Cal OES

GOVERNOR'S OFFICE
OF EMERGENCY SERVICES

CALIFORNIA STATE HAZARD MITIGATION PLAN

Volume 1

Part 2—Profiles & Risk Assessments for Natural Hazards of Interest

Updated November 10, 2023

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2023

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4. WHAT IS AT RISK

S3 – 44 CFR Section 201.4(c)(2)(i): Does the risk assessment include an overview of the type and location of all natural hazards that can affect the state?

Part 2 of this Plan includes the Risk Assessment for the State of California. Each hazard is profiled fully, with specifics about type and location of all natural hazards in the State of California. Section 4.1.3. outlines specific methodology, as well as lists the 15 natural hazards of concern. Natural hazards of concern are presented in order based on Hazard Impact Scores (methodology explained at the end of Section 4.1).

4.1. RISK ASSESSMENT OVERVIEW

4.1.1. What is a Risk Assessment?

Risk is the potential for damage or loss created by the interaction of hazards with people, buildings, infrastructure, and natural and cultural resources. A risk assessment is a process of determining which hazards are of concern and assessing the potential impacts of those hazards statewide. It helps communicate vulnerabilities, develop priorities, and inform decision-making for the hazard mitigation plan and other emergency management efforts.

A risk assessment provides a factual basis for actions recommended in the mitigation strategy. The hazards and associated impacts and vulnerabilities identified in the risk assessment should be the hazards, impacts, and vulnerabilities the mitigation strategy seeks to address. Risk assessments must be based on the best available data and science that incorporate future projections (e.g., climate, land use, demographic, and other potential changes) and equity considerations to ensure that mitigation strategies have the greatest probability of reducing the risks posed by hazards in the most vulnerable areas now and into the future.

4.1.2. How is a Risk Assessment Used in Hazard Mitigation Planning?

Hazard mitigation plans identify the hazards and risks that can impact a community based on historical experience, estimate the potential frequency and magnitude of disasters, and assess potential losses to life, property, and the environment. Risk assessment provides a factual basis for a hazard mitigation strategy. It focuses on areas most in need by evaluating which populations and assets are most vulnerable to the hazards of concern. A risk assessment identifies:

- The hazards to which a community is susceptible
- Which areas and populations are most vulnerable to these hazards
- What these hazards can do to physical, social, environmental, and economic assets
- The resulting cost of damage or cost that can be avoided through mitigation

Risk assessment is a shared responsibility between states, local governments, and the "whole community." While local governments focus on hazards, vulnerabilities, and risks on a local or regional scale, states set the groundwork for those assessments by identifying hazards that impact the state. State plans can further support the local risk assessment process by identifying where hazard events have or could occur. State and local hazard mitigation plans (LHMPs) share the responsibility to communicate risk to the whole community so they can be risk informed.

4.1.3. How the Risk Assessment was Conducted for This Plan

The Risk Assessment for this Plan determined the exposure of identified assets and populations to each hazard of concern and assessed their vulnerability. The assets assessed include State-owned or -leased facilities, critical facilities, and community lifelines. The populations assessed include the general population and the subset of that population identified as "equity priority" communities. The potential for future risk expansion was assessed by looking at buildable lands within each hazard area. Exposure was assessed by overlaying hazard maps with inventories of State-owned or -leased facilities and infrastructure, critical facilities whose loss of function could affect State resilience, and equity priority populations. Vulnerability was evaluated by estimating potential impacts in the event of a hazard incident. Further details on the Risk Assessment methodology used for the 2023 State Hazard Mitigation Plan (SHMP or Plan) are provided in Appendix G.

Hazards of Concern

Standard 4.1.1: The Emergency Management Program identifies the natural and human-caused hazards that potentially impact the jurisdiction using multiple sources. The Emergency Management Program assesses the risk and vulnerability of people, property, the environment, and its own operations from these hazards.

Parts 2 and 3 of the SHMP profile 34 natural, meteorologic, biologic, human-caused, and technological hazards impacting the State of California. These hazards were identified based on California's hazard history statewide and locally, climate change projections, stakeholder input, and technical analysis.

Through coordination with the Hazard Groups, as described in Chapter 1, the State identified 34 hazards of interest that could impact or have impacted the State. They include both natural and non-natural (human-caused) hazards.

