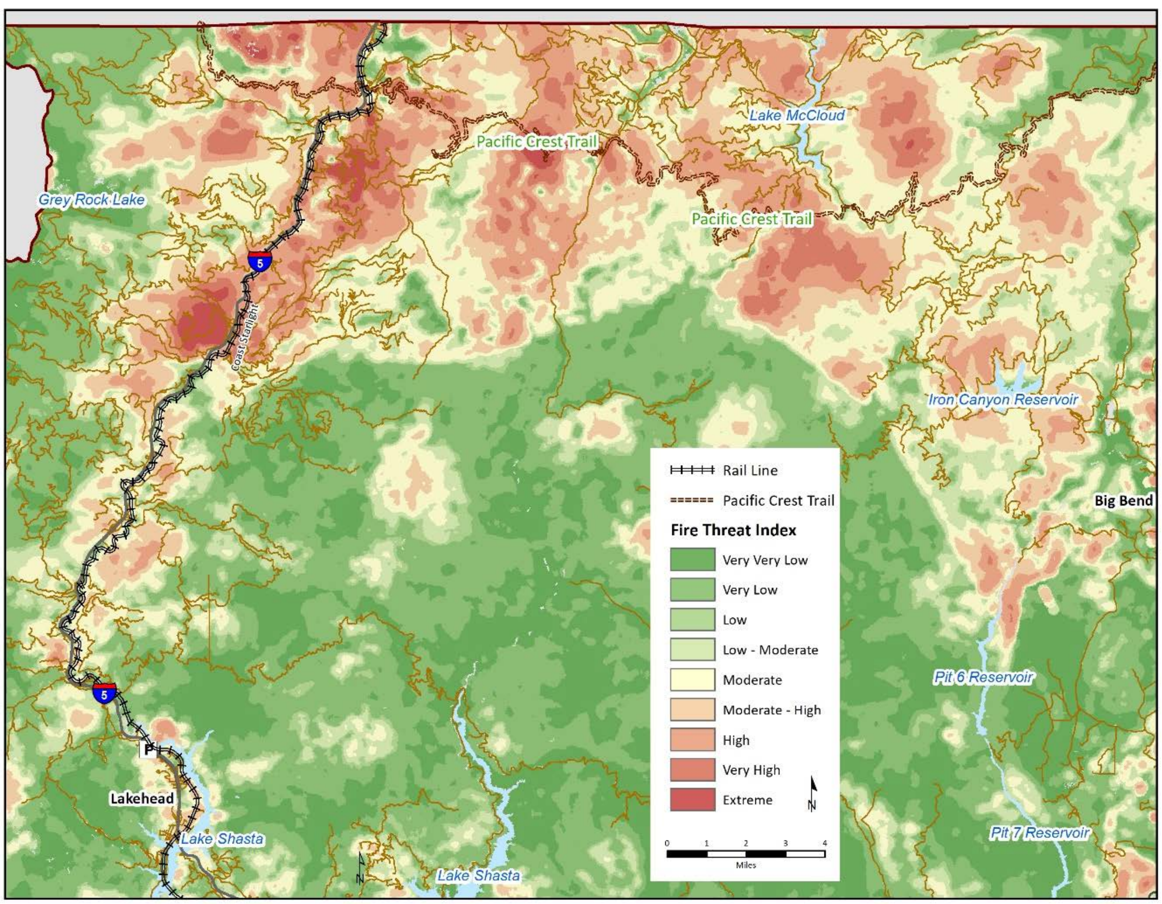

Figure 48. Current Fire Threat Index in Northwestern Shasta Region.

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 49). 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.

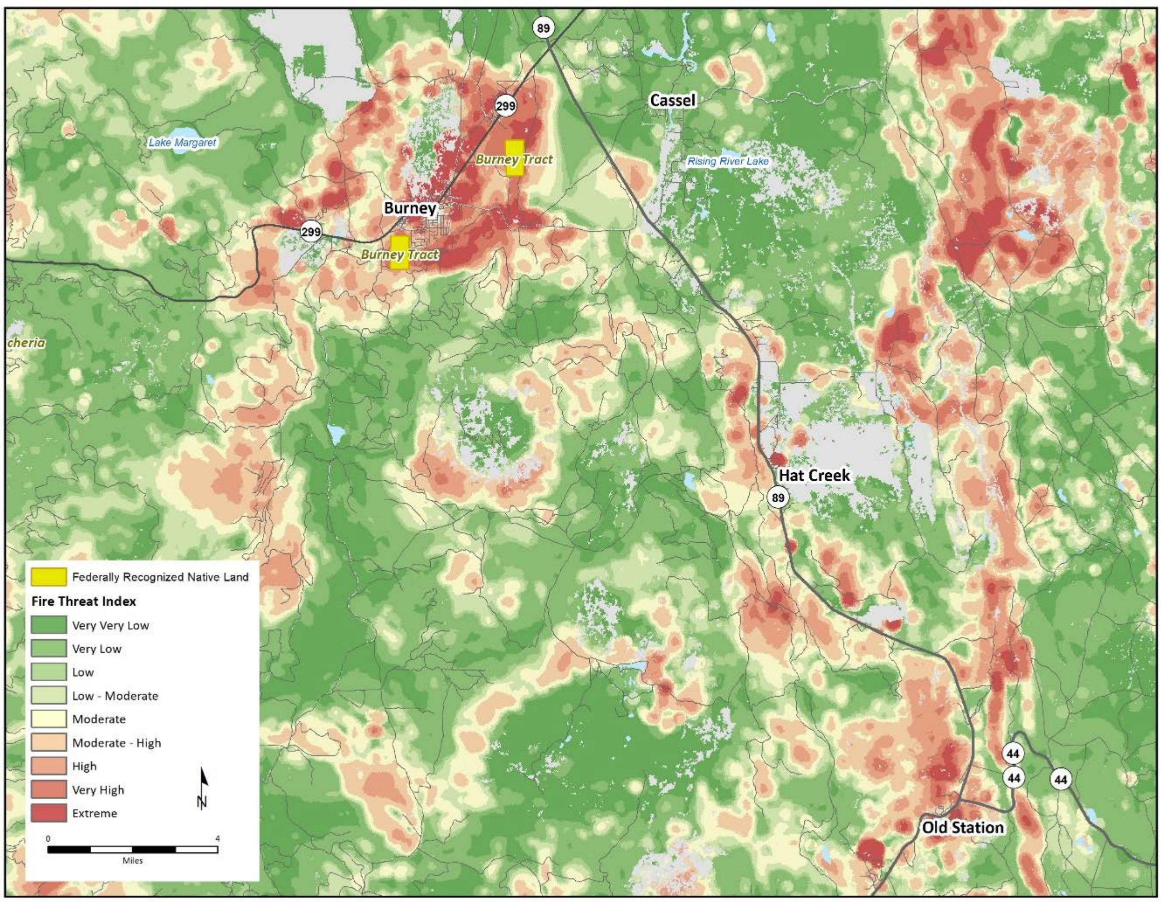

Figure 49. Current Fire Threat Index in Burney, Hat Creek, and Old Station.

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 50). 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).

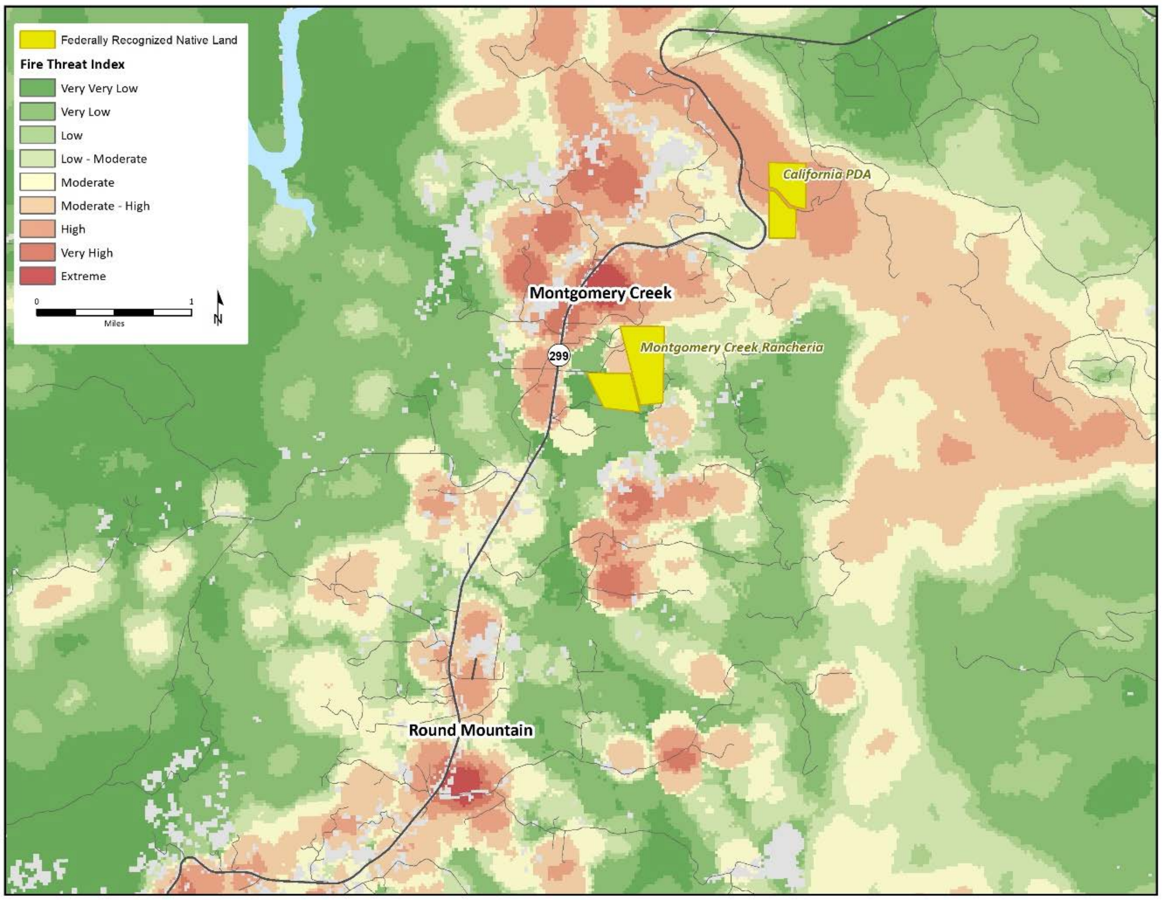

Figure 50. Current Fire Threat Index in Montgomery Creek and Round Mountain.

[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 51.

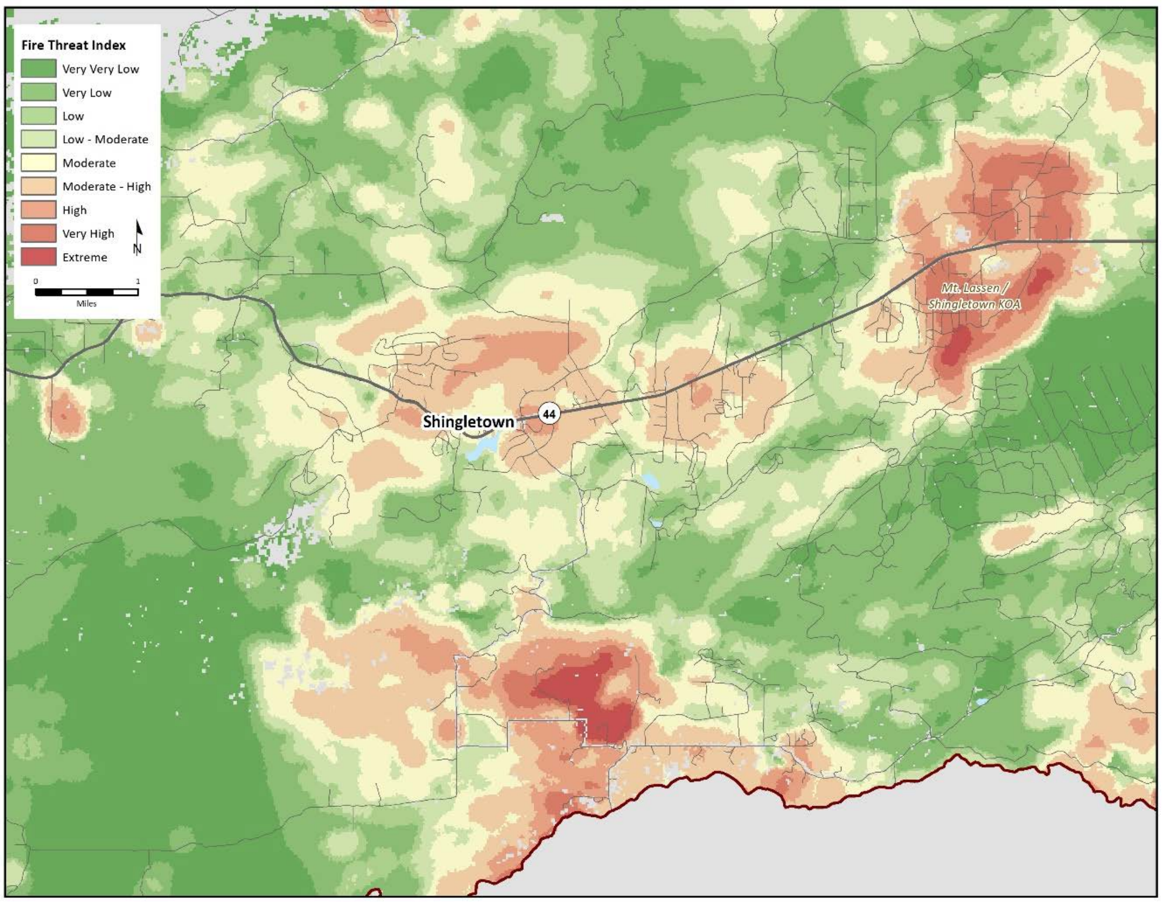

Figure 51. Current Fire Threat Index in Shingletown.

[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 52). 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.

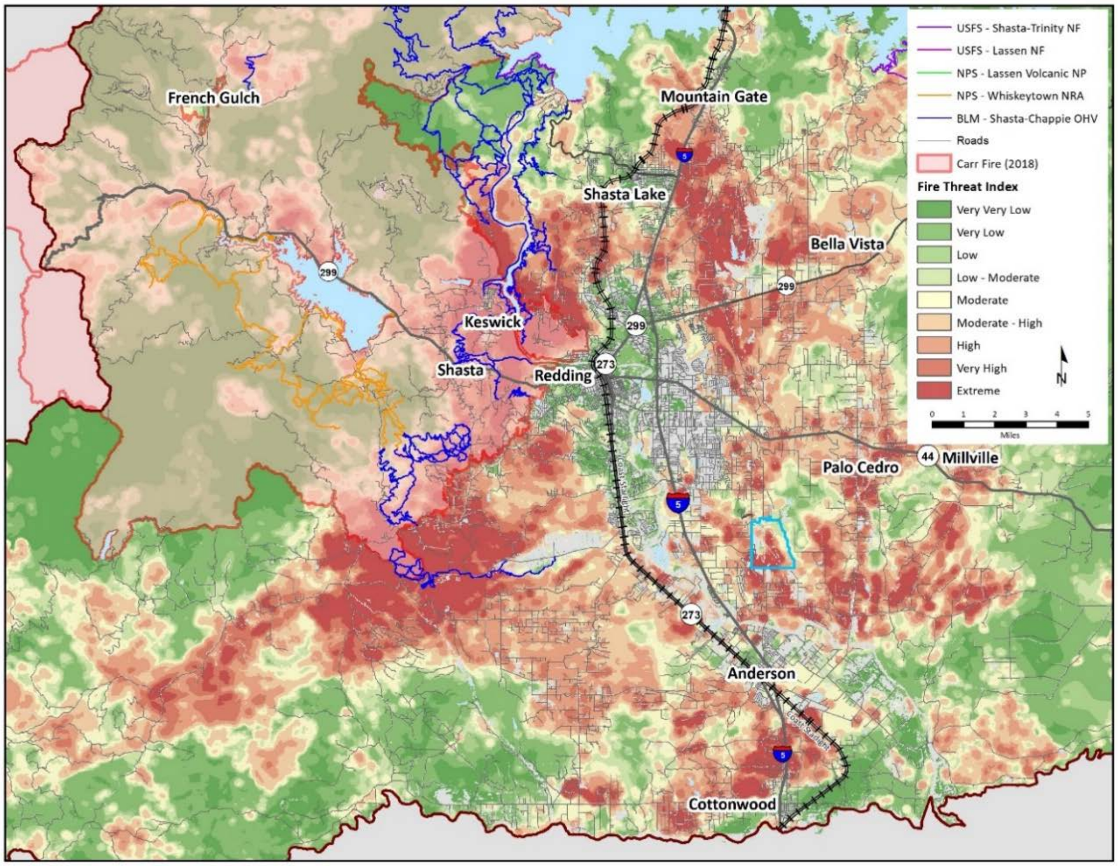

Figure 52. Current Fire Threat Index in the upper Sacramento River Valley.

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.

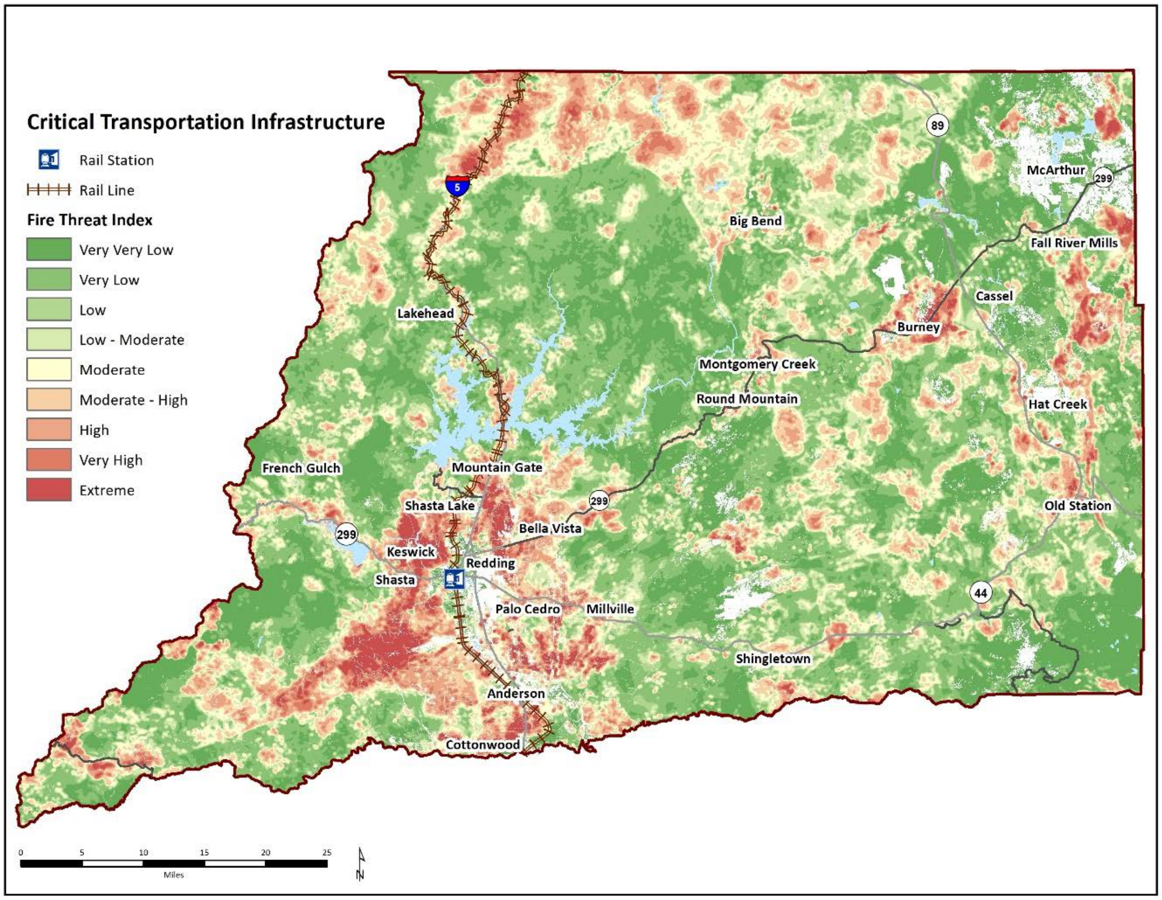

Figure 53. Rail network exposure to current fire hazards.

Airports

The Shasta Region is served by three airports (Figure 54). 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.

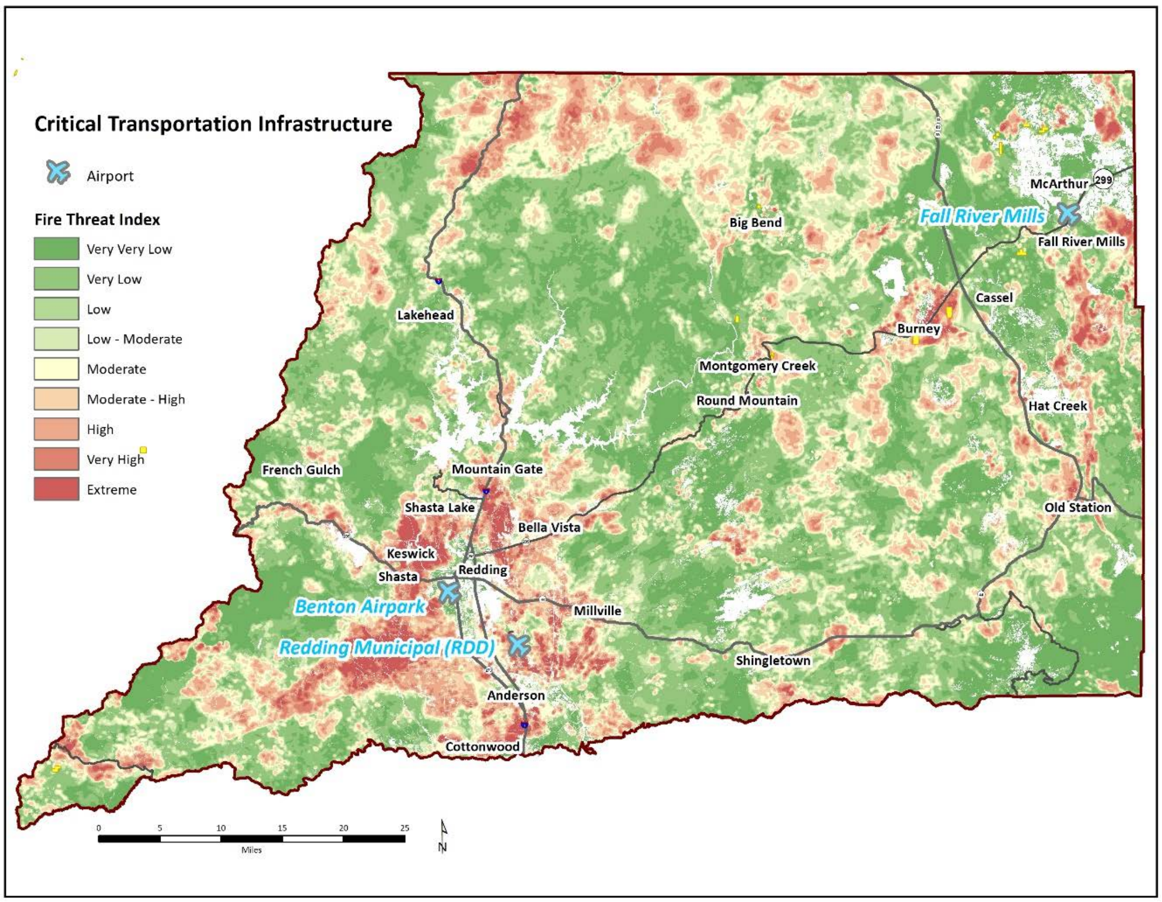

Figure 54. Public Airports in the Shasta Region overlaid with Fire Threat Index. Only Redding Municipal Airport serves commercial aviation traffic.

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 55 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.

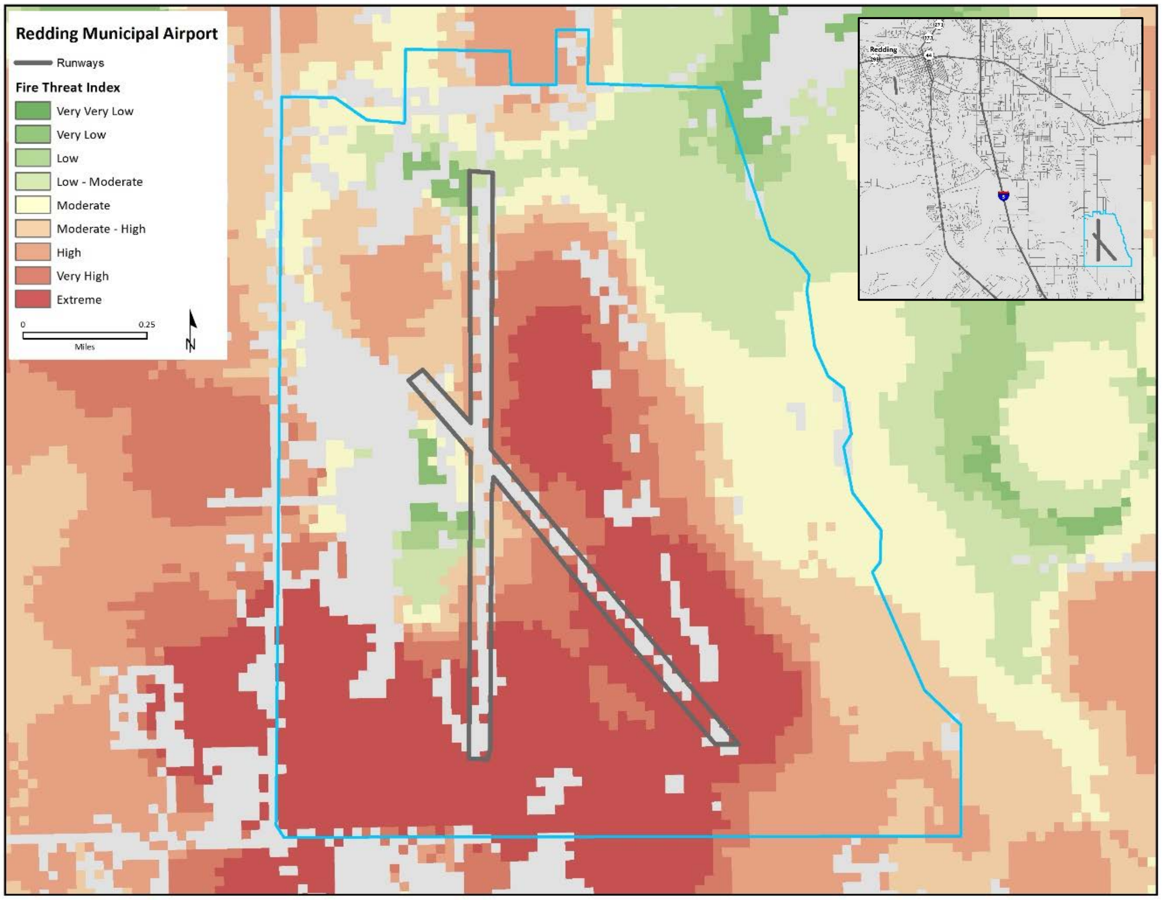

Figure 55. Current Fire Threat Index at Redding Municipal Airport.

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 56. 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.

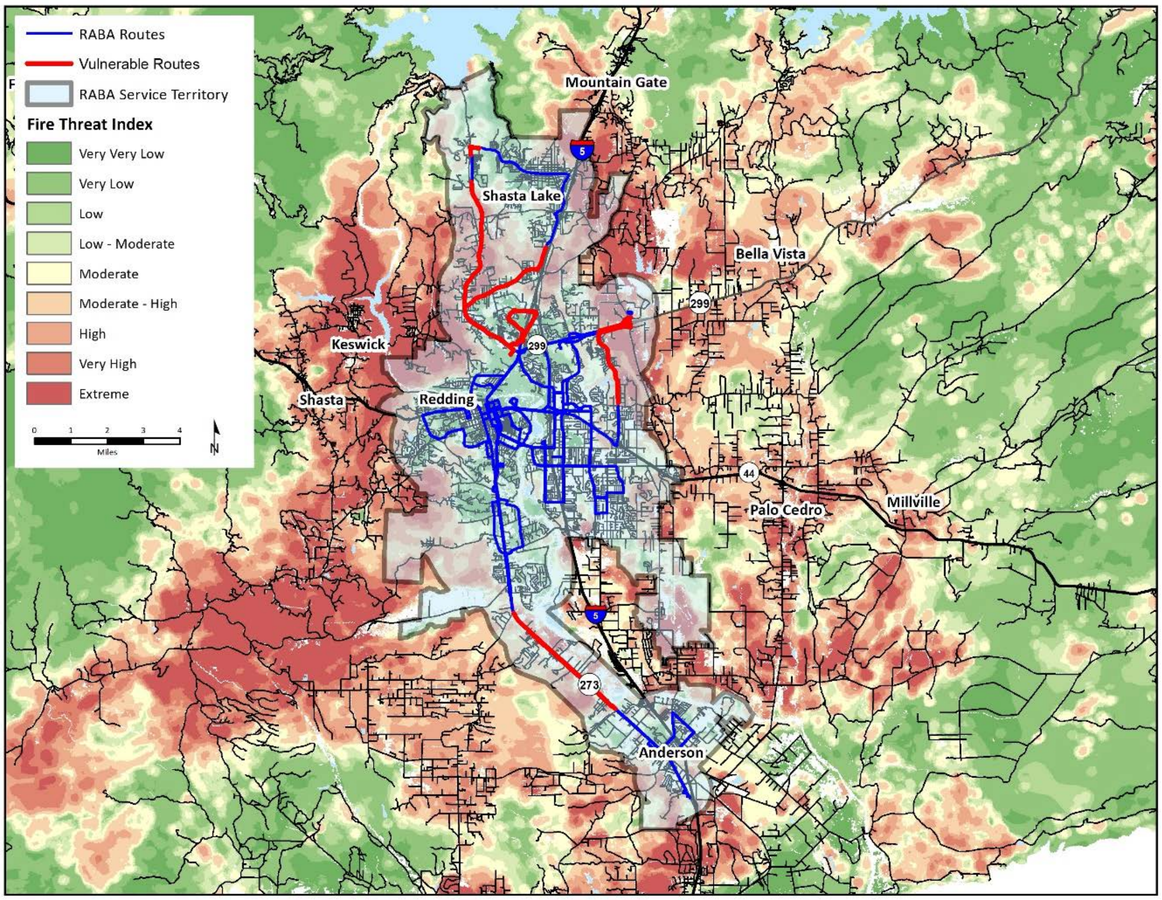

Figure 56. RABA Service Vulnerability based on Fire Threat Index.

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 57). 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.

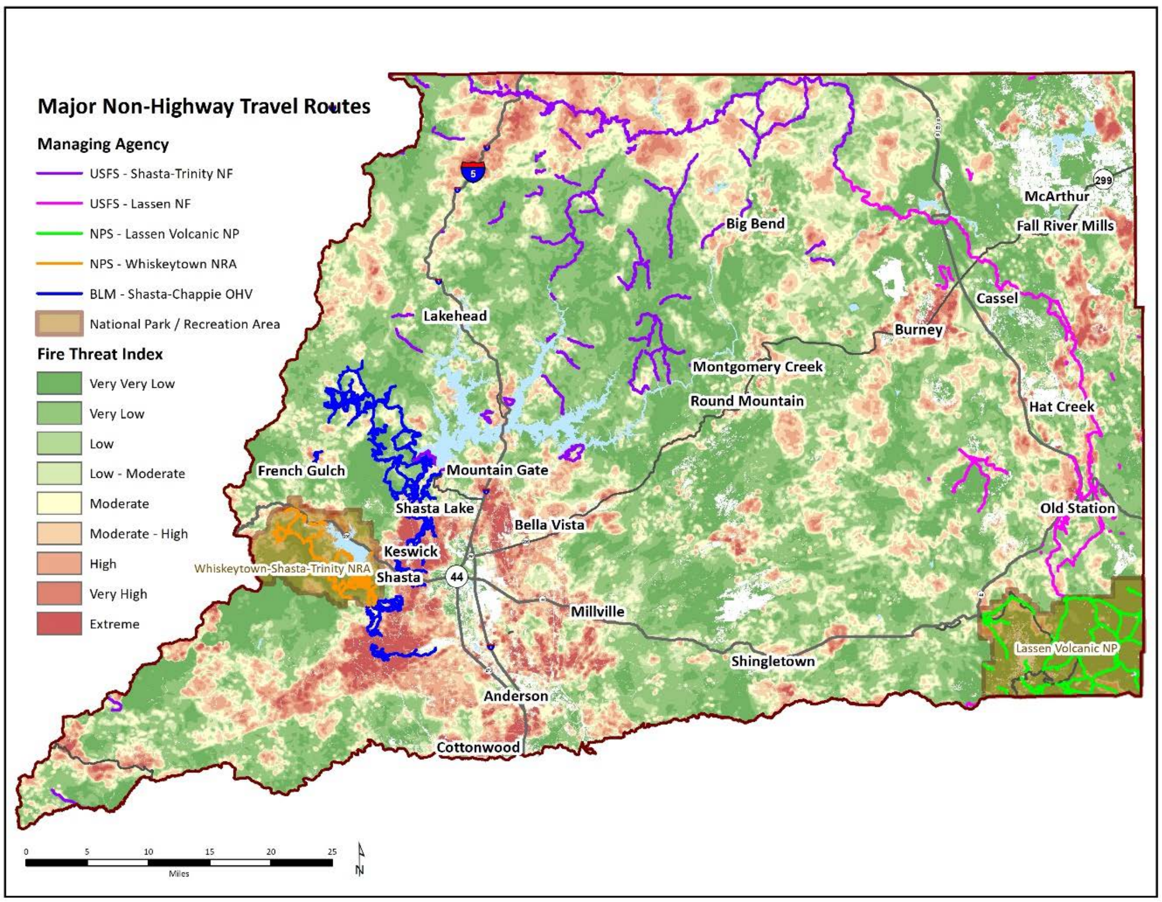

Figure 57. Vulnerable Off-Road Travel Networks and Corridors based on Fire Threat Index.

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 15 details sector-specific impacts of flooding in the transportation sector.

Table 15. 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 58 shows the distribution of FEMA flood hazard mapping.

[12] FEMA 2021

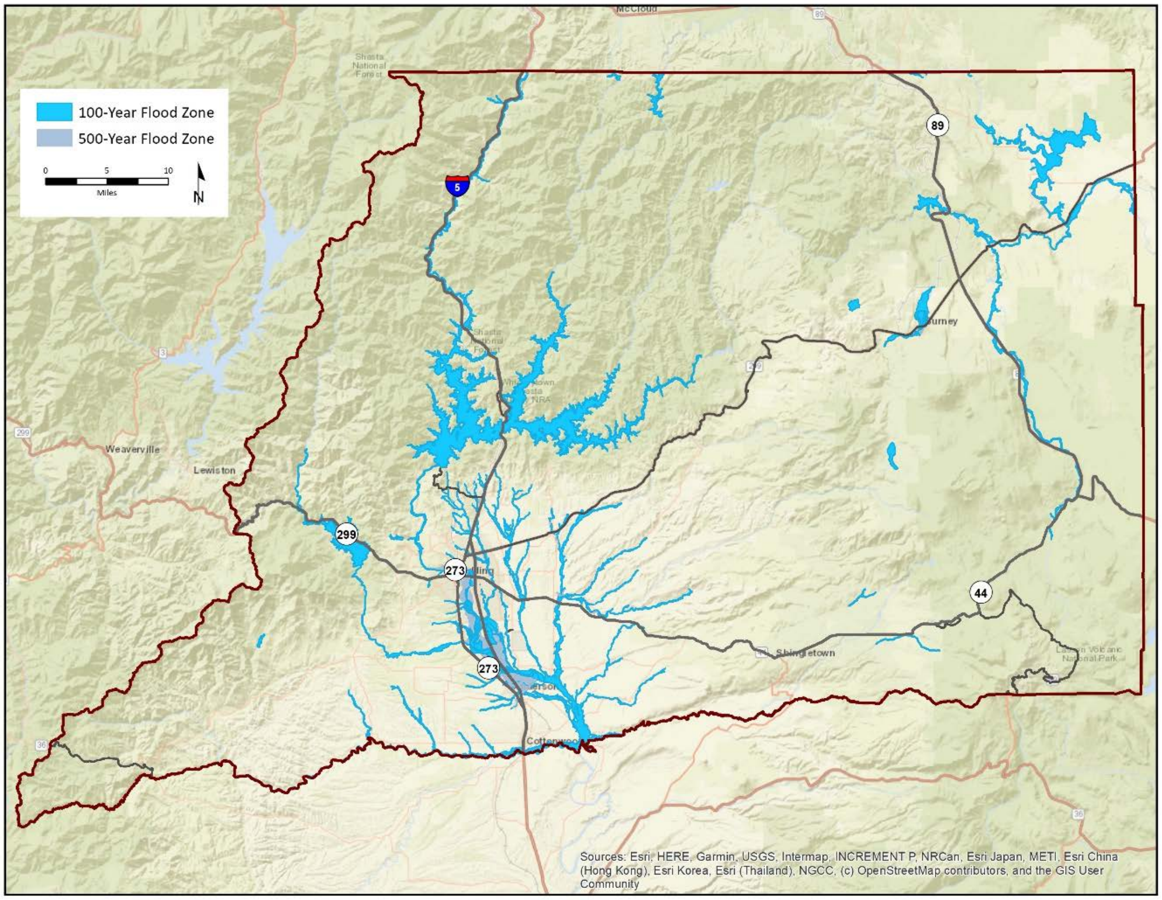

Figure 58. Areas where FEMA FIRMs provide flood hazard mapping in the Shasta Region.

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 59). 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 60).

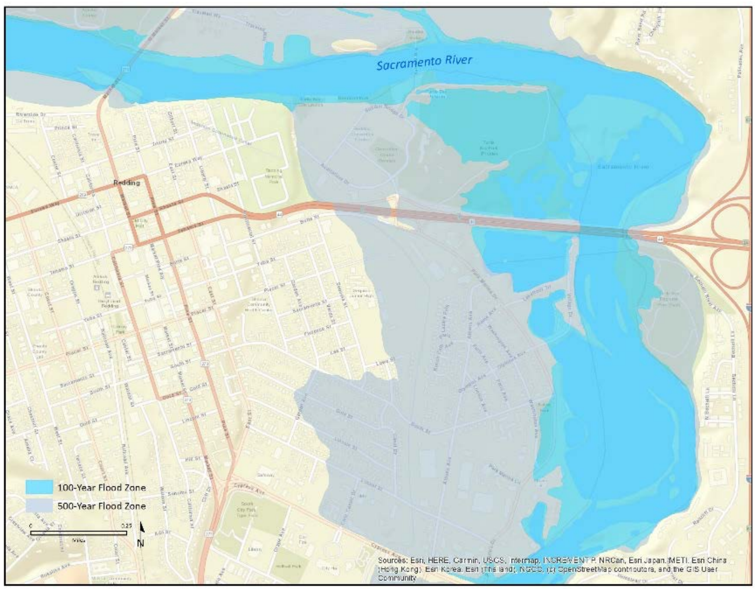

Figure 59. Flooding exposure in Central Redding, Turtle Bay.

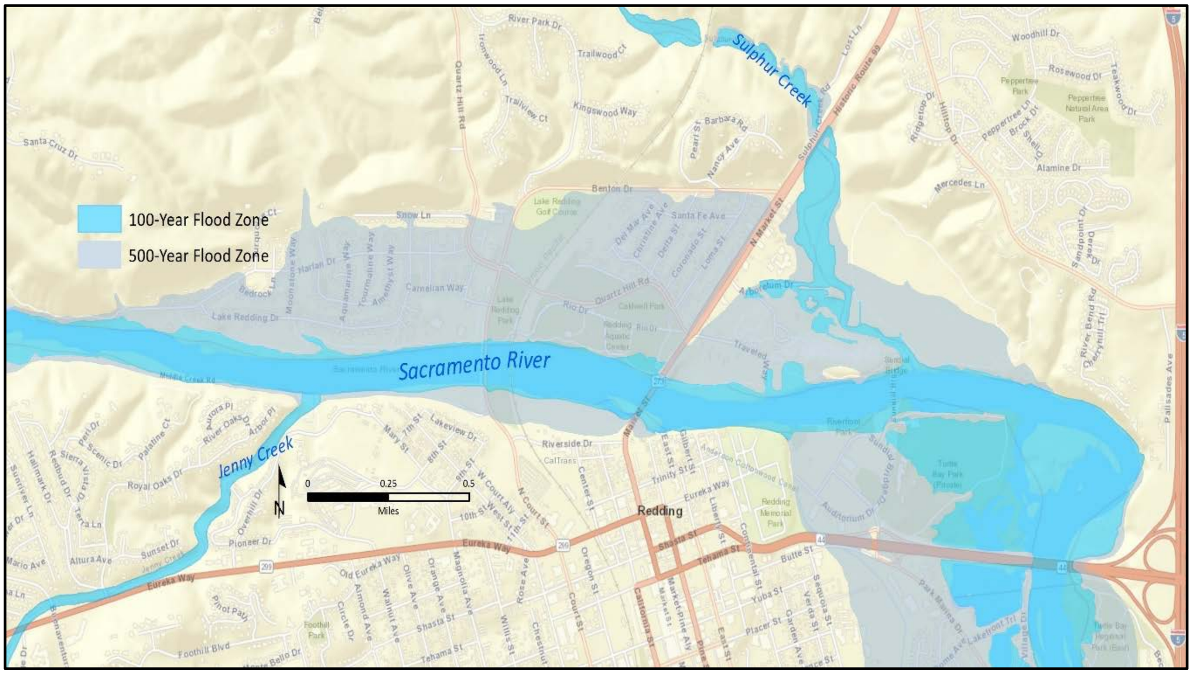

Figure 60. Flooding exposure in Central Redding, north of Highway 299.

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 61).

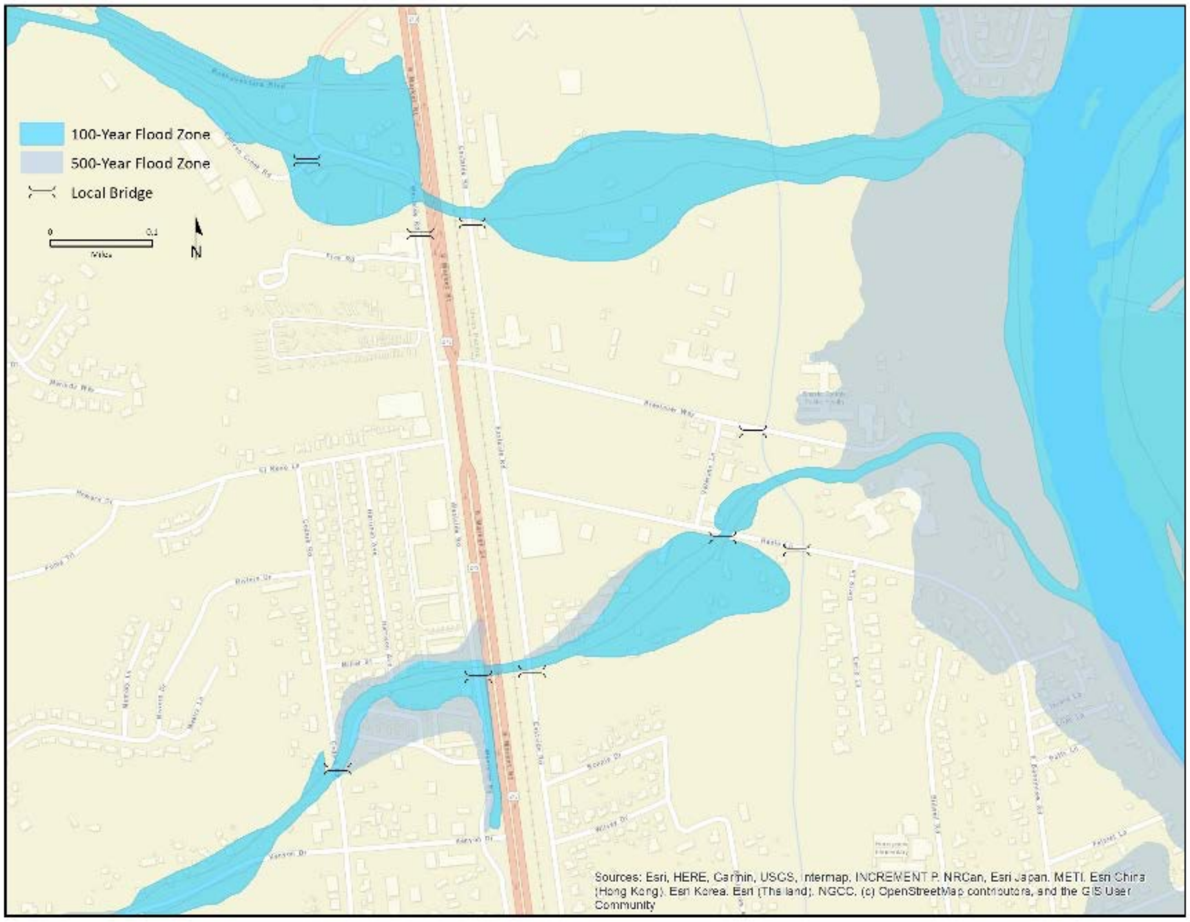

Figure 61. Flooding exposure in along Highway 273, south of Redding..

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 62**,** Figure 63**,** and Figure 64 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.

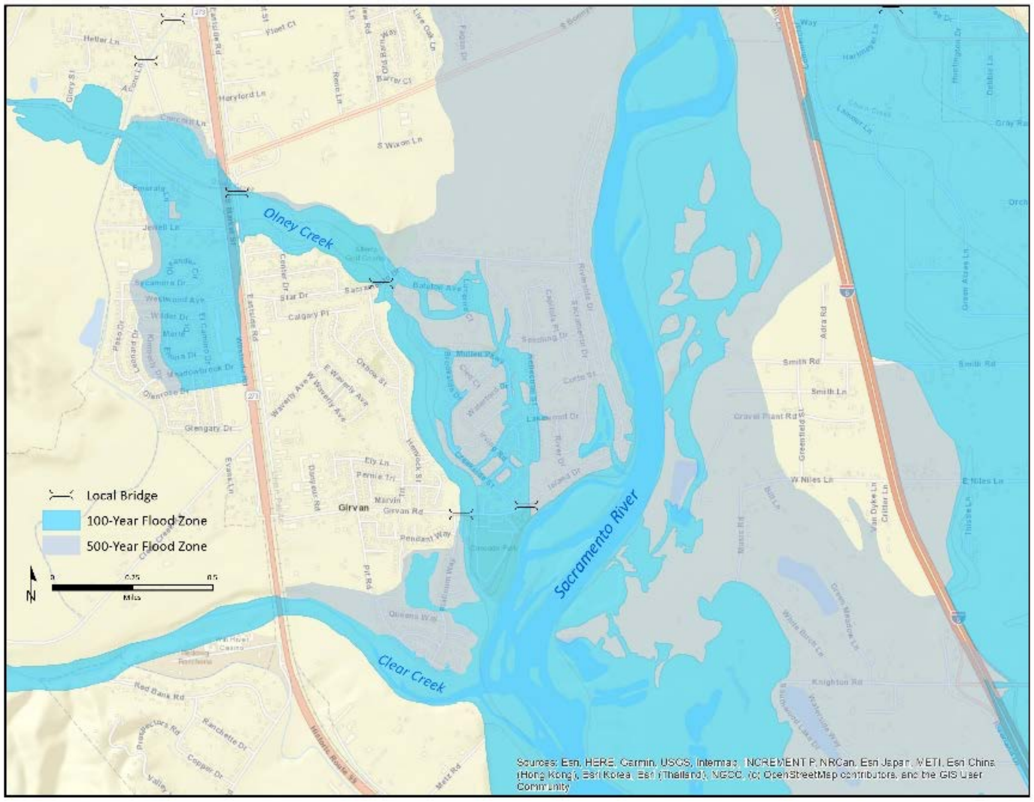

Figure 62. Flooding exposure in along Highway 273, Girvan.

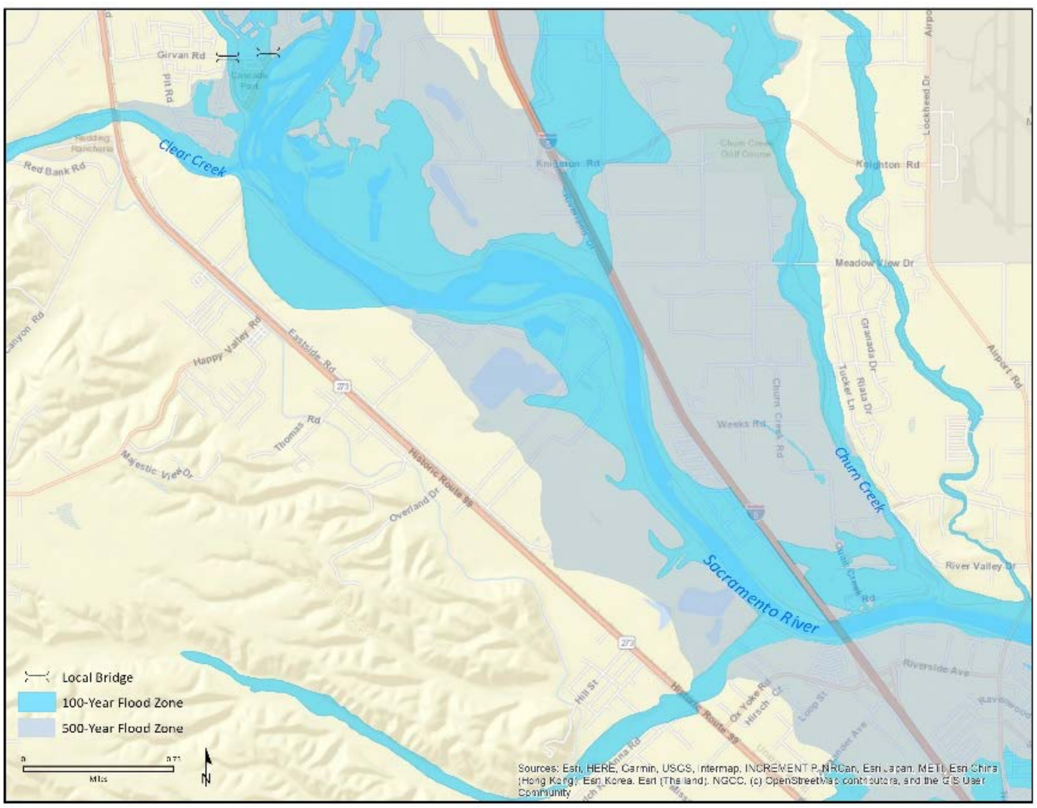

Figure 63. Flooding exposure in along Highway 273, north of Anderson.