- **Natural Hazards of Interests**—These natural hazards, presented in order of impact, are typically assessed by local planning efforts in California and are identified by the Federal Emergency Management Agency (FEMA) as hazards to be addressed in hazard mitigation planning if they are present in the planning area:
  - Earthquake
  - Riverine, stream, and alluvial flood
  - Coastal flood/sea-level rise
  - Extreme heat
  - Extreme cold or freeze
  - Wildfire
  - Severe wind, weather, and storms
  - Landslide, debris flow, and other mass movements
  - Drought
  - Tsunami
  - Dam failure
  - Levee failure
  - Snow avalanche
  - Subsidence
  - Volcano
- **Other Hazards of Interest**—FEMA does not require These human-caused hazards to be assessed in hazard mitigation plans. Local planning efforts in California do not typically assess them. They are listed here in order of impact:

- Urban structural fire
- Other electrical outages
- Public safety power shutoff (PSPS)
- Terrorism
- Air pollution
- Tree mortality
- Energy shortage
- Cyber threats
- Invasive and nuisance species
- Epidemic, pandemic, vector-borne disease
- Civil disorder
- Natural gas pipeline hazards
- Hazardous materials release
- Transportation accidents resulting in explosion
- Well stimulation and hydraulic fracturing
- Oil spills
- Electromagnetic pulse (EMP) attack
- Radiological accidents
- Geomagnetic Storm (Space Weather)

FEMA does not require hazard mitigation plans to assess human-caused hazards and will not review them as part of its plan approval process. However, considering these hazards is required to achieve Emergency Management Accreditation Program (EMAP) accreditation, a State-identified objective for this SHMP. The State's choice to assess human-caused hazards is not binding on LHMPs. To clearly separate the elements required by FEMA from those required by EMAP, the Risk Assessment has been split into two parts of the SHMP:

- In Part 2, natural hazards of interest are fully assessed pursuant to the requirements S1 to S7 of the FEMA Standard State Hazard Mitigation Plan Review Tool (see Appendix E). These hazard profiles are presented in the order of highest impact based on a hazard impact rating protocol applied for this SHMP (see Appendix H).
- In Part 3, the other hazards of interest are profiled but not assessed in the full context applied to the natural hazards of interest. These profiles qualitatively assess the impacts of each hazard and do not strive to meet all of the requirements of 44 CFR Section 201.4(c)(2)(i). These hazards are important to the State of California, but their nature makes it difficult to fully assess them in a consistent approach that allows comparison of impacts.

This approach sets a precedent for local planning in the State that natural hazards of interest are mandatory and other non-natural hazards of interest are optional, as identified in FEMA guidance for hazard mitigation planning.

Data Sources

The California Governor's Office of Emergency Services (Cal OES) is committed to principles of fairness, transparency, and scientific reasoning and therefore conducts risk assessments using consistent methodologies and high-quality data that is peer reviewed and publicly accessible. Higher-resolution data sources might exist for specific communities, and Cal OES encourages communities to use those if available for risk assessments at the local level. The selection of the best available data for this SHMP update was guided by input from the Hazard Working Groups, partner agencies, and other experts advising the State for the update process. Data sources were selected to apply consistency in evaluating statewide risk and vulnerability for all communities throughout California. Appendix G documents sources and metadata for the data used in the Risk Assessment.

Using the National Risk Index

This SHMP uses FEMA's National Risk Index (NRI) to assess potential hazard-related losses for jurisdictions throughout the State (as called for in FEMA's Standard State Mitigation Planning Requirement S6.a). The NRI assigns numerical risk scores (based on percentiles) and descriptive risk ratings (very low to very high) at the Census tract and county levels. These scores and ratings are based on estimates of annual losses due to 18 types of hazard events, with adjustments to account for social vulnerability (which increases risk) and community resilience (which decreases risk).

The NRI multiplies the expected annual loss by a community risk factor derived from the social vulnerability and community resilience scores. Each community's resulting risk value is compared to all communities nationwide to assign its percentile-based score from zero (lowest risk value) to 100 (highest risk value).

The annual losses estimated in the NRI represent economic losses to buildings and agriculture and human fatalities and injuries. Building values and populations are derived from the Hazus model default inventory. Agriculture values are taken from the U.S. Department of Agriculture (USDA) Census of Agriculture.

The NRI online mapping tool was used to assess local vulnerability to identify the California counties with the highest risk for each NRI hazard included in the SHMP.

Those counties and their NRI scores and ratings are listed in the vulnerability analysis for natural hazards in Part 2 of the SHMP. Figure 4-1 shows the composite NRI ratings for all natural hazards for each county in the State.

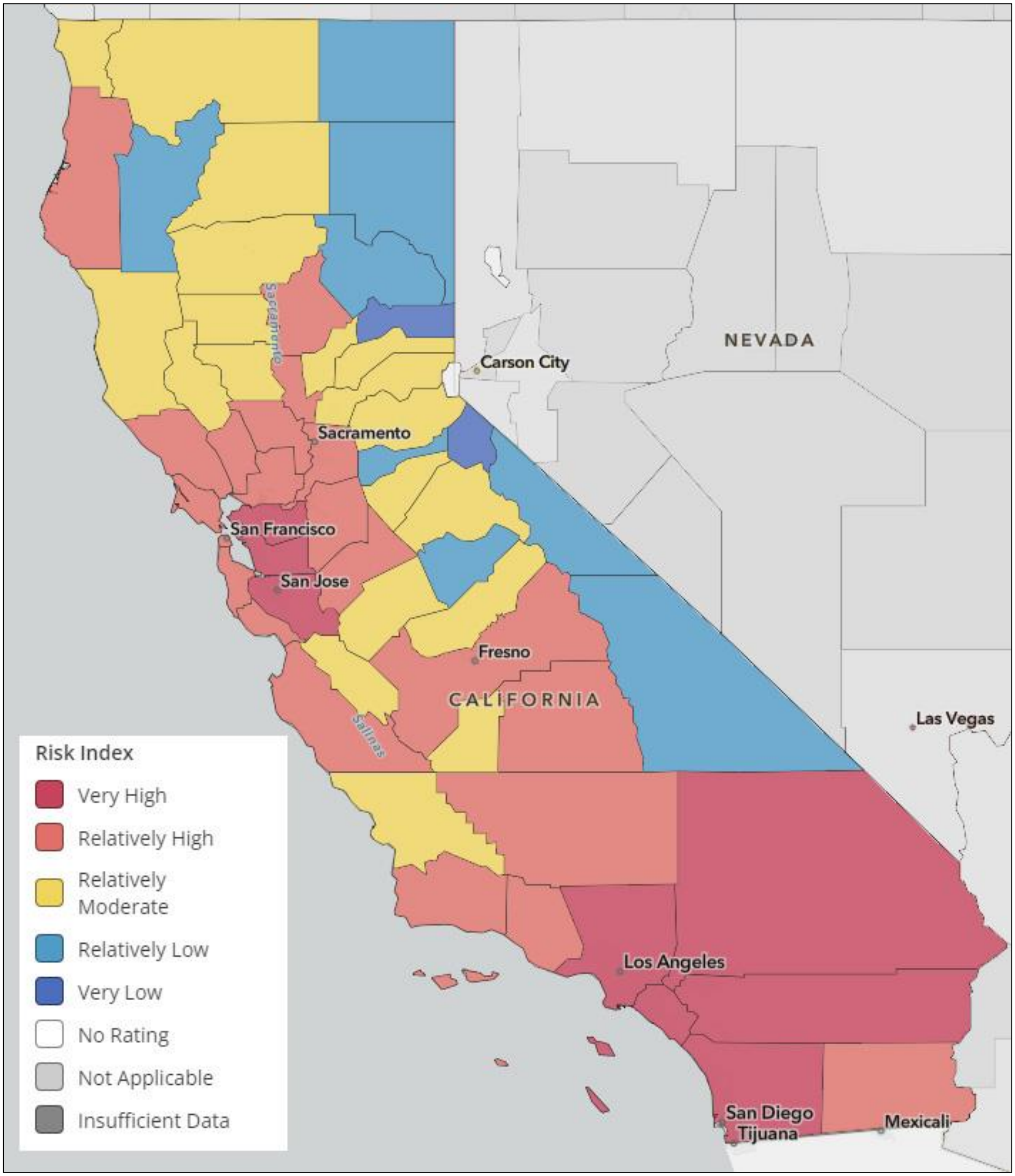
Hazard Impact Scores

To assess the impact of each identified hazard of concern and provide direction to the State for action planning, a hazard impact rating was developed that uses quantitative and qualitative data to assign a score based on the projected impact of each hazard. The scoring looks at the following metrics for each hazard of concern:

- The exposure of State assets
  - State-owned or -leased facilities
  - Community lifelines
- Population exposed
- The percentage of the exposed population identified as living in equity priority communities
- Buildable lands exposed
- Climate change impacts

Quantitative, spatial data was used to generate the impact score for hazards with a clearly defined extent and location, such as flooding. For other hazards, a qualitative approach was applied to generate the score. A hazard impact score is presented at the beginning of each hazard profile chapter in this Plan. Details on the metrics used and scoring for each hazard of concern are provided in Appendix H. The hazards are presented in this SHMP based on the resulting impact ratings, with the highest-impact hazards presented first. These hazard impact ratings have been used to inform the identification of the action plan provided in Chapter 47. The State prioritized hazards that scored either "high" or "medium" for targeted actions to address their impacts. Hazards that ranked "low" are considered to be optional.