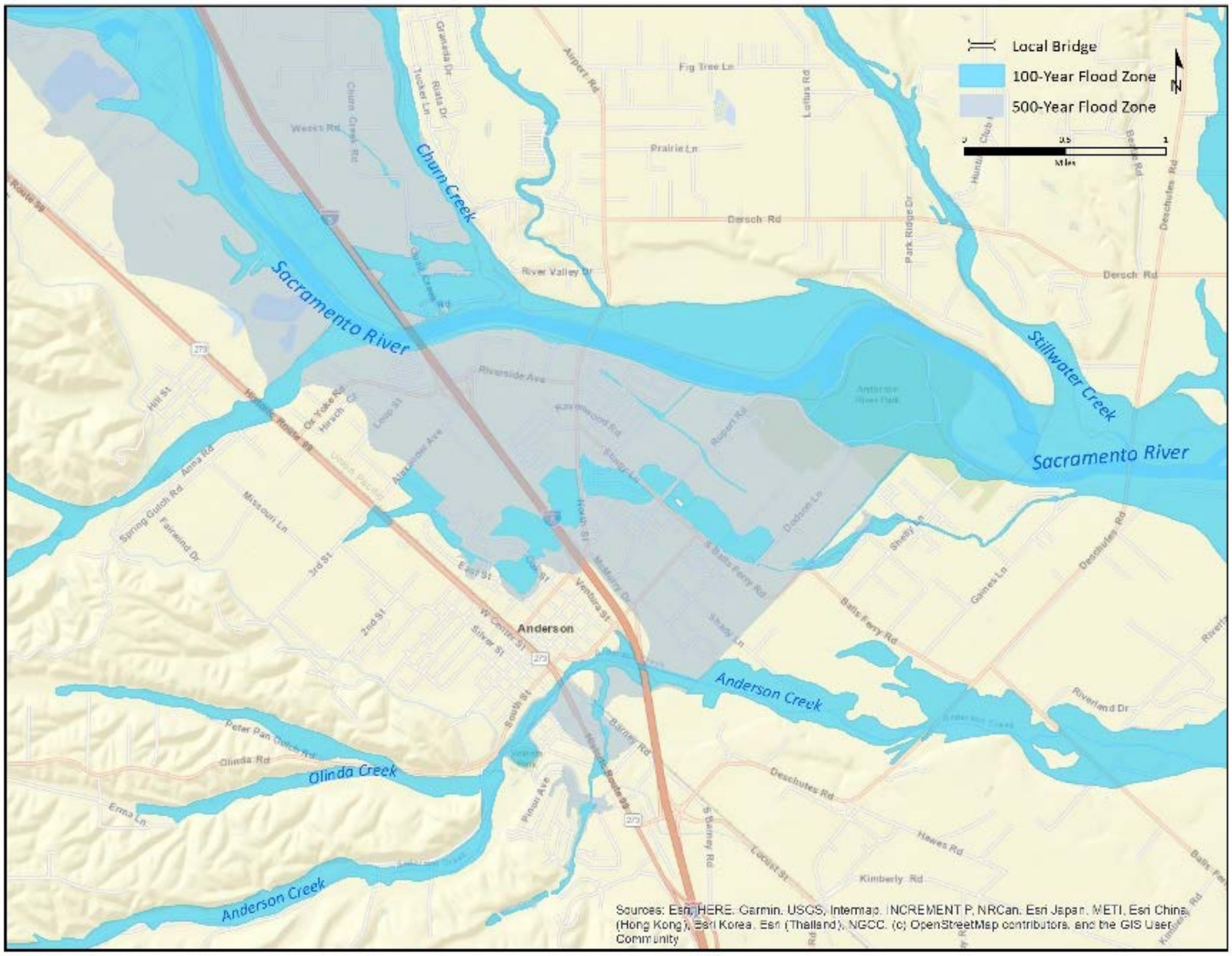

Figure 64. Flooding exposure in Anderson.

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 65). 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.

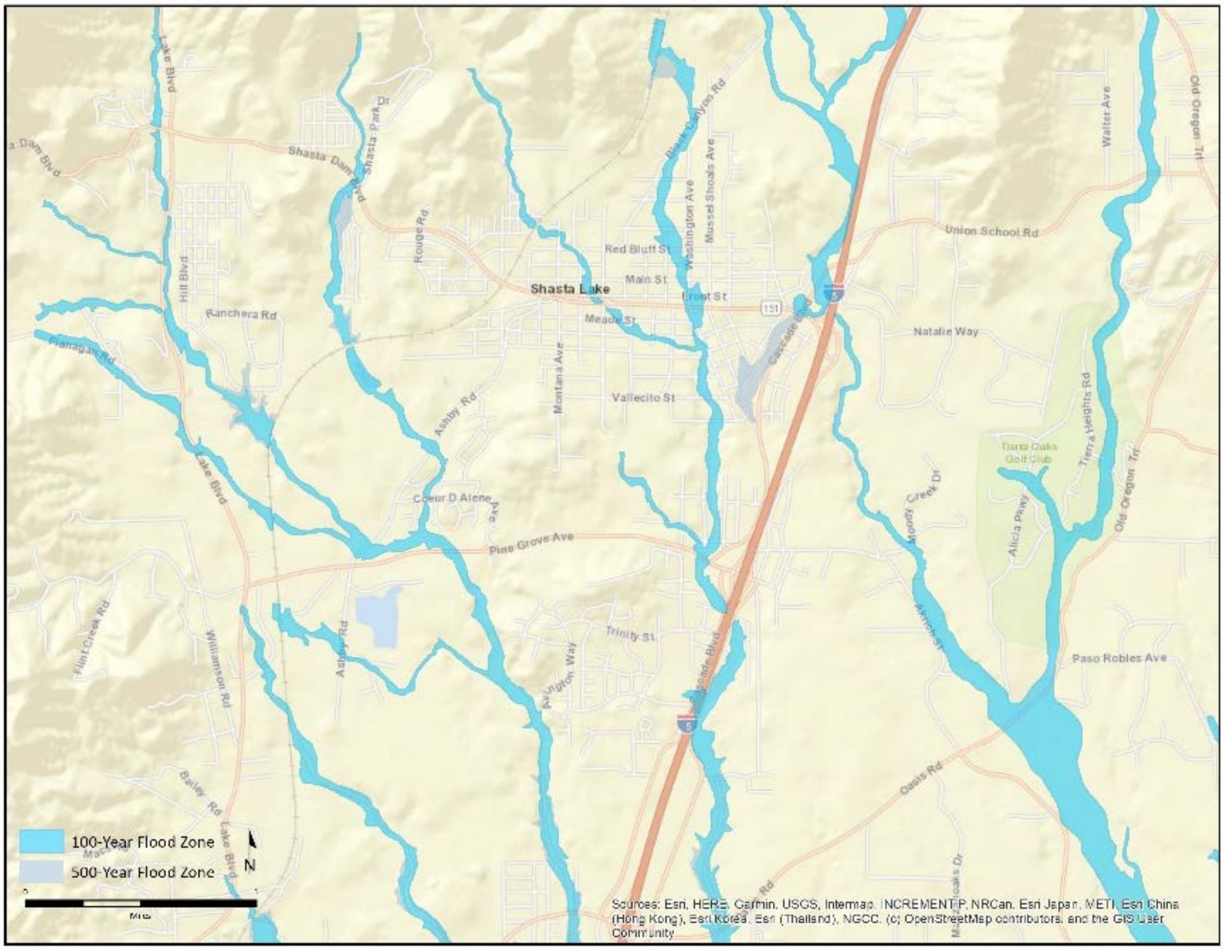

Figure 65. Tributaries and flooding exposure in the City of Shasta Lake.

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 66 and Figure 67 show the flood hazard exposure in these areas.

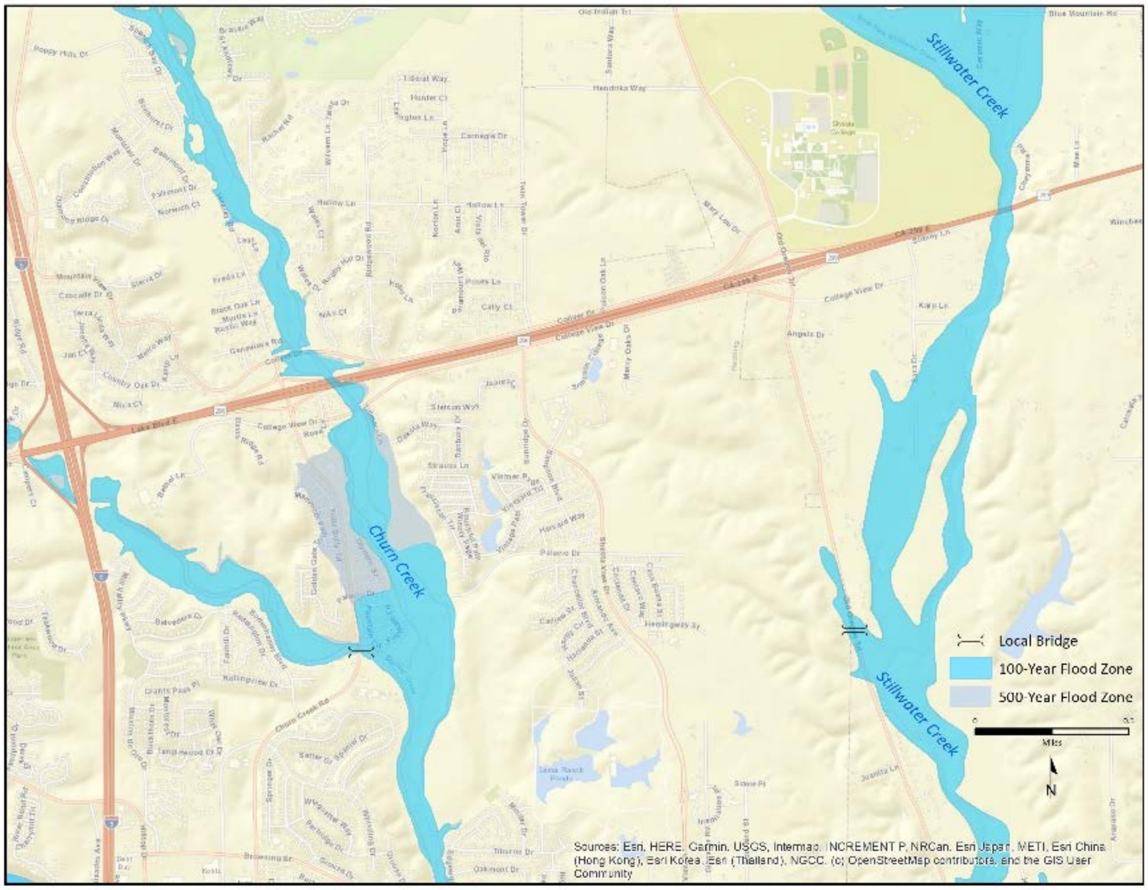

Figure 66. Tributaries and flooding exposure in Bella Vista.

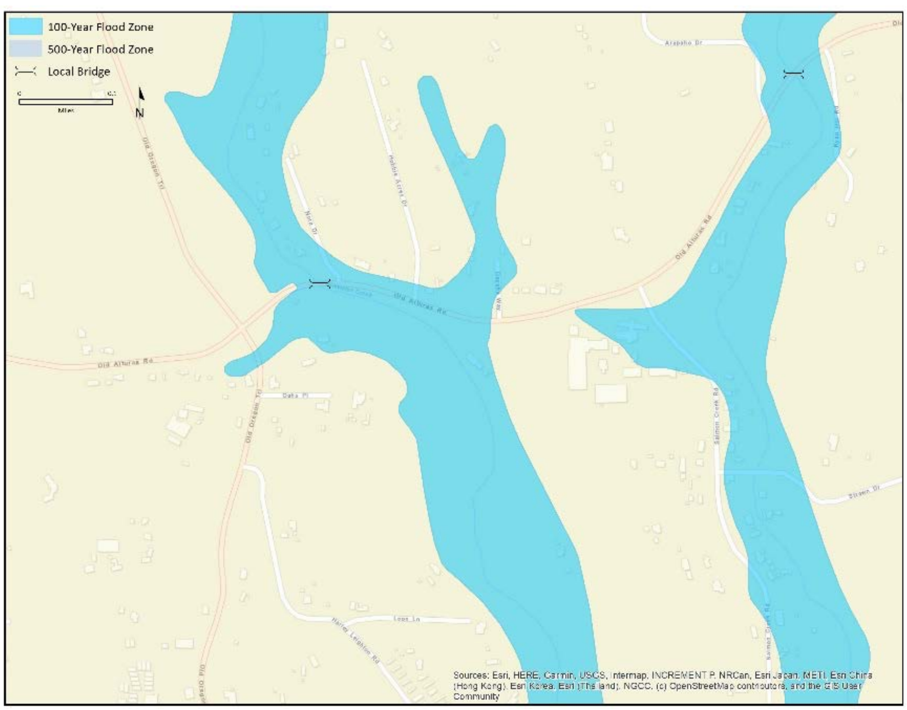

Figure 67. Tributaries and flooding exposure along Old Arturas Road.

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 68 and Figure 69 show the flood hazard exposure in this part of the Shasta Region.

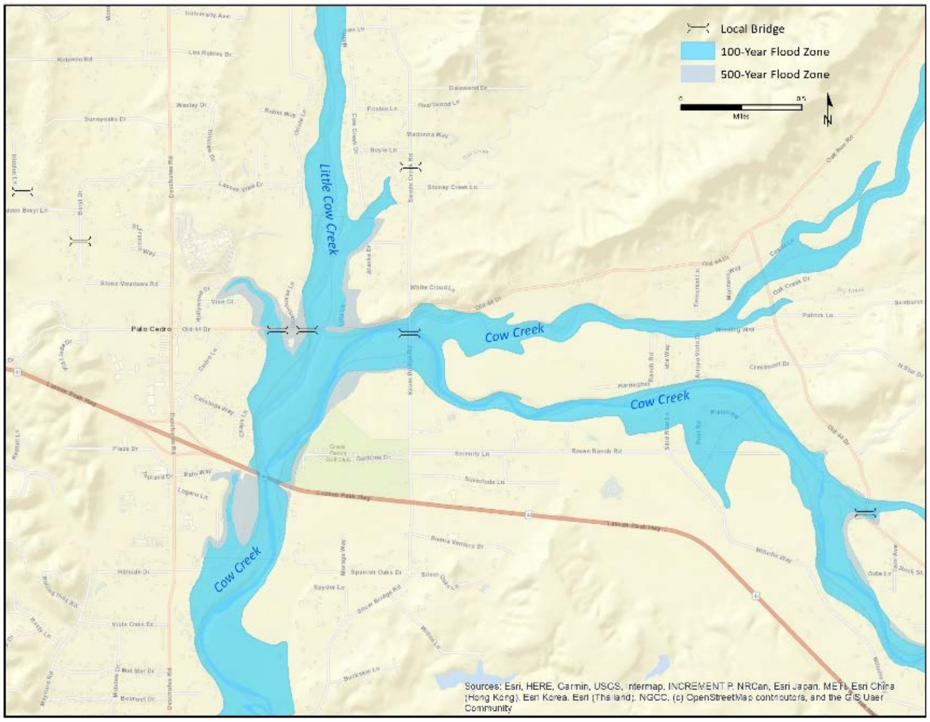

Figure 68. Floodplains in Palo Cedro.

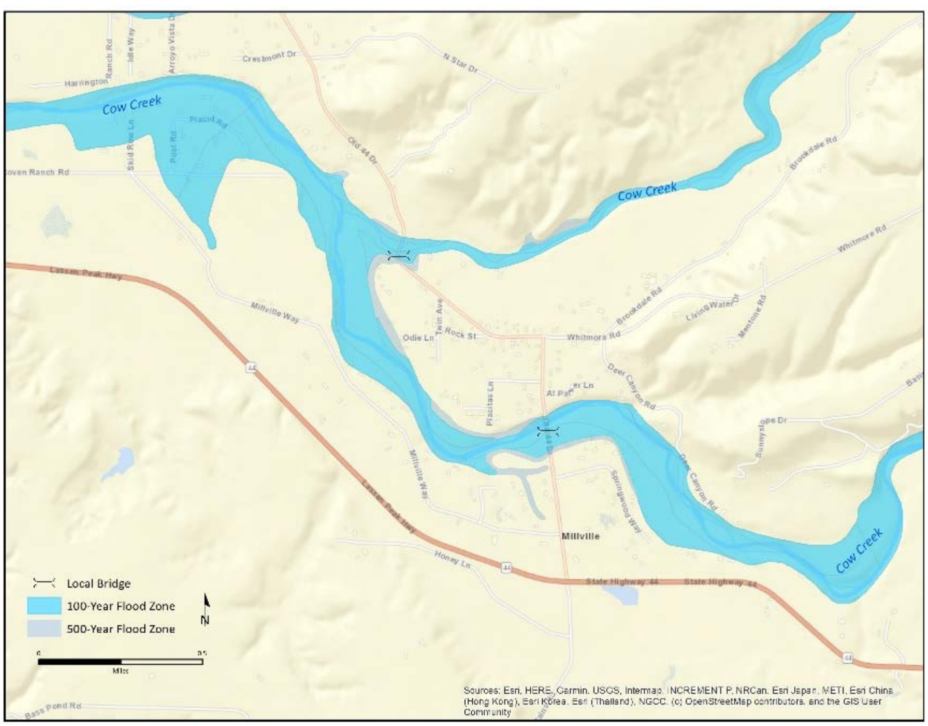

Figure 69. Floodplains in Millville.

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.

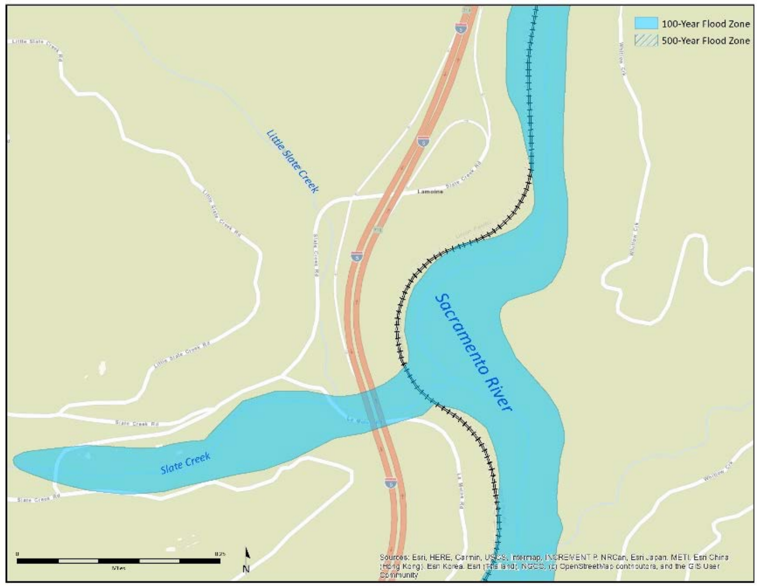

Figure 70. Flooding exposure of the Union Pacific Railroad in the Sacramento River Canyon, near Lamoine.

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 70), in Pollard Flat (Figure 71), 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.

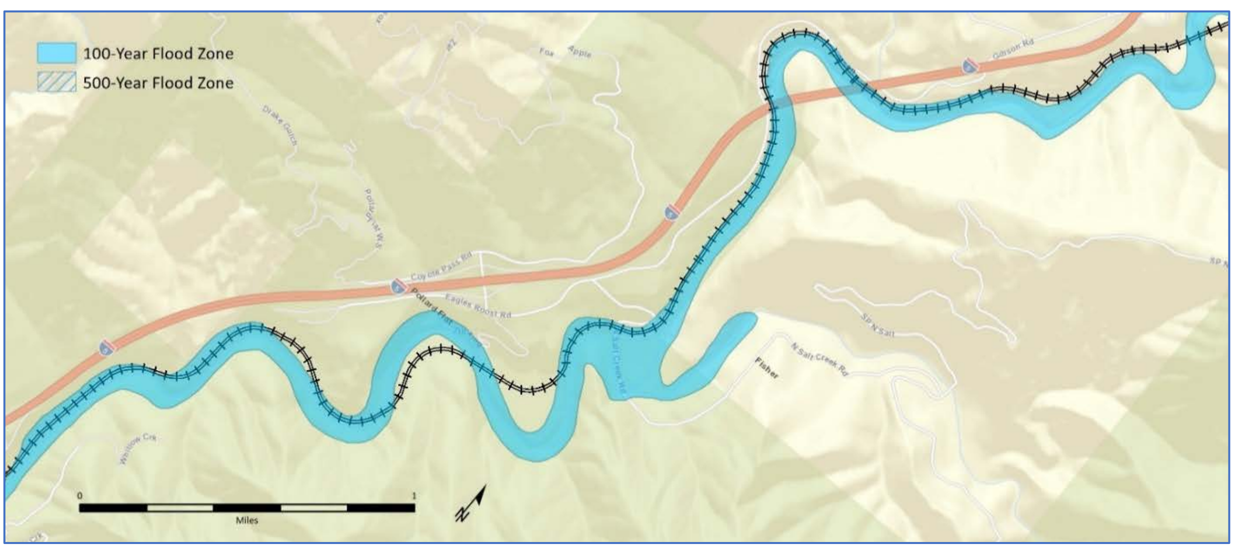

Figure 71. Flooding exposure of the Union Pacific Railroad in the Sacramento River Canyon, near Pollard Flat.

Near Castle Crag, flood hazards expose sections of the railroad to inundation during a 100-year flood (Figure 72). 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.

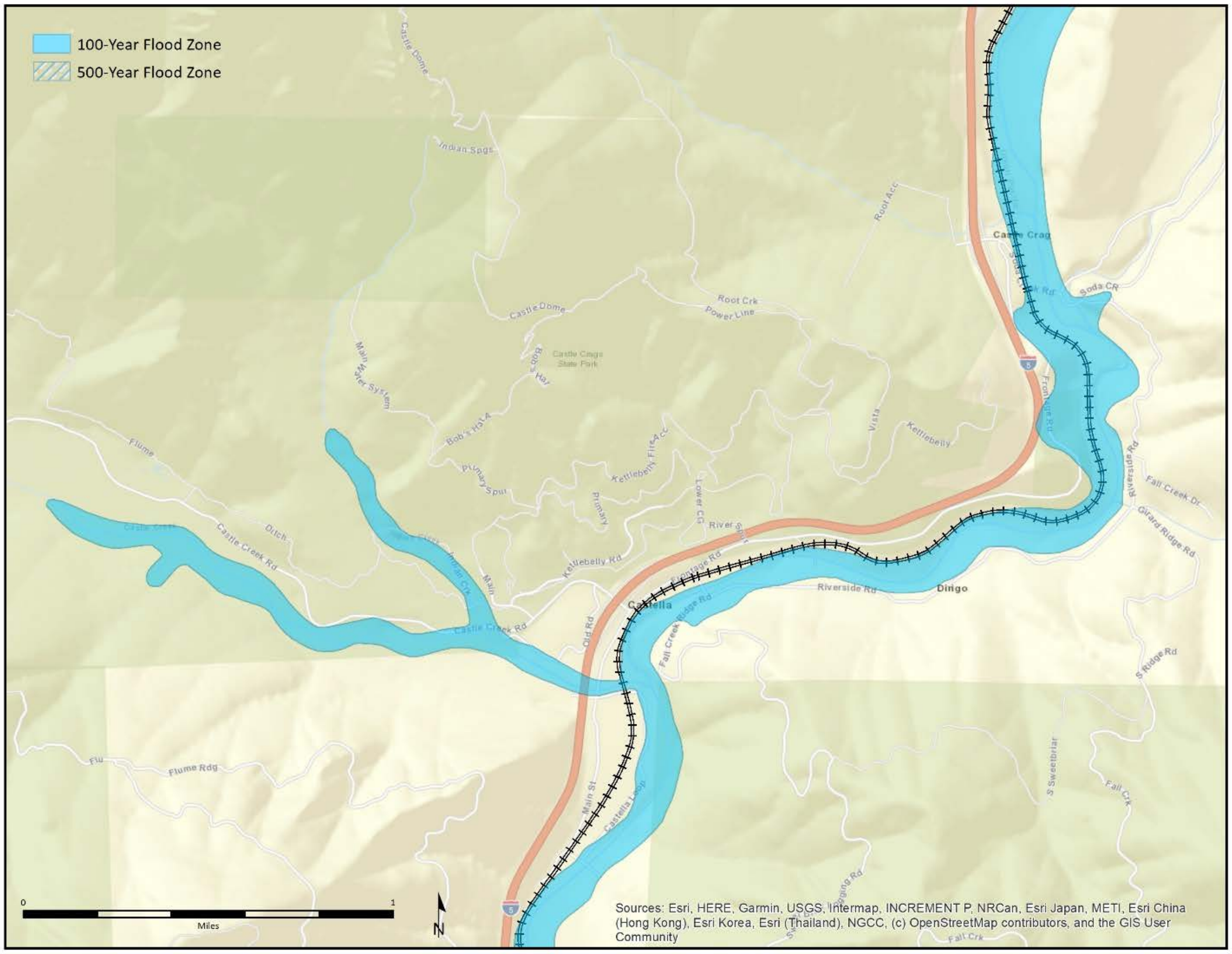

Figure 72. Flooding exposure of the Union Pacific Railroad in the Sacramento River Canyon, near Castle Crag State Park.

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 73). Mapped flood hazards in Clear Creek do not threaten any transportation infrastructure.

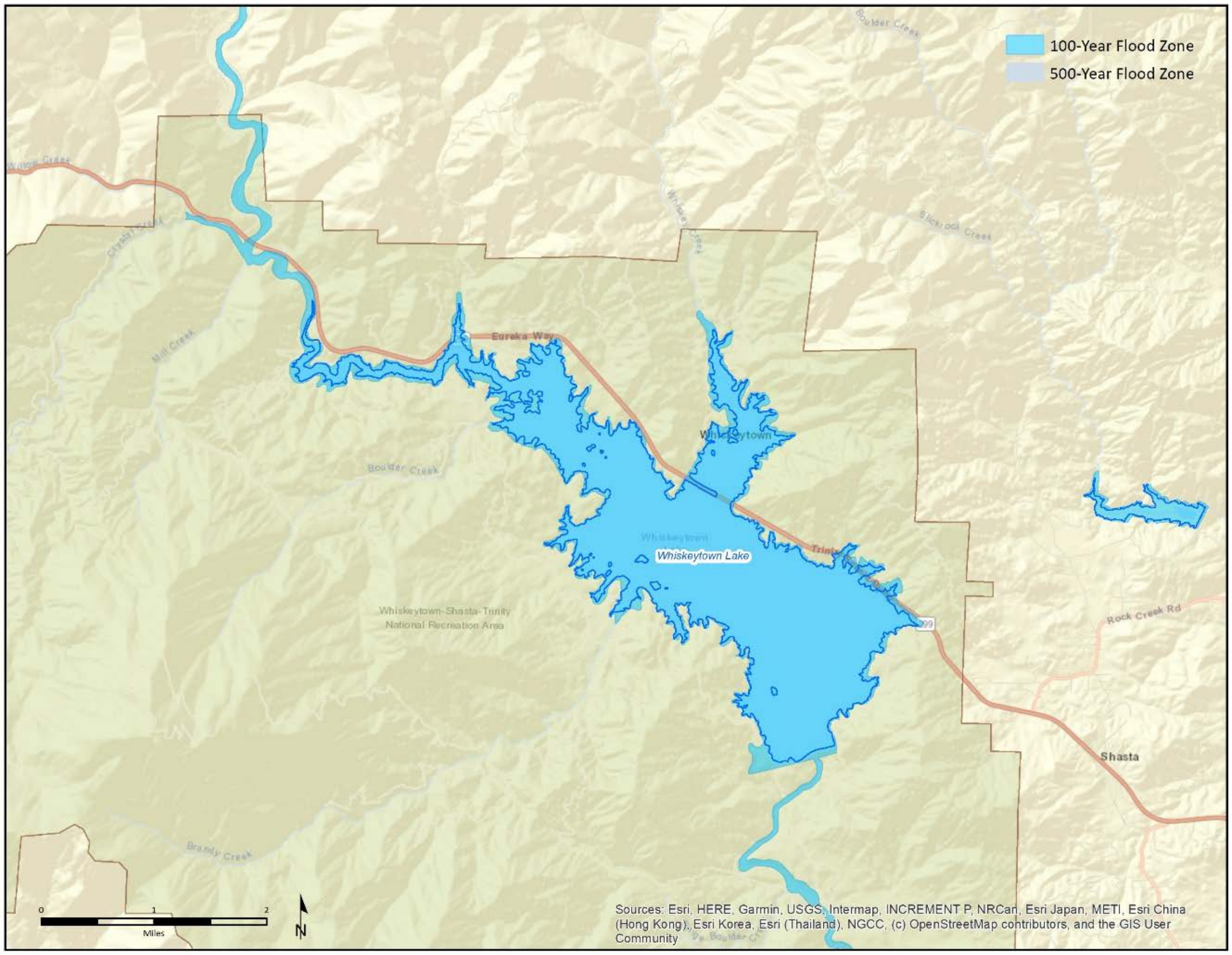

Figure 73. Flood hazard areas in and around Whiskeytown Lake.

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 74). 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.

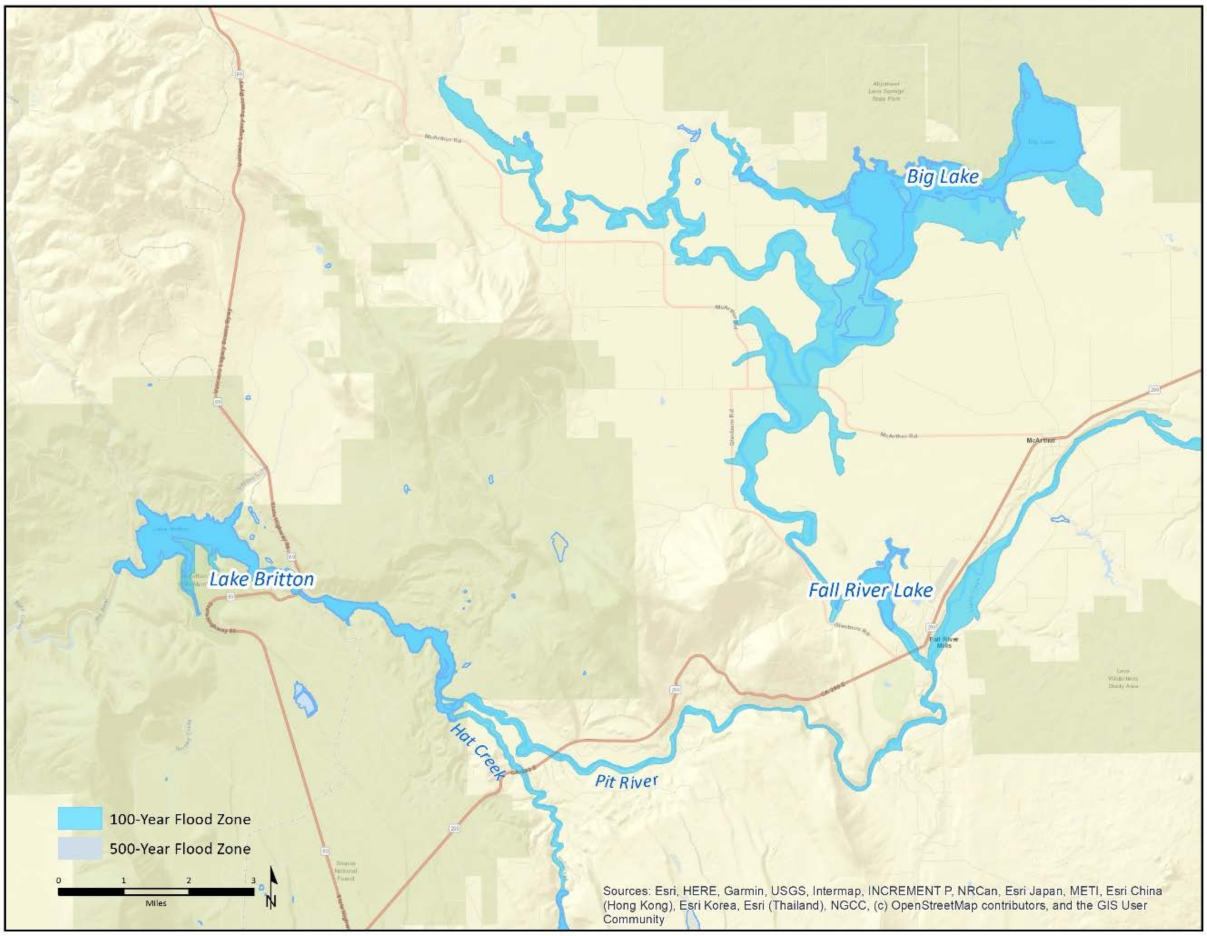

Figure 74. Flood hazard areas in northeastern Shasta Region.

In and around Burney, the 100-year floodplain extends eastward from Burney Creek to an irrigation canal (Figure 75). 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.

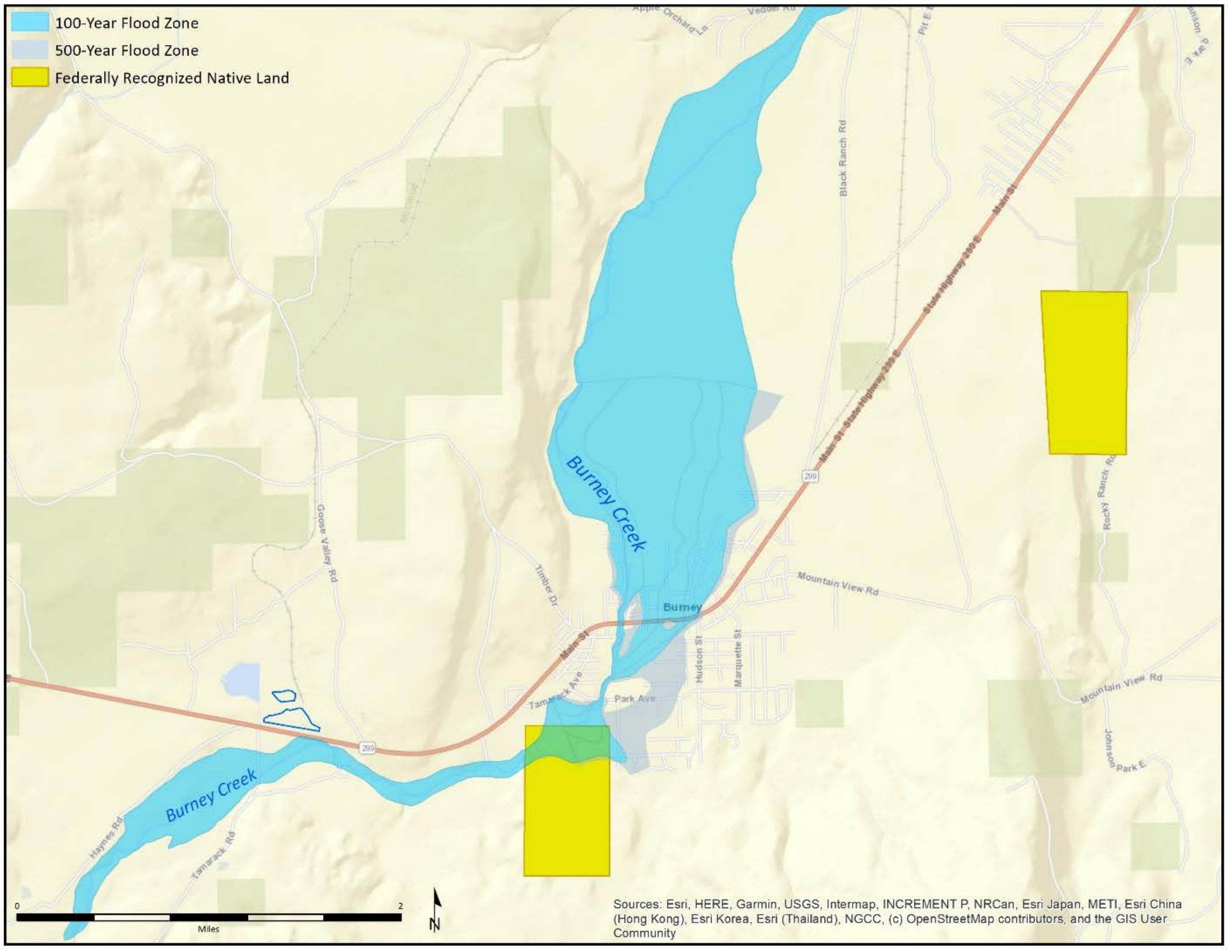

Figure 75. Flood hazard areas in and around Burney.

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 76, Figure 77, and Figure 78). 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.

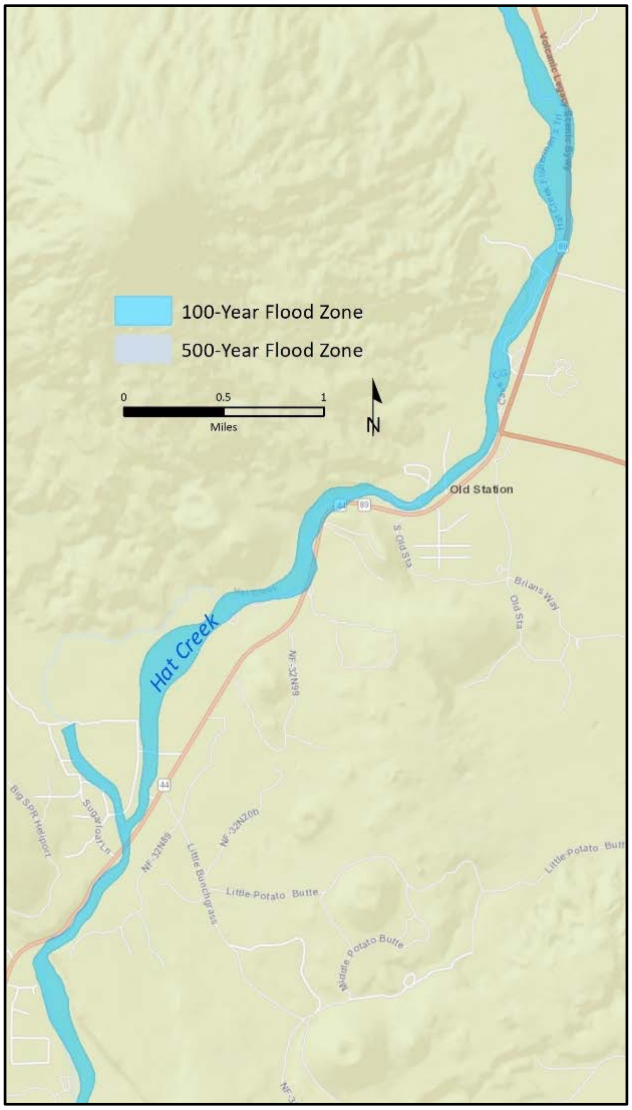

Figure 77. Flooding hazards associated with Hat Creek near Old Station.

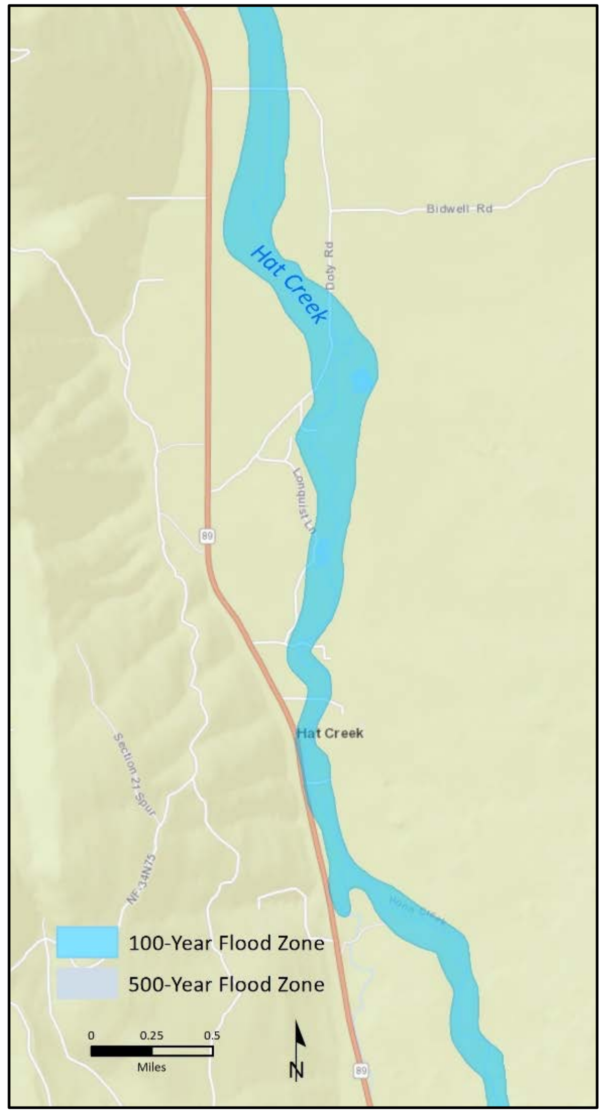

Figure 76. Flooding hazards associated with Hat Creek in the community of Hat Creek.

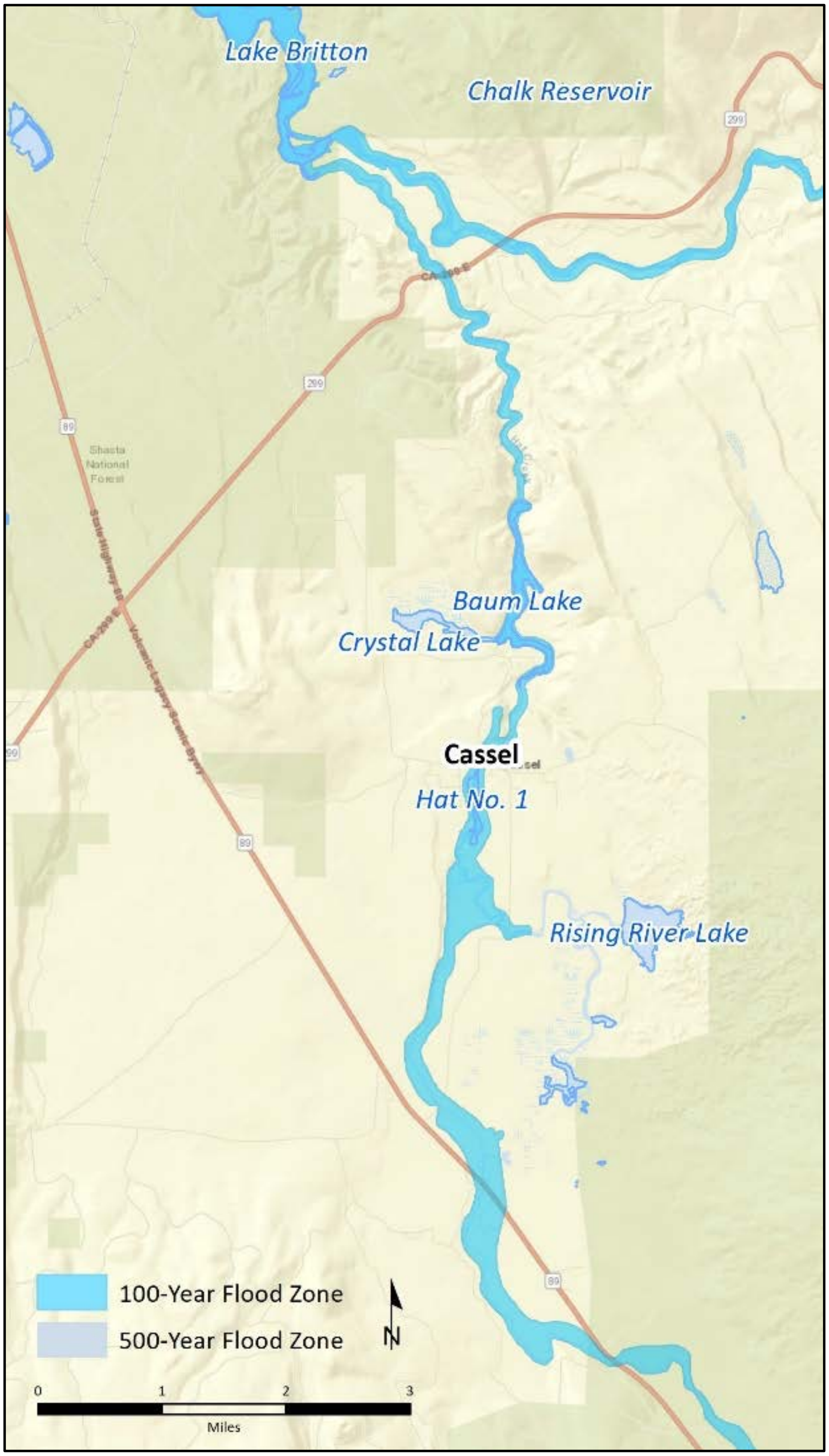

Figure 78. Flooding hazards associated with Hat Creek threaten Highways 89 and 299 near Cassel.

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 79). This is a low priority hazard.

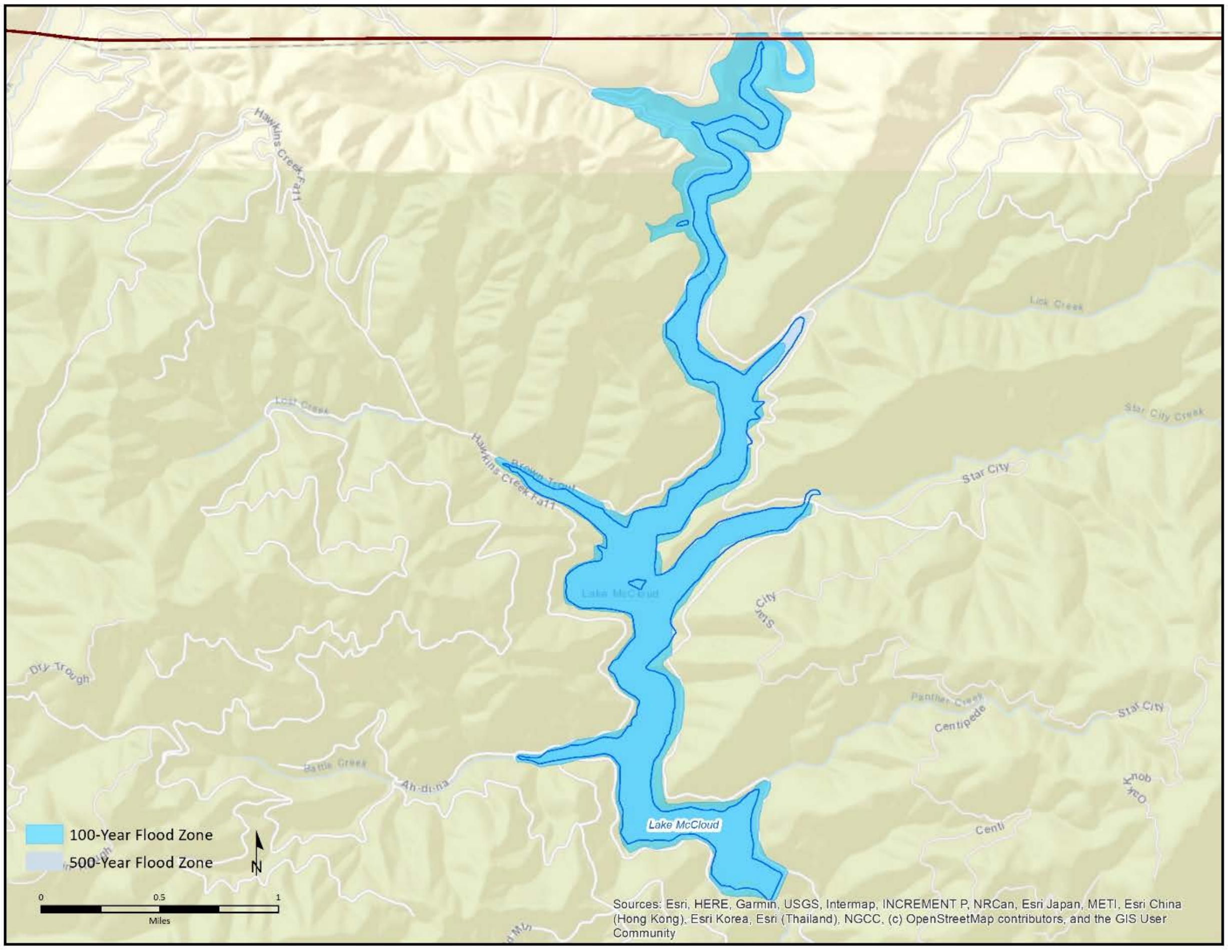

Figure 79. Flood hazards around Lake McCloud.

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 16 lists many of the specific impacts that landslides can have on different transportation systems.

Table 16. 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.” However recent landslide activity near Big French Creek

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

[13] Shasta County 2017

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 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 80 shows the Region-wide distribution of potentially hazardous slopes, as well as the areas of particular concern.

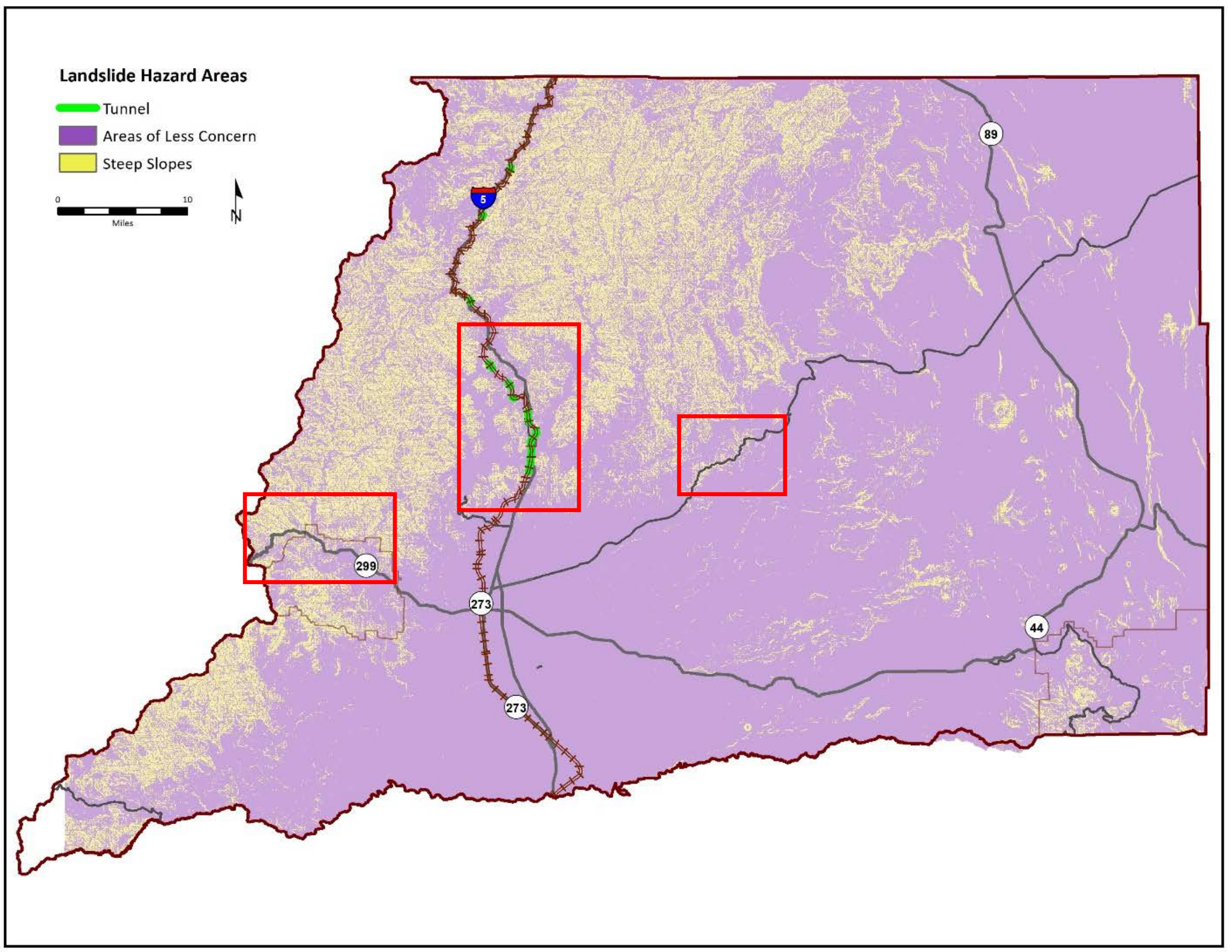

Figure 80. Potentially hazardous landslide slope zones in the Shasta Region. Areas where large numbers of potentially hazardous slopes exist above important transportation systems are identified.

[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 81 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.

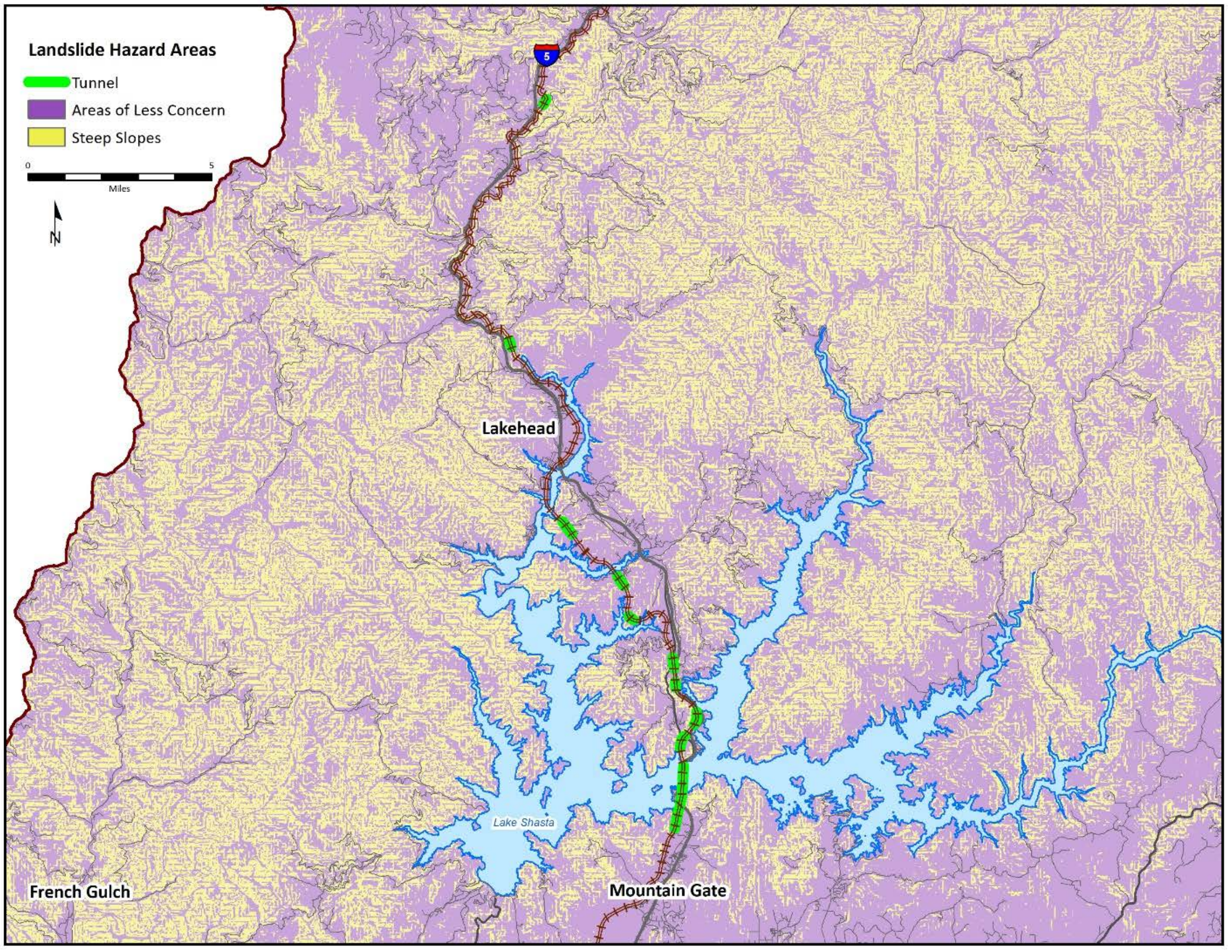

Figure 81. Areas of potentially hazardous landslide slope zones in the Sacramento River Canyon.

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. Multiple recent landslides have disrupted traffic on Highway 299 in Trinity County, including most recently a slide that occurred during the monument Fire in August, 2021.[15] 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 82 shows the potential landslide hazards along Highway 299.

[15] Carroll 2021

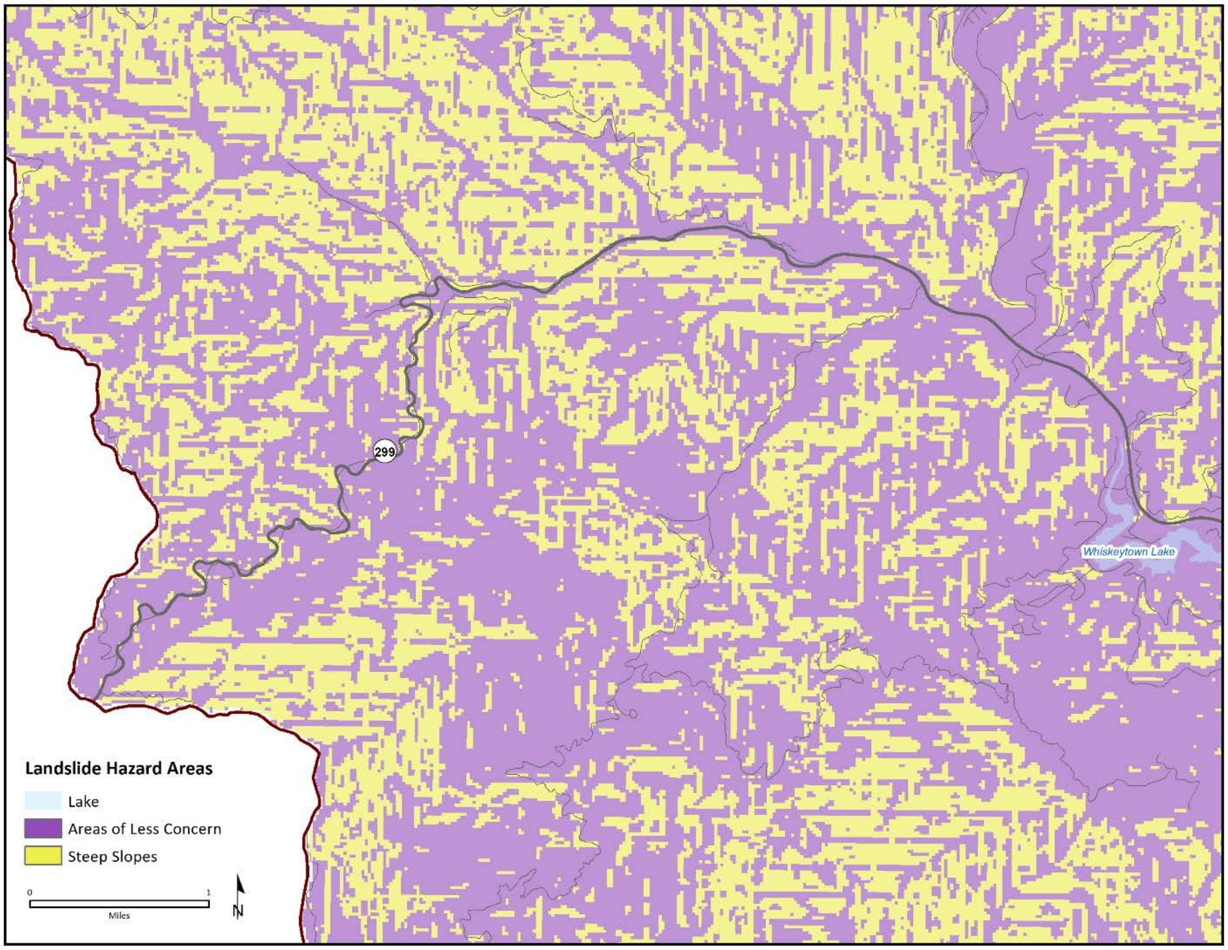

Figure 82. Potentially hazardous landslide slope zones along Highway 299 west of Whiskeytown Lake.

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 83 shows the distribution of potentially hazardous landslide slope zones in this area.

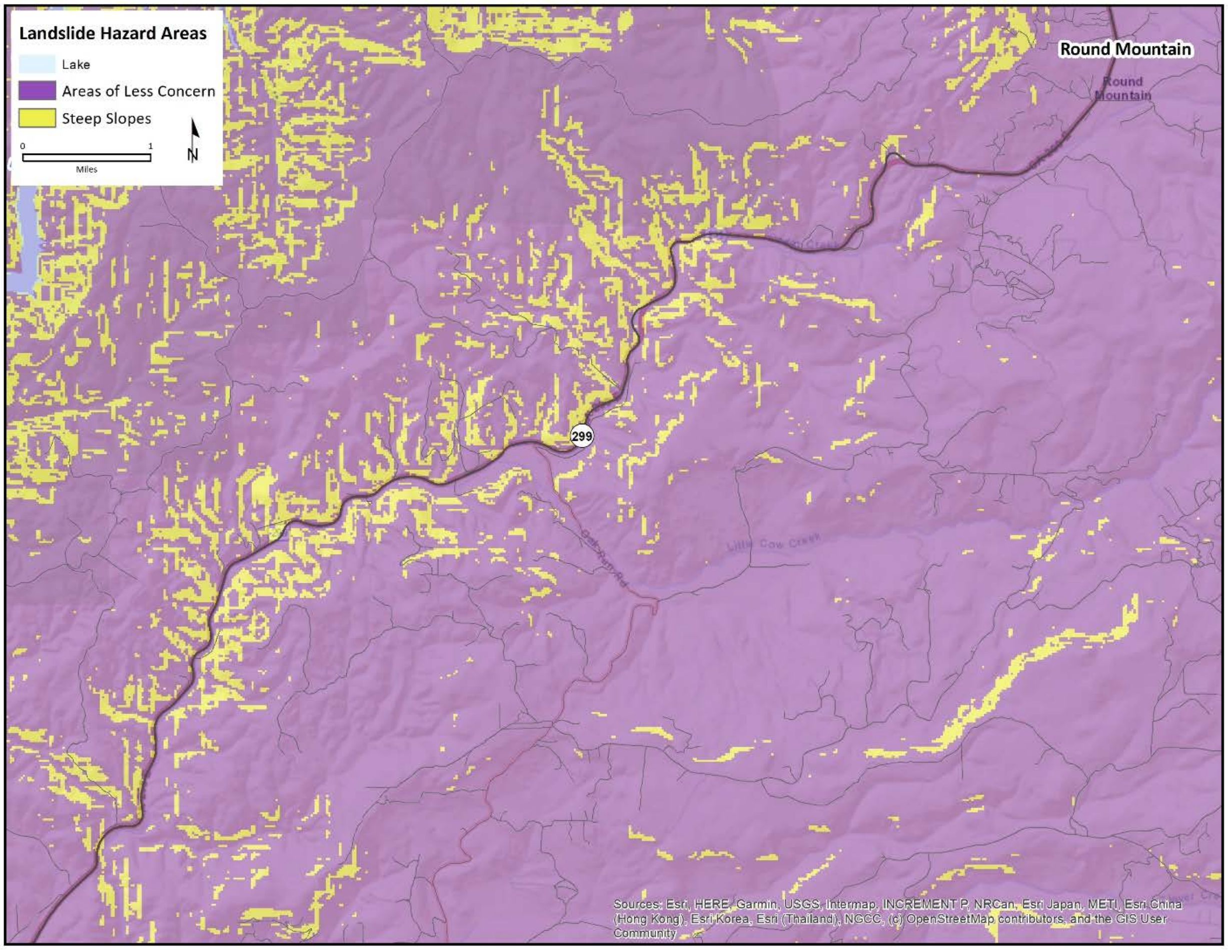

Figure 83. Potentially hazardous landslide slope zones around Highway 299 between Bella Vista and Round Mountain.

Shasta Regional Mobility Adaptation Plan

The warming climate is already affecting extreme weather in the Shasta Region, across California, and around the world. However, the changes are happening gradually, and day-to-day, seasonal, and annual changes in weather are often enough to make the gradual increase in temperature or fire hazard imperceptible.

Adaptation strategies are actions or sets of actions designed to integrate an awareness of climate hazards into transportation and mobility planning, operations, and management decision-making processes at every level. When full information about projected future hazards is available, many adaptation strategies are simply common-sense efforts to build systems today that will be able to withstand future conditions. However, due to incomplete information or uncertainty, it is not always possible to plan precisely for future conditions. Furthermore, extreme weather events like wildfires and floods occur randomly, even when the warming climate makes their occurrence more likely and more severe.

What is Adaptation?

Climate change *adaptation* refers to any action to prepare for and adjust to changing conditions. Adaptation measures are typically designed with the goal of preventing or reducing damage or disruption, but can also include actions that take advantage of new opportunities, or that create co-benefits for communities and the environment. Adaptation planning is occurring in the public and private sectors and at all levels of government. Presently, adaptation actions are rare, and much more work is necessary to protect the both the Region’s and the nation’s infrastructure, but agencies like SRTA are taking steps to begin adapting to climate change.

Types of Hazards

Adaptation strategies must address two different types of climate hazards:

- **Acute hazards**: wildfires, floods, and extreme precipitation events (and to a lesser extent landsides) constitute acute hazards that materialize quickly (in a matter of minutes, hours, or days), disrupt regional mobility, and threaten severe costs (including lives)
- **Chronic hazards**: hotter summers, warmer winters, and changes to regional precipitation patterns affect infrastructure systems slowly, gradually increasing the wear and tear on built systems, machines, or increasing demand from users

Figure 84. Acute and chronic hazards can result from the same underlying change: rising temperatures are expected to result in both acute hazards like heat waves as well as chronic hazards like drought. Image Sources: NIEHS 2017, NOAA 2019.

Acute hazards often draw the attention due to the dramatic nature of natural disasters; however chronic hazards play a major role in setting the stage: hotter, dryer summers increase the risk of wildfires, and more frequent and severe extreme precipitation events increase the risks of regional flooding. Strategies to address these different types of hazards must take different approaches.

Components of Resilient Mobility

Resilient mobility requires implementing multiple facets of resilience. These include:

- **Resistance**: the ability to handle shocks while minimizing disruption or damage
- **Recovery**: the ability to repair infrastructure and restore service quickly and at a minimum cost
- **Adaptive capacity**: the ability to integrate new information and experience into adaptive processes

Combined, resilient mobility means mobility that maintains acceptable service during acute hazards, that recovers quickly and effectively from disruptions, and that retains the ability to adapt to changing conditions based on future lessons learned. In the Shasta Region, resilient mobility means a transportation system that provides clear and reliable evacuation directions and routes during acute hazards, that ensures detours are clear and well-planned, and that ensures all Shasta residents are provided the means of a safe and effective evacuation to the best ability of the region's transportation agencies.

Types of Adaptation Strategies

This strategy discusses several different types of adaptation strategies:

- **Planning strategies**: Planning strategies include actions taken to ensure that future investments are designed and built-in anticipation of future conditions. These may include research efforts, plans and reports, design standards, or even simply policies
- **Operational strategies**: Operational strategies are actions taken to change the current operations of one or more agencies in order to improve resilience to an extreme weather hazard.
- **Hardening strategies**: Hardening strategies involve investments in physical capital for existing infrastructure.
- **Replacement strategies**: Replacement strategies involve abandoning an existing system and replacing it with a new one (also called relocation). This report does not recommend any replacement strategies.

For some strategies, the line between types may blur – for example, many hardening strategies can be framed as planning strategies, where the vulnerable infrastructure is substituted for hardened infrastructure, but only after the existing infrastructure has worn out past its useful lifetime.

Wildfire

Projections show extreme increases in both **wildfire probability** and **severity** over the coming century, including in areas with key transportation infrastructure

Throughout virtually all the Shasta Region, wildfire hazards are projected to grow more extreme in coming decades. Multiple approaches to reduce wildfire hazards statewide are being researched, and proactive clearing of dangerous biomass, alternative forest management strategies, and approaches to reduce risk of ignition such as enhanced vegetation management on transmission line rights-of-way are all important tools to reduce the hazards presented by wildfire from the top.

This plan is focused on strategies to mitigate the threats of wildfire to the mobility of Shasta residents. Rather than reducing the frequency or size of wildfires in general, these strategies are oriented toward protecting and enhancing the transportation infrastructure of the Shasta region and the mobility of its residents. However, because roadside fires are often initiated by vehicles or drivers, reducing the risk of fire ignition within road rights of way (ROW) is a key goal of these strategies.

W.1: Prioritize fire safety and road protection projects through the Regional Transportation Plan

In order to ensure mobility in the Shasta Region under changing climate conditions, there is no more pressing goal than reducing the threat of wildfire on the region's network of roads and highways. SRTA should consider this goal a key objective of updates to the 2022 Regional Transportation Plan (RTP). Using the RTP, SRTA should set out two new long-term maintenance goals: roadside fire safety and road protection.

W.1 strategy roles & Responsibilities	
Type of strategy	Planning
Proposed lead agency	SRTA
Additional agencies/ roles	State and local public works agencies, utilities
SRTA role	Lead
Possible funding	N/A

Roadside fire safety includes activities that reduce the risk of roadside fire ignition. These primarily include thinning trees and shrubs and clearing hazardous fuels within the ROW of high traffic roads and roads that transit areas of elevated wildfire hazard, but can also include public messaging campaigns. Reducing the buildup of hazardous fuels is addressed in other strategies (see **W.2: Convene stakeholder Hazardous Fuels Reduction Working Group**), however SRTA should explore updates to regional transportation policy that provide permanent funding for prioritized vegetation management.

Road protection includes activities that reduce the damage to roads and disruption to mobility caused by fires. When intense wildfires burn over roads, they do damage in several ways, some obvious and some less obvious. Road furniture (including signs, poles, guard rails, and other stationary equipment), communications and utility equipment, bridges, culverts, and pavements can all be damaged by heat, flames, and smoke. Following a fire, the condition of bridge piers, decks, and culverts must all be inspected, and damaged road furniture replaced. In circumstances where utilities have located important equipment in the ROW (e.g., power transformers, communications hubs/switches, etc.), utilities should consider enclosing it in fire resistant cases.

SRTA's ability to dedicate funding for fire safety and road protection through existing funding sources is limited, however SRTA should explore mechanisms to prioritize funding for projects which achieve these goals, especially where the vulnerability is greatest. SRTA should also provide analytical assistance to agencies where necessary.

W.2: Convene stakeholder Hazardous Fuels Reduction Working Group

W.2 strategy roles & responsibilities	
Type of strategy	Planning, Hardening
Proposed lead agency	Cal Fire, local fire districts
Additional agencies/ roles	Public works agencies, Cal Fire, U.S. Forest Service, electric utilities, municipal fire agencies, additional regional partners
SRTA role	Advisory
Possible funding	Calfire Fire Prevention Grants

The most important step to protect road corridors from wildfire is to reduce the density of hazardous fuels along the region's roadsides. In order to prevent future fires, roadside fuels reduction must become a regular component of road maintenance. In support of creating road corridors that minimize the risk of roadside fire ignition and protect evacuating residents, the agencies responsible for planning, coordinating, and executing both hazardous fuels reduction projects and road protection and maintenance projects should convene a working group of stakeholders for the goal of identifying and clearing or mitigating hazardous fuels within and along the right of ways of highways and major arterials. The intended outcome of this working group would be to achieve defensible spaces along the region's major corridors and in areas subject to greater wildfire threats. Figure 85 demonstrates the concept of defensible spaces as areas alongside a road's right of way where combustible biomass is cleared, shredded, or prescribed-burned.

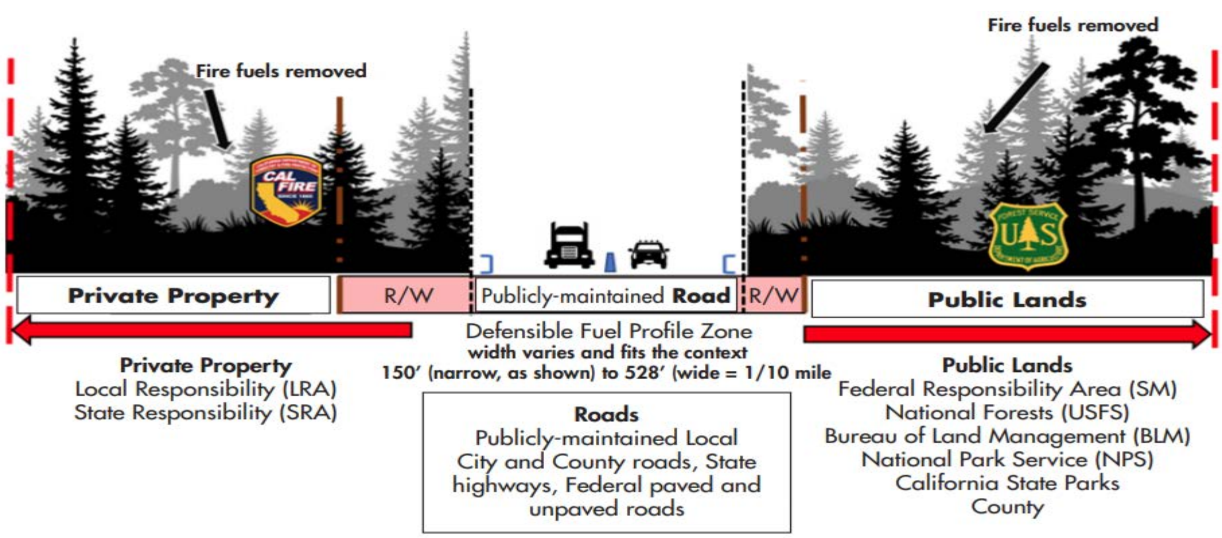

Figure 85. Diagram showing the "defensible fuel profile zone" surrounding a roadway. Responsibilities depend on type of land which public right-of-way transits. Source: California Forest Management Task Force 2021

The purpose of the Hazardous Fuels Reduction Working Group would be to act as an advisory group for fuel reduction projects among the various stakeholders, enabling agencies to share plans, coordinate efforts where possible, and ensure that boundaries between local, county, and state jurisdiction do not lead to areas of hazardous fuel buildup. The working group should include at a minimum any agencies conducting fuel mitigation within the Region, including Cal Fire, Caltrans, and County and municipal public works agencies and fire protection agencies.

The working group should first prioritize cooperation and communication, establishing a means for sharing the timing and scope of scheduled mitigation projects, as well as the internal methods agencies use for planning mitigation projects. Over a longer timeframe, the working group should collectively set goals for clearing high-to-severe hazards within an achievable timeframe and set subsequent goals for maintaining fire safe road corridors along the region’s highways. The working group could further share best practices (including for clearance methods and tools), lessons learned, and opportunities for funding, and provide additional contact points for improved emergency response. The working group should meet at least twice per year – once at the beginning of the year when projects are being planned, and again at the beginning of the summer. Ideally more frequent meetings should be held in order to ensure that the critical work maintains a high priority within agencies.

As a planning agency, SRTA’s role in this working group would be functionally limited, but SRTA can provide long-term planning perspectives, especially related to the prioritization of defensible space clearing near critical routes for secondary access (see adaptation strategy **E.2: Evaluate evacuation bottlenecks and secondary access constraints**). SRTA should seek to be able to provide analysis on current and expected future changes to road usage to facilitate prioritization of working group projects. Additionally, as a part of the ResilientShasta project, SRTA should act as a facilitator to convene stakeholders at the outset and ensure that the working group has commitments from county and city DPWs. This goal may also benefit from use of a new Caltrans collaborative fuels reduction framework (currently under development). As a facilitator, SRTA is also in a prime position to involve additional local stakeholders with relevant input. The Shasta Region has a rich cultural history that can provide important perspectives such as local tribes who may provide indigenous ecological knowledge about forest management. SRTA can also balance inputs from different user groups, for example by working to clear hazardous vegetation without disrupting shade cover essential to alternative transportation user groups such as hikers, pedestrians, cyclists, and others not using automobiles. Finally, SRTA can play an important role in identifying sources of funding to facilitate this working group.

W.3: Convene private landowners for collaborative hazardous fuels reduction

Following establishment of the Hazardous Fuels Working Group, stakeholders (including public works agencies) should seek ways to integrate key private landowners into a new group focused on hazardous fuel clearing efforts on private lands adjacent to public roads. While critical evacuation corridors often have sufficiently wide rights of way (the land on either side of the road owned by a public agency), many county and local roads have far narrower ROWs. State highways often have ROWs of 150' or wider, while county and local roads can be 60' or narrower. When hazardous fuels accumulate on private lands directly adjacent to county roads that serve as essential access roads to subdivisions or for rural communities, clearing vegetation requires complex arrangements between private landowners, public agencies, and potentially regulators. Additionally, even roads which do not serve any critical evacuation role may be good targets for collaborative fuel clearing efforts. Fires can be sparked on small roads that quickly spread to wider areas.

W.3 strategy roles & responsibilities	
Type of strategy	Planning, Hardening
Proposed lead agency	Cal Fire, fire districts
Additional agencies/ roles	Hazardous Fuels Reduction Working Group, private landowners
SRTA role	Advisory
Possible funding	California Fire Foundation Fire Prevention and Preparedness Grants

The goal of convening select private landowners would be to facilitate cooperative fuel clearing efforts, educate landowners about their important role in mitigating fire hazards, and share resources and lessons learned from the Hazardous Fuels Reduction Working Group. While formal engagement with private landowners may require action from Regional governments to overcome legal or political barriers, the work of the working group would comprise an important element of a Regional response to mitigating fire hazards. The group would focus on the largest landowners with the highest-priority lands (i.e., lands with very high to severe fire hazard adjacent to critical evacuation corridors). The group should also serve as a resource for landowners seeking information on means to commercialize hazardous fuels on their property.

As with the Hazardous Fuels Reduction Working Group, SRTA's role in this group would be limited to advising participants with data and analysis (including current and projected traffic on road segments, road conditions). SRTA's efforts to identify critical secondary access routes and evacuation bottlenecks (see adaptation strategy **E.2: Evaluate evacuation bottlenecks and secondary access constraints**) will also be essential input for these efforts. SRTA should also seek an ongoing dialogue with local landowners and local foundations dedicated to finding funding and revenue sources for hazardous fuel clearing. In the long-term, roadside fuel clearing will need to become a cohesive element of SRTA's prioritization of transportation projects in the region. For example, recent efforts by the McConnell Foundation to reduce hazardous fuel buildup along roadways from Redding to French Gulch has been delayed by administrative barriers between FEMA, Cal Fire, Shasta County, and the foundation.[16] SRTA

[16] Arthur 2021

should explore using future versions of the RTP to secure funding for fuels reduction and defensible space on the region's roads.

W.4: Proactively plan road resurfacing following heavy firefighting activity as part of recovery grants

W.4 strategy roles & responsibilities	
Type of strategy	Operational
Proposed lead agency	SRTA
Additional agencies/ roles	State and local public works agencies
SRTA role	Analytical, advisory
Potential funding	FEMA BRIC Grants

Following a fire, accelerated degradation of road surfaces and subgrades often occurs, especially on low-traffic and low-capacity roads in rural locations (or serving as secondary access routes to subdivisions). During a fire, some roads will experience a sudden increase in use by heavy firefighting and support equipment. Water trucks, bulldozers, and other types of heavy loads will use roads designed to carry much smaller loads. Additionally, in the weeks and months after a fire trucks of equipment and supplies to support recovery and reconstruction may cause further damage. When this heavy traffic gets concentrated on individual road segments, rapid wear and tear can occur, significantly shortening the useful lifetime of the pavement and subgrade.[17] While this can be difficult to detect in the immediate aftermath of a fire, symptoms of deeper damage to the road structure (such as alligator cracking or rutting) may begin to appear soon after.

Along with the relevant transportation agencies in the county, SRTA should work to ensure that these potentially damaged areas receive appropriate recovery funding and repair. Although SRTA cannot lead these efforts, SRTA can provide necessary monitoring, data, and analysis as well as play an important role convening stakeholders in the region to share experiences and best practices. For example, the City of Redding currently has an extensive process for utilizing emergency funds for resurfacing and repair and could share and compare this process with the Region's other public works agencies. When disaster declarations enable state and local agencies to apply for recovery grants, the Shasta Region's applications must specify the areas damage and the necessary repairs.

Damage to road pavements can be evaluated using metrics like the Pavement Condition Index (PCI) or other observation-based measures. By comparing pre- to post-fire conditions, agencies can plan maintenance approaches accordingly (anything from resealing to reconstruction). Assessment of pavement condition is essential as damage may go unnoticed until after recovery funding is no longer available. PCI (or alternative measures of pavement condition) are likely to be an important component of federal performance measures required for interstate and national highways in the 2022 RTP. Whether the lead agency for a recovery grant is Caltrans District 2, Shasta County DPW, or another municipal agency, SRTA should seek to ensure this data is available for post-disaster grant applications.

[17] https://www.cacities.org/Resources-Documents/Education-and-Events-Section/Public-Works-Officers-Institute/2020-Session-Materials/The-Unseen-Impact-of-California-Wildfires-on-Affec

SRTA can further advise lead agencies by providing the primary analysis to identify potentially damaged segments. In some cases, heavy traffic on roads already known to be under-built for large vehicles, or already in fair to poor condition should indicate that recovery grants should be considered even before signs of deterioration emerge. By proactively planning these projects – especially on rural state and county roads – the mobility of rural residents will not need to be impaired by failed road surfaces before repairs can be scheduled.

Evacuation Planning

Evacuation planning (for all emergencies) does not address **key mobility gaps**, including those for **vulnerable populations**, and rural areas with limited transportation options

Evacuation planning and execution poses a critical challenge to the Shasta Region's mobility. Without an effective system to ensure rapid and universal evacuations, the growing fire hazards in the region will become deadlier. But while evacuation planning can be a useful tool for increasing response times and accelerating evacuations, plans are useless unless they provide workable, flexible frameworks and help develop relevant knowledge and skillsets among the public servants charged with implementing them.

Recommended improvements to evacuation planning in the Shasta Region are focused predominantly on operational and planning measures, but also include a focus on building infrastructure to facilitate evacuations. Evacuation planning should address evacuations resulting from all causes, not just wildfires (including floods, landslides, etc.).

E.1: Plan for the evacuation of mobility-challenged populations

E.1 strategy roles & responsibilities	
Type of strategy	Operational
Proposed lead agency	Public health agency
Additional agencies/ roles	Shasta County OES, Shasta County Sheriff's Office, private hospital networks/housing providers, RABA
SRTA role	Advisory
Possible funding	FTA Section 5310 Grants

Currently, the Shasta County Office of Emergency Services (OES) Emergency Operations Plan (EOP) assigns the primary responsibility for the evacuation of "Access and Functional Needs populations" (including individuals with physical disabilities, no access to vehicles, children and the elderly, limited English speakers, the deaf and hard of hearing, and those with special dietary needs) to the individual. The EOP states the county will assist these mobility-challenged by providing "preparedness information, emergency public information, and critical public services in an accessible manner."

Given projected increases in wildfire probability and intensity across the region, it is essential that the Shasta Region establish formal procedures to ensure that mobility-challenged are able to evacuate. Although some of these goals are already achieved through agreements between RABA, the Shasta County Sheriff's Office (SCSO), and other agencies, these agreements do not achieve the goal of ensuring comprehensive outreach and evacuation of mobility-challenged populations. Public safety, health, and transportation agencies and stakeholders in the Shasta Region should seek to achieve this goal. One approach would be to convene a working group to solve this problem and establish a workable plan. The Shasta County Health and Human Services Agency is the proposed lead agency for this effort, although several agencies could lead this effort, and any effort will require multiple agencies and institutions to effectuate any evacuation. These include Shasta County OES, SCSO, and private/non-profit healthcare networks and providers (including Mercy Medical, Dignity Health, Hill Country Community Clinic), assisted living, nursing care, and palliative/hospice care providers, and organizations dedicated to seniors and residents living with disabilities (e.g., Disability Action Center, Far Northern Regional Center, etc.).

Currently, the county plan only indicates that transportation is available for residents with some level of mobility. The EOP's transportation element identifies three conditions required to transport mobility-challenged residents:

- Evacuees can be accommodated at both embarkation points and at destination general population shelters
- Evacuees can travel on commercial long-haul buses, aircraft, passenger trains, or lift-equipped buses
- Evacuees do not have medical needs indicating they should be transported by specialized medical transport

The goals of the working group should be to identify the mobility-challenged residents in each community and to understand their mobility challenges, the available assets, where gaps in capacity exist, and which measures would be most productive for assisting in their evacuation. The working group should seek to determine a policy for the rapid and comprehensive evacuation of mobility-challenged residents and explore paths forward toward implementing the policy. The working group should also define the roles and responsibilities of agencies and organizations that are involved. The working group should consider several approaches, including:

- An expansive rapid telephone or text notification system for outpatient clients with significant disabilities or other known mobility challenges, ideally run by healthcare providers with access to patient data and assisted by Shasta County OES for the development of language and advisories
- A county-level official tasked with managing evacuations of mobility-challenged residents during an evacuation, and charged with coordinating evacuations with SCSO, OES, and healthcare/housing providers, as well as an update to the EOP articulating the mobility coordinator's place in the chain of command
- A targeted messaging campaign through healthcare and housing providers for mobility-challenged residents (including non-English and non-native English speakers) informing them of their responsibilities during an evacuation under the updated policy, how to plan ahead for an evacuation, and resources available for evacuation assistance
- An opt-in directory of qualified chronically mobility-challenged residents who will rely on assistance for evacuation

SRTA's role in the working group will necessarily be limited, but should include an articulation of the system's vulnerabilities identified in the Transportation Vulnerability Assessment as well as an ongoing evaluation of the distribution and transportation capabilities of mobility-challenged populations in the region. SRTA should seek to collect data on mobility-challenged populations as part of its ongoing efforts to understand the distribution of disadvantaged and vulnerable communities in the Shasta Region. Over the long-term, SRTA's involvement should also include relevant updates to planned transportation projects and planning documents in accordance with projects resulting from this working group.

E.2: Evaluate evacuation bottlenecks and secondary access constraints

E.2 strategy roles & responsibilities	
Type of strategy	Operational
Proposed lead agency	SRTA
Additional agencies	State and local public works agencies, SCSO, CHP
SRTA role	Lead, Planning
Potential funding	FEMA Building Resilient Infrastructure and Communities (BRIC) Grants

Across the Shasta Region, subdivisions (in both urban and rural areas) and rural communities are served by road networks with limited access routes or with access routes that pose potential bottlenecks during a mass evacuation. For example, the community of Burney is served by only one highway (299) that provides evacuation routes east and west (Figure 86). However, both routes cross areas of very high to severe fire threat, and in an area projected to see significant increases in fire probability and severity. The only other road out of town is an unpaved rural road.

As the region's transportation planning agency, SRTA should seek means to complete an evaluation of the availability, adequacy, and vulnerability of the region's secondary access routes, and to correct these evacuation inadequacies through future road network investments or technological solutions. In subdivisions (which are currently required to have secondary access routes), the emphasis should be on the adequacy of secondary access routes for evacuation of the served population (e.g., including the current condition and capacity of the route), and the exposure of the route to fire hazards (using the Fire Threat Index, satellite imagery, and ground truthing when necessary). This effort should also seek to identify any subdivisions or communities which do not have a required secondary access route.

Figure 86. Highway 299 in the mountains between Montgomery Creek and Burney. Highway 299 is two lanes, with some three-lane passing sections, and is the only viable evacuation route out of communities like Burney, Montgomery Creek, and Round Mountain. Source: Caltrans 2021b.

For rural communities (outside subdivisions), evacuation corridors are typically highways capable of carrying larger capacities of traffic, but served by access roads that are maintained by the county. SRTA's evacuation adequacy evaluation should address whether rural highways have sufficient capacity for evacuation of the communities they serve, keeping in mind that multiple communities may face the same evacuation order at the same time. This evaluation should consider the appropriateness and capacity of roads when contraflow traffic management strategies are implemented. SRTA should also screen these corridors for potential bottlenecks for the entire distance along the road connecting a community and the extended road network. Bottlenecks could include high traffic intersections, bridges/overpasses with weight/height constraints, lane reductions/merges, or even tight turns that cause vehicles to slow. Even insufficient shoulder/turnout capacity can pose a bottleneck hazard during evacuations due to disabled vehicles. Bottlenecks can also result from a fire (or flood) interacting with the road, for example roads with narrow rights of way and large accumulations of hazardous fuel may cause traffic to slow or stop if fire burns too close. During a flood emergency, undersized culverts may cause overtopping of road surfaces, creating traffic jams.

Where bottlenecks are identified, SRTA should evaluate options to mitigate them. Options may include road upgrades or improvements such as widening or intersection redesigns, as well as technological solutions such as trip-to-green signalization[18] or contraflow traffic management that can be automatically activated during evacuations. Prioritization of mitigation actions in the RTP can be informed by projected changes to fire probability and severity, known inadequacies, and the expected volume of traffic during an evacuation order.

E.3: Promote pooling of fleet transportation assets among public, private, and non-profit entities in the region

E.3 strategy roles & responsibilities	
Type of strategy	Planning
Proposed lead agency	SRTA
Additional agencies	RABA, school districts/colleges, churches, regional public and private fleet owners
SRTA role	Lead, facilitation
Potential funding	N/A

As part of its transportation system data collection efforts, SRTA should create and maintain a directory of fleet transportation managers and an inventory (or approximate inventory) of transit vehicles owned or held by public agencies (incl. RABA, SRTA, regional school districts, etc.), private companies, and other institutions (including churches, colleges, etc.) located in and near the region.[19] The list should be an internal resource maintained and updated by SRTA staff for the sole purpose of providing SCSO, Shasta County OES, and Shasta County DPW with up-to-date information about the number, location, and contact information of fleets in the region during an emergency. The list should include the contact information for two responsible parties in the event of an evacuation. The list should not be considered an agreement or contract, but simply an informational resource that can be called on when needed.

The purpose of maintaining the inventory of fleet transportation assets is not only to assist in increasing evacuation capacity, but also to avoid unnecessary delays associated with calling resources from other parts of the region during an evacuation. While obtaining buy-in across all agencies for future evacuations may face challenges, accelerating response times of transportation fleets is an important response to recent fires with evacuation orders giving residents mere minutes to evacuate. By facilitating access to fleet transportation assets distributed across the Shasta Region, the list will increase the flexibility and resilience of mass evacuation actions, especially in rural parts of the region. In the future, SRTA should seek to build on this initiative by formalizing relationships with fleet owners and SCSO/Shasta County OES (e.g., similar to the current arrangement for fleet sharing between RABA and SCSO).

[18] Trip-to-green signalization is a traffic management approach where all signals are set to green in the dominant direction of traffic flow, effectively blocking cross traffic or making small feeder roads right turn only.
[19] This effort should generally not seek to include specialized medical transports or fleets dedicated for serving vulnerable populations that would likely be needed for such purposes during any emergency.

E.4: Plan evacuation corridor network and install CMS signage

In collaboration with SCSO, Shasta County OES, California OES, and local governments, a public works agency should plan an evacuation corridor network that includes the following elements:

- **Defines regional evacuation zones and** the major evacuation routes for each zone (e.g., Burney and Highway 299)
- Identifies essential evacuation corridors across the region, specifically including the major highways
- Acknowledge the need for agility and flexibility in real world evacuation orders and route selection

E.4 strategy roles & responsibilities	
Type of strategy	Planning
Proposed lead agency	State and local public works agencies
Additional agencies	State and local public works agencies, SCSO, California OES, Shasta County OES
SRTA role	Analysis
Potential funding	FEMA BRIC Grants

Using fire hazard, population, and road network capacity, identify evacuation zones, designate primary and secondary evacuation routes, and plan segments for contraflow traffic in the event of mass evacuation. The plan should identify which evacuation corridors are likely to see evacuation loads greater than road capacity. Caltrans, along with the region's departments of public works, should identify locations for a permanent signage and traffic control system for facilitating evacuations. Permanent signage should include customizable message signage (CMS) and fixed signage, including reverse-directional signage for use during contraflow traffic management. Traffic control devices should include reversible lane lighting and cameras at key junctions.

SRTA should support this effort by providing traffic data and analysis in support of public works' zone and route planning, and data on the locations and types of projected hazards. SRTA should also use the evacuation planning efforts to complement the analysis in strategy E.2: Evaluate evacuation bottlenecks and secondary access constraints, especially for future capacity upgrades and bottleneck mitigation.

Where possible, improvements to evacuation routes should be designed to serve multiple purposes. For example, CMS signage and other ITS infrastructure on I-5 and Highway 299 should be designed to allow use for notifying drivers of I-5 closures and chain requirements and directing drivers to detour routes or off-highway staging areas during extreme snowfall events.

E.5: Conduct evacuation drills (including contraflow traffic management) on key corridors

E.5 strategy roles & responsibilities	
Type of strategy	Planning
Proposed lead agency	SCSO
Additional agencies	Caltrans District 2, State and local public works agencies, SCSO, Shasta County Fire Department, California OES, Shasta County OES, SHASCOM, and city FDs and PDs
SRTA role	Analysis
Potential funding	N/A

Evacuation drills are an essential tool to build and reinforce interagency contacts, identify potential barriers or bottlenecks, and test new ideas – particularly related to evacuation of mobility-challenged individuals. While evacuation drills represent a major investment of time and resources, and local agencies may resist participating, SRTA should use its role as a transportation planning agency to encourage state and regional agencies to coordinate annual evacuation planning drills along the routes most likely to be used in future evacuations. The goals of the drills will be to test emergency communications equipment and systems (including radio interoperability) and ensure that crews and officers from the various agencies know how to communicate, coordinate checkpoints and road closures, implement contraflow traffic, clear stuck vehicles, and prevent congestion.

Establishing temporary contraflow traffic on a highway can be an effective tool for increasing road capacity during an evacuation, but can also create dangerous conditions if executed poorly. Experience across the country has found that establishing a contraflow traffic corridor during an evacuation typically requires significant forward notice to implement safely.[20] If communications or coordination failures occur during a real evacuation, the results can be deadly. For example, in Paradise, a 2016 evacuation drill ensured that when the Camp fire struck in 2018, congestion was minimized, but tragically not eliminated.[21]

Figure 87. Colorado Springs, CO conducts annual community wildfire drills, rotating communities each year. Members of the Colorado Springs Fire Department are pictured in the 2016 drill. Source: FEMA 2016.

Because the goals of evacuation drills are focused on coordination of agency systems, assets, and staff (rather than specific routes), drills should be conducted in different locations each year, following the county emergency operations plan. Drills can be coordinated with local Fire Safety Councils such as those in Shingletown, Whitmore, and Cottonwood, or

[20] FHWA 2006
[21] Arthur 2019

with other community groups, tribes, or local institutions. Drills can also include testing emergency notification systems, including through media channels.

While SRTA is not directly involved in evacuation drills, it can play an important role in encouraging regional partners to conduct drills. SRTA should explore means of encouraging evacuation planning and drills along key corridors by seeking funding for projects based on their public safety priority for evacuations, and base prioritization on metrics established in evacuation drills.

E.6: Pre-stage evacuation resources

E.6 strategy roles & responsibilities	
Type of strategy	Operational
Proposed lead agency	Public works agencies
Additional agencies	Caltrans District 2
SRTA role	Analysis
Potential funding	N/A

Following establishment of evacuation zones, corridors, and a program of evacuation drills, additional reductions in response time can be found by staging necessary evacuation resources throughout the region. Pre-staging traffic management resources can reduce the time necessary to implement evacuation routes, especially if they require coordinated signage as in a contraflow traffic situation. While local governments play a role, the primary responsibility for managing transportation over the Shasta Region's expansive rural areas is carried by Caltrans and Shasta County DPW. Public works agencies should seek to distribute county equipment – including portable generators/lights, radio equipment, ITS equipment (incl. remote sensors and cameras), and movable electronic signs – to multiple locations throughout the region, ideally located to minimize travel times to establish and manage evacuation corridors. Evacuation drills are likely to be especially informative for identifying optimal locations for storing resources.

E.7: Explore advanced evacuation notification and information systems

Presently, Shasta Region residents rely on a wide array of sources for information on evacuations. From text alerts and Code Red to local news and social media, residents report that while evacuation information is often prompt, it is often difficult to evaluate if rapidly changing evacuation orders are current or accurate. Furthermore, text-based evacuation orders can be confusing, leading some residents outside of evacuation zones to begin evacuating (clogging roads) or residents inside evacuation zones to fail to evacuate. Residents also report lacking confidence in the currency of evacuation orders, particularly when signs of fire may be near.

E.7 strategy roles & responsibilities	
Type of strategy	Planning
Proposed lead agency	SHASCOM
Additional agencies	SCSO, SRTA, county government, municipal governments
SRTA role	Evaluation, Implementation
Potential funding	N/A

To address resident concerns and ensure that evacuation orders are easy to understand and up to date, SHASCOM should explore working with SRTA, SCSO, and Regional governments to invest in a Shasta Region Evacuation Map tool that can be hosted on the Shasta Ready website and be updated by SHASCOM staff during emergencies. The map would show a clear overlay of evacuation order areas over an easy-to-read online street map, allowing users to fully understand the extent of evacuation zones. Further, the map will be updated directly by SHASCOM, avoiding potential confusion resulting from 3rd party maps (e.g., from local news).

Additionally, Shasta Region public safety agencies should continue to explore and evaluate new technologies to inform and update the public during emergencies, potentially including technologies like the Alert FM emergency broadcast system. SRTA should support this effort by facilitating meetings, evaluating technologies, and supplying geospatial data where available.

Average & Extreme Temperatures

Increases in extreme temperature are likely to accelerate wear & tear on roads and vehicles, impair use of pedestrian, cyclist, and transit systems

Temperatures are increasing and are projected to continue increasing across the Shasta Region. By 2085, the average summer day in Redding will be as hot the average heat wave under current conditions.

Extreme temperatures pose few acute hazards but create long-term operating and maintenance costs associated with accelerated degradation of roads and vehicles and impair the mobility of residents who travel without a vehicle. These recommendations are focused on reducing the long-term costs of extreme temperatures by investing in adaptation early.

T.1: Integrate extreme temperature hazards into complete streets planning

Complete streets are streets designed to meet the mobility needs of all users, including mobility-challenged users, as well as pedestrians, cyclists, and transit users. Complete streets can address extreme heat hazards through general strategies to reduce the urban heat island (UHI) effect – the phenomenon where the dark surfaces of roads, rooftops, and other built infrastructure trap and re-emit heat. Approaches to mitigate UHI impacts on transportation include provision of shade, cooling, and hydration facilities along key routes, as well as general strategies to combat UHI. Protecting and enhancing the urban forests in the Shasta Region is an important first step: increased shade tree cover – in particular the use of trees to create continuous shade along the highest traffic bicycle and pedestrian routes and around transit stops – will improve the utility of these facilities on extreme heat days. For transit users, SRTA should promote bus shelters designed to maximize cooling, and advocate to RABA that bus stops without adequate shade should be prioritized for installation of bus shelters or other shade (Figure 88).