Figure 4-1. National Risk Index Composite Risk Scores for California Counties



Source: (FEMA 2023c)

4.2. STATE ASSETS

S5 – 44 CFR 201.4(c)(2)(ii) and 201.4(c)(2)(iii): Does the risk assessment address the vulnerability of State assets located in hazard areas and estimate the potential dollar losses to these assets?
All 34 hazard profiles in Parts 2 and 3 of the SHMP have sections dedicated to the vulnerability of State assets that is inclusive of both an exposure analysis and loss estimation. Section 4.2. describes the assets evaluated.

This Plan defines a "State asset" as a facility, infrastructure, or community lifeline that serves a critical function on behalf of the State of California. A detailed inventory of assets identified two categories: State-owned or -leased facilities; and critical facilities or community lifelines.

4.2.1. State-Owned or -Leased Facilities

State-owned or -leased facilities are critical to the continuity of operations following hazard events. These assets have been inventoried and categorized in a geospatial format so that an exposure analysis can be performed for each hazard of concern. The source for the State-owned or -leased facility data is the California Department of General Services (DGS). Table 4-1 and Table 4-2 summarize this data for State-owned or -leased facilities.

Table 4-1. State-Owned or -Leased Facilities

Type of Facility	Number of Structures	Total Area (sq. ft.)	Replacement Cost Value*		
			Structure	Content	Total
State-Leased Facilities	1,893	N/A	$9,216,928,646	$9,438,197,133	$18,655,125,778
State-Owned Facilities					
Facilities Housing Vulnerable Populations					
Correctional Facility	3,896	42,442,942	$3,419,731,320	$2,254,012,157	$5,673,743,477
Development Center	247	2,320,939	$305,783,571	$390,885,847	$696,669,418
Hospital	525	6,470,903	$382,822,433	$454,638,764	$837,461,197
Migrant Center	25	1,588,233	$655,289,706	$341,691,270	$996,980,976
Special School	137	959,233	$64,705,505	$63,904,858	$128,610,363
All Other Facilities	19,131	188,844,446	$14,334,593,292	$14,057,592,693	$28,392,185,985
Total State-Owned	***23,961***	***242,626,696***	***$19,162,925,827***	***$17,562,725,589***	***$36,725,651,416***
Total State Facilities	25,854	N/A	$28,379,854,473	$27,000,922,722	$55,380,777,194

* Replacement cost values calculated using the *2022 Square Foot Costs* by RS Means

Table 4-2. State-Owned Infrastructure

Type of Facility	Number or Length
Bridges	13,201
Highway (miles)	30,098
Dams	49
Water Project (miles)	714.5

Note that the inventory does not include building area for State-leased facilities, so no total area for all State facilities is provided; risk assessments throughout this SHMP show the building area of vulnerable assets only for State-owned facilities. Appendix I includes a detailed breakdown of the number and type of assets by county and other data parameters.

The following are notable statistics from the inventory of State-owned assets:

- The average building area of State-owned facilities statewide is 10,125 square feet, and the average replacement cost value is $1.5 million
- The average replacement cost value for State-leased facilities statewide is $9.8 million
- The agencies with the most State-owned or -leased facilities are as follows:
    - The California Department of Parks and Recreation (State Parks) (6,014)
    - The University of California (UC) (4,010)
    - The California Department of Corrections and Rehabilitation (CDCR) (3,993)
    - The California Department of Transportation (Caltrans) (2,224)
    - The California Department of Forestry and Fire Protection (CAL FIRE) (2,059)
- The State agency with the highest total replacement cost value for State-owned or -leased facilities is the California Employment Development Department (EDD)($1.1 billion)

Figure 4-2 shows the distribution of State-owned or -leased facilities. The distribution of State-owned or -leased infrastructure is shown in Figure 4-3 through Figure 4-6.