Although not explicitly directed at mobility resilience, strategies to combat UHI generally may be another component of protecting pedestrian, cyclist, and transit users during extreme heat events. Use of reflective surfaces (such as silvered roof coatings), reflective pavements, and increasing urban forest cover are all practical strategies for combatting UHI.

Strategy roles & responsibilities	
Type of strategy	Operational
Proposed lead agency	SRTA
Additional agencies	State and local public works agencies, RABA
SRTA role	Lead
Potential funding	Calfire Urban and Community Forestry Grants (with partner), CalEPA Environmental Justice Small Grants, California ReLeaf Treecovery Grants

Increasing public drinking water access is another way to enable mobility disconnected from vehicles. Providing public drinking water facilities enables non-vehicle transportation users to avoid heat stress without relying on vehicles.

Figure 88. Top: The RABA bus stop at Lincoln St. and S. Market St. lacks shade trees or a bus shelter to provide riders with relief during extreme temperatures. Middle: The RABA bus stop at Placer St. and East St. features street trees which provide ample shade, albeit no seating. Bottom: The RABA bus shelter at East St. and Butte St. provides shade both shade and seating, as well as shelter from rain.

Another consideration of extreme heat for pedestrians and cyclists are the elevated safety hazards resulting from heat stress. Drivers, pedestrians, and cyclists alike are more likely to be involved in crashes during heat waves, indicating the increased need to design streets with all users' safety in mind.[22] Complete streets design principles focused on deconflicting pedestrians, bicycles, and motor vehicles should be pursued in order to reduce the increasing risk of heat-related crashes. An overall strategy of designing streets for all users will improve the resilience of non-vehicle transportation in the Shasta Region and help SRTA implement its Sustainable Communities Strategies.

T.2: Ensure fleet investments and management are designed for future extreme temperatures

SRTA should adopt an initiative to promote resilient fleet management among the Shasta Region's state, regional, and local agencies responsible for fleet purchasing and management. Using the projections in this study, SRTA should work to provide agencies with large fleets (particularly emergency response and transit fleets) with the information necessary to make resilient investment and management decisions.

Fleet managers investing in new rolling stock for the Shasta Region's fleets should ensure that the vehicles are capable of operating in extreme temperatures, including those projected for the Shasta Region (and particularly the upper Sacramento River Valley) over the lifetime of the vehicle. For fleet vehicles, this typically means investing in extended-life coolants and—if available—vehicles with upsized cooling

[22] Basagana et al. 2015

systems. For new technologies such as battery electric vehicles and hydrogen electric vehicles, fleet purchasers should work with OEMs to ensure that vehicles are designed to operate in the Shasta Region's projected extreme temperatures.

T.2 Strategy roles & responsibilities	
Type of strategy	Operational
Proposed lead agency	SRTA
Additional agencies	State and local public works agencies, RABA
SRTA role	Analysis, outreach
Potential funding	N/A

Fleet operations should also be adjusted to ensure that cooling systems are well maintained prior to each summer. Coolant levels, hoses, clamps, and radiators are of primary importance, as are parts subject to accelerated wear during extreme heat, including belts and tires, as well as fluids like automatic transmission fluid, brake fluid, and engine oil.

T.3: Promote proactive seasonal fleet management to prepare for hot summers

T.3 Strategy roles and responsibilities	
Type of strategy	Operational
Proposed lead agency	SRTA
Additional agencies	RABA, public and private fleet owners (e.g., CARE-A-VAN, etc.)
SRTA role	Outreach
Potential funding	N/A

Multiple agencies – each with unique fleet management challenges – are required to work together in the event of an evacuation order. During extreme heat events (which can occur simultaneously with major fires), essential fleet vehicles can break down in numerous ways. In order to prepare for these emergencies, fleet maintenance should focus on proactively mitigating common modes of heat failure (e.g., coolant levels & leaks, aged belts, tires, and batteries, fluids condition, etc.) in their essential fleets during the cool season.

As part of its initiative to ensure mobility during extreme heat events, SRTA should conduct outreach and communicate heat hazards and design principles to the region's transit fleet operators, including RABA, as well as private operators like CARE-A-VAN. In addition to vehicle resilience, this initiative should encourage transit operators to prepare, monitor, and quickly repair failing air conditioning systems in fleet vehicles. While air conditioning is ubiquitous, delayed maintenance and unexpected outages can take inconvenient or uncomfortable heat waves and turn them into dangerous extreme heat events that impair the mobility of transit-dependent residents. SRTA's efforts to communicate the importance of heat health to the region's transit operators can support a culture of heat health awareness and impress the importance of proactive maintenance for extreme heat upon Regional fleet operators.

T.4: Convene Caltrans, county, and city public works departments to set upgraded design temperatures for roads

Using the temperature projections in this assessment (and Caltrans D2 Assessment), the state and local public works agencies in the Shasta Region should explore ways to work together to discuss and agree upon temperature specifications for road segments. Ideally, Caltrans D2 would lead a working group, and membership could include additional county and municipal agencies from the across District 2. The

T.4 strategy roles & responsibilities	
Type of strategy	Hardening
Proposed lead agency	Caltrans D2
Additional agencies	County and local public works agencies, additional regional partners
SRTA role	Advisory, planning
Potential funding	N/A

goal of the group would be to disseminate information, coordinate planning, and ensure best practices are available to road crews. Caltrans has already identified the highest priority asphalt upgrades required on state highways in the northern state, and the most vulnerable roads are centered in the Shasta Region, including most of I-5 and highway 273 and major sections of Highways 299 and 44 in the Sacramento River Valley.[23] Additionally, as a larger regional transportation authority, Caltrans has the capacity to assess and disseminate technical advice to the region's local governments.

The goal of the meetings should be to review projected temperatures across the Shasta Region and determine the performance grade binder specification(s) optimal for road resurfacing projects across the region. The design temperatures should address the projected shift in temperature regimes away from freeze thaw cycles in lower-lying areas, and towards higher extreme summer temperatures. Design temperatures should reflect the large spatial variation in projected extreme temperatures across the region, and several specifications are likely to be necessary for different parts of the region. The group should share information and expertise on identifying alternative asphalt mixtures and suppliers, as well as lessons learned in upgrading road pavements.

Although SRTA's role in this strategy is limited to advisory and planning tasks, SRTA should actively participate by promoting the working group concept, seeking participation from Shasta Region participants, providing historical and projected future temperature data for the Shasta Region, and by seeking means to incorporate upgraded binders into future resurfacing projects across the region through the RTP.

[23] Caltrans 2021a

Extreme Precipitation

Projected increases to **extreme precipitation** are likely to intensify current hazards related to **localized flooding** and **road delays/closures** due to snow

Extreme precipitation events are projected to grow in both frequency and intensity. While flooding is the primary hazard associated with extreme precipitation events, the Shasta Region's major rivers and streams are all controlled by dams and reservoirs designed to mitigate large-scale floodplain flooding.

The primary mobility hazards associated with extreme precipitation events are extreme snow events that can cause major roads (especially I-5) to back up, localized flooding (including inundation and erosion) that can disrupt and damage traffic on highways and arterial roads, small ponding that can disrupt pedestrian and cyclist traffic.

P.1 strategy roles & responsibilities	
Type of strategy	Operational
Proposed lead agency	State and local public works agencies
Additional agencies	State and local public works agencies
SRTA role	Advisory, planning
Potential funding	FEMA Flood Mitigation Assistance

P.1: Convene Public Works stakeholders to identify and accelerate clearing of priority culverts

Caltrans has identified several high priority culverts on state highways that are most likely to face localized flooding in excess of their capacity (Table 17 and Table 18). In the Shasta Region, multiple state and local public works agencies already administer culverts with increased flood risk, often based just on historical experience (i.e., 'problem culverts') without conducting comprehensive flood hazard assessments. SRTA should work with the local agency staff to advance a regional goal of monitoring major culverts outside of Caltrans' responsibility areas, especially where these culverts have the potential to obstruct roads if culverts flood.

SRTA should work to convene a culvert flooding working group comprised of all state and local agencies with maintenance responsibilities for culverts. As a first step, the group should pool information on known problem culverts and develop a regionally-focused awareness of flooding hazards. The working group should include opportunities to share experiences, lessons learned, and best practices, as well as advance the awareness among Regional transportation and emergency planners about the projected increases in extreme precipitation events throughout the Region.

As a long-term goal, the working group should contribute to the development of a Regional prioritization of culvert upgrades for flooding prevention. The effort should focus on areas with large projected increases of extreme precipitation, including:

- The Sacramento River Canyon
- Central mountainous areas from Big Bend to Round Mountain
- The southern portion of the Upper Sacramento River Valley around Palo Cedro and Anderson
- The southeastern mountainous areas around Lassen National Volcanic Park

As a technical adviser to the effort, SRTA should work with working group members to collect and centralize data on ongoing culvert clearing projects, problem culverts, and culvert-related flooding (especially after major precipitation events) in order to help identify potentially undersized culverts and prioritize upgrade projects for mobility-critical roads.

Table 17 and Table 18 show priority culverts identified by Caltrans D2's Adaptation Priorities Report. SRTA should encourage a working group of Regional agencies to work toward producing a similar effort.

Table 17. Highest priority large culverts (facing greatest flood hazards) under Caltrans jurisdiction in the Shasta Region. Source: Caltrans 2021a.

Route	Crossing	Postmile
Highway 273	China Gulch	11
Highway 299	Little Hatchet Creek	65
Highway 44	A.C.I.D. Canal	L7
Highway 44	W.Branch Churn Creek	R0
Highway 44	Clover Creek	R2
I-5	W. Fork Stillwater Creek	R25
I-5	Boulder Creek	R17
I-5	Spring Branch Creek	R25
I-5	Salt Creek	R21

Table 18. Highest priority small culverts (facing greatest flood hazards) under Caltrans jurisdiction in the Shasta Region. Source: Caltrans 2021a.

Route	Postmile
Highway 36	4
Highway 36	4
Highway 36	6
Highway 44	26
I-5	26
I-5	30
I-5	30
I-5	30
I-5	30
I-5	31
I-5	31
I-5	32
I-5	33
I-5	44
I-5	48

P.2: Prepare I-5 Shutdown Traffic Management Plan

P.2 strategy roles & responsibilities	
Type of strategy	Planning
Proposed lead agency	State and local public works agencies
Additional agencies	Caltrans D2, CHP, SCSO, Shasta Lake PD, Redding PD, Anderson PD
SRTA role	Analysis, planning
Potential funding	US DOT RAISE Grant

Regional stakeholders (including state and local public works agencies, CHP, SCSO, and private sector partners) should agree to a common goal of developing a plan to manage traffic shutdowns on I-5. One approach could be a comprehensive I-5 Shutdown Traffic Management Plan (STMP). A STMP would seek the dual goals of 1) reducing the number of weather-related shutdowns on I-5 and, 2) managing and mitigating congestion when shutdowns are inevitable. The STMP would focus on management strategies and potential capital upgrades as well as operations plans for both goals.

Keeping I-5 clear and open during extreme precipitation/snowfall events should be the first emphasis of an STMP. The plan should balance the region's competing demands for snow clearing resources against the economic and human costs of significant delays and congestion on I-5, as well as the capital costs of shutdown-related upgrades. Caltrans and CHP should work with Shasta Region agencies as well as the cities of Shasta Lake, Redding, and Anderson to develop a snow clearing element of the plan, incorporating lessons learned from similar snow bottlenecks such as "Operation Snowflake," the management plan for clearing snow from the Grapevine in Los Angeles.[24]

When shutdowns are inevitable, the plan should explore and select new strategies for managing traffic and avoiding congestion/blockages to the south. The STMP operations plan would specify traffic management policies during shutdowns and delegate shared tasks to partner agencies during a shutdown. Ideally, the STMP's operational element would explore and consider several traffic management strategies, including:

- Use of CMS and static signage alerting northbound drivers to upcoming chain checkpoints or road closures well south of potential congestion, likely into Tehama County
- Use of CMS signage along I-5 in the Sacramento River Canyon to alert drivers to incoming inclement weather that may impose chain requirements or closures
- Staging delayed truck traffic in the left shoulder and left lane during extended closures
- Closing the right lane (using lighted signs) to all traffic except emergency vehicles and buses
- Establishing multiple snow closure detour routes (299/44 to 89 or 299 to 3), including emergency use improvements for these routes[25]
- Establishing partnerships with large shopping centers with hardened drives and lots for chain installation/truck staging off of I-5 (e.g., Mt. Shasta Mall) during extended closures
- Deployment and coordination of local PD and SCSO resources for traffic management off of I-5, including for staging truck traffic and managing detour routes

[24] Caltrans 2020

[25] Both detour options would impose significant limitations: Highway 299 currently has only limited operating hours due to repairs following the Monument fire; Highway 3 has large truck limitations south of Callahan

- Deployment and coordination of CHP units on I-5 for targeted enforcement of right lane closure and clearing blocked on/offramps
- Use of CMS and static signage to identify off-highway staging and chain installation locations
- Use of static signage to identify snow closure detour routes
- Use of CMS and static signage to implement right-lane closures and warn drivers not to block on/offramps
- Deployment of and novel communication methods to alert residents and drivers to potential or effected closures, potentially including radio, text, social media, push notifications, or IOT communications technologies

The STMP would also explore and prioritize capital projects to enable selected strategies, including those recommended in the Fix 5 Cascade Gateway project, as well as strategies to improve communications with drivers, create space for designated lanes, and facilitating access for emergency vehicles.[26] The STMP should explore capital improvements to the I-5 Corridor including:

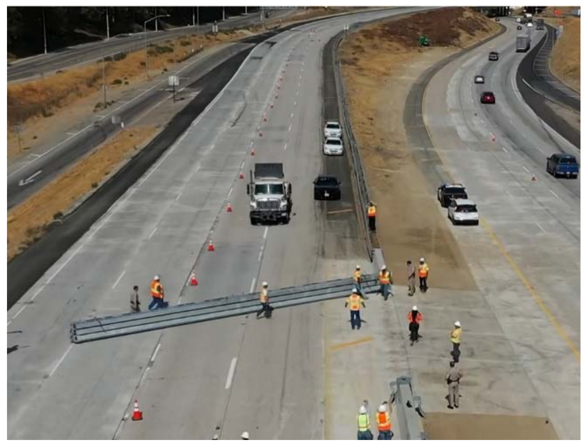

Figure 89. A median turnaround gate installed on the I-5 Grapevine at the Tejon Pass in Los Angeles. The gate allows Caltrans to create a turnaround for vehicles, including large trucks, when snow closes the pass. Alongside "Operation Snowflake" the gate is part of a coordinated strategy to reduce closures and avoid congestion when closures occur. Source: Caltrans 2020.

- Permanent CMS & static signage south of the Fawndale Rd. exit, the junctions with Highway 299, Highway 44, and Highway 273, and Highway 36 for notification of chain check requirements, closures, alternative routes, and traffic management strategies
- Large, movable median turnaround gate for NB traffic at the Fawndale Rd. exit, allowing stranded trucks and vehicles to enter the SB lanes and seek a detour route (a similar gate would likely be appropriate for SB traffic in Siskiyou County)
- Expanded and hardened shoulders for use of staging delayed trucks
- Designated pull outs at multiple locations south of Fawndale Rd. for chain installation
- SRTA should ensure that any capital upgrades to I-5 through Shasta Lake, Redding, and Anderson are implemented with other adaptation strategies in mind. For example, CMS and static signage should be installed to enable use for additional I-5 evacuation planning goals, including usability for contraflow traffic management strategies.

SRTA should ensure that any capital upgrades to I-5 through Shasta Lake, Redding, and Anderson are implemented with other adaptation strategies in mind. For example, CMS and static signage should be installed to enable use for additional I-5 evacuation planning goals, including usability for contraflow traffic management strategies.

[26] SRTA 2020

Additional considerations for discussion in the STMP may include projected reductions in the likelihood of extreme snow events, the projected increase in likelihood of extreme rain events, and the eventuality of wildfire closures.

P.3: Improve I-5 management with resource sharing

P.3 strategy roles & responsibilities	
Type of strategy	Operational
Proposed lead agency	State public works agency
Additional agencies	Local public works agencies
SRTA role	Facilitation
Potential funding	N/A

Backups on I-5 occur when rates of snow accumulation outpace the ability of Caltrans operations crews to clear snow. Hardening I-5 between Shasta Lake and Mt. Shasta against extreme precipitation should include an evaluation of operational needs (See strategy **P.2: Prepare I-5 Shutdown Traffic Management Plan**), and investment in equipment, facilities, and road construction upgrades that increase snow clearing capacity, reduce snowplow travel time, reduce the accumulation of snow, and enhance drainage.

In order to increase the snow clearing capacity of snowplow crews on I-5, SRTA should convene Caltrans Operations staff with County DPW staff to discuss resource capacity, the potential for sharing resources, and the potential need for additional snowplows and snowplow crews. Snowplow response time could be improved through investments in additional snowplow staging sites/salt stockpiles closer to the Sacramento River Canyon.

P.4: Optimize complete streets for extreme precipitation impacts

P.4 strategy roles & responsibilities	
Type of strategy	Planning
Proposed lead agency	SRTA
Additional agencies	State and local public works agencies
SRTA role	Analysis, planning
Potential funding	N/A

A common impact of extreme precipitation is localized flooding caused by excessive runoff and insufficient drainage. While localized flooding rarely leads to catastrophic impacts, the immediate disruption to the mobility of pedestrians, cyclists, transit-dependent, and mobility-challenged individuals can be significant. This is especially problematic in cities where simple drainage options are not always available. Flooding of sidewalks, trails, curb cuts, parking lots, or intersections can create substantial barriers to mobility, especially for mobility-challenged residents.

SRTA should take a lead in evaluating the scope of the problem and recommending solutions which can remedy ponding as a part of future streets projects. SRTA should work with city and county DPWs to identify problem areas on sidewalks and trails in the Shasta Region. This effort could include soliciting feedback from the public about known problem areas.

Measures to mitigate problematic ponding could include:

- Construction of drainage for sidewalks and trails – in built environments, new drainage is often cost prohibitive to construct, however streets and sidewalks can be regraded to direct stormwater to existing drainage; for unpaved trails new drainage can be as little as a water diversion built into the trail

- Construction of runoff reduction including permeable pavements, detention basins, etc. – Where larger areas of ponding pose a threat, runoff reduction methods can reduce the flow rate of water into low-lying spaces. Use of permeable pavements can remove runoff, and detention basis can hold large volumes of runoff to reduce the peak rate entering sewers
- Promotion of street designs that resist flooding – In areas with persistent ponding issues, SRTA should identify and promote best practices (e.g., curb cut and curb ramp designs) that minimize the opportunity for ponding

Flooding

Flood hazards are likely to increase with **extreme precipitation**, particularly on **uncontrolled streams**, and with **unknown implications for dams**

Flood hazards in the Shasta Region include both damage and direct disruption of roads and highways, rail, transit, and pedestrian and cyclist infrastructure due to inundation and erosion. Based on the limited FEMA hazard modeling available in the region, existing flood hazards pose a significant threat, and are likely to be present in areas not modeled by FEMA. In the Upper Sacramento River Valley, particularly between Redding and Anderson, flooding along the riverbanks is associated with a 100-year streamflow event, including inundation of several important roads such as Highway 273, Highway 299, Park Marina Drive, Churn Creek Road, Girvan Road, and Eastside Road, and potentially shallow flooding on I-5, as well as Highway 151 in Shasta Lake and several locations on the Union Pacific railroad.

If projected increases in extreme precipitation result in a flood stage associated with a 500-year streamflow event, widespread inundation would threaten many more roads, including large segments of I-5, the Highway 44 junction in Redding, several areas of Highway 273, as well as other arterials like North Street, Riverside Avenue, Ox Yoke Road, McMurray Drive, and South Balls Ferry Road in Anderson. Many river crossings throughout the Upper Sacramento River Valley would be threatened as well. In Palo Cedro and Millville, a 500-year streamflow event could lead to flooding of Highway 44, as well as extensive flooding along Old 44 Drive.

Approaches to adapt to flood hazards should rely on FEMA hazard assessments as a starting point, however planners should be aware of the limited perspective supplied by these projections.

F.1: Harden road segments subject to inundation hazards

F.1 strategy roles & responsibilities	
Type of strategy	Planning
Proposed lead agency	State and local public works agencies
Additional agencies	N/A
SRTA role	Analysis, planning
Potential funding	FEMA BRIC Grants, FEMA Flood Mitigation Assistance

Inundation of road surfaces can reduce the load-bearing capacity of the road base, sub-base, and subgrade, sometimes with sudden and significant loss of strength. Because inundation of roads occurs at the same time as emergency response, evacuation, and eventually recovery activities, inundated roads are often most heavily loaded when they are at their weakest, accelerating wear and tear. Complicating matters further, some roads may be weakened even after flood waters recede below grade, as elevated water tables can affect the stability and strength of roads. The strength of roadbeds under partial saturation can vary dramatically, depending on soil and pavement types.[27]

Inundation of roads in the Shasta Region is a predictable outcome where 100- and 500-year floodplains have been mapped. Known flood hazards threaten to inundate several areas with high traffic roads in

[27] Elshaer et al. 2017

Redding and the upper Sacramento River Valley where flooding would likely result in heavy traffic related to response, evacuation, or recovery.

There are two approaches to hardening roads against inundation: replacement of asphalt roads with stronger materials that are less susceptible to weakening like reinforced concrete, and elevation of roads above the base flood elevation (BFE). Elevation of roads is typically more costly than replacement with concrete, but has the advantage that hardened roads remain accessible during flooding events. For highways and arterial roads with high potential to be used during evacuation, selective elevation can be an appropriate investment. For example, the eastern approach to the Highway 44 bridge in downtown Redding is located within the 500-year floodplain where Highway 44 passes underneath Sundial Bridge Drive. A 500-year flood would cut off this river crossing, but only at one point. Selective elevation could reduce this hazard, especially since a 500-year flood would also affect the abutments and approaches of the Market Street/Highway 299/273 Bridge. Caltrans has similarly identified six priority 1 bridges that may make good candidates for elevation:[28]

- Highway 299 crossing the Pit River east of Four Corners
- Highway 299 crossing Hat Creek east of Four Corners
- Highway 299 crossing Dry Gulch in Bella Vista
- I-5 crossing Castle Creek in Castella
- Highway 273 crossing Spring Gulch in Anderson
- Highway 36 crossing Begum Creek at the southwestern corner of the region

Hardening high traffic roads in the 100-year floodplain by upgrading asphalt to concrete can reduce the damage from emergency response, evacuation, and recovery, leading to long-term reductions in cost and improvements to mobility. Targeted hardening of road segments subject to flood hazards could be incorporated into road maintenance programs, although hardening will require more substantial reconstruction of the road surface and subgrade.

SRTA does not have a direct role in individual hardening projects; each project is the prerogative of the managing road agency. However, SRTA has an important role as a facilitator of information necessary to prioritize hardening projects. Although flood hardening should be considered a lower priority than fire hardening projects, SRTA should use the RTP process to highlight the need for flood hardening on specific routes.

[28] Caltrans 2021a

F.2: Evaluate unknown flood risks

F.2 strategy roles & responsibilities	
Type of strategy	Planning
Proposed lead agency	SRTA
Additional agencies	N/A
SRTA role	Analysis
Potential funding	FEMA Flood Mitigation Assistance (through a partner), CalEPA Environmental Justice Small Grants

Much of the Shasta Region's mobility is served by a small number of highways that connect rural communities over large distances. These roads constitute critical transportation corridors (including Highway 299, Highway 44, Highway 36, and Highway 89), but many face flood hazards which have never been evaluated or mapped.

SRTA should pursue updated region-wide understanding of flood hazards affecting regional mobility, either by seeking FEMA analysis of the region's rural streams, or by seeking alternative grant funding for an independent flood hazard analysis. While each approach has advantages, FEMA assessments cannot incorporate projected future change, but are provided as a public good at no cost to regional agencies. However FEMA assessments affect Flood Insurance Rate Maps (FIRMs) which can impose significantly higher insurance costs on the insured in the Region.

Seeking an independent evaluation of flood hazards on uncontrolled streams would require separate funding, but doing so provides the significant advantage that projected changes to extreme precipitation can be integrated into streamflow models. In areas where unknown flood hazards or outdated flood hazard assessments may pose threats to both mobility and public safety, awareness of flood hazards is essential.

F.3: Upgrade undersized culverts

F.3 strategy roles & responsibilities	
Type of strategy	Hardening
Proposed lead agency	Public works agencies
Additional agencies	State and local public works agencies
SRTA role	Analysis
Potential funding	FEMA BRIC Grants, FEMA Flood Mitigation Assistance Grants

Most of the rivers and streams in the Shasta Region are controlled by dams which effectively minimize flooding hazards in all but extreme cases. However, many smaller streams – some of which only flow intermittently – are not dammed and can pose hazards associated with uncontrolled flow following extreme precipitation events, or during especially wet periods. Complicating matters, many of these streams are located in rural areas of the region and have not previously been evaluated for flooding hazards by FEMA. Where these streams cross major roads and highways, they may pose overtopping or erosion risks during flood conditions.

Building on the efforts to identify and accelerate clearing of problem culverts (see strategy **P.1: Convene Public Works stakeholders to identify and accelerate clearing of culverts**) and efforts to map additional flood hazards in the region (see strategy **F.2: Evaluate unknown flood risks**) SRTA should work with the relevant local agency to seek funding opportunities to replace and upgrade the capacity of problem culverts. This effort should ensure that planned culvert capacity accounts for projected increases in extreme precipitation. County and city DPWs should be especially proactive in cases where a road crosses an uncontrolled stream channel, or where the FEMA flood hazard has not been evaluated.

Where culvert capacity cannot be upgraded (or where funding is not sufficient), SRTA should promote projects to harden problem culverts. Hardening roadways can include the use of riprap, vegetation, or other soil stabilization techniques to harden embankments, as well as reconstruction of segments subject to inundation with concrete surfaces which can withstand heavy traffic after inundation.

F.4: Access dam flood hazard maps and integrate them into regional evacuation planning

F.4 strategy roles & responsibilities	
Type of strategy	Planning
Proposed lead agency	SRTA
Additional agencies	Shasta County, Redding, Shasta Lake, Anderson
SRTA role	Policy, planning
Potential funding	N/A

The Shasta Region's flood control infrastructure provides safe and predictable streamflow through the controlled rivers and streams in most circumstances. However, in the event of dam failure, serious to catastrophic flooding could result, necessitating mass evacuations, likely with very short warning. Problematically, the flood maps associated with modeled dam failure scenarios are not publicly available, nor are they currently available to regional planning agencies. As a result, regional evacuation planning efforts cannot anticipate which evacuation routes would be subject to dangerous flooding hazards, and which would be safe. In a worst-case scenario, county officials could conceivably direct evacuating residents to unsafe routes, increasing the risk of fatalities.

Figure 90. Shasta Dam and the Keswick Dam downstream power the region and protect downstream communities from flooding. Key regional agencies do not know how a dam failure would affect communities and infrastructure. Source: USBR 2021.

As part of its efforts to promote mobility in evacuation planning, SRTA should seek to convene stakeholders from the U.S. Bureau of Reclamation, California Office of Emergency Services, and Caltrans, along with SCSO and county and city DPWs to discuss dam safety and flood hazards, evacuation protocols, and identify how projected increases to seasonal and extreme precipitation will affect dam operations. The goals of such meetings should be to identify the roles and responsibilities of various agencies in the event of a dam-related emergency, identify which roads and bridges should not be used, and ensure that evacuation plans account for alternative routes. At a minimum, SCSO should be granted access to dam failure scenario flooding maps so that officials charged with managing evacuations are aware of the overall hazard and the specific corridors expected to be safe. Additionally, sharing information with county and city DPWs could allow hardening of river crossings and key corridors in the Upper Sacramento River Valley against dam-related emergencies. Convening stakeholders also provides evacuation planning officials with contacts which can be relied upon in a real-world evacuation.

Landslides

> Increases in extreme precipitation and wildfire hazards increase the risk of **landslide activity on burned slopes**, especially during **extreme precipitation events**

Landslide hazards are not typically a major threat to highways and roads in the Shasta Region, but can affect mobility in the region when landslides occur on roads connecting the region with surrounding counties. With projected changes to extreme precipitation and wildfire activity, The Shasta Region may also see land sliding that threatens the region's roads. Landslides can include a wide range of incidents that involve rocks, soil, or debris (such as dead or living vegetation) sliding down a slope, as well as major deep-seated failures of slopes resulting in hundreds or thousands of tons of soil and rock crashing down on infrastructure below. Small rockfalls can pose an acute hazard to drivers, but can be cleared relatively quickly by Caltrans maintenance crews. Larger landslides and debris flows can create significant blockages that take days or weeks to clear. The largest landslides can sweep roads clear off the sides of slopes, requiring extended periods to realign, cut, and reconstruct the road to fit on the new slope geometry.

Figure 91. Following the Carr Fire, accelerated erosion of burned slopes on Shasta Bally began depositing large amounts of debris on Mill Creek Road in the Whiskeytown National Recreation Area. Source: NPS 2021.

Because there are not currently any known landslide hazards in the region, the recommendations in this section are to increase the monitoring of minor landslide activity, and to study the region's slopes in order to gain a better understanding of landslide hazard.

L.1: Enhanced monitoring of potentially hazardous landslide slopes following wildfires

L.1 strategy roles & responsibilities	
Type of strategy	Operational
Proposed lead agency	State and local public works agencies
Additional agencies	N/A
SRTA role	Facilitation
Potential funding	N/A

Currently, landslide monitoring along Caltrans roads is conducted by maintenance crews who observe and report rocks, soils, or debris which slide down slopes onto state highways. In the three corridors identified by the Transportation Vulnerability Assessment's potentially hazardous landslide slope zone screening analysis (including Highway 299 along and west of Whiskeytown Lake, Highway 299 between Buena Vista and Round Mountain, and along I-5 in the Sacramento River Canyon), the primary concern for landslide hazard is not historical landslides, but the risk of a severe wildfire that destroys slope-side vegetation, followed by an extreme precipitation event that triggers anything from increased sedimentation, rockfall, or debris flows, up to and including large, deep-seated landslides and rockslides.

Enhanced monitoring should be initiated after a major wildfire and would include anything from proactive observations of slope conditions up to conducting landslide hazard assessments of slope soils and hydrology. SRTA's role in this strategy could be as simple as facilitation and data collection for state and county agencies. While minimal effort, observation of slopes is the optimal approach to identifying potential landslide hazards before they occur.

L.2: Highway 299 Corridor Landslide Hazard Assessment

If a funding opportunity becomes available, SRTA should seek funding for a more comprehensive landslide hazard assessment across the entire Highway 299 corridor. Ideally, this assessment would survey hillsides above Highway 299 across the northern state, both within the Shasta Region and in Trinity and Humboldt Counties to the west. Beginning with the 2006 California Geological Survey study of landslide hazards along Highway 299 in Humboldt County and incorporating findings from the 2016 Big French Creek landslides in Trinity County, the study would focus on collecting slope data (including high resolution DEMs, soils and bedrock data, and historical hydrological conditions), categorizing slope features throughout the corridor, identifying the factors that led to past slope failures, and identifying those same features in slopes throughout the corridor.[29]

Figure 92. Landslide on Highway 299 near Big French Creek in Trinity County. Highway 299 was closed for several weeks to repair the road and construct a new catchment for future landslides (area between the slope and the road). Source: Caltrans 2018b.

In addition to supplying Caltrans with critical data for planning slope stabilization projects in the face of projected increases to extreme precipitation, the study would also provide SRTA and county DPWs with a baseline of information necessary to identify hazardous slopes elsewhere in the region, including above local and county roads.

L.2 strategy roles & responsibilities	
Type of strategy	Operational
Proposed lead agency	State and local public works agencies
Additional agencies	N/A
SRTA role	Facilitation
Potential funding	N/A

[29] California Geological Survey 2006

Crosscutting Strategies

Several adaptation strategies apply to multiple hazard categories. These crosscutting strategies target the process of planning and the interdependency of infrastructure systems on one another.

C.1: Integrate resilient approaches into all recovery/reconstruction projects

C.1 strategy roles & responsibilities	
Type of strategy	Planning
Proposed lead agency	SRTA
Additional agencies	N/A
SRTA role	Facilitation, data collection, analysis
Potential funding	N/A

When disasters strike, agencies are frequently able to access funds to rebuild essential infrastructure. Two strategies recommend the integration of mobility resilience principles into recovery (**W.4: Proactively plan road resurfacing following heavy firefighting activity as part of recovery grants** and **F.1: Harden road segments subject to inundation hazards**). The common theme of these strategies is that when funding is available to rebuild infrastructure, lessons about past and expected future hazard exposure should be integrated into the design.

SRTA should embrace a role as a resource for regional partners to help share resilient development practices and ensure that any future recovery/reconstruction grants implement adaptation strategies for all potential hazards. For example, in the event of a road reconstruction following a fire, segments subject to flood hazards should also be hardened against these hazards. SRTA should use its contacts with local and regional transportation infrastructure agencies to share information about ongoing and planned projects, success implementing adaptation strategies, and resources for additional information.

Another important way to coordinate recovery & restoration efforts with adaptation goals is to ensure that the region's many agency partners work together to inform each other about ongoing or planned projects. For example, the Western Shasta Resource Conservation District (WSRCD) implemented slope revegetation projects following the Carr Fire with resources provided by the California State Water Resources Control Board.[30] The goal of this project was to stabilize soils on slopes with grades less than 40% in order to prevent increased sediment loading in key Sacramento River watersheds. While the primary goal of the project was improving water quality, any transportation resilience co-benefits were not accounted for. In this example, potential coordination between WSRCD and transportation agencies would enable similar projects to adjust scope in order to target key slopes above threatened culverts, drainage systems, or even directly above roadways.

[30] WSRCD 2019

C.2: Plan for interdependencies with vulnerable interconnected infrastructure systems

C.2 strategy roles & responsibilities	
Type of strategy	Planning
Proposed lead agency	SRTA
Additional agencies	State and local public works agencies, Shasta County Fire Department, California OES, Shasta County OES, SHASCOM, city FDs and PDs
SRTA role	Facilitation
Potential funding	N/A

Fires, floods, and other extreme weather hazards never affect just one infrastructure system in isolation. Electricity, fuel, communications, and water infrastructure systems are all subject to sudden disruption in the event of an emergency, and first responders must consider the risk of loss of service when responding to an emergency. These hazards are extremely relevant in areas where disruptions to service are regular occurrences, such as rural areas with poor radio or cellular signal, or in communities experiencing public safety power shutoff (PSPS) events. Since PSPS events occur during periods of elevated fire hazard, the risk of a major fire occurring during a PSPS event should be considered.

In general, agencies responding to emergencies should plan to operate with power, fuel, water, and communications independent from vulnerable infrastructure systems and hardened to the threats of extreme weather hazards. In the Shasta Region, that likely means that portable generators, radio repeaters, and alternative water sources should be components of evacuation plans. The importance of service continuity to evacuating residents should also play into evacuation planning and drills, with simulated shortages of fuel, disruptions to power, and communications outages considered.

Funding Opportunities

Many of the adaptation strategies outlined here could be aided or funded by grant opportunities that are currently or recurrently available from federal and state government agencies.

Funding Opportunities Available to RPOs

California Agencies

State of Good Repair, Caltrans

This Caltrans program can provide additional revenues for transit infrastructure repair and service improvements. Annual funding is approximately $105 million and is made available for eligible transit maintenance, rehabilitation, and capital projects. Eligible applications include transportation planning agency, county transportation commission, and Metropolitan Transit System. SRTA has policies in place for the use of State of Good Repair grants.

State Transportation Improvement Program (STIP), Caltrans

STIP is a multi-year capital improvement program of transportation projects on and off the State Highway System. Caltrans and regional planning agencies prepare transportation improvement plans after amount of funding is decided. Local agencies work through their Regional Transportation Planning Agency, County Transportation Commission, or Metropolitan Planning Organization to nominate projects.

FTA Section 5310- Enhanced Mobility of Seniors and Individuals with Disabilities Program, Caltrans

The goal of this program is to improve the mobility of seniors and individuals with disabilities by removing barriers to transportation services and expanding mobility options available. It provides grant funds for capital (vehicles and related equipment such as cameras, radios, scheduling software), mobility management (travel training, one stop call center) and operating expenses. Eligible public agencies include agencies where no private non-profits are readily available to provide service and agencies that have been approved by the State to coordinate transportation services.

Local Streets and Roads Program (LSRP), California Transportation Commission

This funding is for basic road maintenance, rehabilitation, critical safety projects, traffic control devices, drainage and stormwater capture, etc. Funding could be used for installing permanent signage and traffic control devices to enable contraflow traffic. Eligible applicants include cities and counties, funding is awarded annually.

Prop 84 Wildfire Resiliency & Recovery Planning Grants, California Strategic Growth Council

This past opportunity was advertised by the California Strategic Growth Council (CSGC), the Governor's Office of Planning and Research, and the California Dept. of Conservation. Proposition 84 funded projects that protected natural resources, but concluded with about $720,000 in unused funding. CSGC dedicated the leftover funds to help CA communities affected by wildfire with recovery and adaptation planning. Eligible organizations included local and regional governments (cities, counties, tribes, and metropolitan planning organizations) representing California areas affected by wildfires between 2017-2019.

Federal Agencies

Federal funding programs with relevance to the Adaptation Plan's goals include:

Rebuilding American Infrastructure with Sustainability and Equity, or RAISE Discretionary Grant program, Department of Transportation

The RAISE Discretionary Grant program provides an opportunity for US DOT to invest in road, rail, transit and port projects that promise to achieve national objectives. The grant program is a competitive discretionary fund for multi-modal, multi-jurisdictional projects that are more difficult to support through traditional DOT programs. State, local, and regional agencies are eligible. Recent infrastructure legislation has added $1 billion in funding.

Other Relevant Funding Opportunities (not directly available to RPOs)

California Agencies

Urban & Community Forestry Grants, Calfire

Grant program offers up to $23 million available for urban forestry programs (including forest expansion, maintenance, and workforce development). Grants focused on disadvantaged communities in urban areas. Benefits of the projects include reduced greenhouse gas (GHG) emissions, increased water supply, clean air and water, reduced energy use, flood and storm water management, recreation, urban revitalization, improved public health, and producing useful products such as bio-fuel, clean energy, high quality wood and job creation. These grants are designed for projects that have multiple of the listed benefits and must not be used for mitigation measures. Eligible applicants include a city, a county, a qualifying district or non-profit, but partnering with other organizations is allowed.

Environmental Justice Small Grants, CalEPA

This program offers funding opportunities to assist non-profit community organizations and federally recognized Tribal governments address environmental justice issues in areas disproportionately affected by environmental pollution and hazards.

Relevance to this project: example projects include enhancing local capacity to respond, adapt, and prepare for climate change impacts, developing emergency management plans, etc. – several concepts could be relevant to Shasta Region adaptation strategies.

Building Resilient Infrastructure and Communities (BRIC), FEMA via CalOES

BRIC is a new FEMA pre-disaster hazard mitigation program for hazard mitigation projects that reduce risks from disasters and natural hazards. BRIC is targeted at innovative projects and funding mechanisms to prevent impacts prior to hazards occurring.

Flood Mitigation Assistance (FMA), FEMA via CalOES

The goal of FMA is to reduce or eliminate claims under the National Flood Insurance Program (NFIP), so FMA covers a broad array of investments and activities (including technical assistance) related to flood mitigation. Eligibility is limited to federal disaster areas, but applicants include states, local communities, tribes, and territories, and some private non-profits.

Fire Prevention Grants Program, Calfire

The goal of this Calfire program is to reduce the risk of wildland fires to habitable structures and communities and maximize carbon sequestration. Project categories include Hazardous Fuel Reduction and Fire Prevention Planning, Fire Prevention Education.

2021 Treecovery Grant Program, California ReLeaf

This program is funded by a grant from CalFire, projects must reduce GHG and focus on disadvantaged and low-income communities. Eligible organizations include incorporated non-profits, non-incorporated community-based groups (with fiscal sponsor). Public entities may serve as a fiscal sponsor for an organization but can't apply for funds directly.

Urban Greening, CA Natural Resources Agency

Urban Greening projects result in the conversion of an existing built environment into green space that uses natural and green infrastructure approaches to create sustainable and vibrant communities. Eligible applicants include a city, county, special district, or non-profit, or agency/entity formed pursuant to the Joint Exercise of Powers Act.

Federal

FEMA Hazard Mitigation Grant Program, FEMA

Provides funding to state, local, tribal, and territorial governments so they can rebuild in a way that reduces, or mitigates, future disaster losses in their communities. This grant funding is available after a presidentially declared disaster. Includes "Post-Fire Assistance" for hazard mitigation measures that substantially reduce the risk of future damage, hardship, loss, or suffering in any area affected by a major disaster, or any area affected by a fire for which assistance was provided under Section 420 Fire Management Assistance Grant (FMAG)

Non-Profit Community Organizations

Fire Prevention & Preparedness, CA Fire Foundation

The goal of these grants is to prevent, prepare, and or respond to major events in California, including wildfires, floods, and climate-caused disasters. Eligible applications include fire departments, firefighter associations, fire safe councils, and other community organizations.

2021 County Coordinators Grant, California Fire Safe Council (Info Coming Soon, Opens in Aug.)

The California Fire Safe Council administers U.S. Forest Service State Fire Assistance grant programs and offers a variety of other federal, state and private funding opportunities. Eligible organizations include nonprofits, Native American tribes, municipalities (towns, cities), special districts, state agencies, counties, and for-profit companies.

Appendix A: References

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Appendix B: Vulnerability Assessment 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.[31]

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).[32] 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.[33] For each period, the central year is used to describe the overall period.

Historical:

- 1990 (1975 – 2004)[34]

Projections:

- 2025 (2010 – 2039)[35]
- 2055 (2040 – 2069)

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[31] Caltrans 2018a
[32] IPCC 2014
[33] Caltrans 2018a
[34] 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.
[35] 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

- 2085 (2070 – 2099)

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,[36] 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.[37] 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[38]

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.

[36] Bracken et al. 2016
[37] Pierce et al. 2018
[38] Cal Adapt 2021a

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.

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.[39] The UC Merced model evaluated historical wildfires to identify relationships between key

[39] Westerling 2018

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.

Wildfire area burned projections are hosted on Cal Adapt, and this study uses only the central growth scenario.[40]

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.[41] 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.[42]

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.[43] 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.

[40] Cal Adapt 2021b
[41] Dale et al. 2018
[42] Cal Adapt 2021b
[43] Oregon Department of Forestry 2013

FIRMs are hosted on the FEMA NFHL Viewer.[44]

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 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°.[45] 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.[46]

[44] FEMA 2021
[45] California Dept. of Conservation 1997
[46] Shasta County 2017

Appendix C: 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

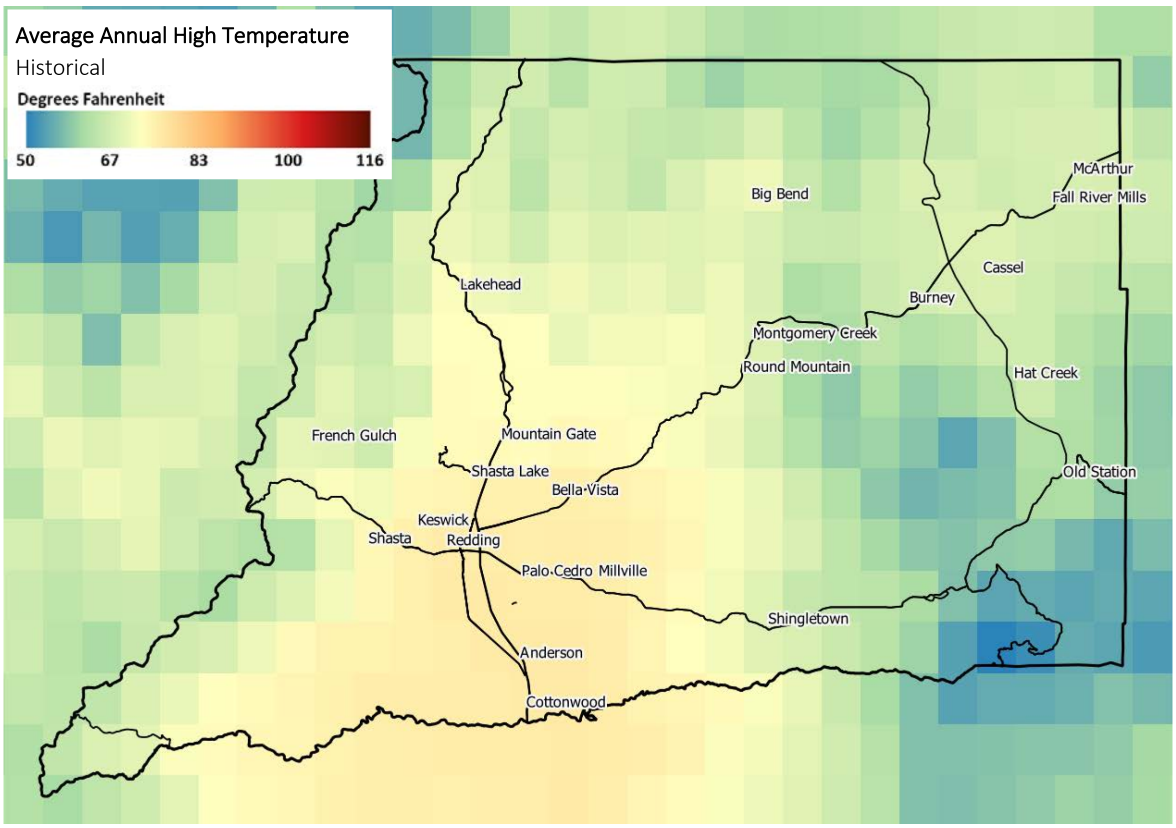

Figure 93. Historical average annual high temperatures.

Reduced Emissions Scenario (RCP4.5)

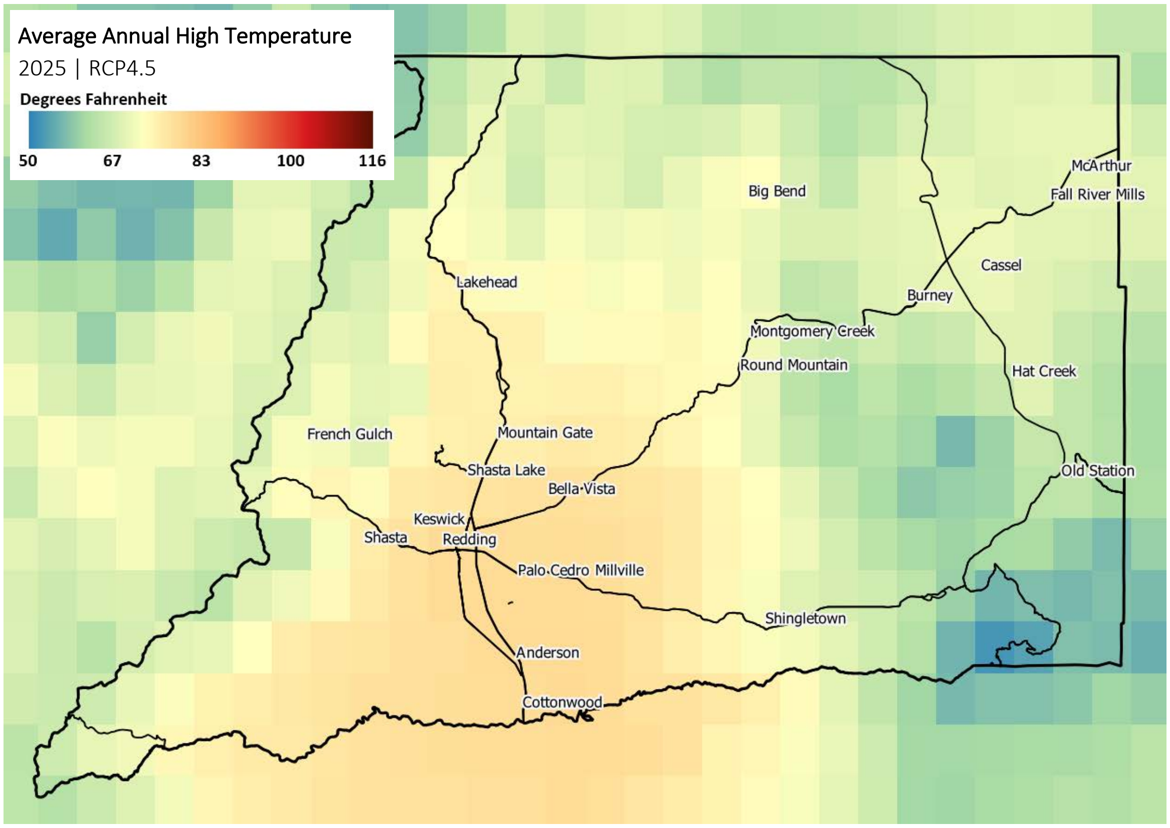

Figure 94. Average annual high temperatures in 2025, RCP4.5.

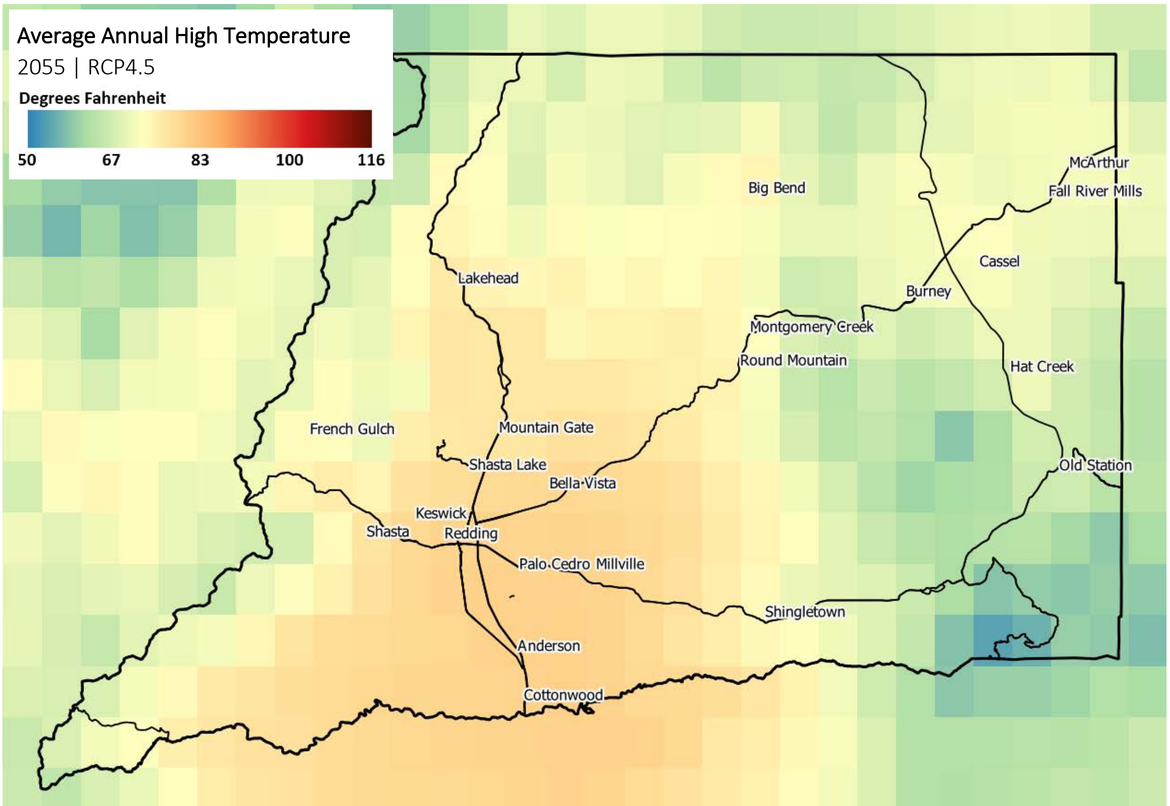

Figure 95. Average annual high temperatures in 2055, RCP4.5.

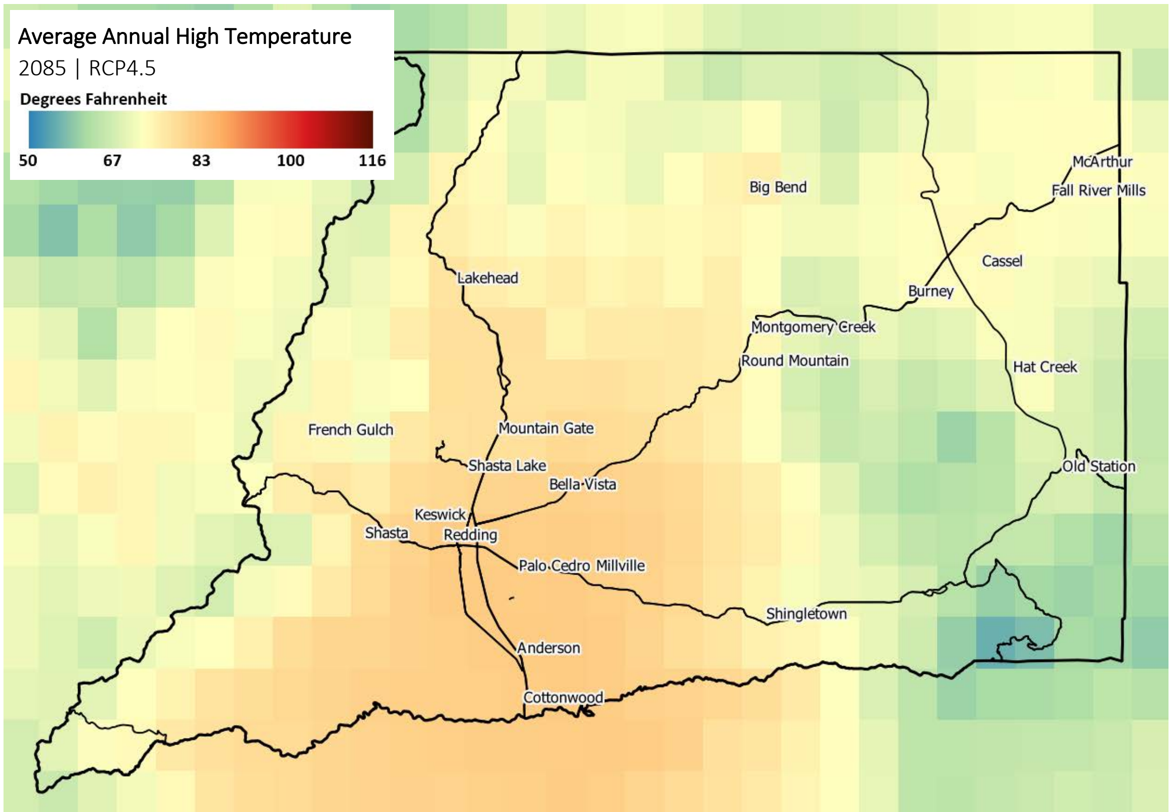

Figure 96. Average annual high temperatures in 2085, RCP4.5.

Unconstrained Emissions Scenario (RCP8.5)

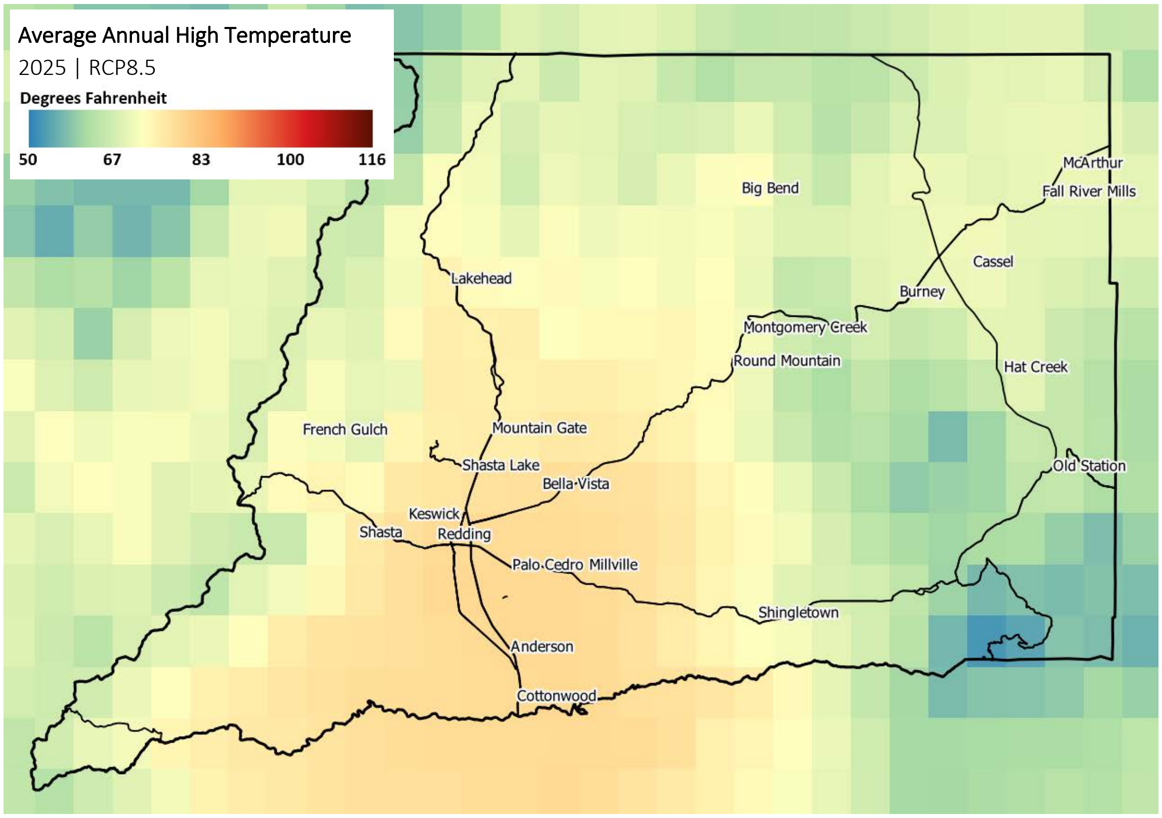

Figure 97. Average annual high temperatures in 2025, RCP8.5.

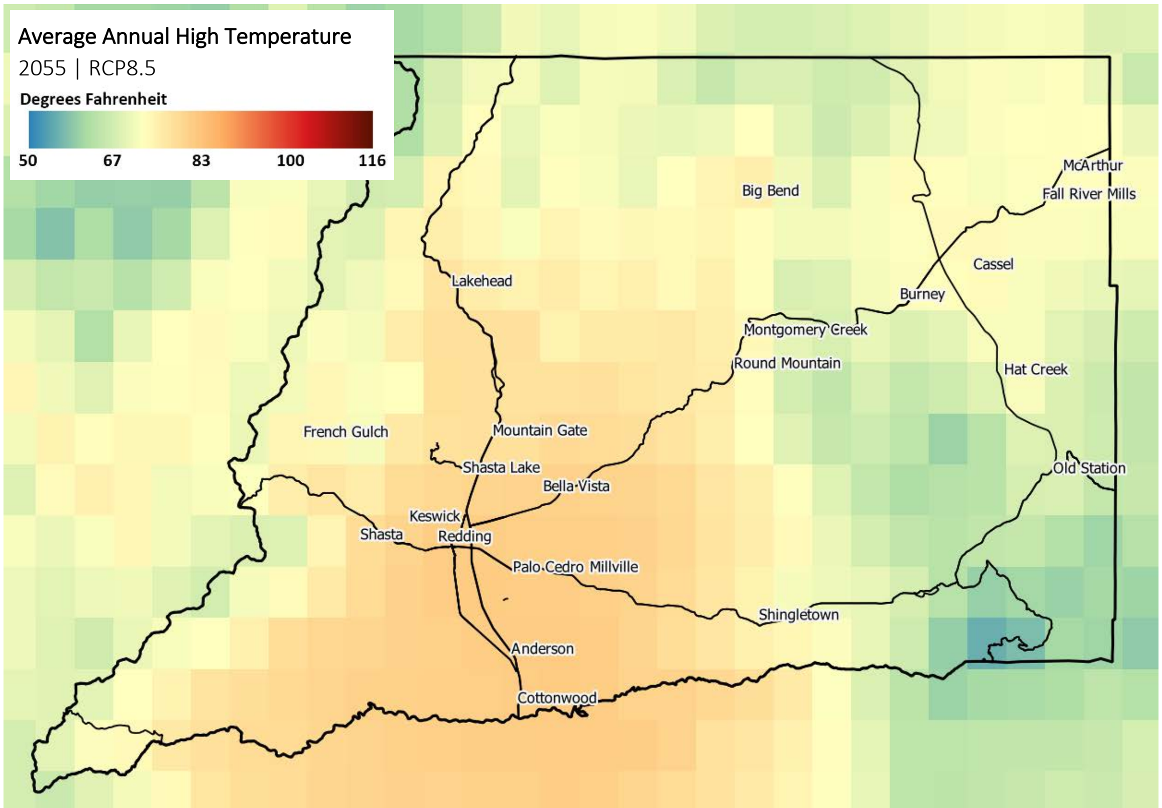

Figure 98. Average annual high temperatures in 2055, RCP8.5.

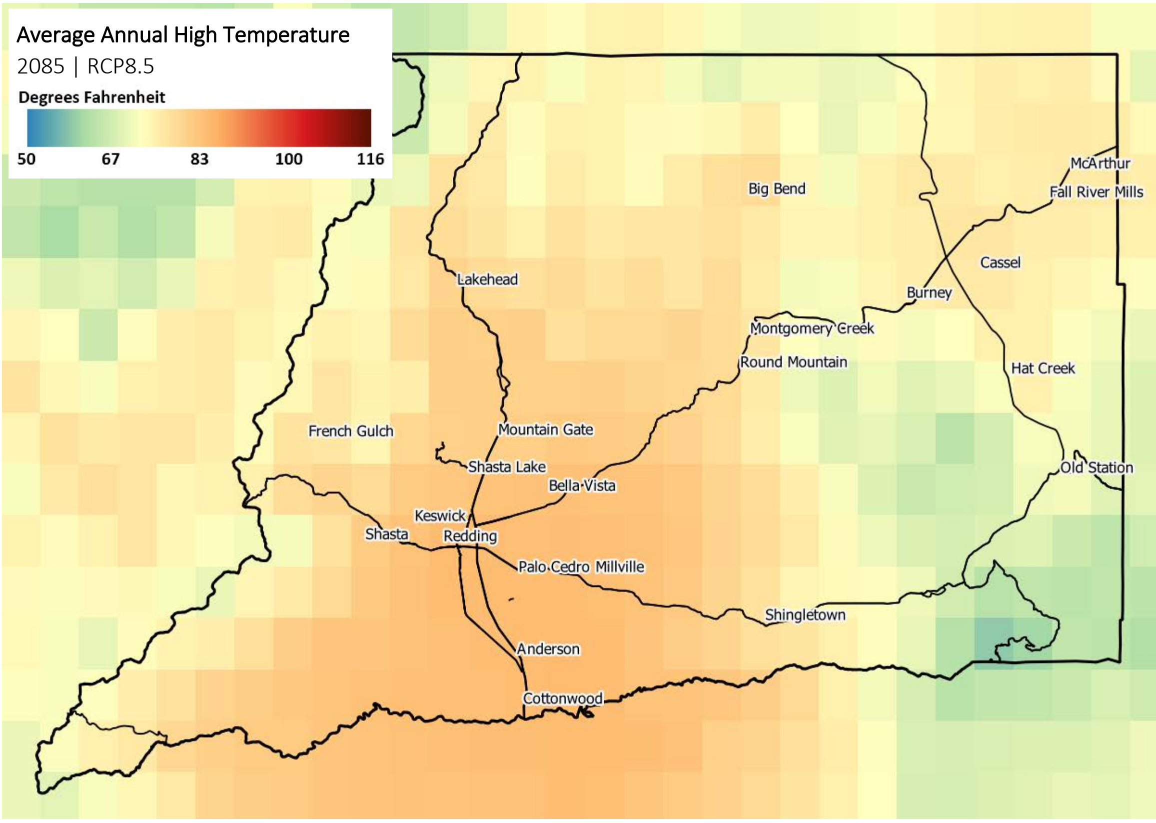

Figure 99. Average annual high temperatures in 2085, RCP8.5.

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

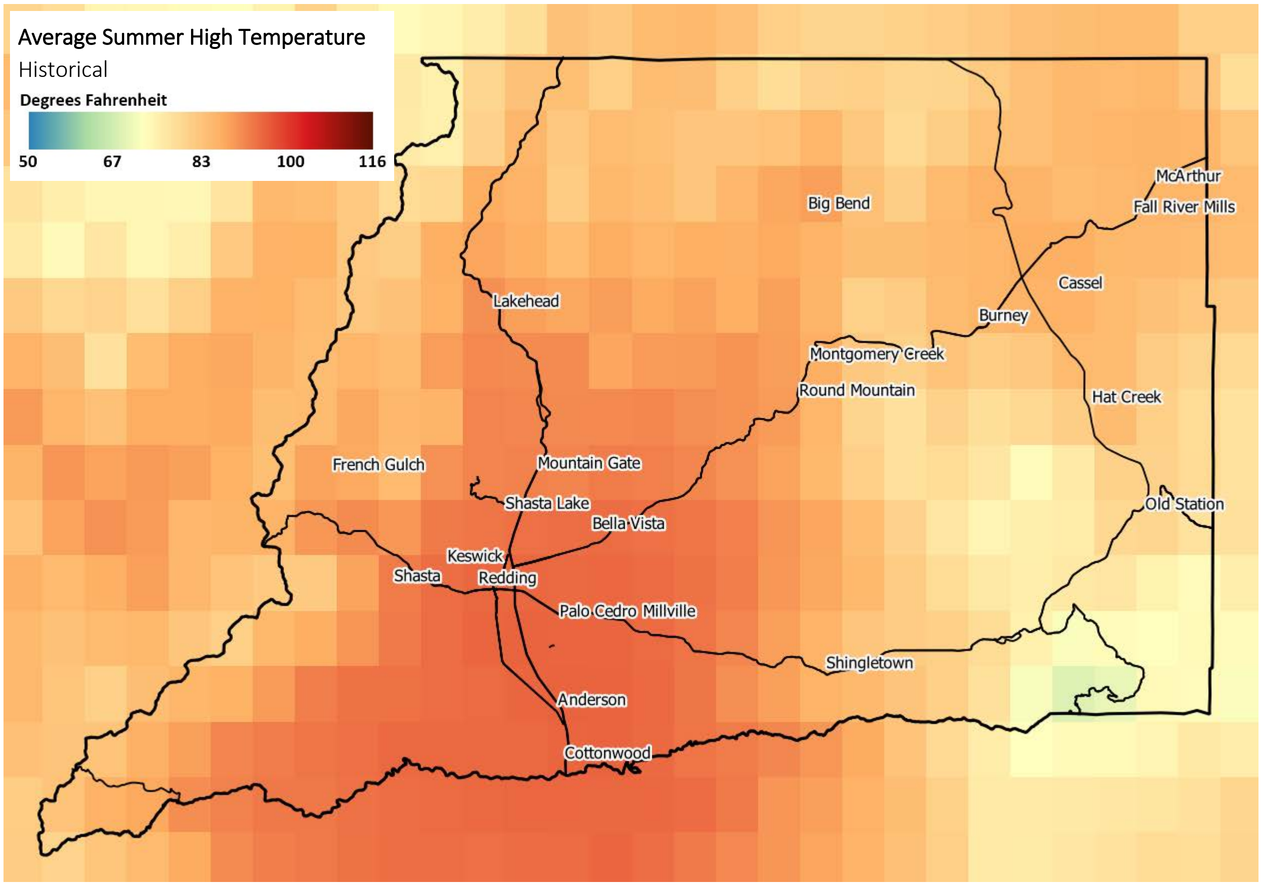

Figure 100. Historical average summer high temperatures.

Reduced Emissions Scenario (RCP4.5)

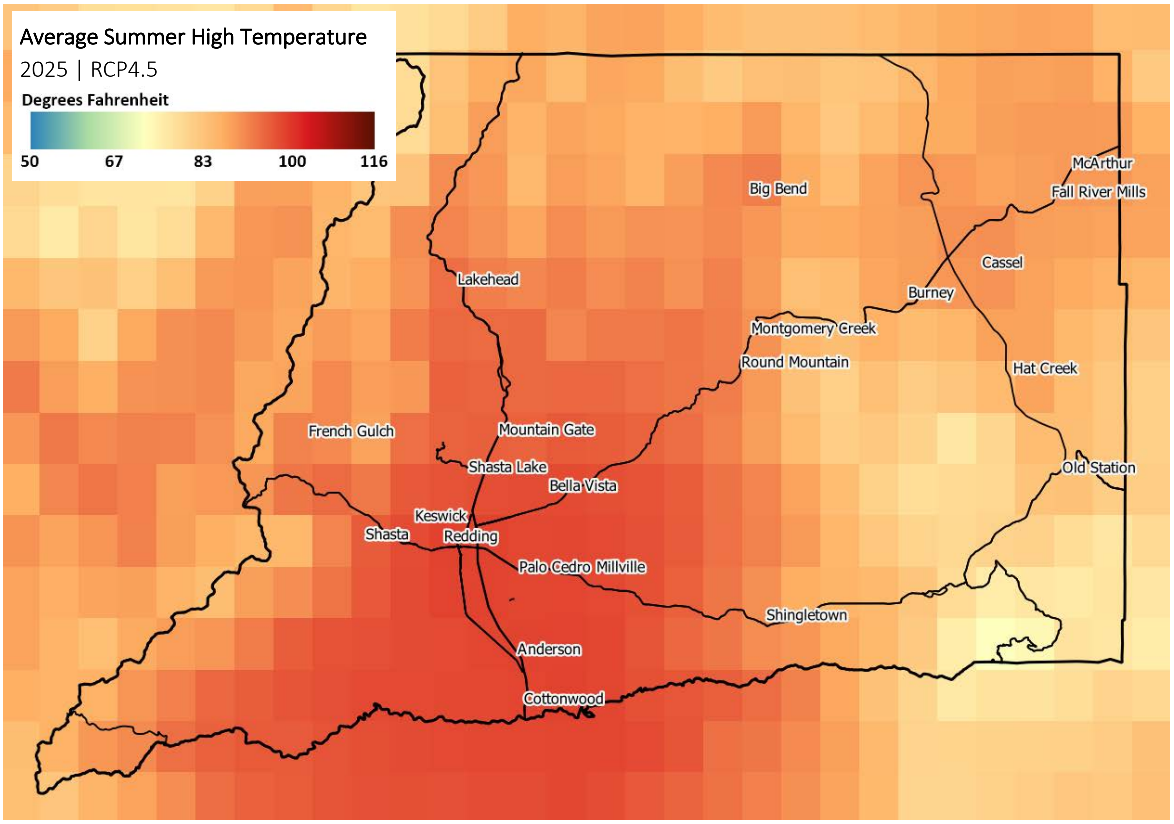

Figure 101. Average summer high temperatures, 2025, RCP4.5.

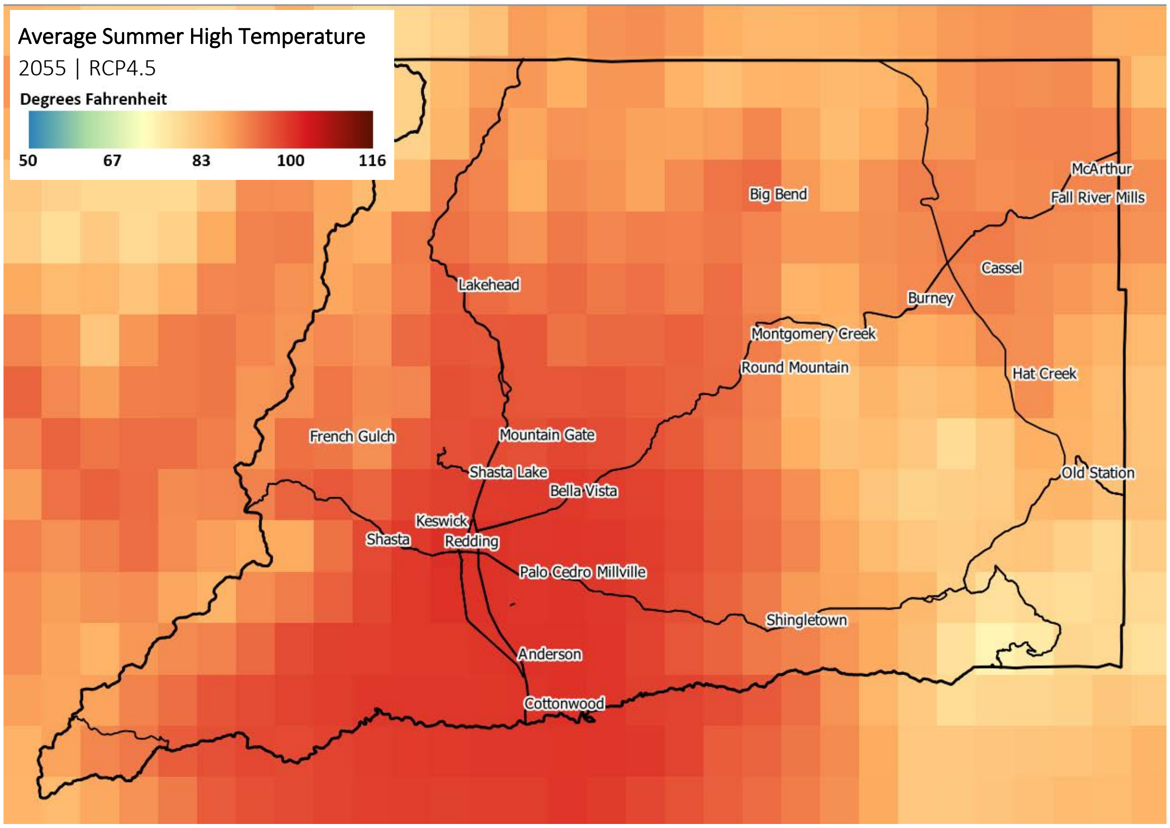

Figure 102. Average summer high temperatures, 2055, RCP4.5.

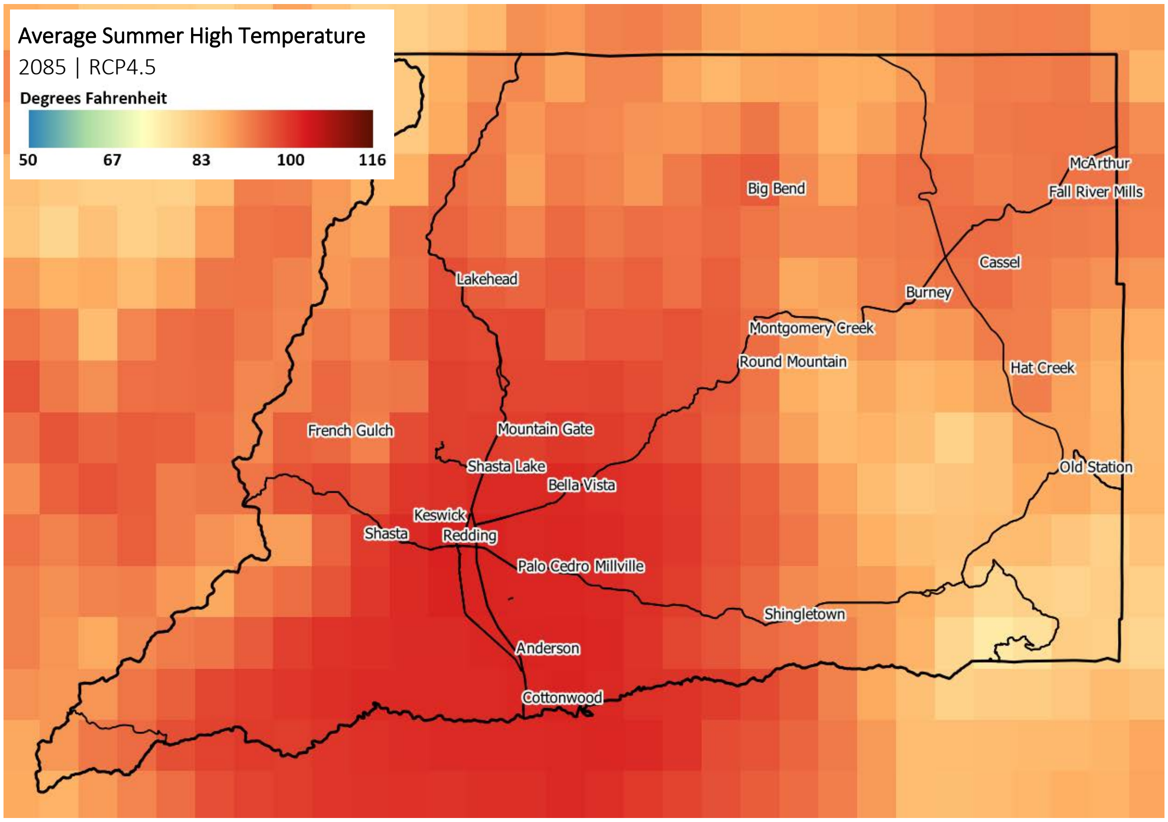

Figure 103. Average summer high temperatures, 2085, RCP4.5.

Unconstrained Emissions Scenario (RCP8.5)

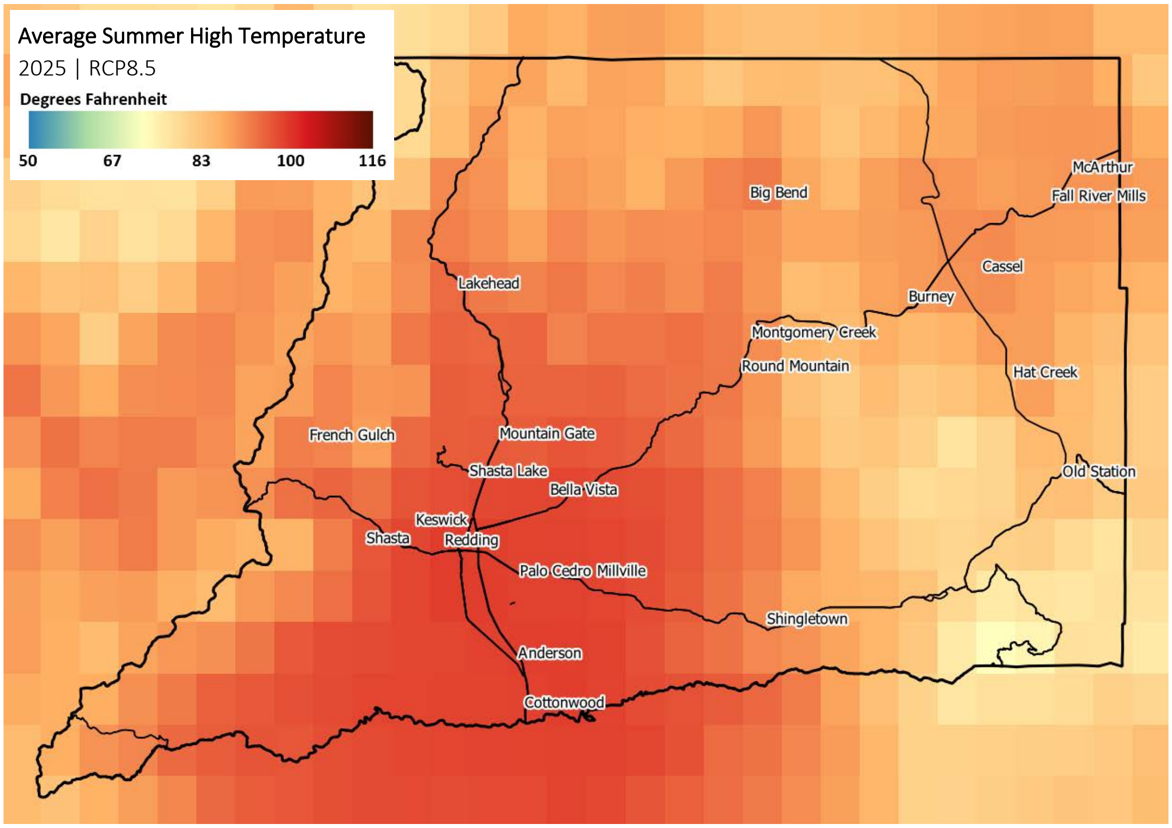

Figure 104. Average summer high temperatures, 2025, RCP8.5.

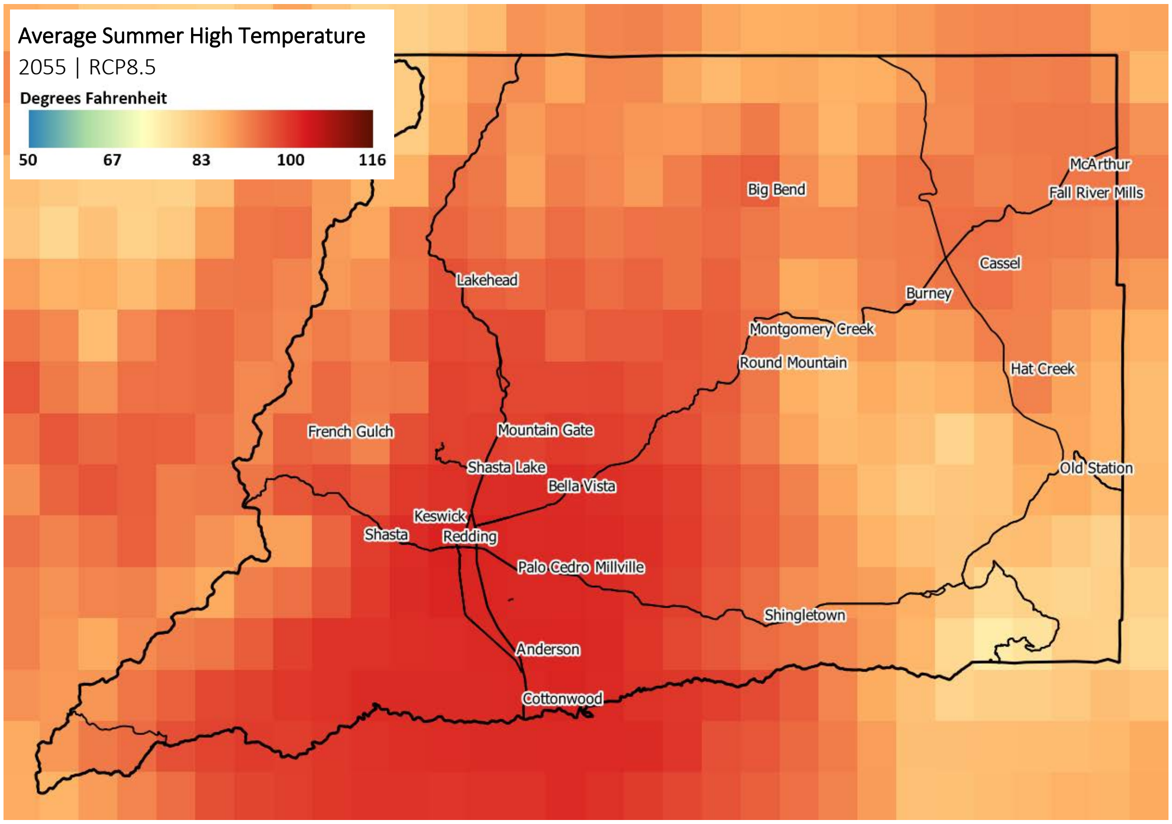

Figure 105. Average summer high temperatures, 2055, RCP8.5.

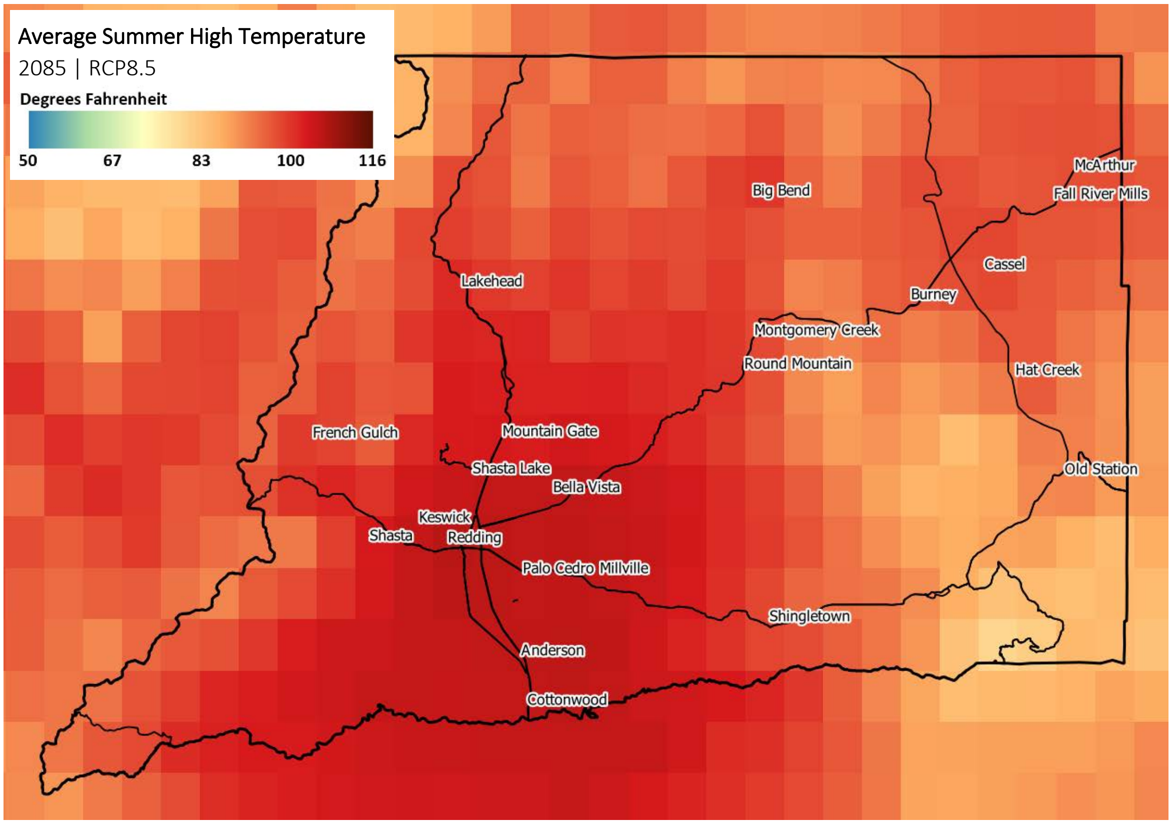

Figure 106. Average summer high temperatures in 2085, RCP8.5.

Average Heat Wave Temperature Projections

Historical Conditions

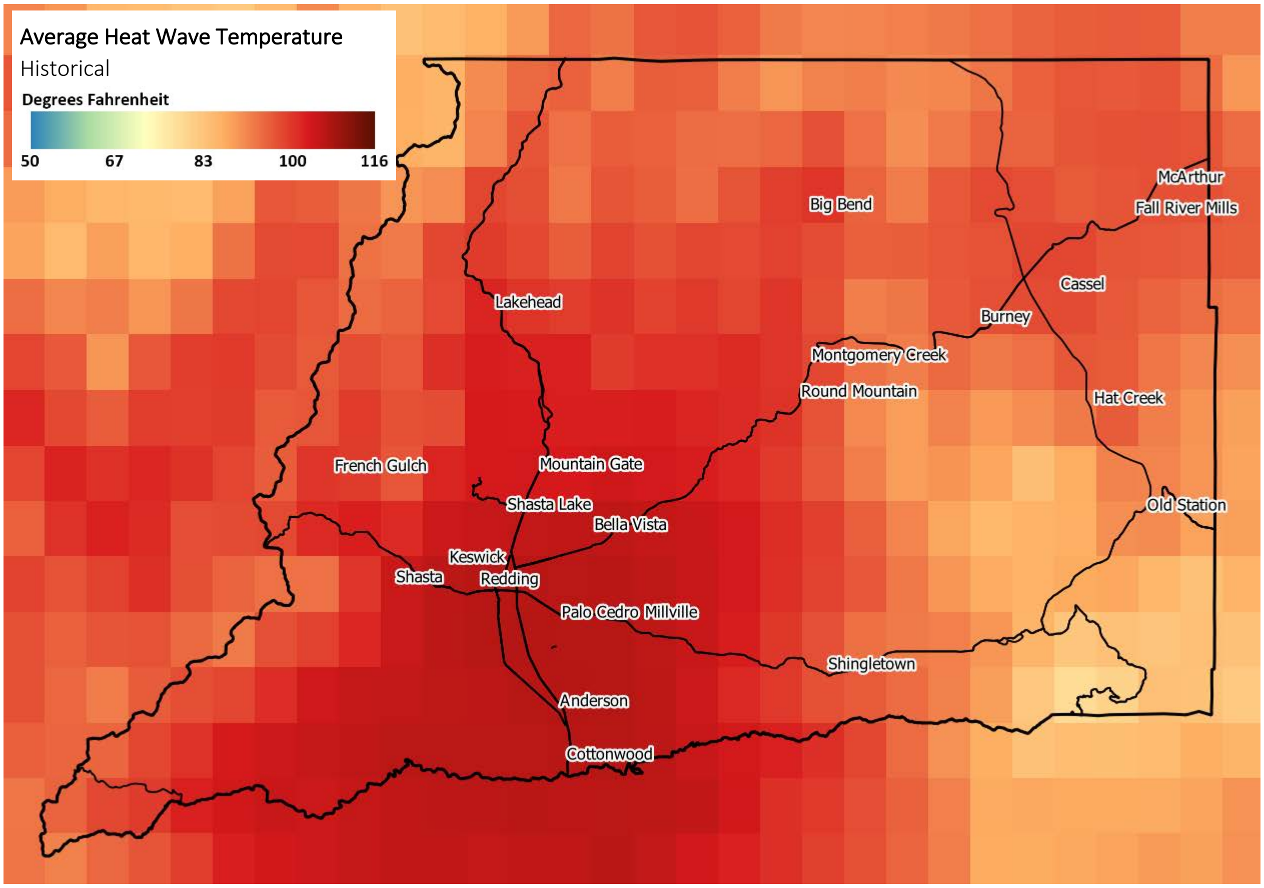

Figure 107. Average heat wave high temperatures in the Shasta region under historical conditions (1975 - 2004).

Reduced Emissions Scenario (RCP4.5)

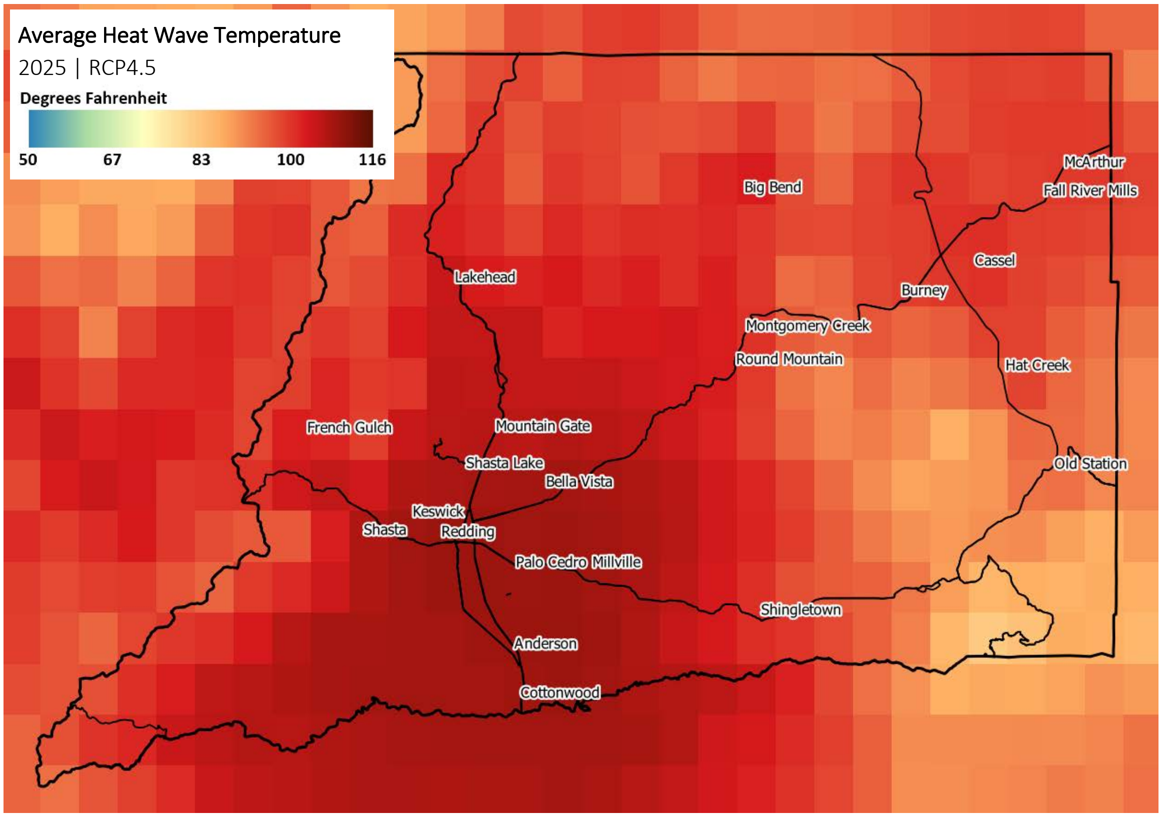

Figure 108. Average heat wave high temperatures, 2025, RCP4.5.

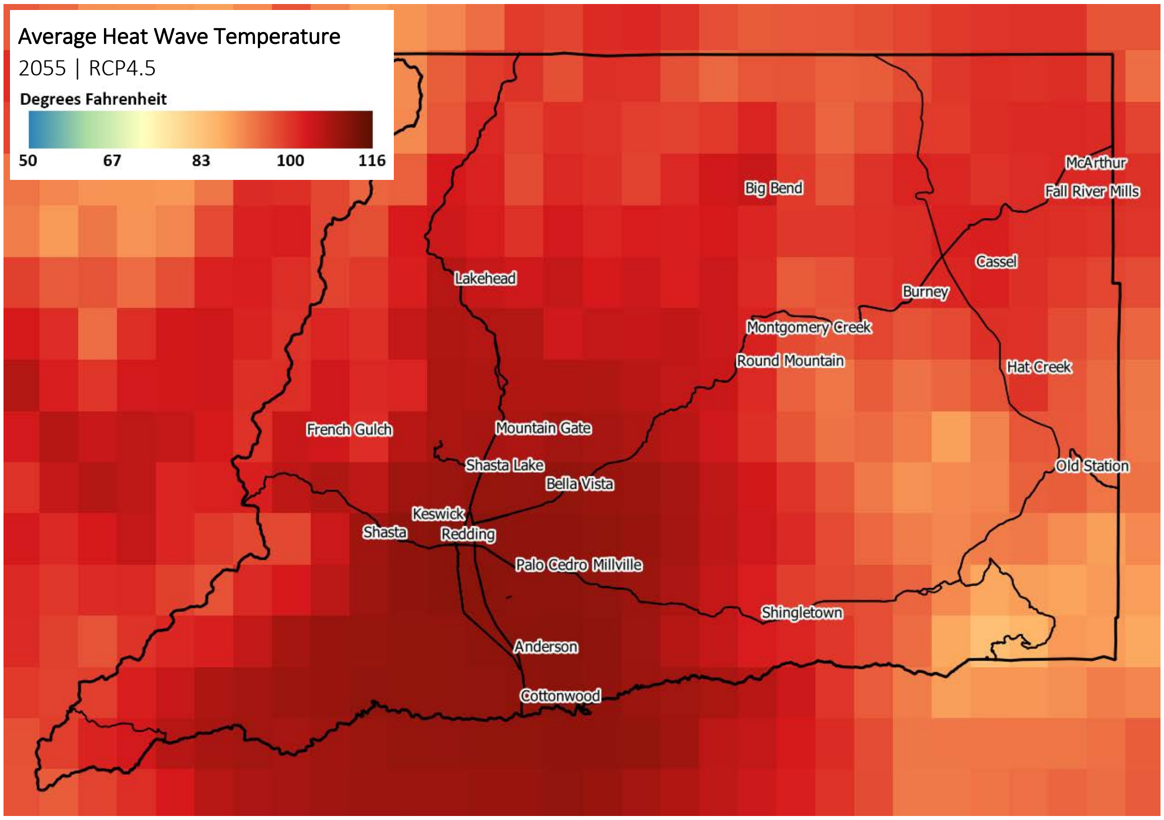

Figure 109. Average heat wave high temperatures, 2055, RCP4.5.

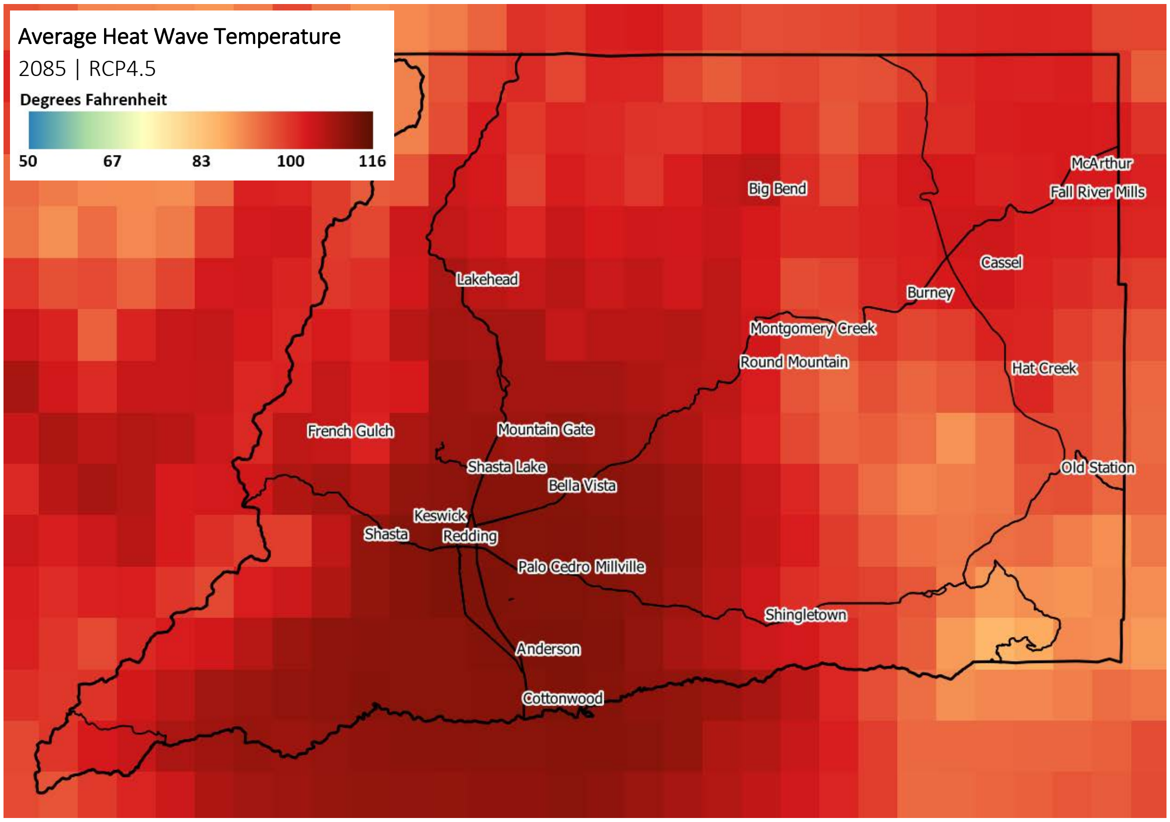

Figure 110. Average heat wave high temperatures, 2085, RCP4.5.