Figure 4-2. State-Owned and State-Leased Facilities

Figure 4-3. State Highways

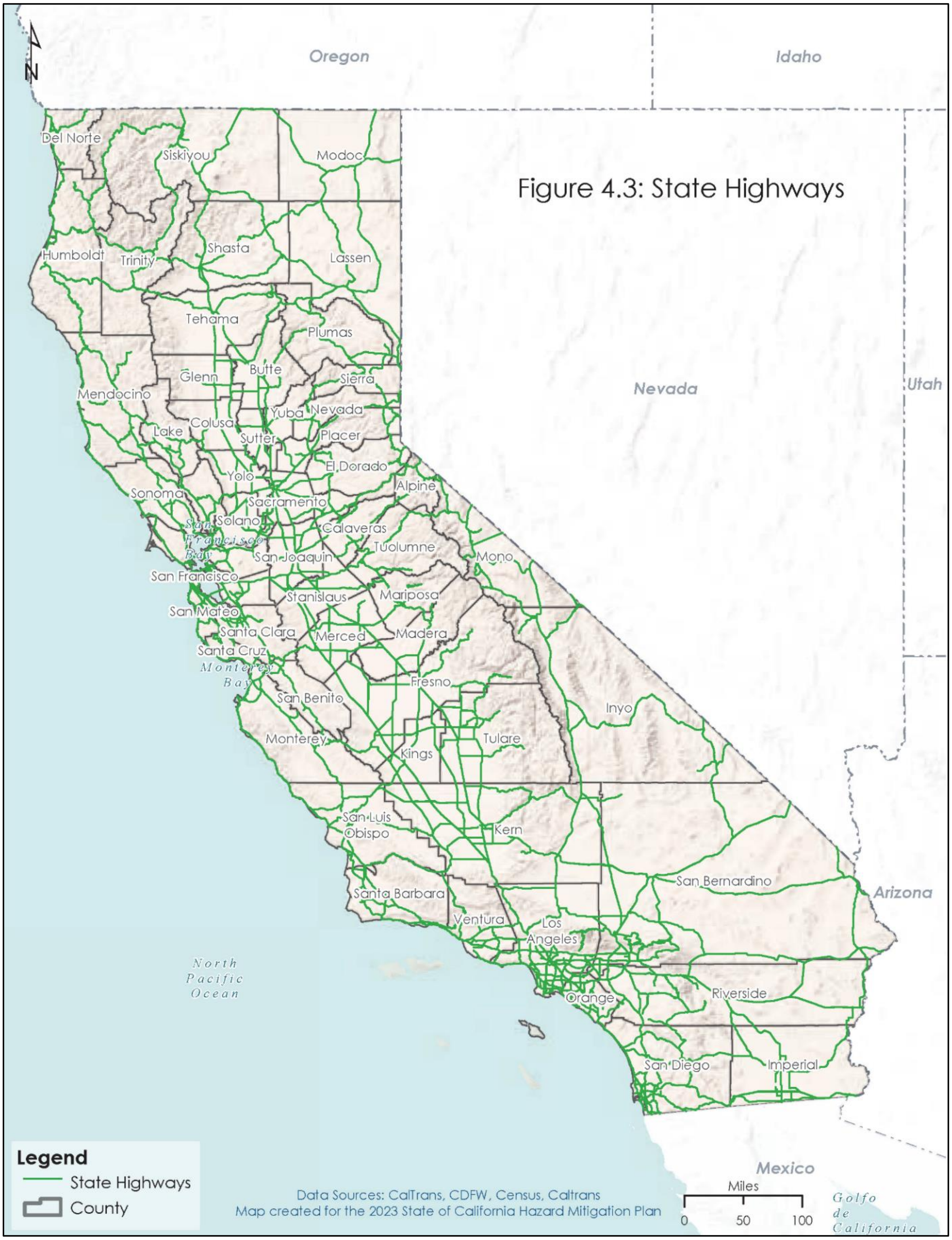


Figure 4-4. State Bridges

Figure 4-5. State Dams

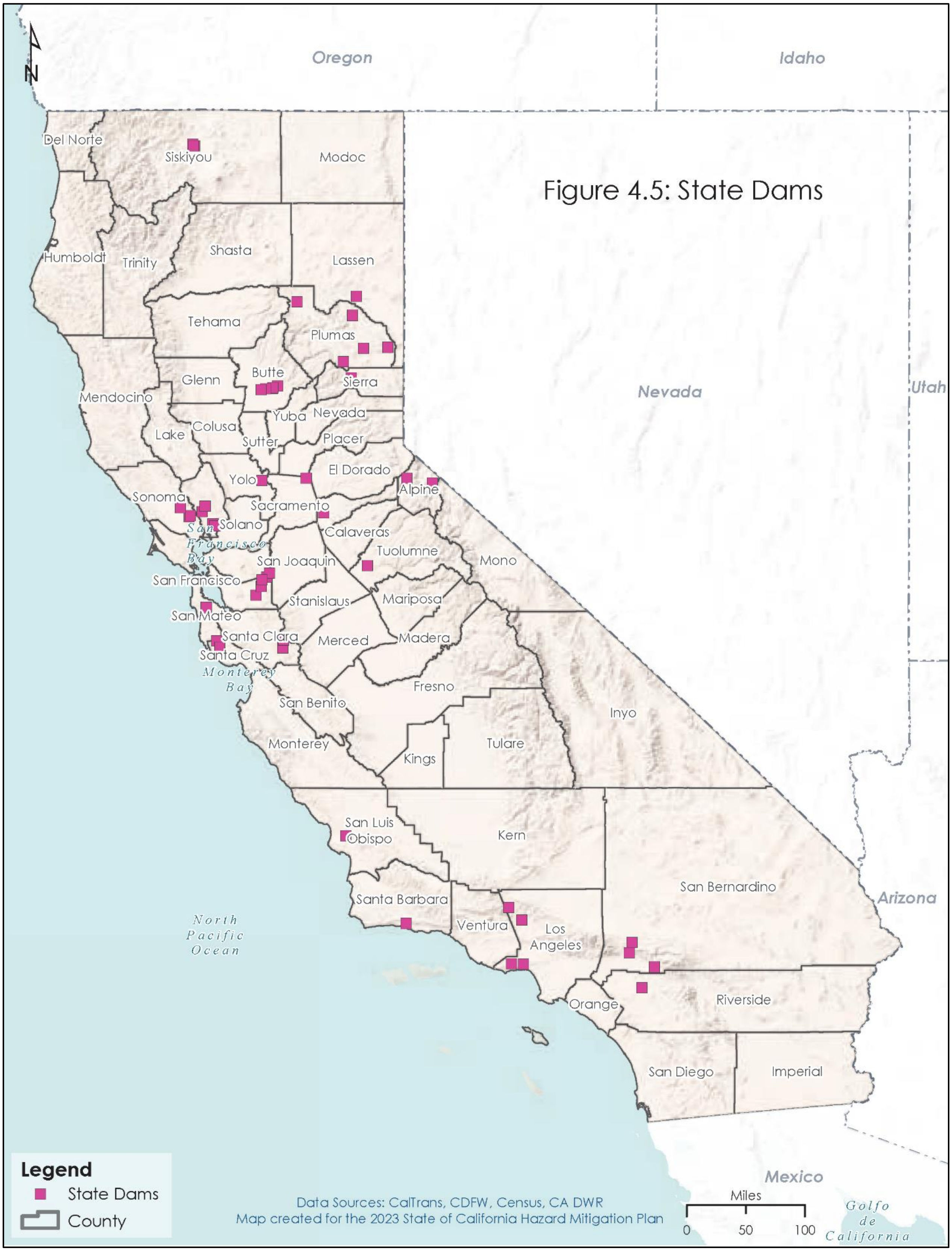
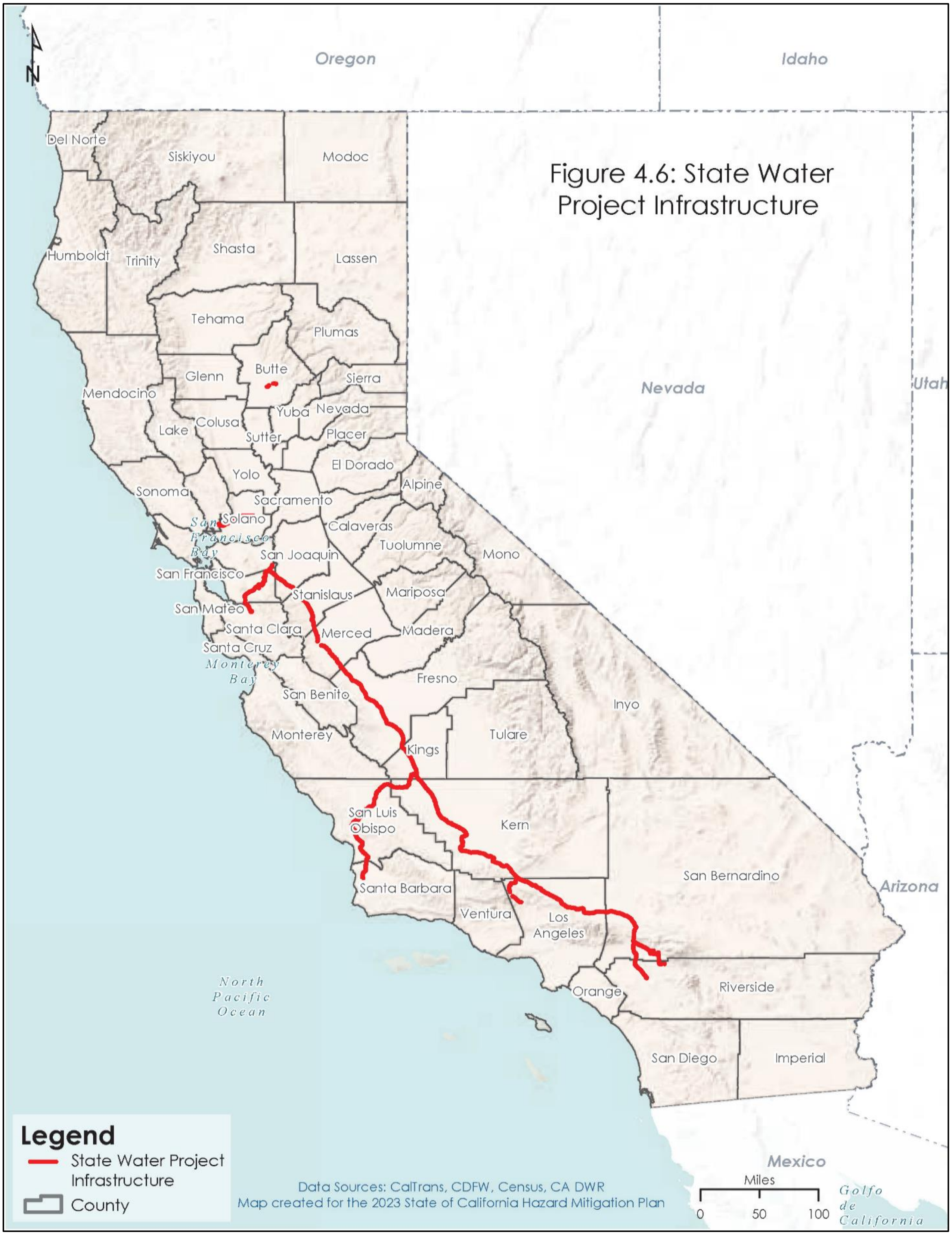