Unconstrained Emissions Scenario (RCP8.5)

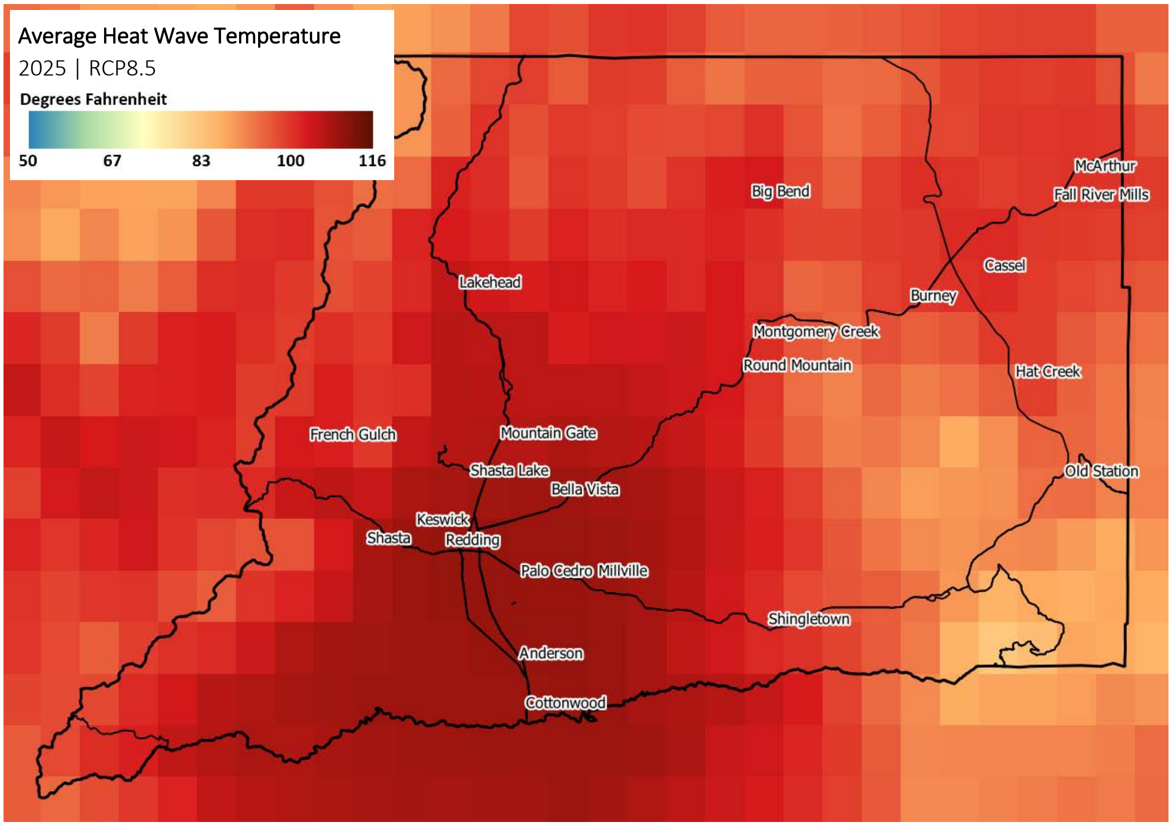

Figure 111. Average heat wave high temperatures, 2025, RCP8.5.

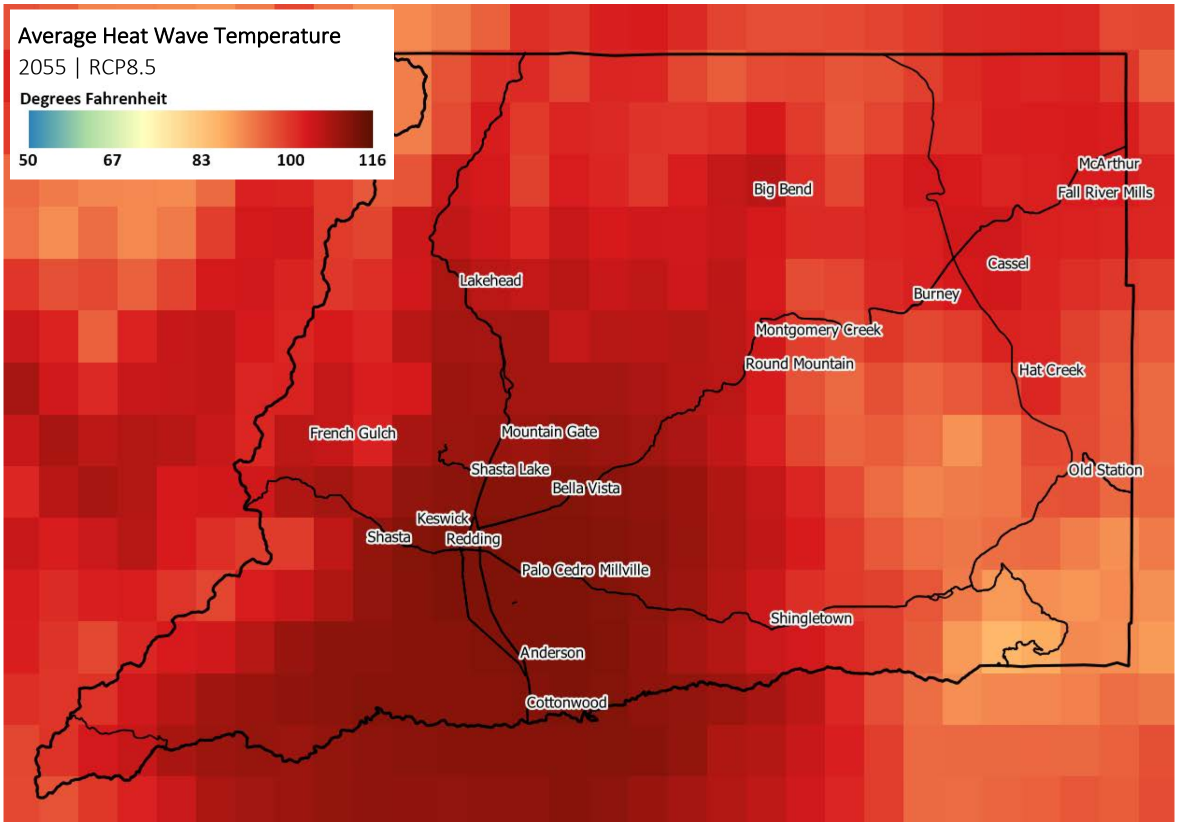

Figure 112. Average heat wave high temperatures, 2055, RCP8.5.

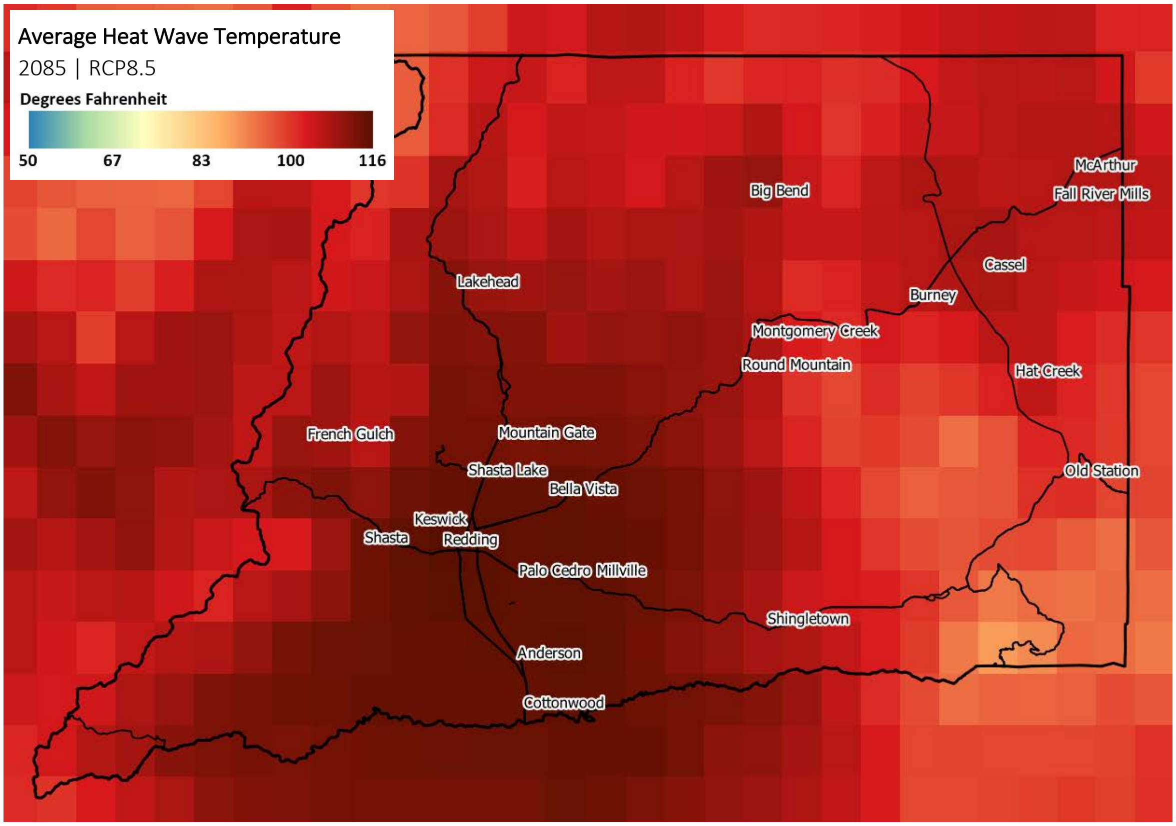

Figure 113. Average heat wave high temperatures, 2085, RCP8.5.

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)

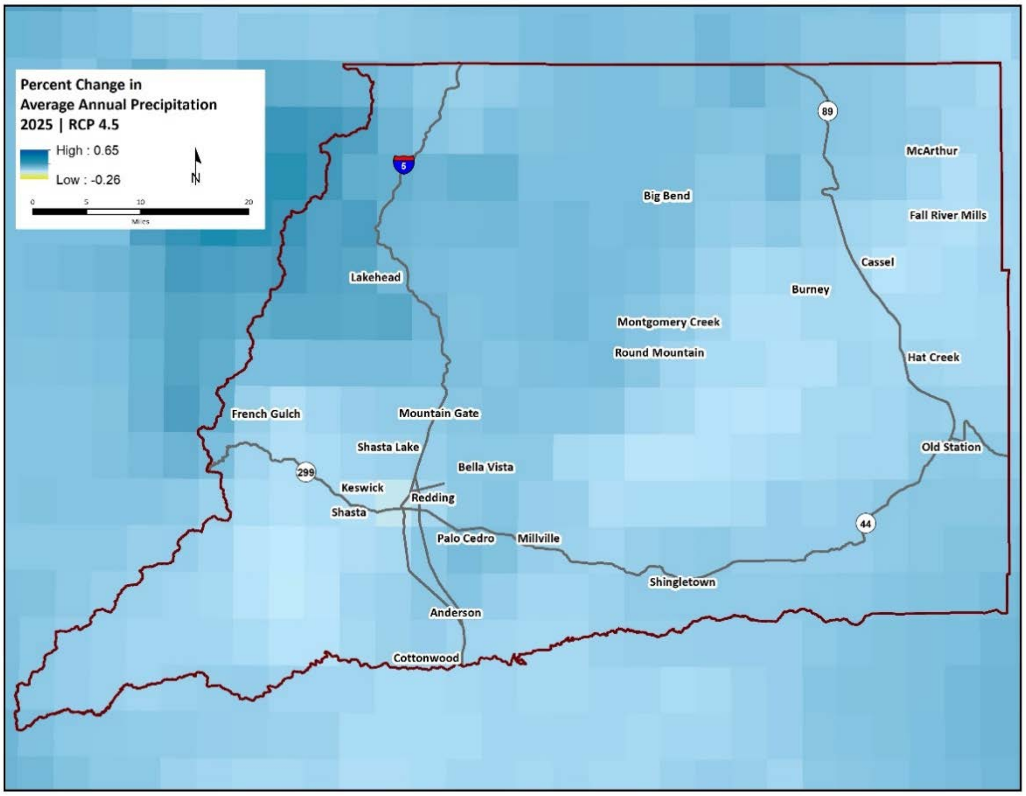

Figure 114. Projected change in average annual precipitation in the Shasta Region. 2025, RCP4.5 scenario.

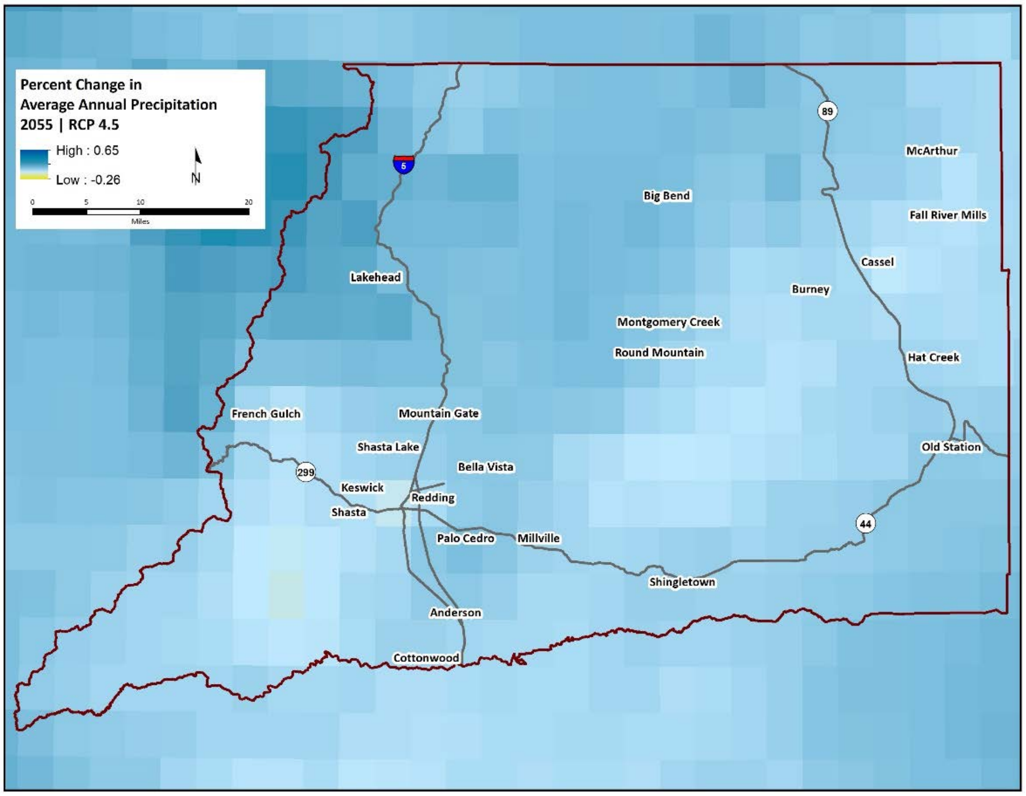

Figure 115. Projected change in average annual precipitation in the Shasta Region. 2055, RCP4.5 scenario.

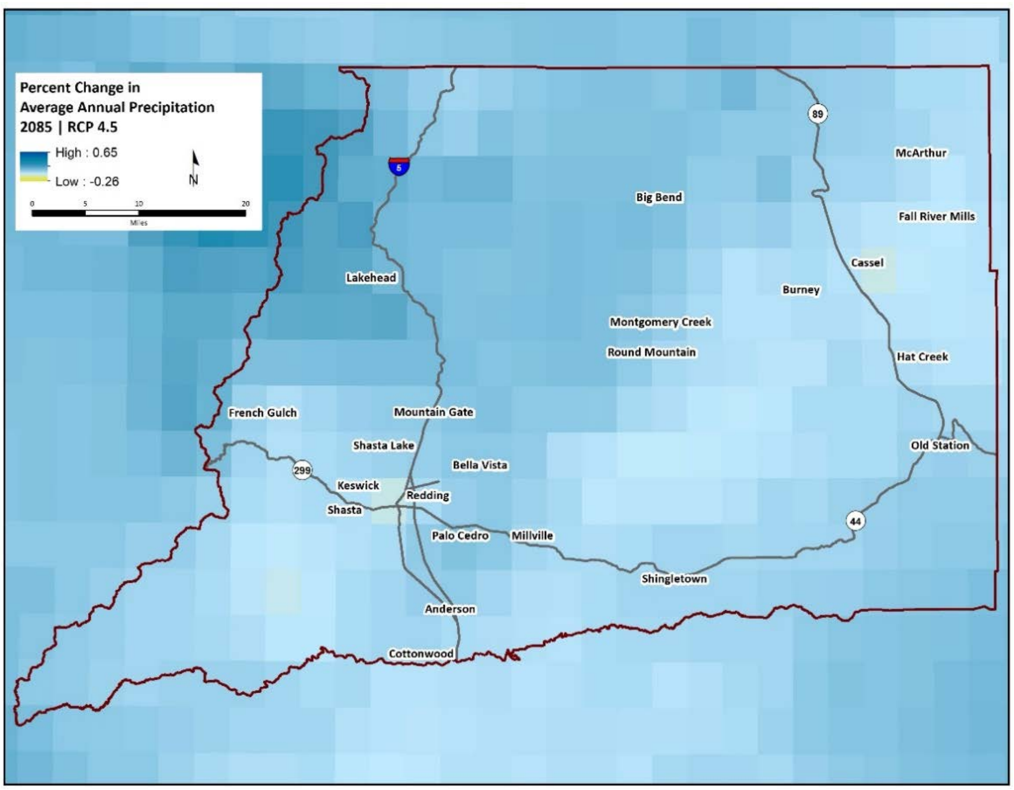

Figure 116. Projected change in average annual precipitation in the Shasta Region. 2085, RCP4.5 scenario.

Unconstrained Emissions Scenario (RCP8.5)

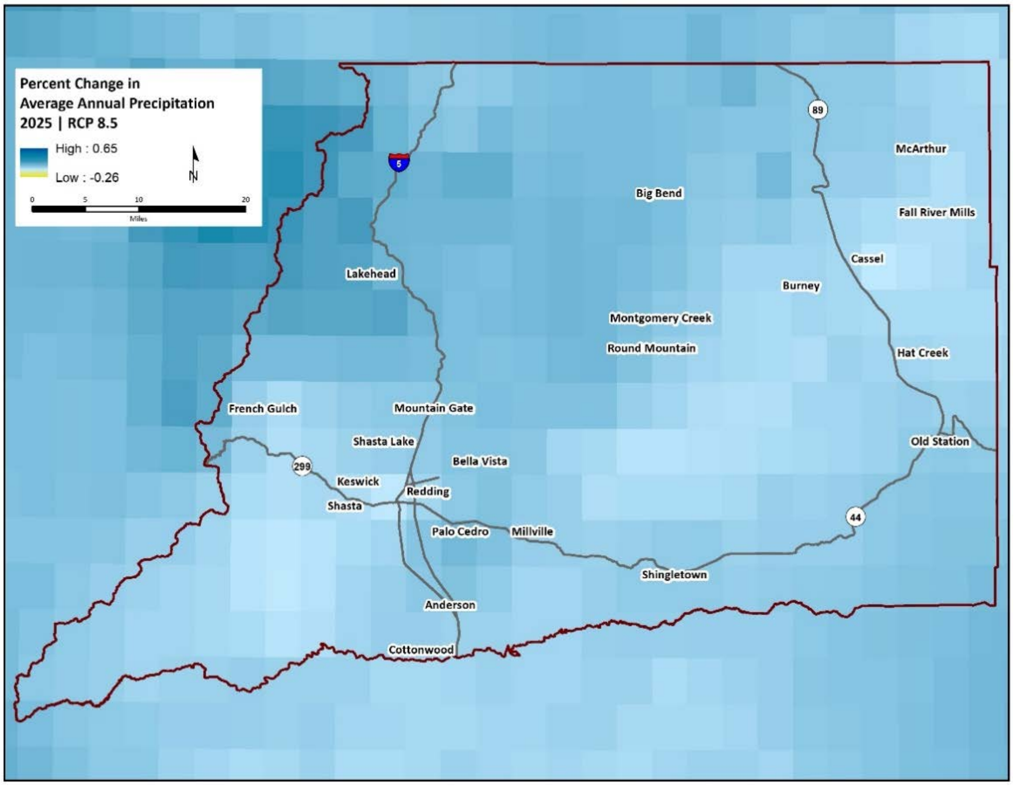

Figure 117. Projected change in average annual precipitation in the Shasta Region. 2025, RCP8.5 scenario.

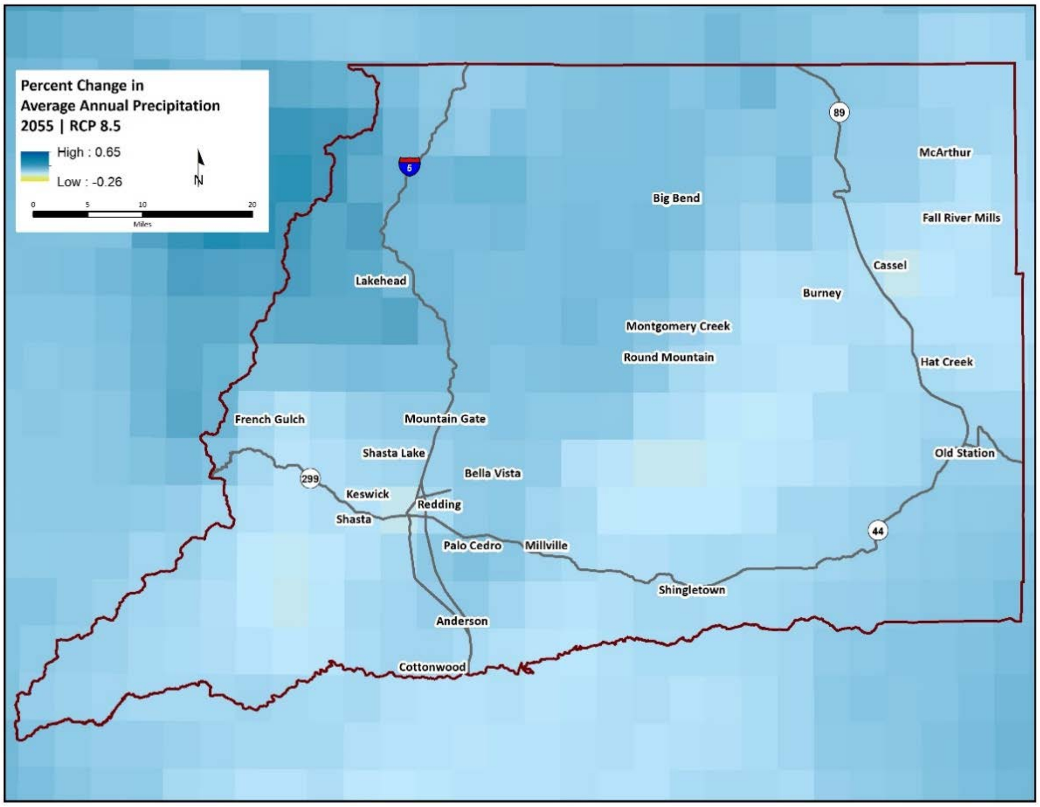

Figure 118. Projected change in average annual precipitation in the Shasta Region. 2055, RCP8.5 scenario.

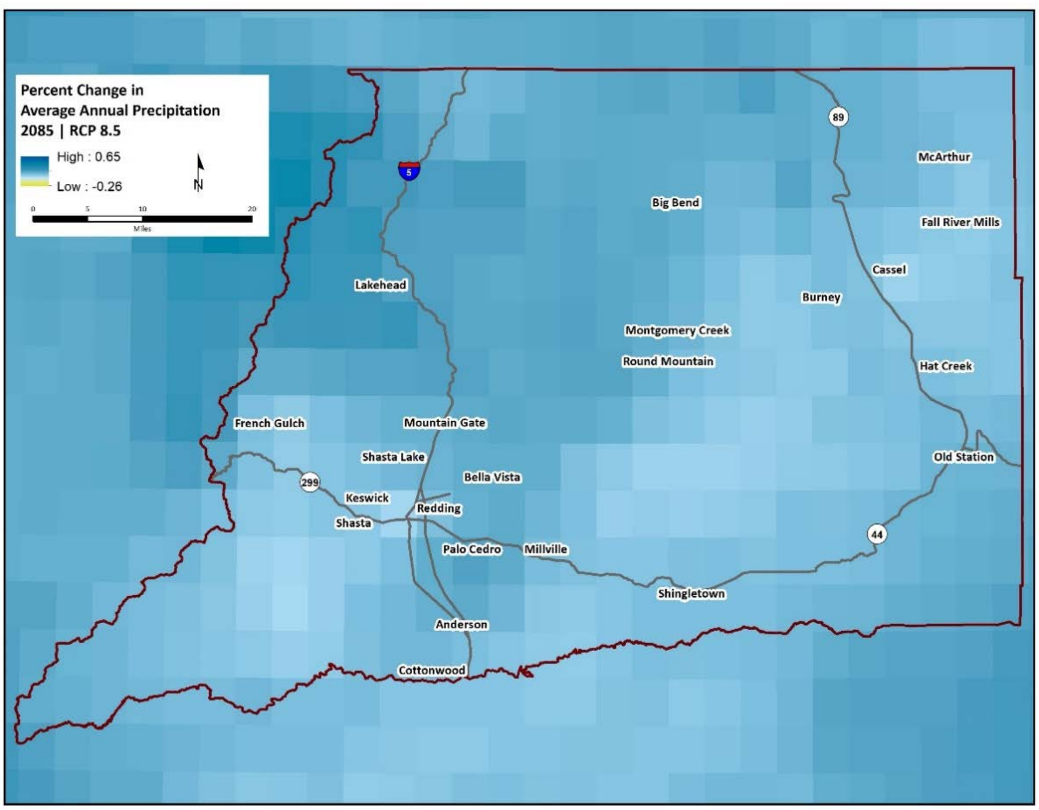

Figure 119. Projected change in average annual precipitation in the Shasta Region. 2085, RCP8.5 scenario.

Percent Change in Dry Season Average Precipitation

Dry season precipitation projections are only shown for 2055.

Reduced Emissions Scenario (RCP4.5)

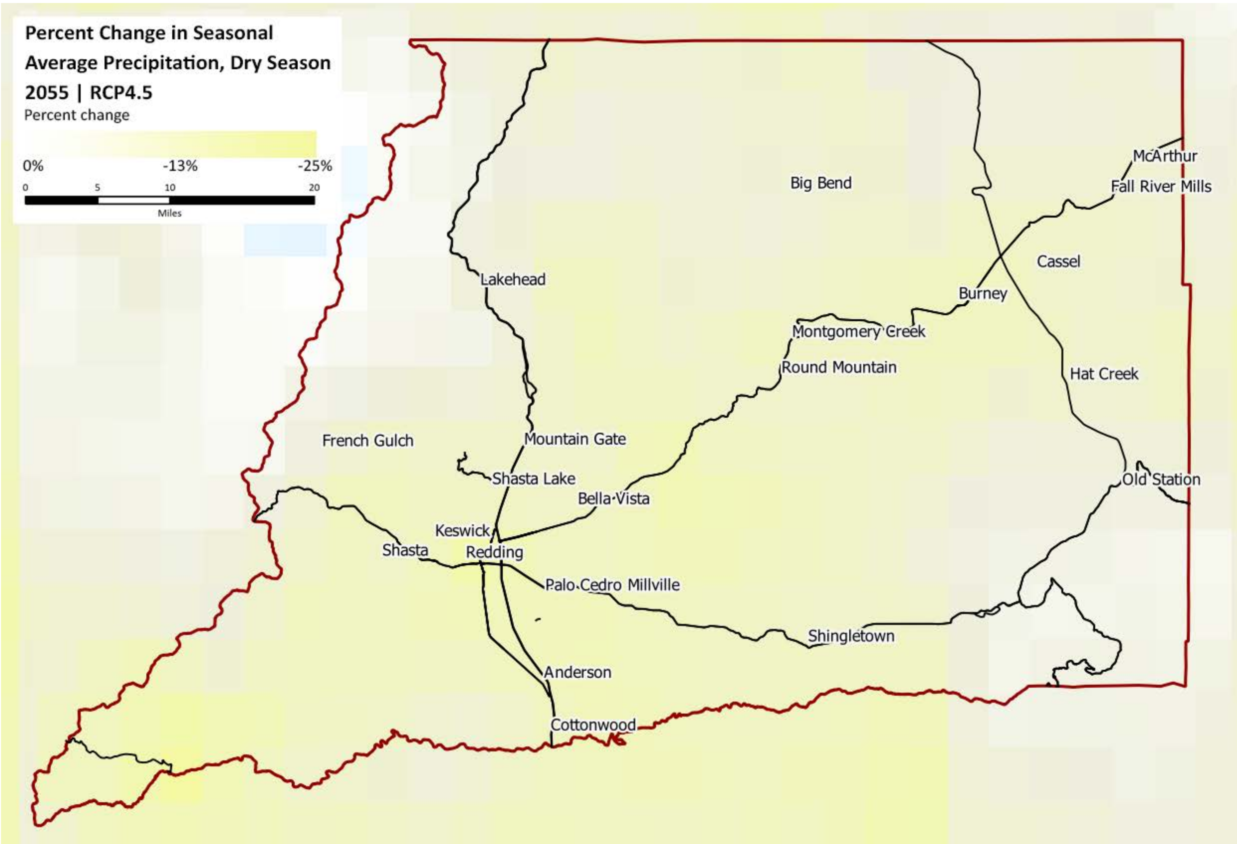

Figure 120. Percent change in dry season precipitation, 2055 RCP4.5.

Unconstrained Emissions Scenario (RCP8.5)

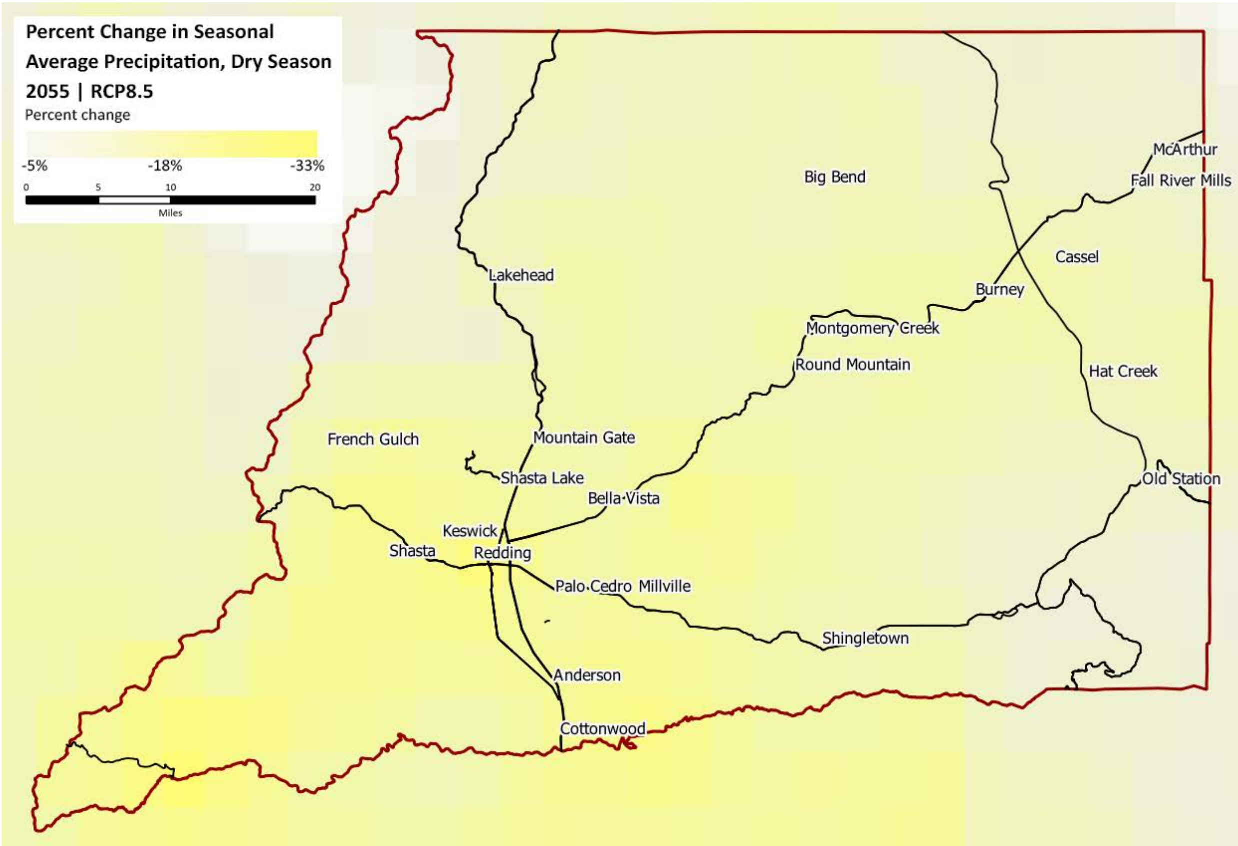

Figure 121. Percent change in dry season precipitation, 2055 RCP8.5.

Percent Change in Wet Season Average Precipitation

Reduced Emissions Scenario (RCP4.5)

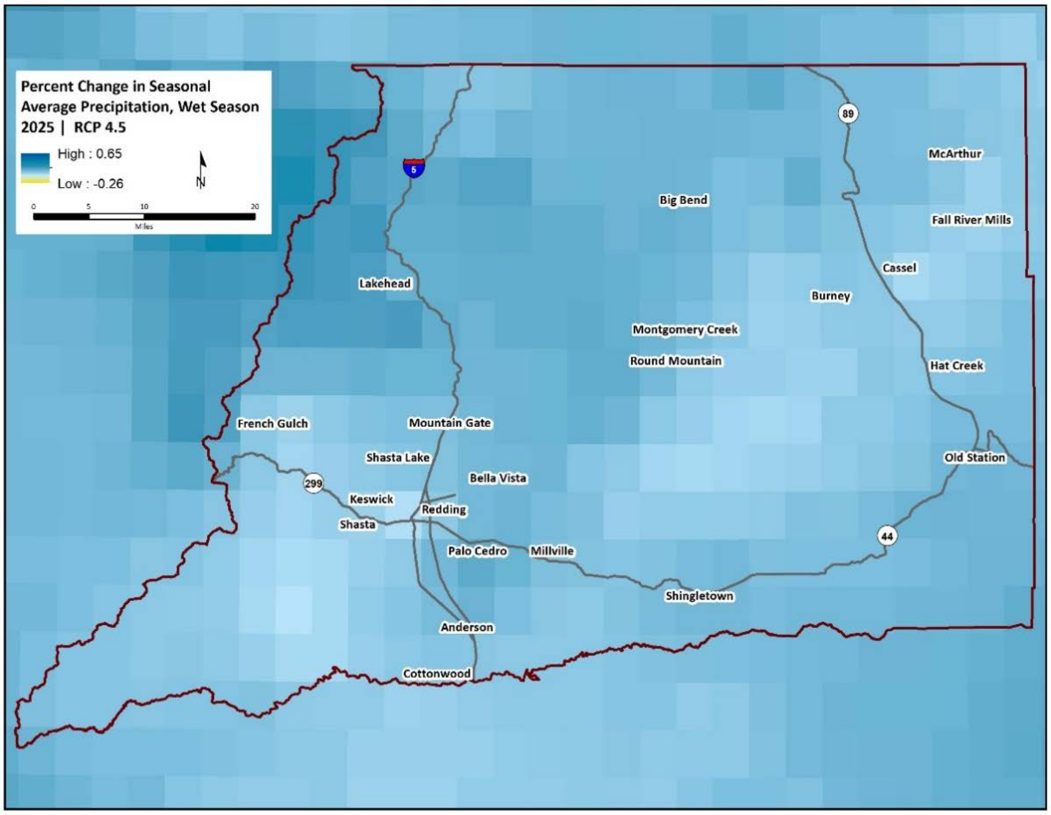

Figure 122. Projected change in average wet season precipitation in the Shasta Region. 2025, RCP4.5 scenario.

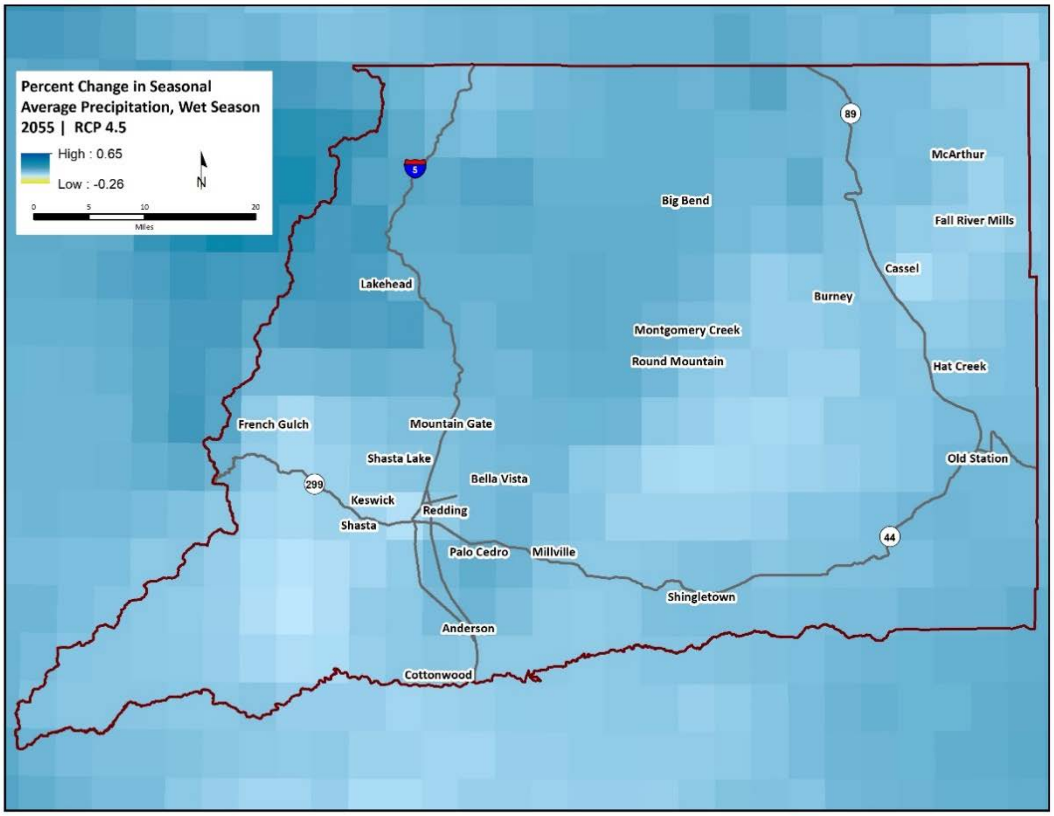

Figure 123. Projected change in average wet season precipitation in the Shasta Region. 2055, RCP4.5 scenario.

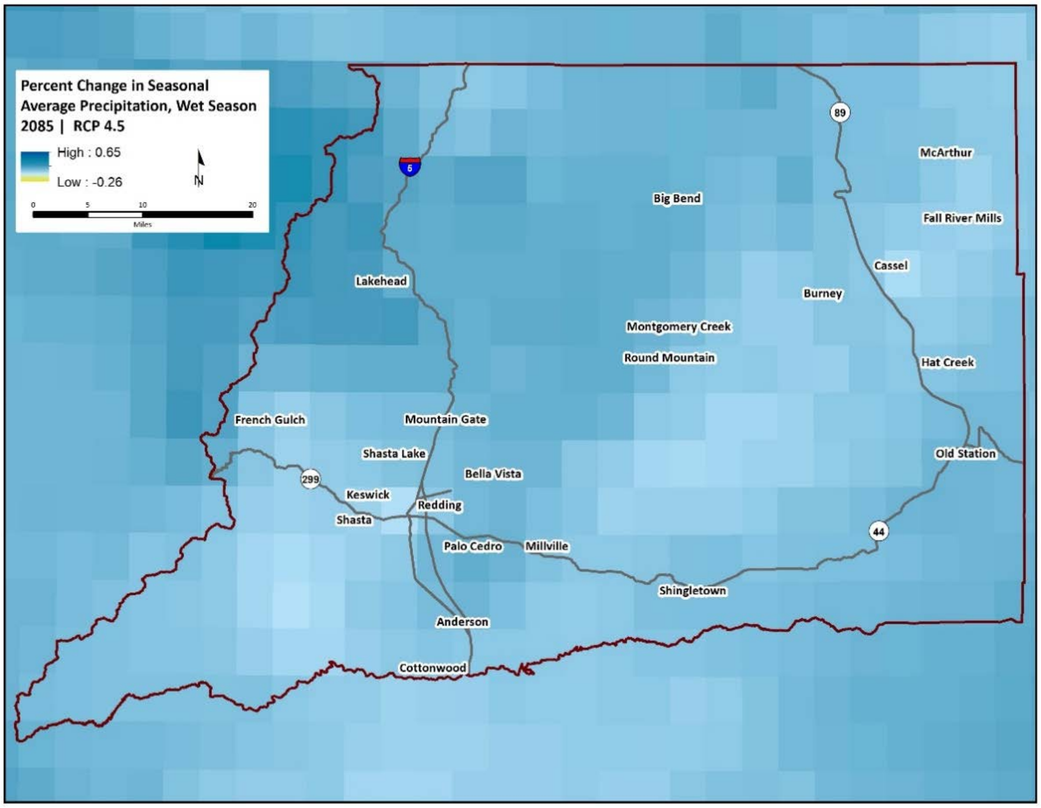

Figure 124.Projected change in average wet season precipitation in the Shasta Region. 2085, RCP4.5 scenario.

Unconstrained Emissions Scenario (RCP8.5)

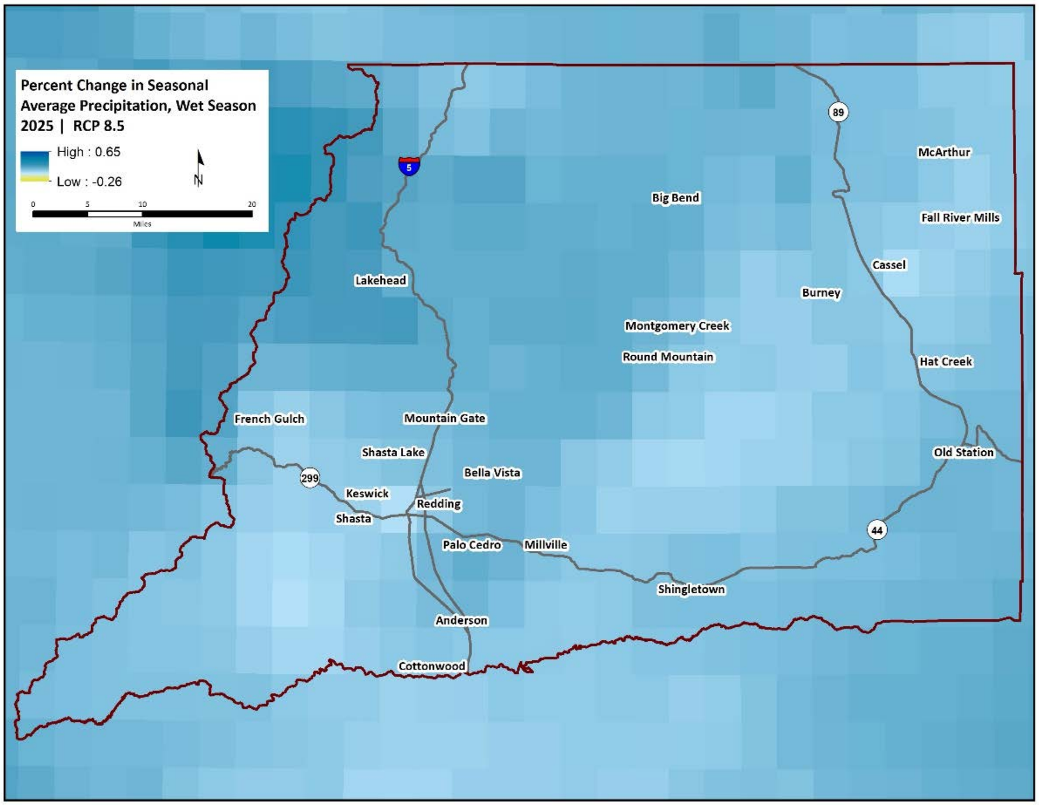

Figure 125.Projected change in average wet season precipitation in the Shasta Region. 2025, RCP8.5 scenario.

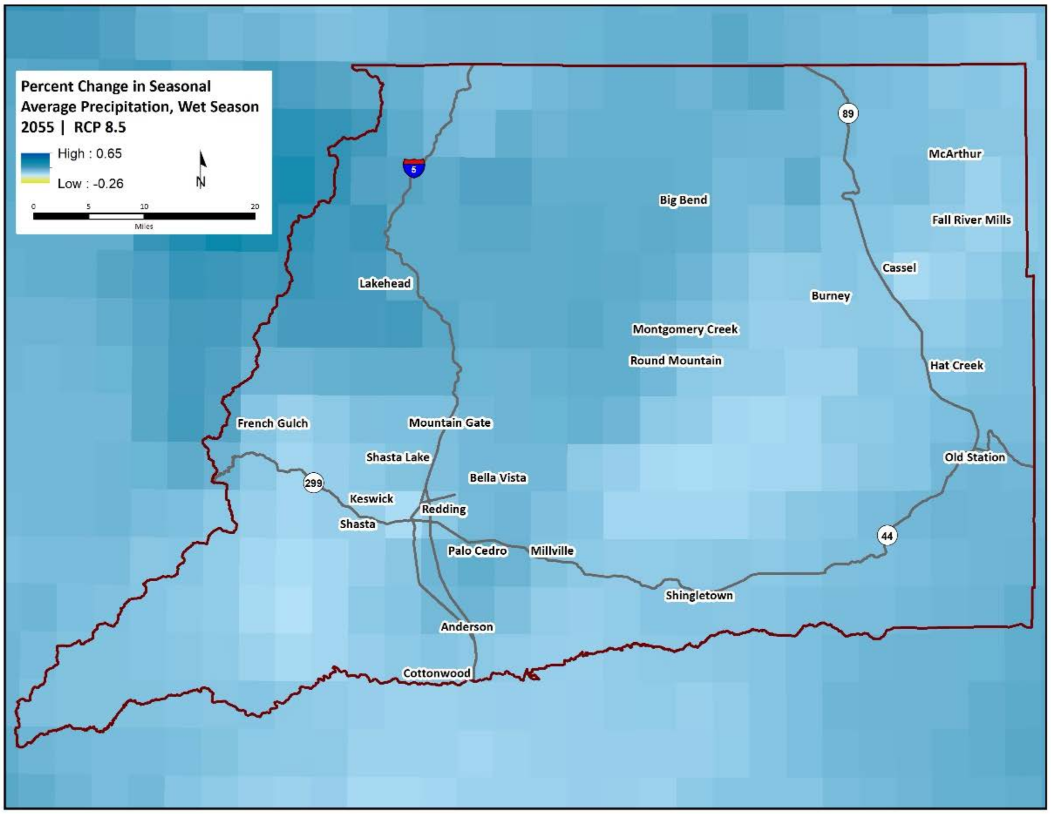

Figure 126. Projected change in average wet season precipitation in the Shasta Region. 2055, RCP8.5 scenario.

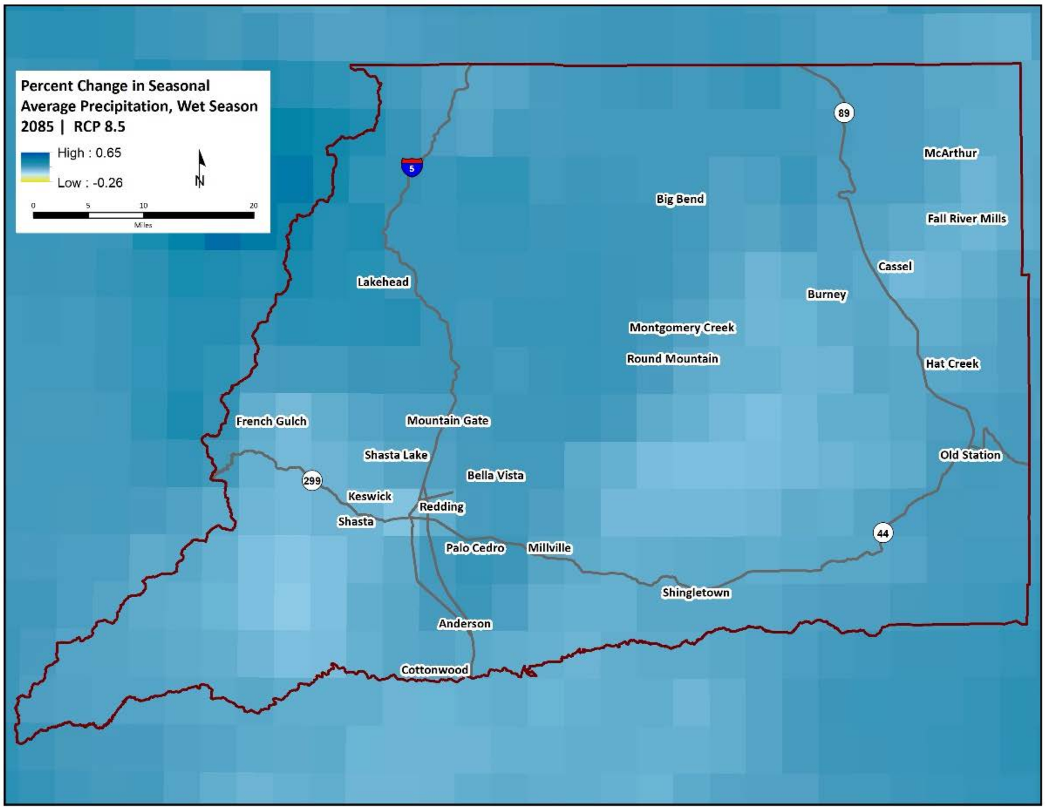

Figure 127. Projected change in average wet season precipitation in the Shasta Region. 2085, RCP8.5 scenario.