Figure 4-6. State Water Project Infrastructure



4.2.2. Critical Facilities and Community Lifelines

Critical facilities and community lifelines are key assets and resources that assist the State in maintaining the continuity of operations before, during, and after hazard (disaster)events. Lifelines are the most fundamental services in a community that, when stabilized, enable all other aspects of society. FEMA has broken down lifelines into eight categories, as shown in Figure 4-7.

FEMA created the concept of community lifelines to establish a unified nationwide approach to emergency response for these critical assets. However, the concept can be applied beyond questions of response to cover the entire preparedness cycle, including hazard mitigation. Efforts to protect lifelines and build them back stronger and smarter during recovery will benefit overall resilience across the United States.

Impacts on critical facilities and community lifelines can lead to catastrophic and cascading fatal impacts throughout multiple communities. For example, if power is lost for life-sustaining medical devices or refrigeration of essential medications, health-dependent communities, and systems that rely on them may face severe health events. Road or bridge failure could result in an inability to evacuate an impacted area or inaccessibility for emergency medical services. If potable water treatment systems are disrupted, water- and food-borne disease may spread, and access to clean water becomes difficult. If untreated wastewater or other hazardous materials spill, exposure could result in infection, rash, gastrointestinal illness, tetanus, or leptospirosis (CDC 2022d).

For mitigation planning, the most important impact on community lifelines to avoid through mitigation actions is loss of function. Each lifeline can be associated with a critical service needed for the State and local governments to respond and recover from hazard events. Maintaining the continuity of operation of these lifelines is critical for community resilience.

For the inventory of critical facilities and community lifelines, the Cal OES Critical Infrastructure Protection Unit provided data from the State Critical Infrastructure Prioritization Initiative. That initiative establishes an inventory of significant infrastructure prioritized by sector. Table 4-3 summarizes the facility counts for the FEMA Community Lifeline categories.

Figure 4-7. FEMA Community Lifeline Categories

Source: (FEMA 2023a)

Table 4-3. Community Lifeline Counts by Category

Communications	42
Energy	176
Food, Water, Shelter	257
Hazardous Material	56
Health & Medical	47
Safety & Security	46
Transportation	131
Total	**755**

The "food, water, shelter," "energy," and "transportation" categories account for 74 percent of community lifelines in the State. The County with the largest percentage of these facilities was Los Angeles (20.9 percent of the State total), followed by San Diego (9.6 percent), San Bernardino (6.1 percent), and Alameda (5.6 percent). Appendix I provides a detailed breakdown of facility counts by county.