Percent Change in Extreme Precipitation Event Intensity

25-year Event

Reduced Emissions Scenario (RCP4.5)

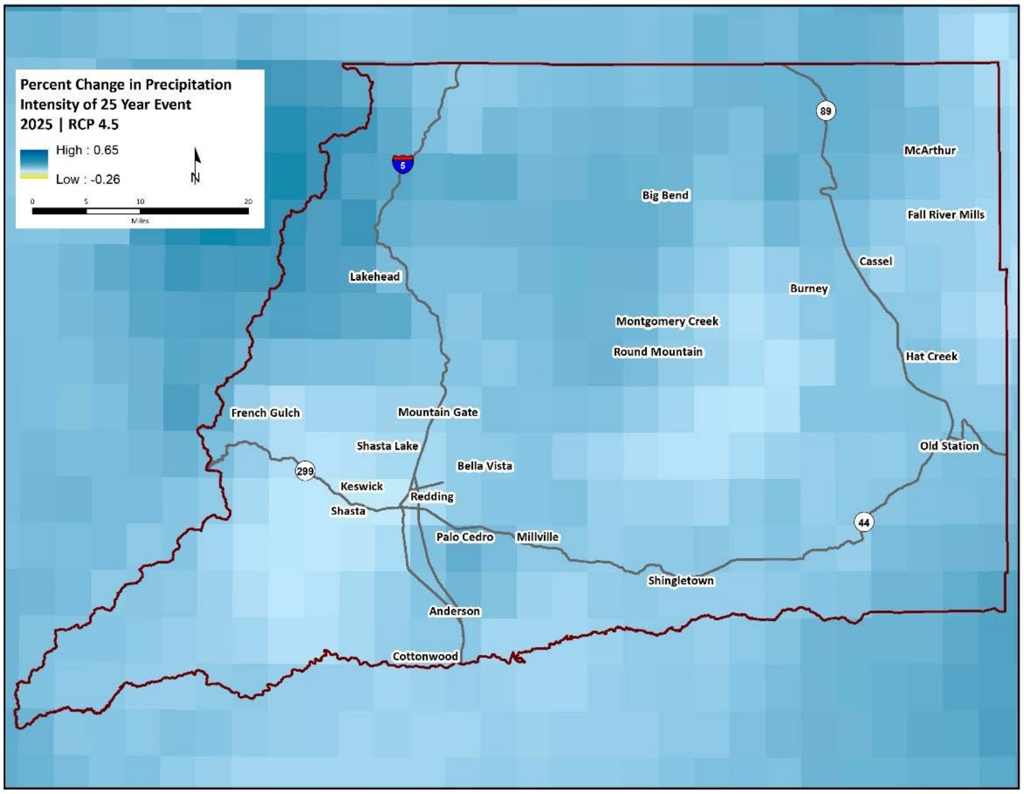

Figure 128. Projected percent change in intensity of 25-year extreme precipitation event. 2025, RCP4.5.

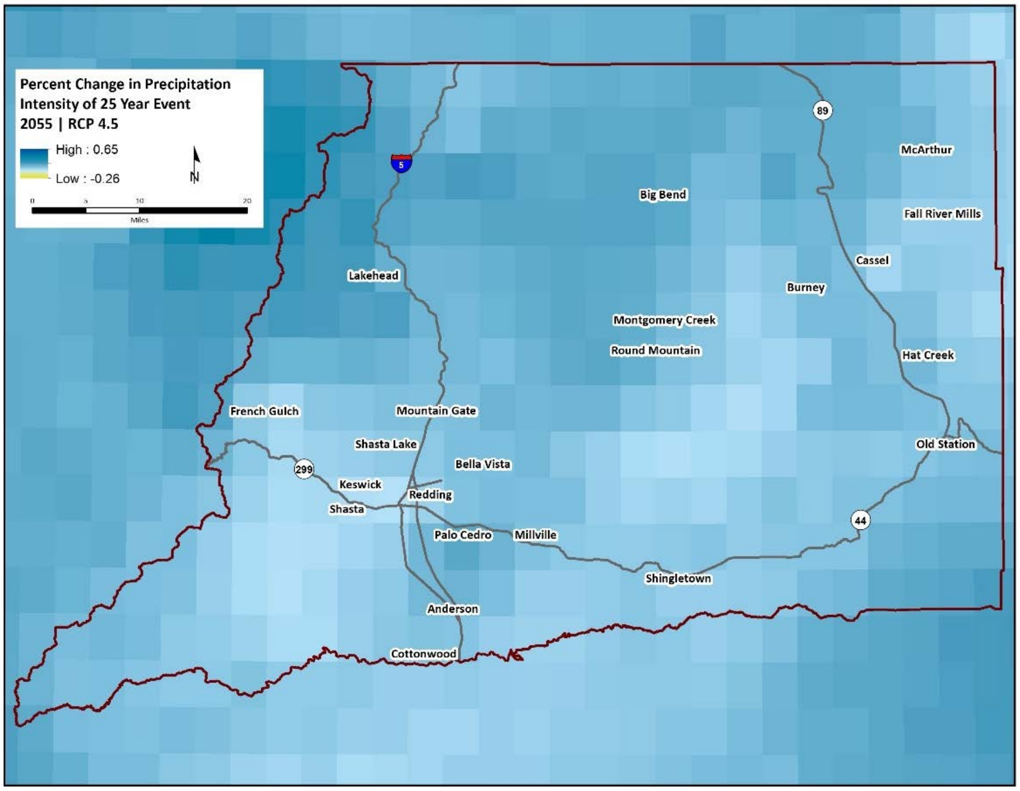

Figure 129. Projected percent change in intensity of 25-year extreme precipitation event. 2055, RCP4.5.

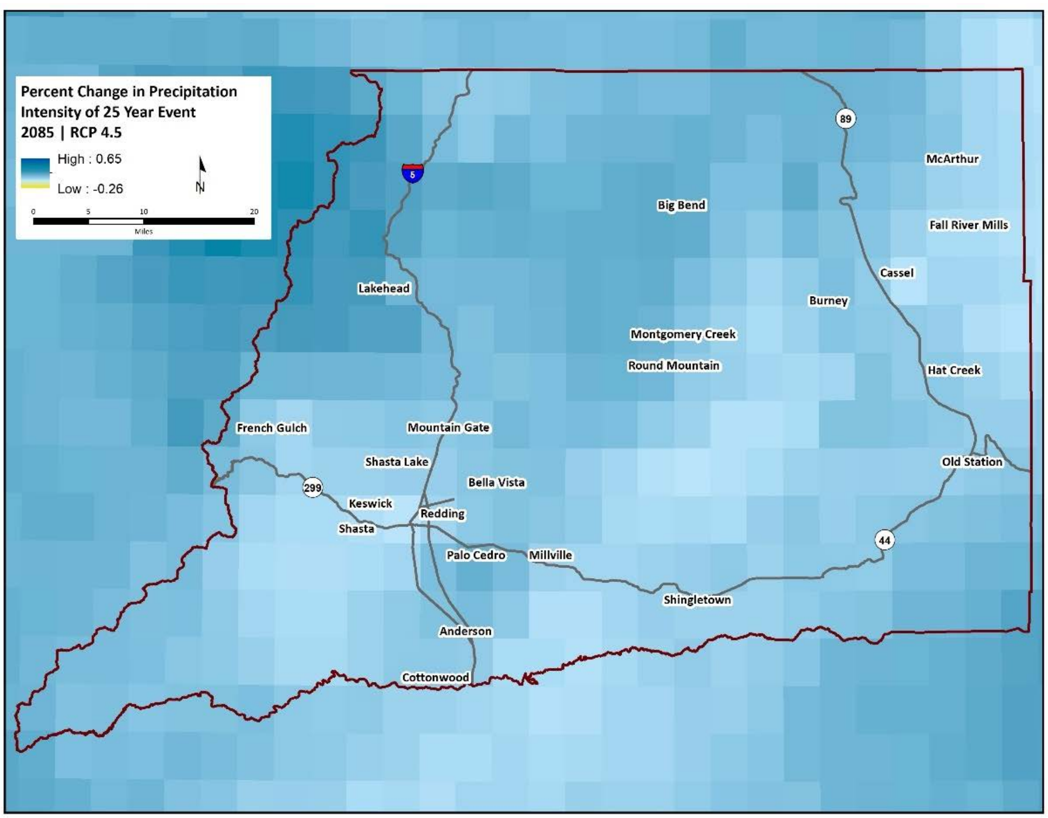

Figure 130. Projected percent change in intensity of 25-year extreme precipitation event. 2085, RCP4.5.

Unconstrained Emissions Scenario (RCP8.5)

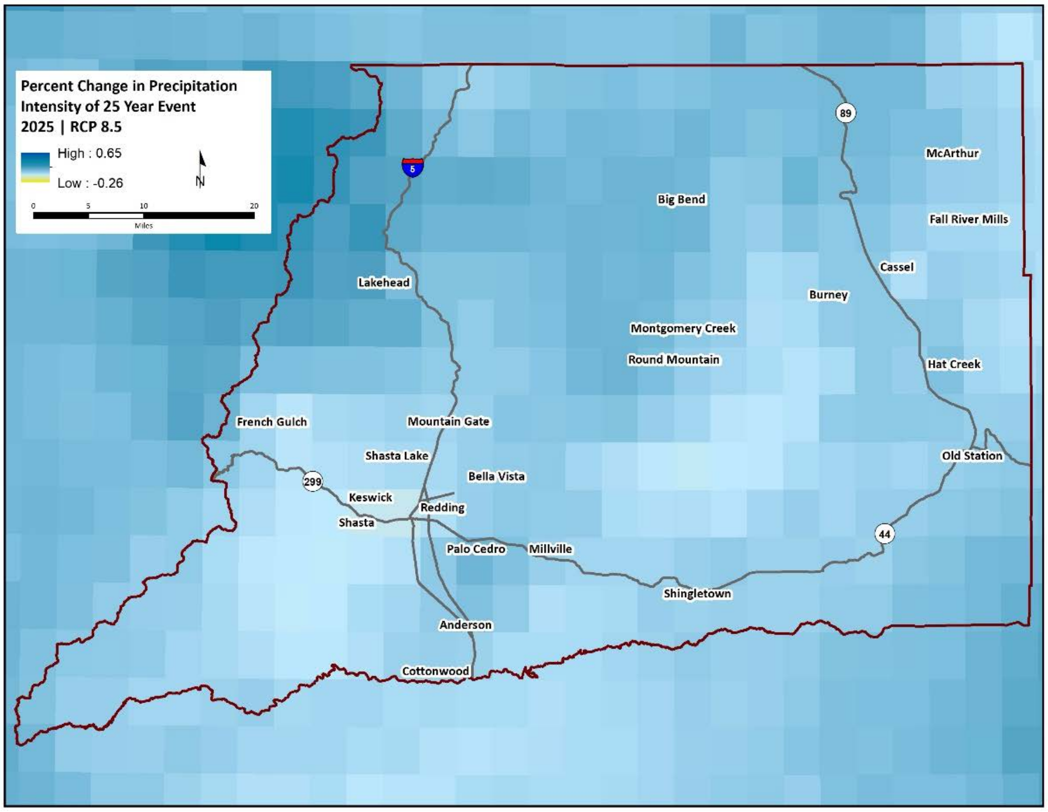

Figure 131. Projected percent change in intensity of 25-year extreme precipitation event. 2025, RCP8.5.

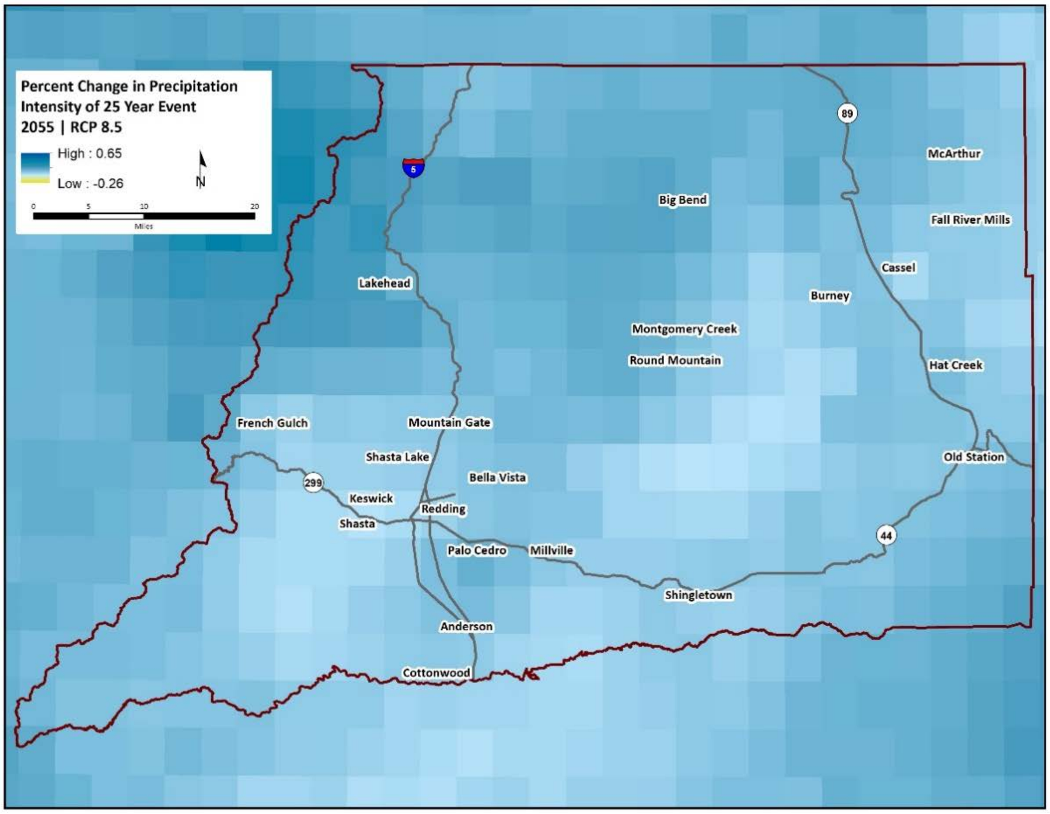

Figure 132. Projected percent change in intensity of 25-year extreme precipitation event. 2055, RCP8.5.

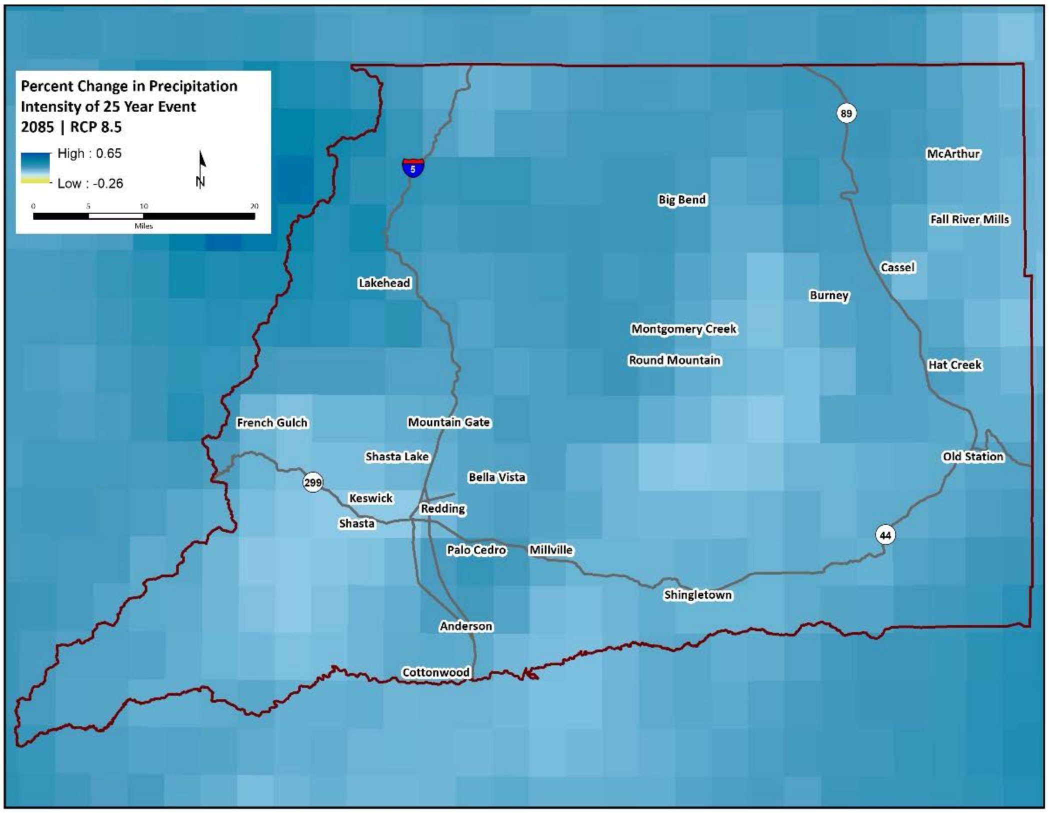

Figure 133. Projected percent change in intensity of 25-year extreme precipitation event. 2085, RCP8.5.

100-year Event

Reduced Emissions Scenario (RCP4.5)

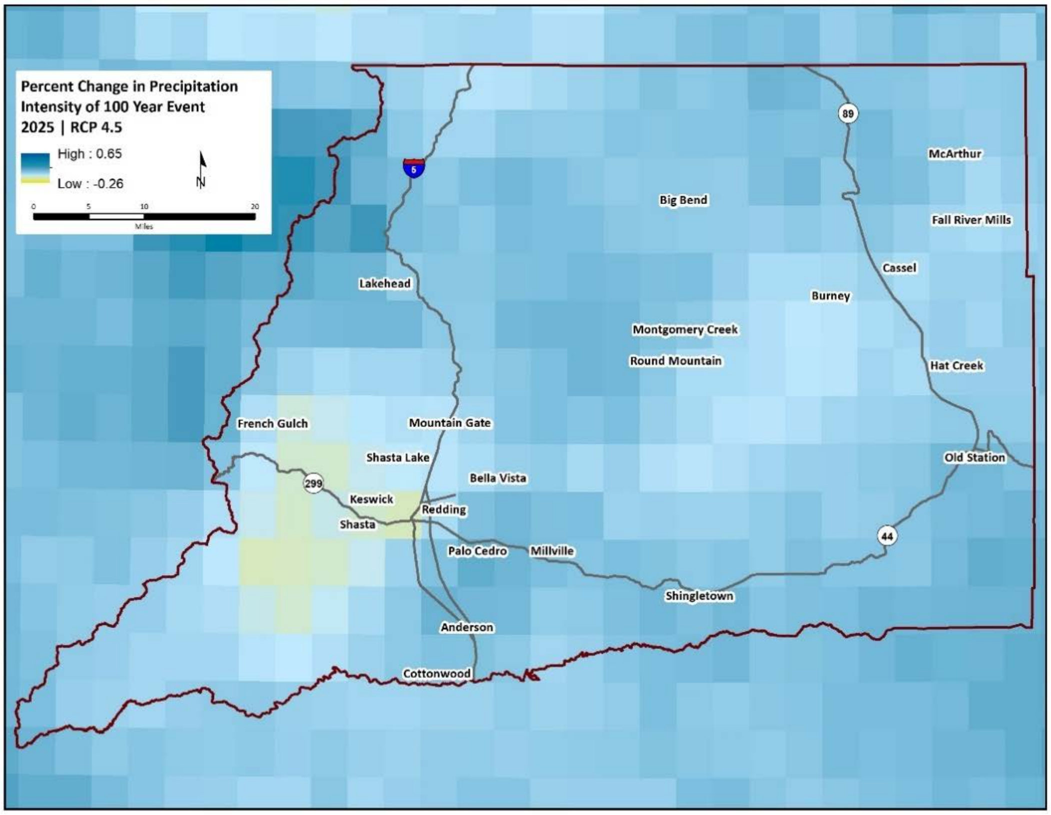

Figure 134. Projected percent change in intensity of 100-year extreme precipitation event. 2025, RCP4.5.

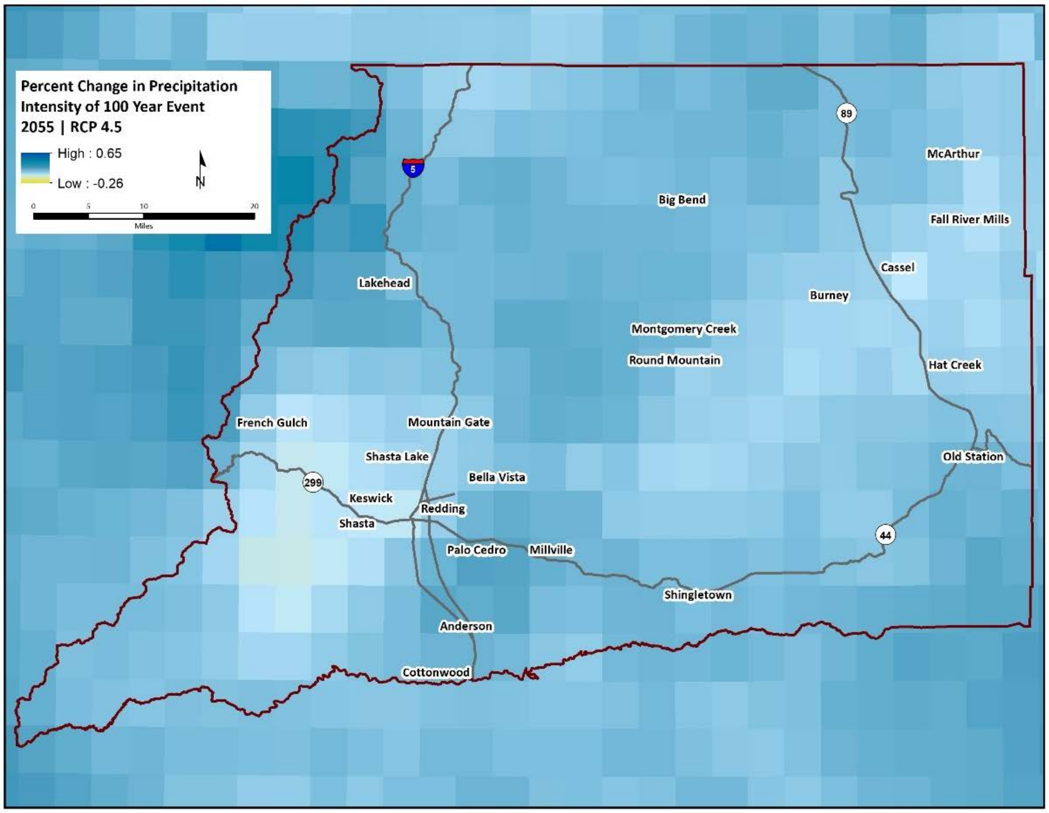

Figure 135. Projected percent change in intensity of 100-year extreme precipitation event. 2055, RCP4.5.

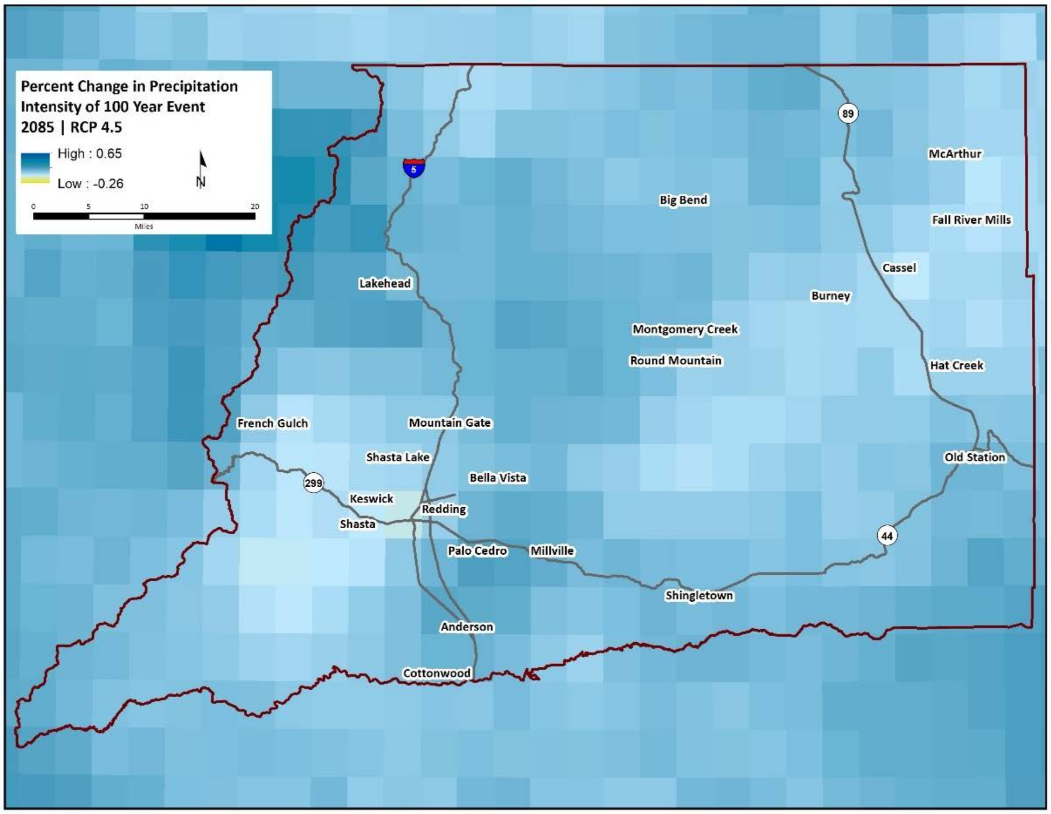

Figure 136. Projected percent change in intensity of 100-year extreme precipitation event. 2085, RCP4.5.

Unconstrained Emissions Scenario (RCP8.5)

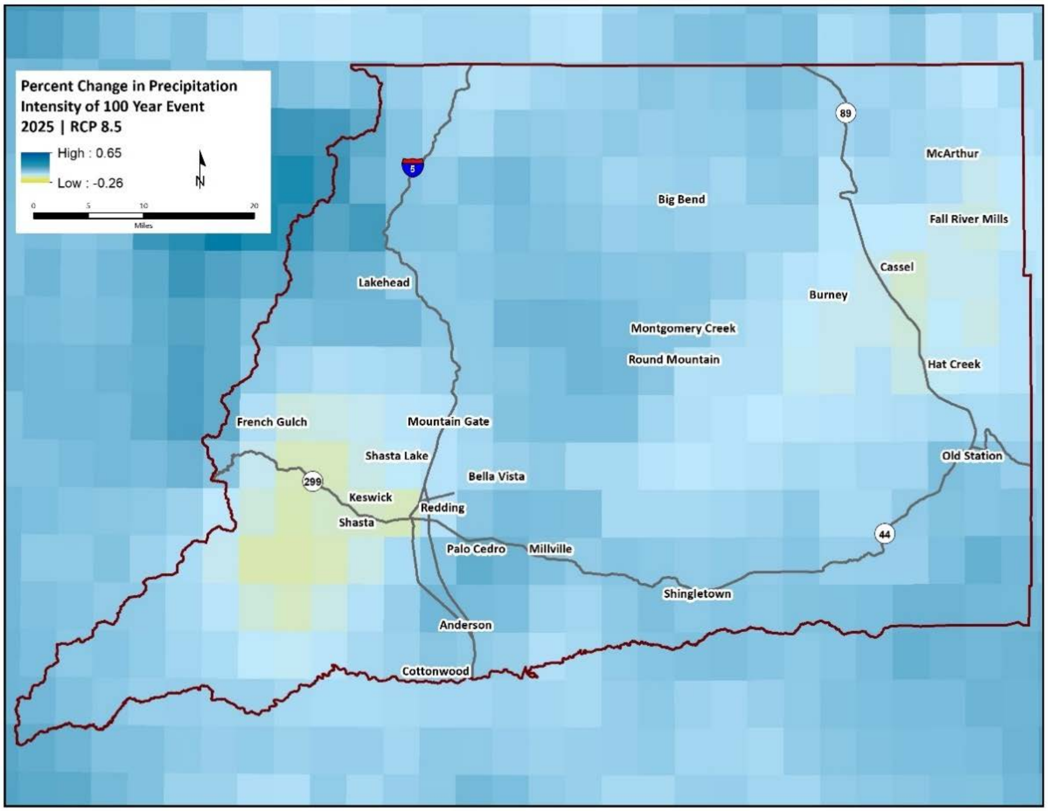

Figure 137. Projected percent change in intensity of 100-year extreme precipitation event. 2025, RCP8.5.

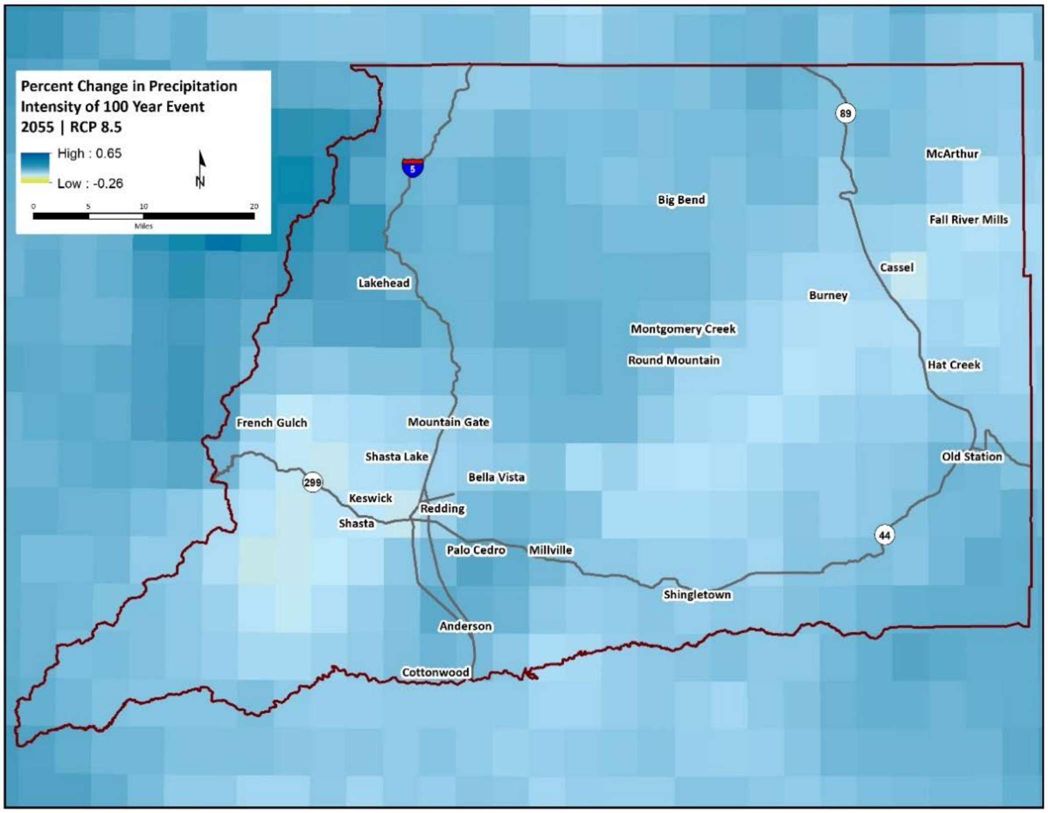

Figure 138. Projected percent change in intensity of 100-year extreme precipitation event. 2055, RCP8.5.

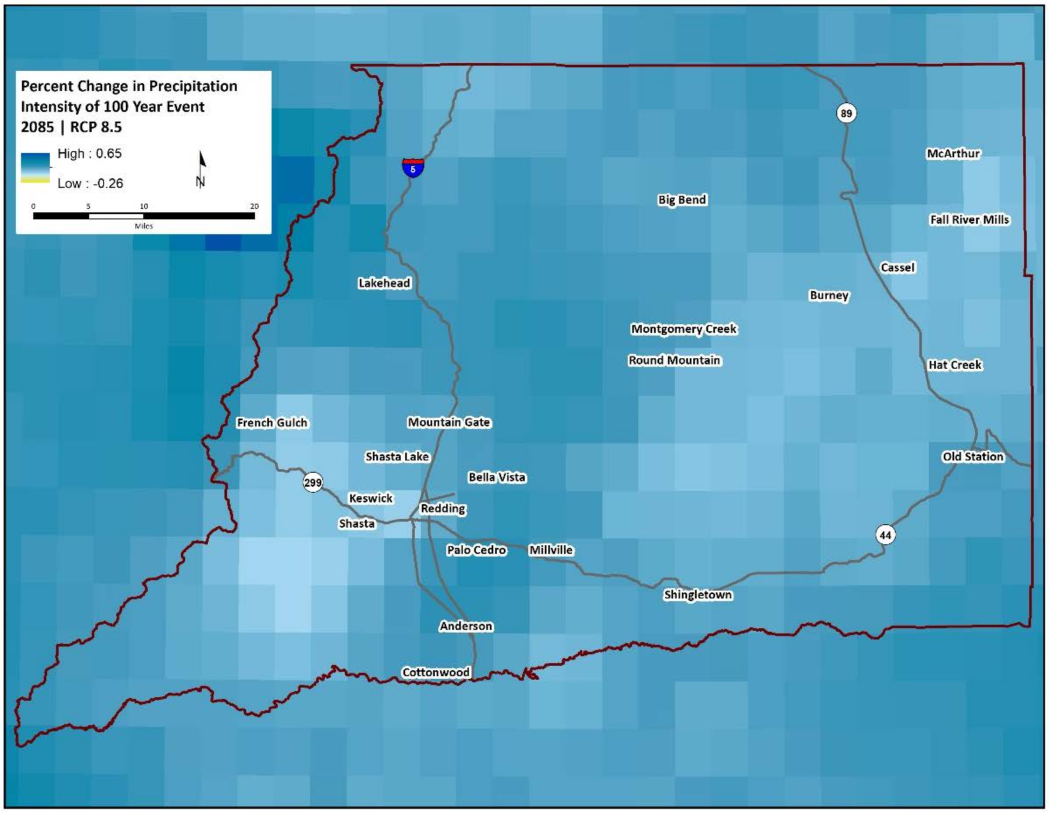

Figure 139. Projected percent change in intensity of 100-year extreme precipitation event. 2085, RCP8.5.

500-year Event

Reduced Emissions Scenario (RCP4.5)

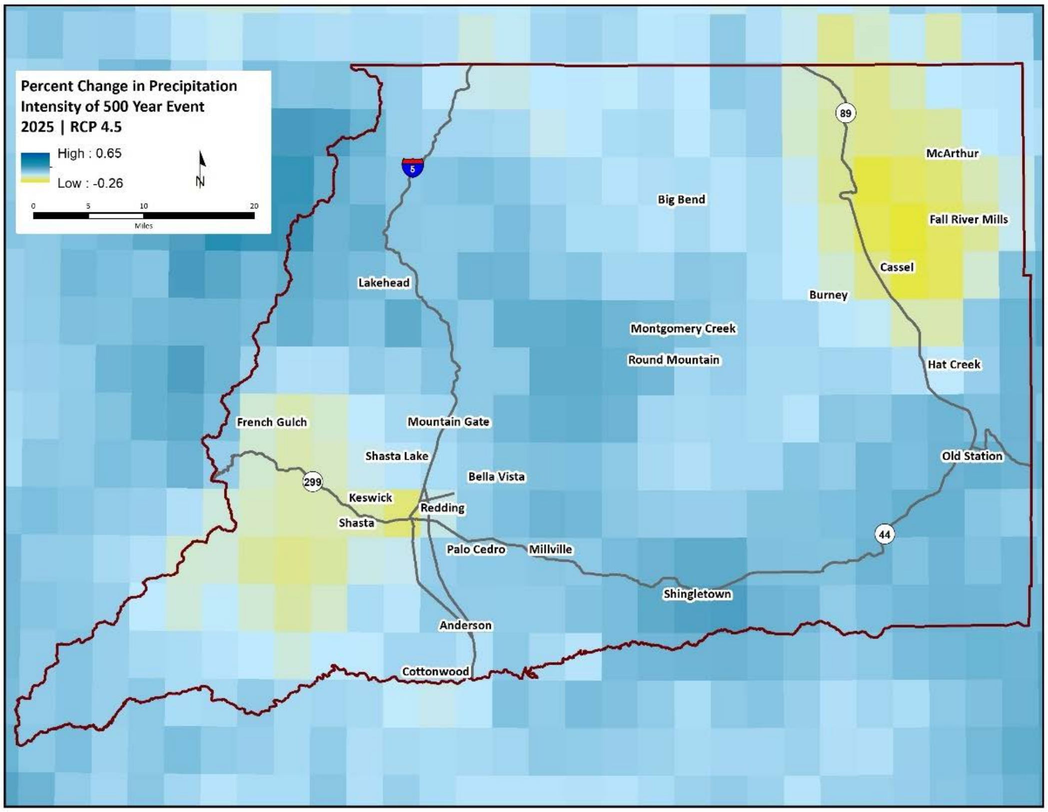

Figure 140. Projected percent change in intensity of 500-year extreme precipitation event. 2025, RCP4.5.

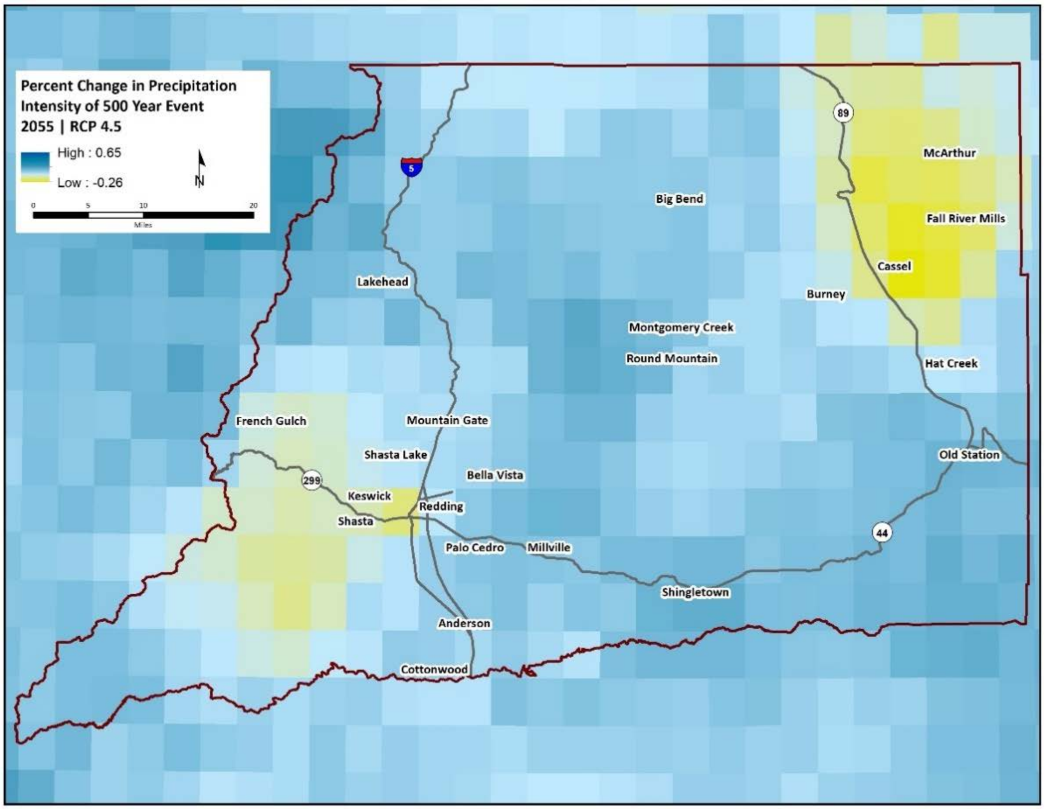

Figure 141. Projected percent change in intensity of 500-year extreme precipitation event. 2055, RCP4.5.

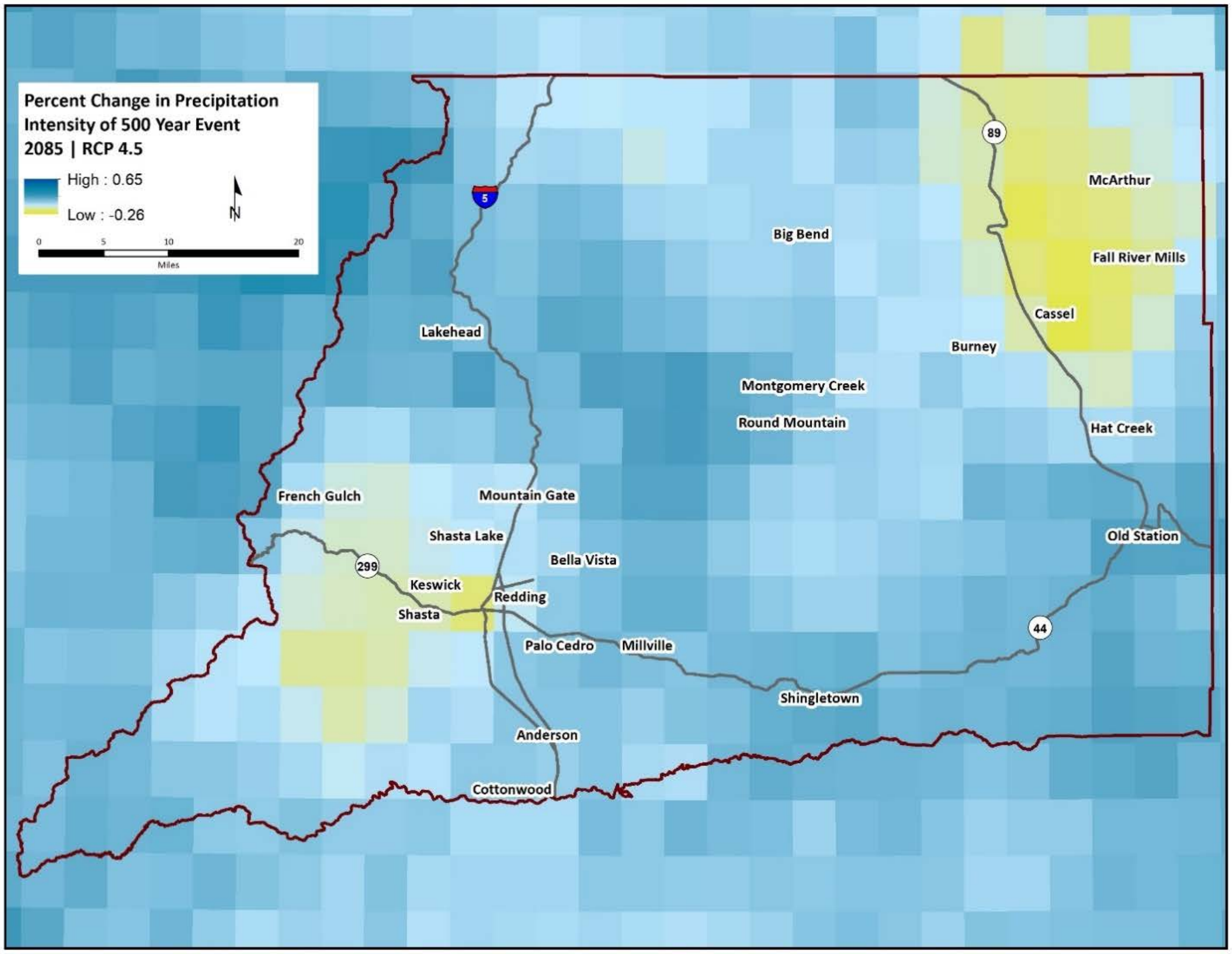

Figure 142. Projected percent change in intensity of 500-year extreme precipitation event. 2085, RCP4.5.

Unconstrained Emissions Scenario (RCP8.5)

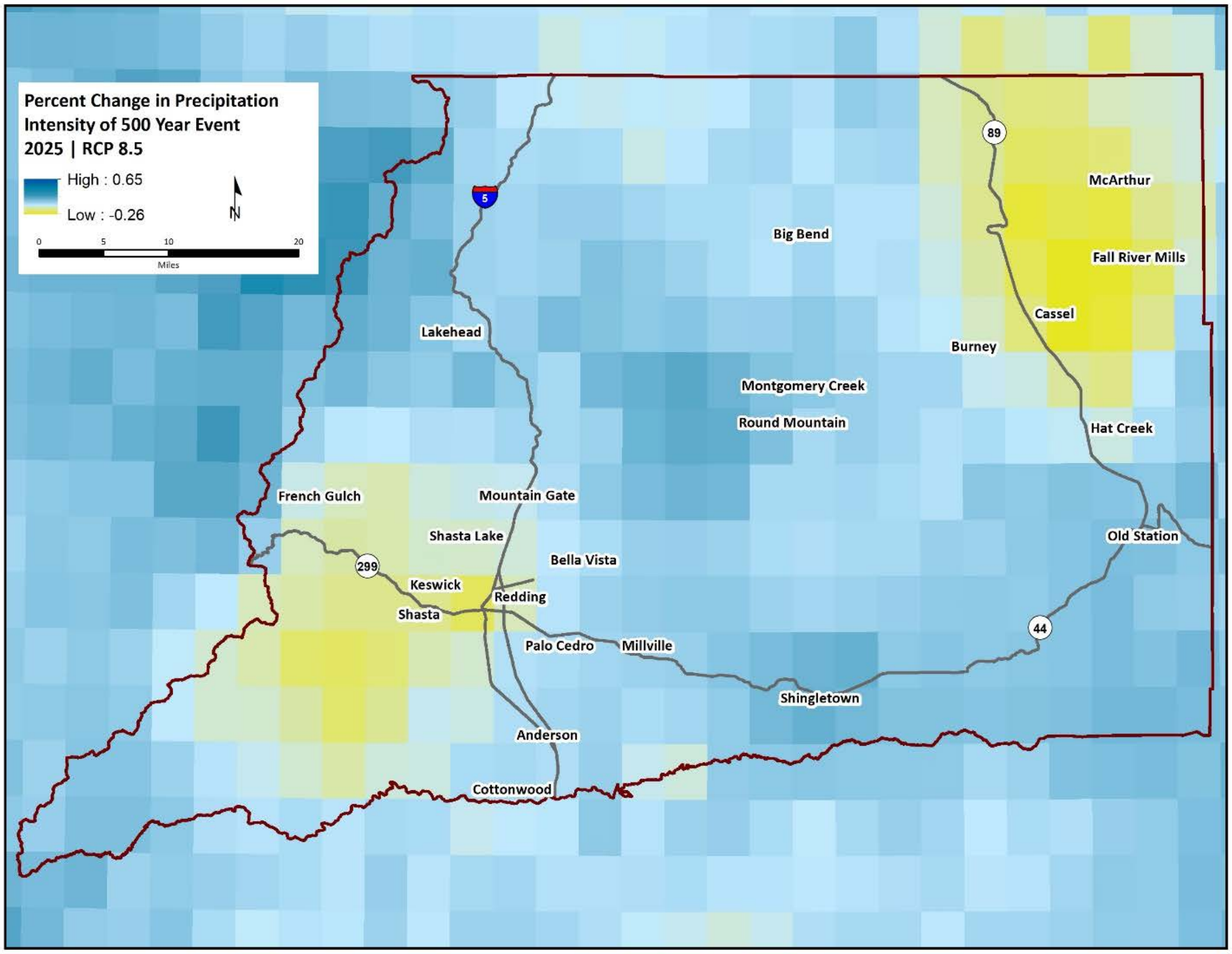

Figure 143. Projected percent change in intensity of 500-year extreme precipitation event. 2025, RCP8.5.

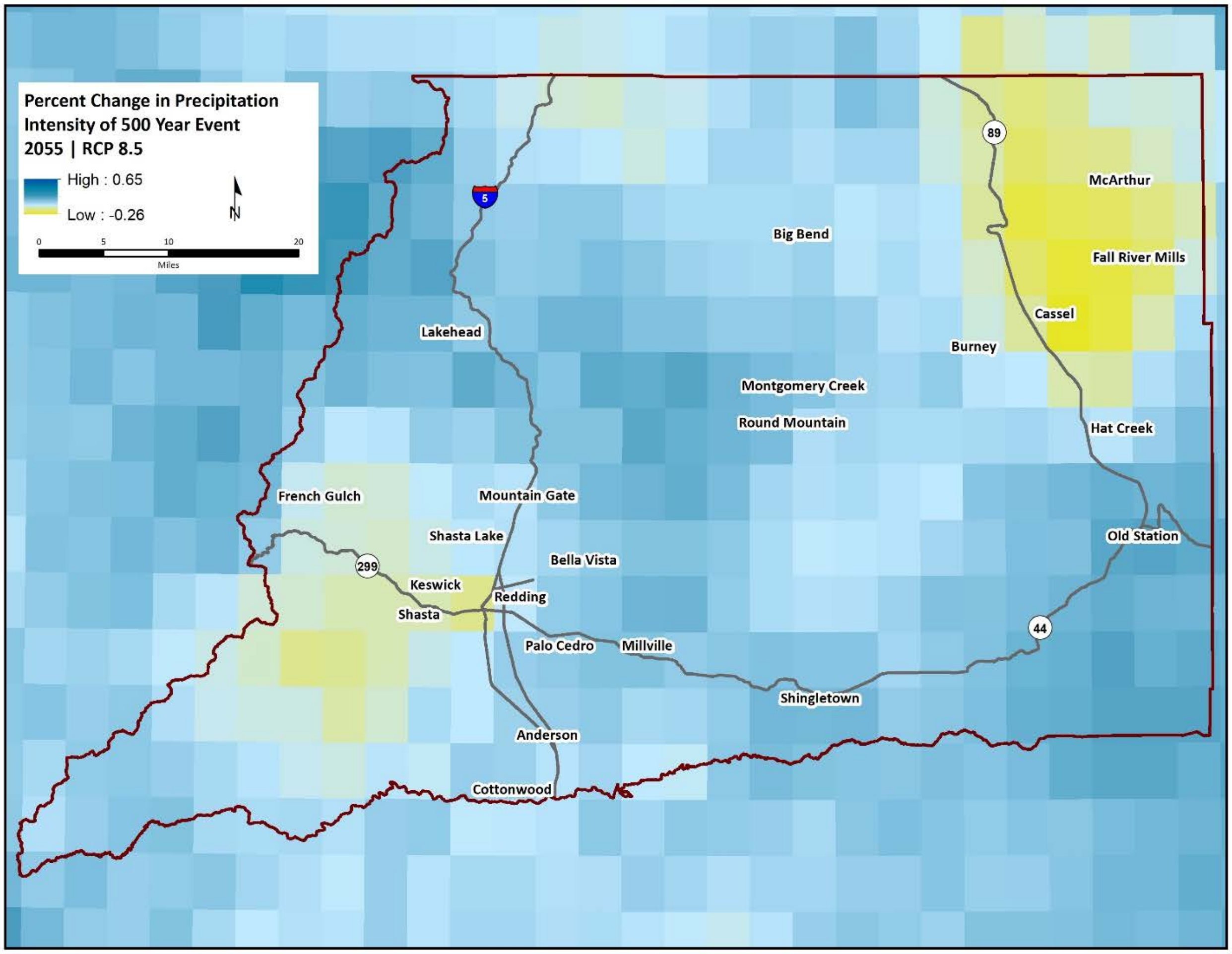

Figure 144. Projected percent change in intensity of 500-year extreme precipitation event. 2055, RCP8.5.

Wildfire Projections

Decadal Wildfire Probability

Historical

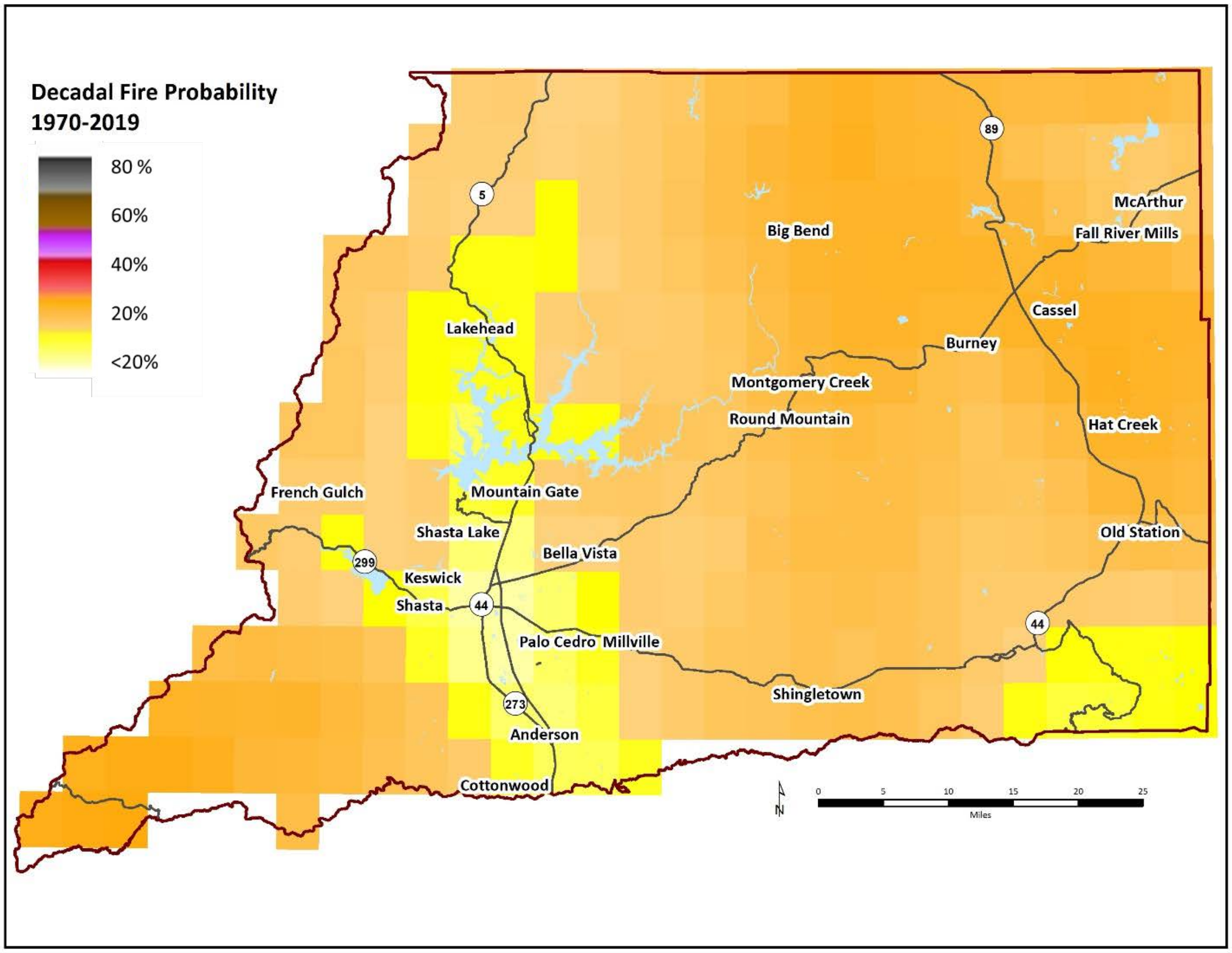

Figure 145. Average decadal Fire Probability in the historical period (1970 - 2019).

Reduced Emissions Scenario (RCP4.5)

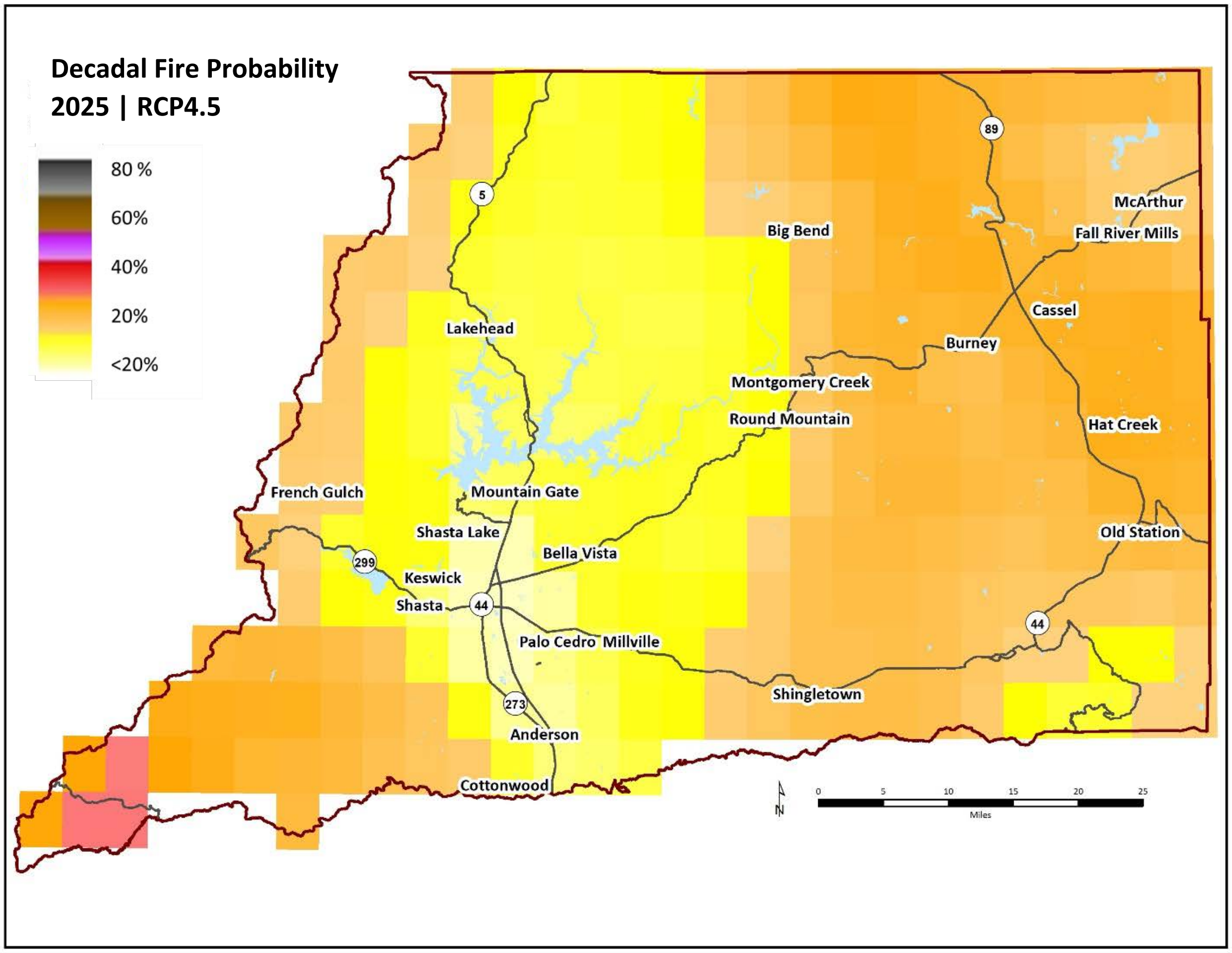

Figure 146. Decadal Fire Probability in 2025, RCP4.5.

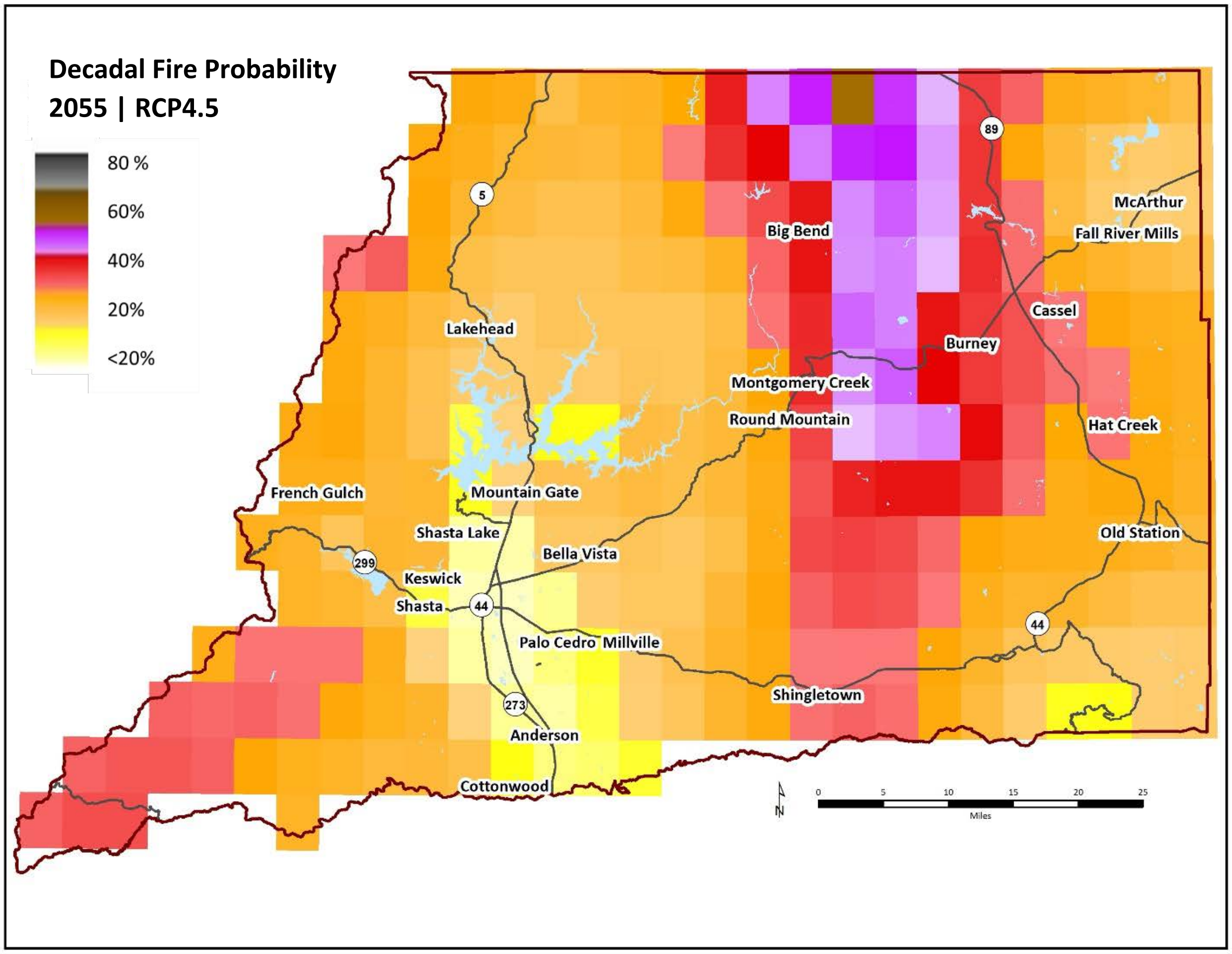

Figure 147. Decadal Fire Probability in 2055, RCP4.5.

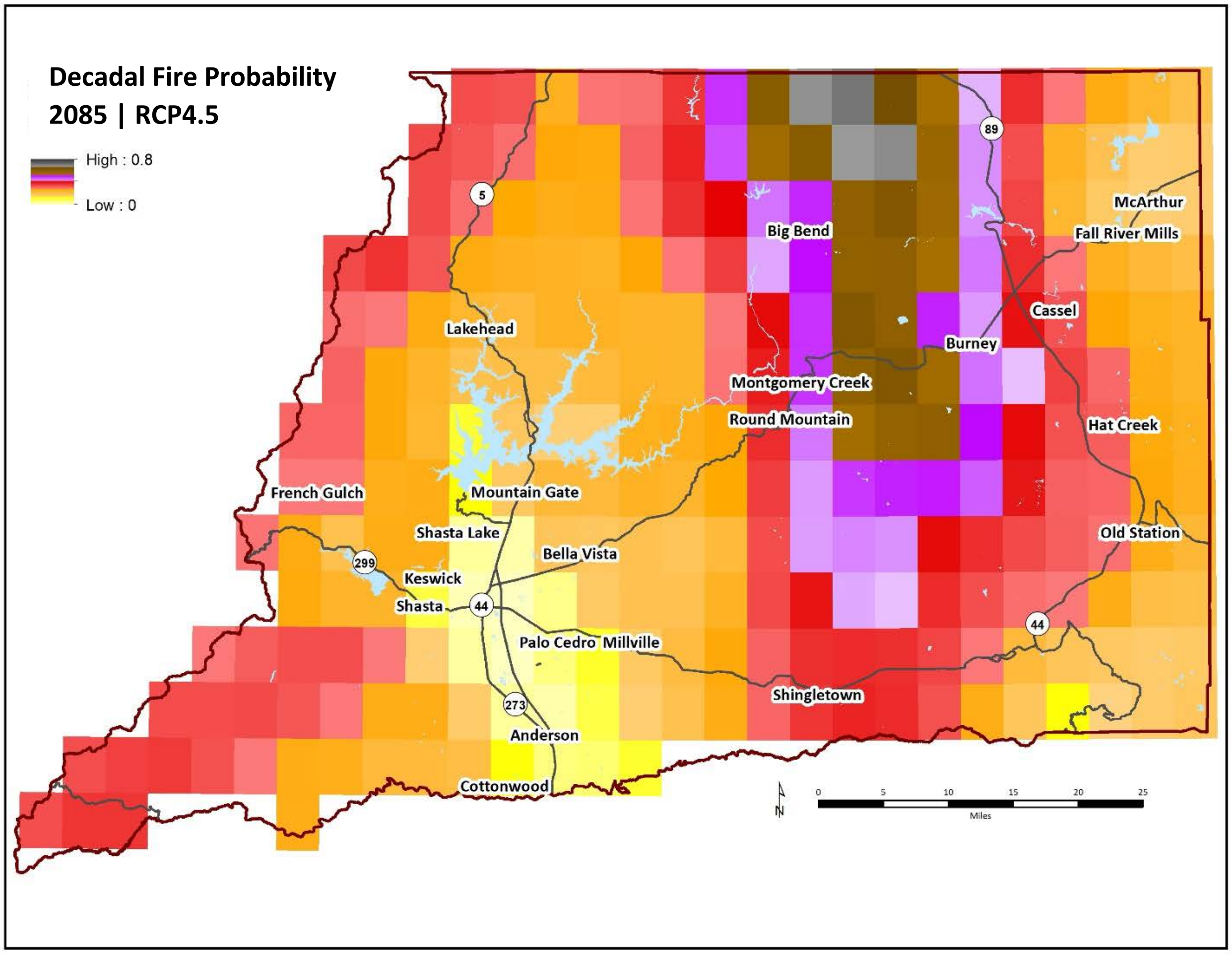

Figure 148. Decadal Fire Probability in 2085, RCP4.5.

Unconstrained Emissions Scenario (RCP8.5)

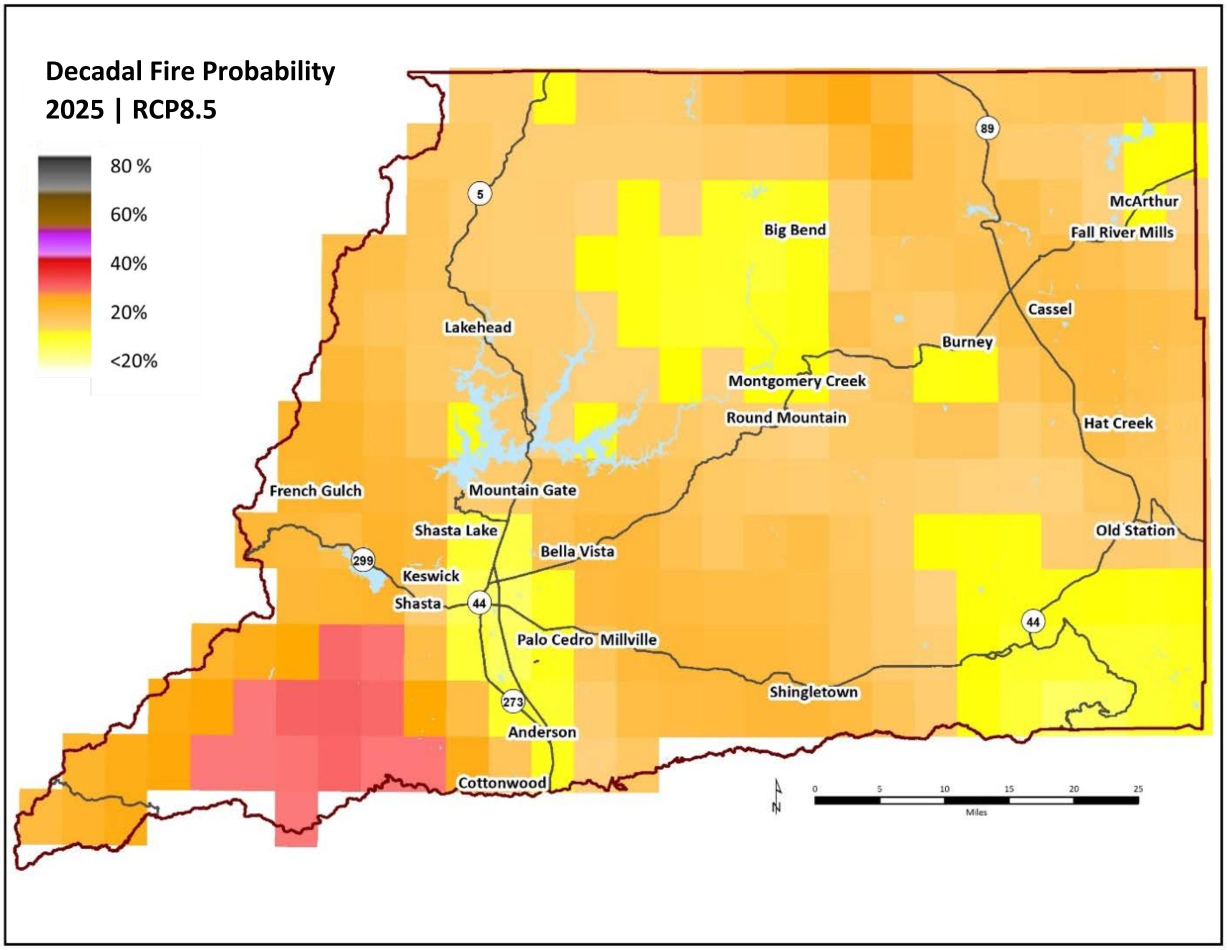

Figure 149. Decadal Fire Probability in 2025, RCP8.5.

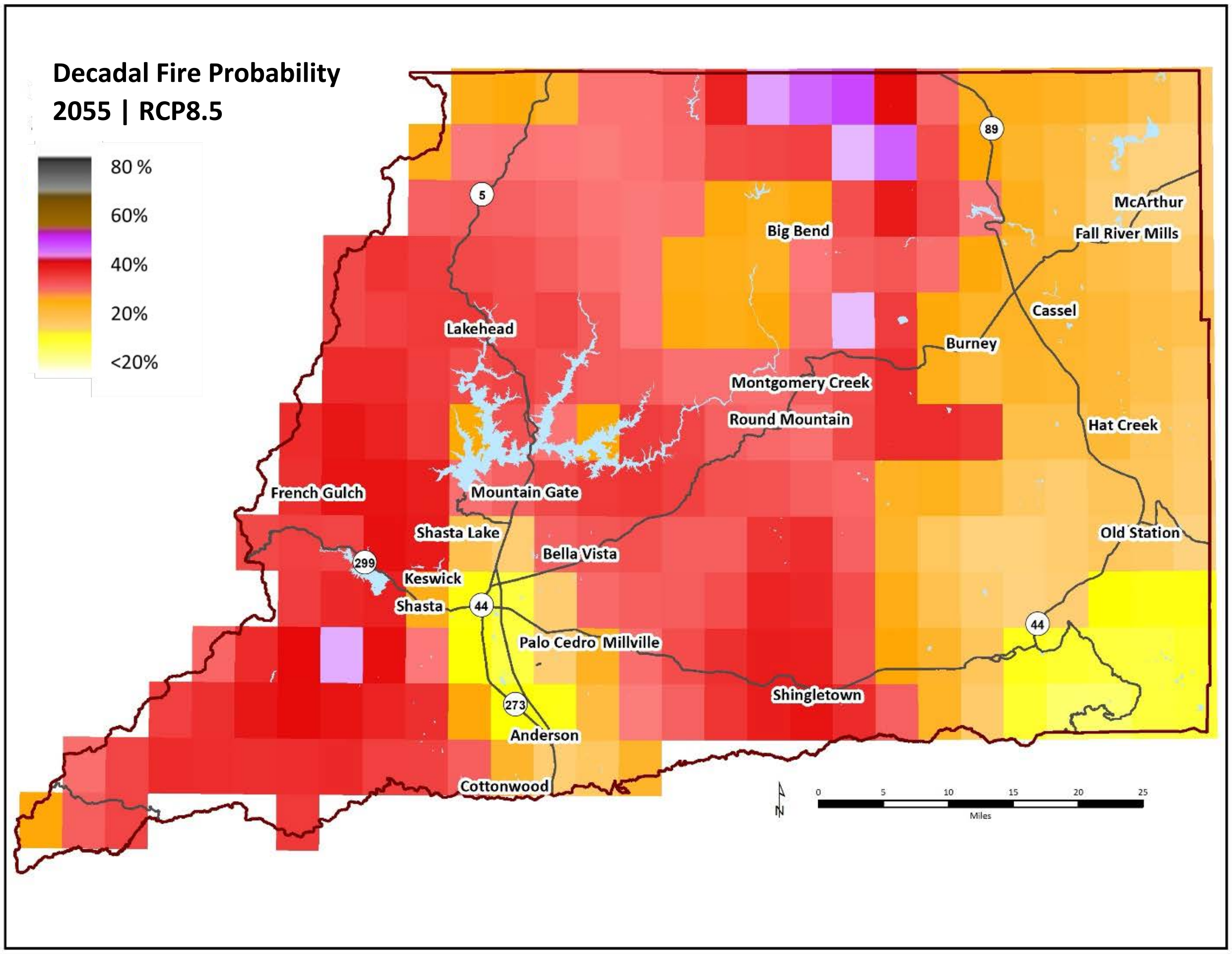

Figure 150. Decadal Fire Probability in 2055, RCP8.5.

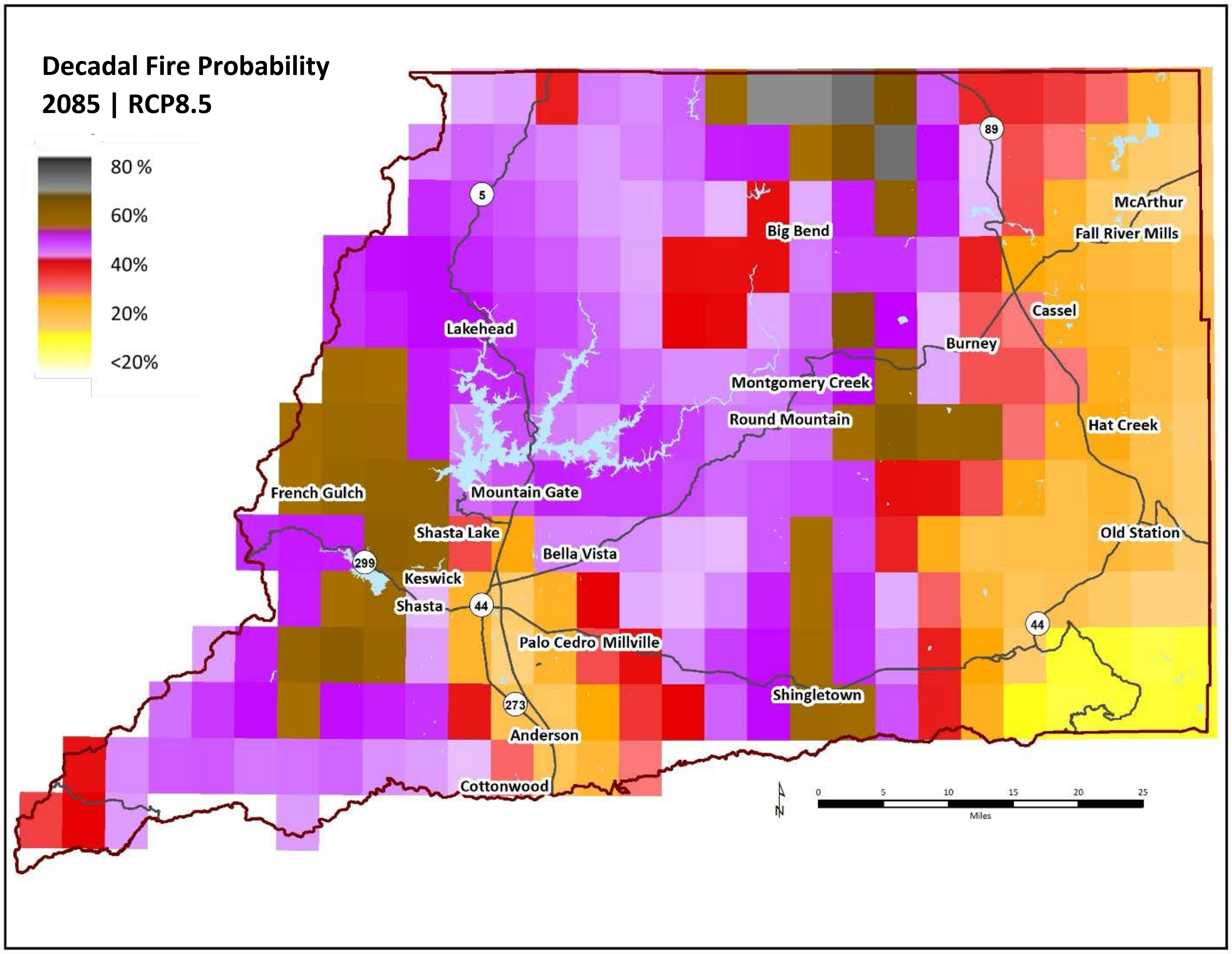

Figure 151. Decadal Fire Probability in 2085, RCP8.5.

Wildfire Area Burned

Historical

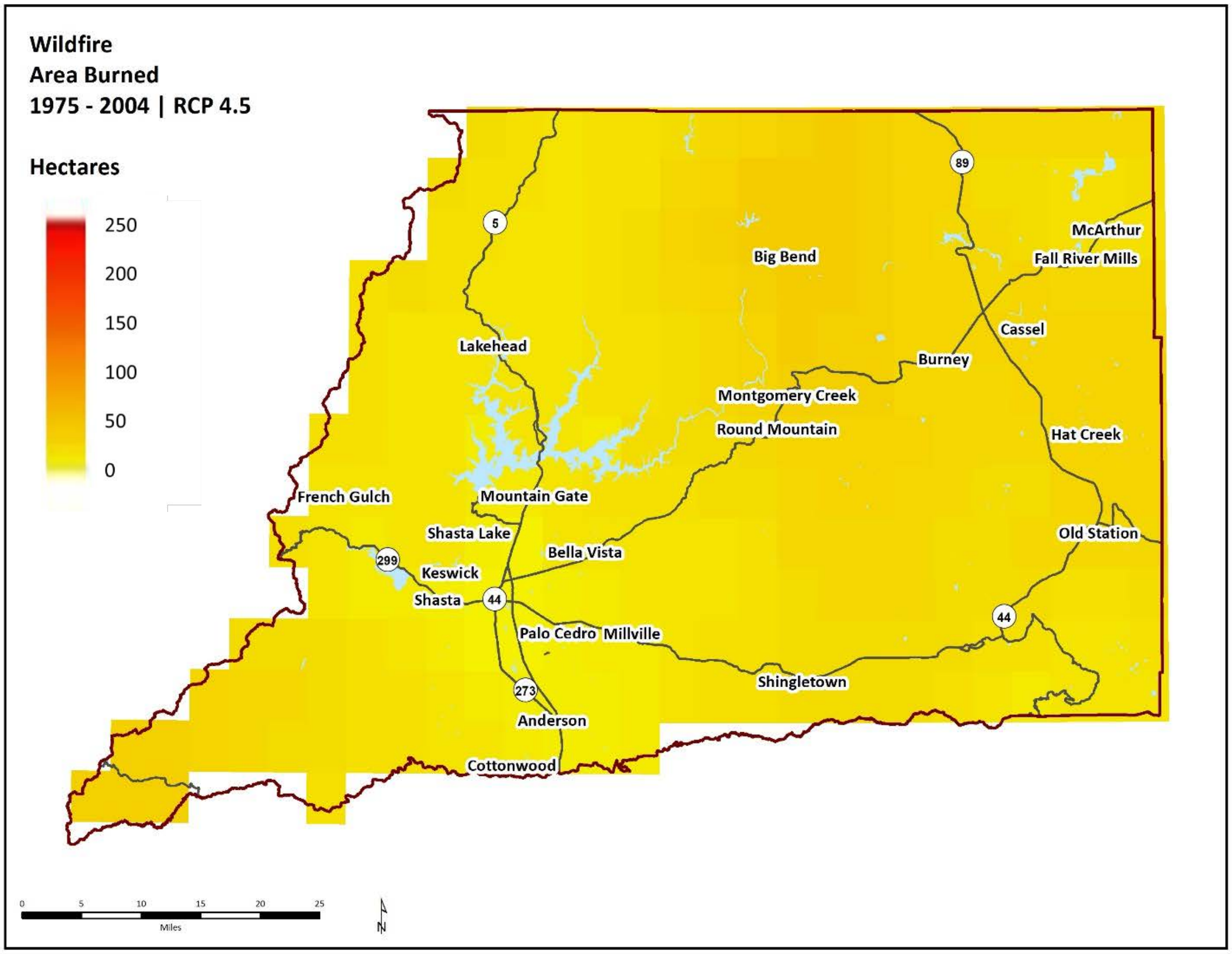

Figure 152. Average annual area burned in the historical period (1975 - 2004).

Reduced Emissions Scenario (RCP4.5)

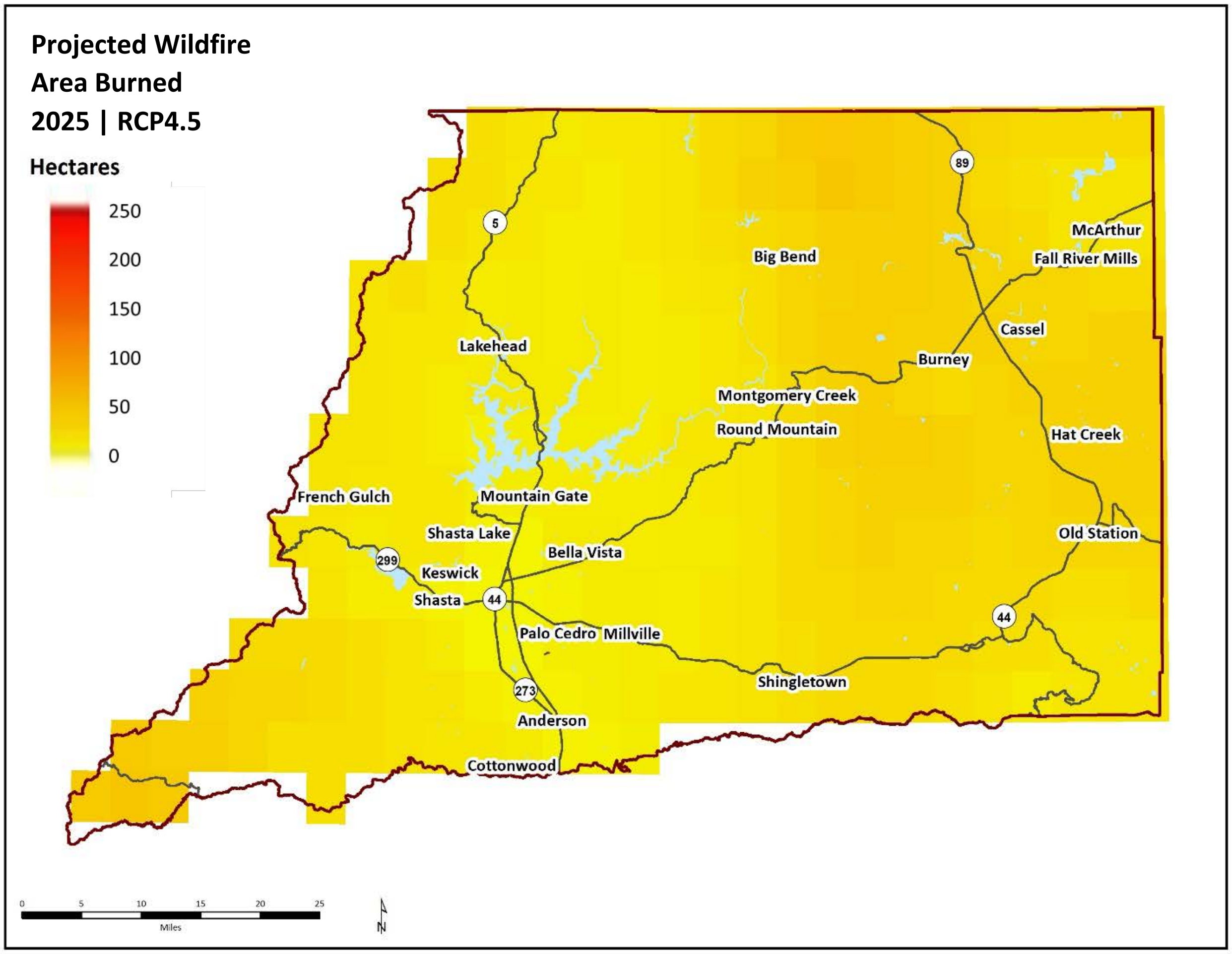

Figure 153. Average annual area burned in 2025, RCP4.5.

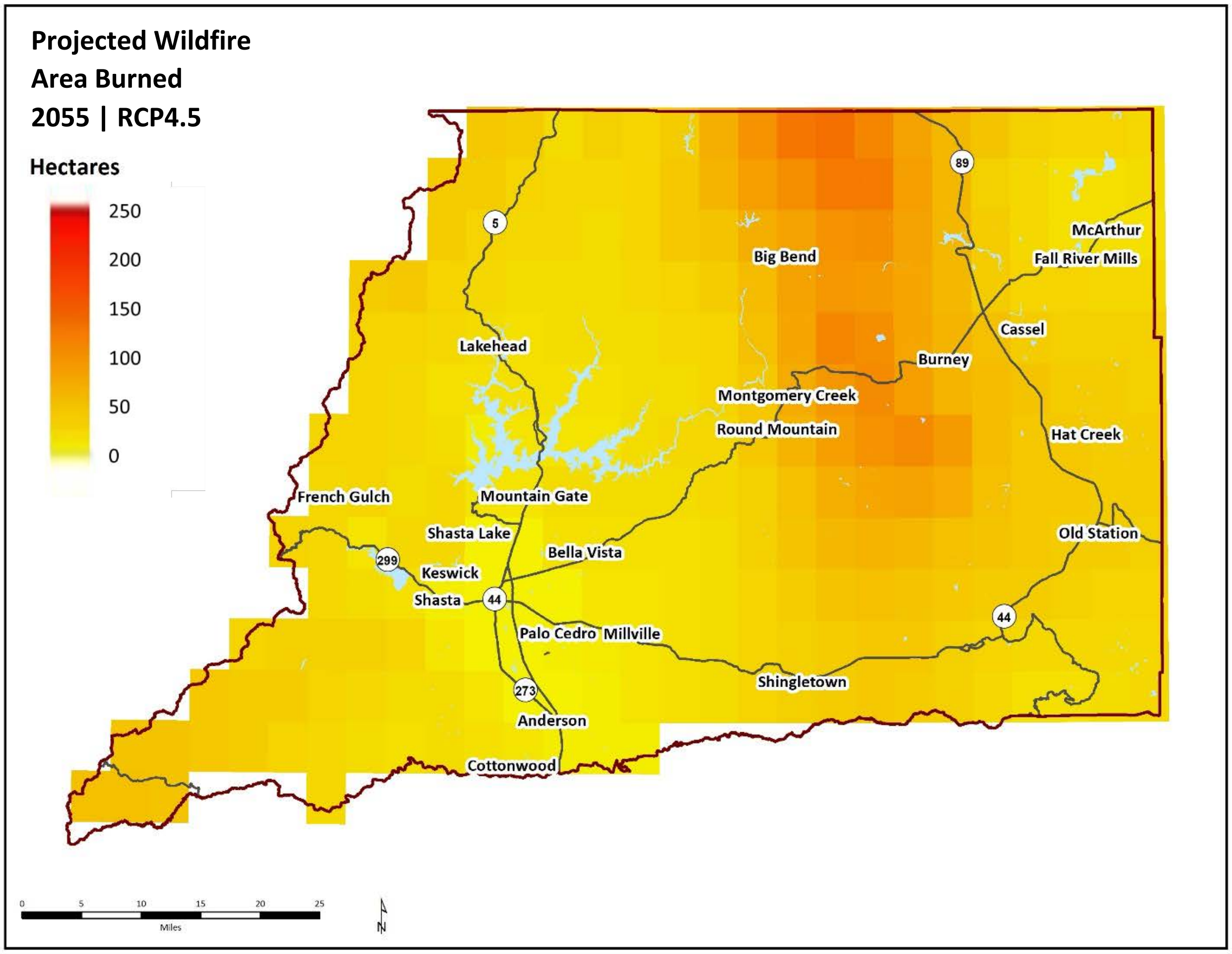

Figure 154. Average annual area burned in 2055, RCP4.5.

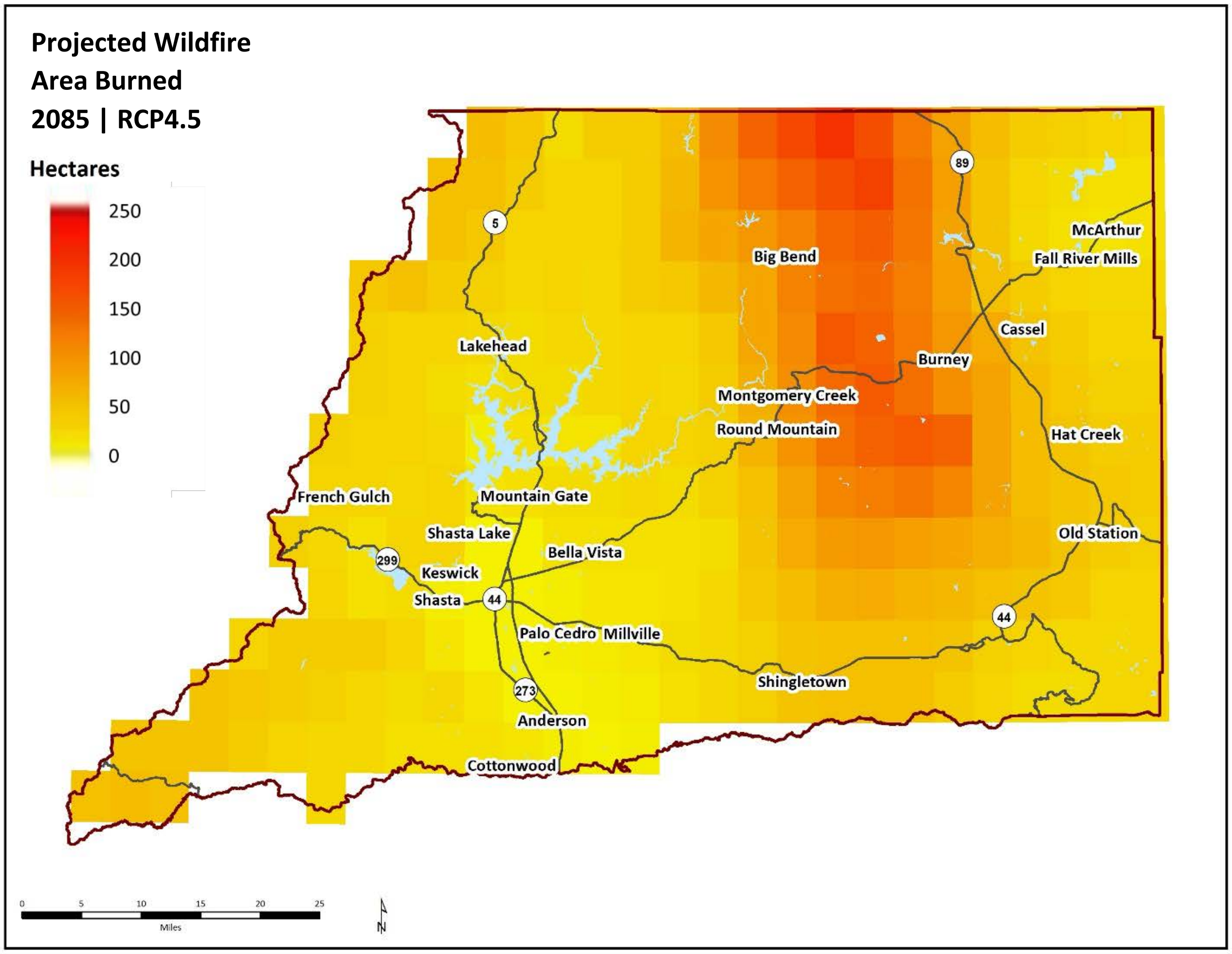

Figure 155. Average annual area burned in 2085, RCP4.5.

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Appendix D: Additional Comments

After several opportunities for review and feedback at multiple stages of this planning effort, the following comments were received from the partners below as the ResilientShasta plan was presented for adoption. SRTA staff is including in them as an appendix to this document as instructed by the SRTA Board of Directors.

City of Redding:

Here are some perspectives you may want to take into account as a SRTA Board Member when considering adoption of this document:

- Regional Mobility Adaptation Plan (RMAP) – W1 – note that post wildfire event inspections of bridge and culvert infrastructure is already done as a matter of standard practice. Projects are developed post-fire based on these inspections and forwarded to FEMA for project scoping and funding. Having a discussion in the Regional Transportation Plan is certainly valid and may help with obtaining funding but just know that agency staff will always accomplish this effort.

  [SRTA acknowledges this comment and hopes the balance of recommendations in this item (pages 106–107 of the ResilientShasta Plan) will be considered.]

- RMAP -W2 – note that document suggests Cal-Fire convene a twice yearly Hazardous Fuels Reduction Working Group with local agencies, counties, utilities and fire districts. While not a bad idea, should make sure Cal-Fire is on board and it does not overlap with already designed coordination processes. They also suggest meeting with large private landowners to coordinate and collaborate fuels reduction. This may be a significant challenge.

  [SRTA acknowledges this comment and takes it under advisement.]

- RMAP – E1 – this section makes assertions that current evacuation planning "….does not address key mobility gaps, including those for vulnerable populations…." This statement can be a liability post event and construed to place blame on a public agency for losses during events. Suggest modifying to soften language (like "should work to better address" or something similar.

  [Upon review, SRTA has changed the language in this section as the original language did not accurately reflect SRTA's views and intent.]

- RMAP – E1 – again, this section suggests a working group convene and lead by Shasta County Public Health to coordinate the needs of mobility challenged persons. Need to be considerate of who is given the responsibility, if they are willing and impact on agency resources. This is a huge challenge to identify where these persons may be located (and continuously updated). However, there are resources like RABA Demand Response Ridership lists, group home and senior center locations, and technology programs already in existence like the SNAP program (self-registration required) used by RPD to identify impaired persons prior to responding to calls for service.

[SRTA acknowledges this comment as well as the reality that all partner agencies are working within constraints.]

- RMAP – E2 – this section assigns primary responsibility to SRTA for assessing evacuation routes and identifying constraints on those roadways. Just note that ultimately these roadways are the responsibility of agencies and we hope that any suggested modifications to roadway width, CMS infrastructure, culverts, etc come with the additional funding needed (not redirect existing already stressed streets and road funding sources) to make these modifications. The concern is mandating improvements be done without sufficient funding or identifying constraints that could open us up to liability concerns post event. Fires can occur anywhere and there simply are [not] sufficient funds to address every scenario.

  [The recommendation is that "SRTA seek means (i.e., funding) to complete an evaluation… of the region's secondary access routes." This was brought up by partners as a challenge area. It is expected that any future evaluation would be a collaborative process with regional partners.]

- RMAP – E4 – this section places responsibility on agencies to develop evacuation plans and provide improvements including customized message signs, cameras, reversable lane lighting, etc. Again, the concern is placing the requirements on agencies without sufficient funding. In most cases all roads in the City are evacuation routes and we use them as such during events. They need to be flexible depending on the event and factors like wind condition, etc. Its not as simple as designating certain routes. The Incident Commander during the event will use all available resources to plan the safe evacuation as conditions warrant and/or change.

  [SRTA is aware funding is a perpetual challenge, howeveradaptation and resiliency activities are starting to become funding priorities at both the state and federal levels and we anticipate seeing more funding opportunities soon.]

- RMAP – E5-7 – not sure what SRTA's role would be in conducting evacuation drills, pre-staging equipment and efforts to secure SHASCOM notification equipment. Would expect the agencies already charged with emergency operations have their own processes and procedures. Maybe help to secure funding.

  [As stated in the text of these recommendations, SRTA should use its role as a transportation planning agency to encourage development of mapping tools, provide data, or support acquisition of funds.]

- RMAP – T1 – Most agencies already have complete streets principles incorporated into their General Plans and agency planning policies. Don't see a need for SRTA to play a role in designating what goes into local planning efforts other than providing suggested resources like this document and helping to fund grants. Would not want SRTA to withhold funding for future efforts that do not match or conflict with their planning priorities. Also, on this item, RABA typically works with our advertiser on shelters (RABA does not own or maintain) and locations – SRTA is not involved. There are many constraints and issues with sufficient right of way, transient concerns, and maintenance once installed.

[SRTA recognizes the local jurisdictions are the ultimate authority over their own streets. SRTA encourages our partners to consider how to integrate extreme weather hazards into Complete Streets efforts to further reduce barriers to cycling and walking in our communities, particularly on facilities with regional significance.]

- RMAP – T2-3 – Fleet management and particularly maintenance activities are well outside the prevue of SRTA's roles. Agencies are well aware of heating and cooling needs of their public vehicles and already considers these issues in daily operations. There is no need to introduce additional regional efforts or coordination for these activities and not a need for dedication of SRTA staff to these efforts.

  [SRTA acknowledges receipt of this comment. SRTA has a responsibility to periodically bring together various providers of public transportation to coordinate services as appropriate.]

- RMAP – T4 – this type of planning document is not necessarily the appropriate forum to discuss technical roadway design parameters. There are sufficient industry standard design considerations built into Caltrans, AASHTO and other design standards to account for any needed modifications predicated by temperature changes. I don't see a need to formally assign Caltrans to convene any meetings or coordination efforts for this purpose.

  [SRTA acknowledges that current standards may be adequate for current conditions, but is encouraging partner agencies to be planning for more extreme conditions in the future.]

- RMAP – P1 – again, not that it's a bad idea to prioritize undersized culverts. This is done on a daily basis in our maintenance strategies that target areas of "hot spots" for clearing prior to major events or seasons. We also understand where we have capacity issues. However, this section again suggests SRTA convene another working group to talk about each other's efforts. This takes resources, slows down processes and potentially inserts unnecessary requirements imposed by outside agencies. Agencies can't open up all routine processes to regional discussions simply because they have a connection to climate change. These factors are engrained in our daily decision making processes. Providing resources to replace aging infrastructure is what should be the focus of efforts.

  [SRTA's role is to be advisory and to assist with planning efforts on regionally significant corridors. Where projects overlap with two or more agencies, coordination efforts should be considered.]

- RMAP - P4 – these efforts are already done and there is no need for a SRTA to get involved in local drainage issues or detention basins. We have development standards, ordinances and City Council policies that ensure proper detention and we incorporate drainage into all street maintenance and capital projects. There is no need for any regional input on this front. More funding is all that is needed.

  [SRTA's effort would focus on analysis, planning, and funding support for regionally significant corridors.]

- RMAP – F3 – similar comments as P1 above. Infrastructure funding is all that is needed for this effort.

  [SRTA acknowledges receipt of this comment. Please see the response to RMAP P4 above.]

- RMAP – F4 – dam failure and the inundation zone are closely held with the appropriate responsible agencies including the US Bureau of Reclamation. SRTA should consult with them.

  [SRTA acknowledges receipt of this comment.]

Redding Area CHP:

Mark,

First, thank you for allowing us to provide input regarding this document.
I have conferred with CalTrans and they advised they have already reviewed the document and provided input. In regards to the document we would like the opportunity to work with the City Council and have input regarding the following:

1. E.2. Evaluating evacuation bottlenecks and secondary access constraints
2. E.5. Evacuation drills (including contraflow traffic management) conducted, this would include our Dispatch center supervisors.
3. P.2/P.3. I-5 Shutdown Traffic Management Plan (P.2). We have an Operation Snowflake plan and annual meetings, in place, and can share that information.

We agree that fuels reduction/mitigation is key, moving forward; however, CHP would not need to be involved with the Mitigation Group, in my opinion. That would be more for fire agencies.

Please let me know if I can provide further information.

Kevin Alexander, Captain
Commander

CHP-Redding Area

(530) 225-0500

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[SRTA acknowledges receipt of this comment.]