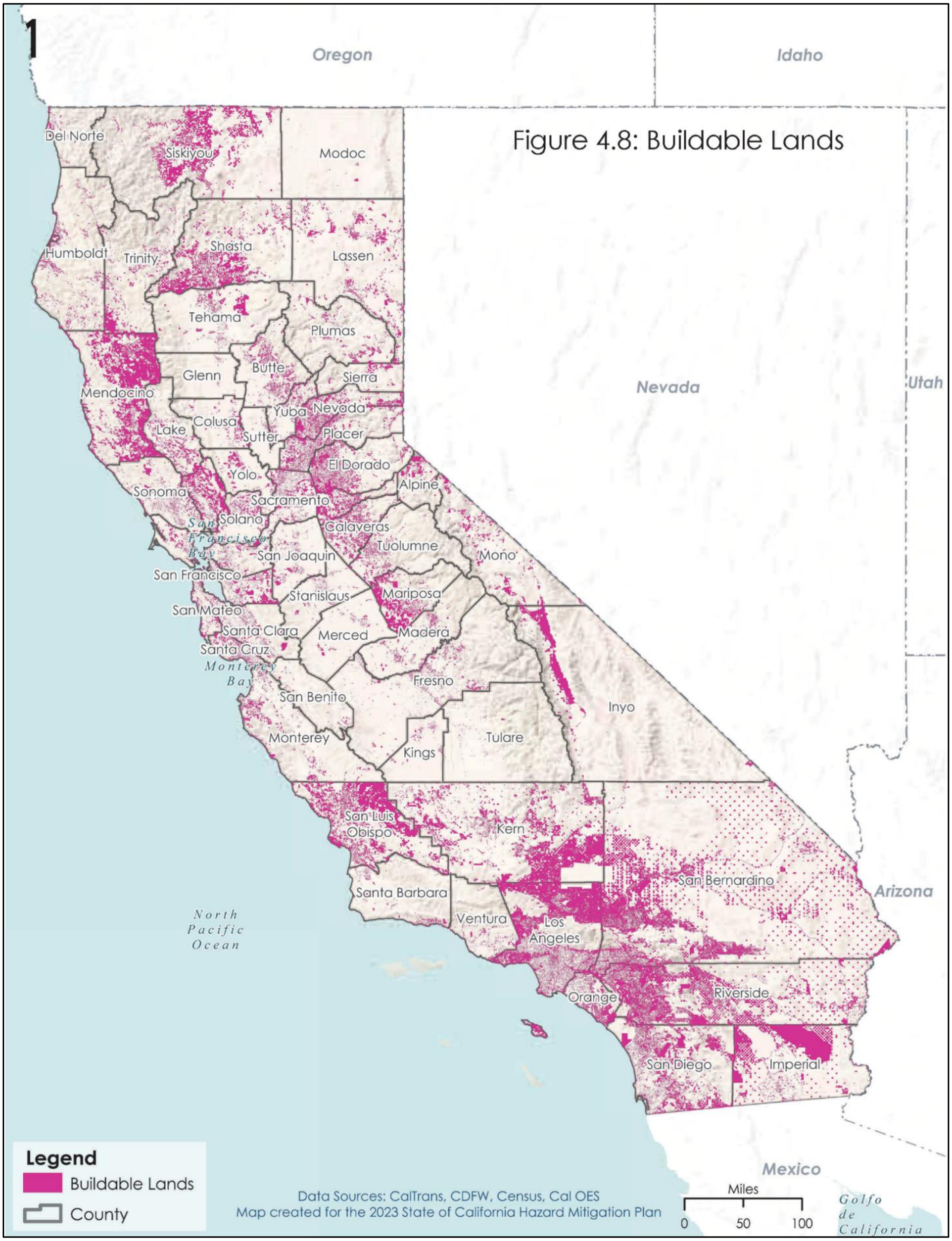
4.3. BUILDABLE LANDS

Buildable Lands are currently vacant lands with land use or zoning designations that would allow them to be developed in the future. Information on such lands is valuable for assessing where future growth could intersect known hazard areas, thus increasing hazard risk. The generation of this data was supported by a software application accessible by Cal OES called LandVision, as described in Appendix G. Figure 4-8 shows the distribution of buildable lands across California. Table 4-4 summarizes total buildable lands by county.

Table 4-4. Buildable Lands by County

County	Acres	County	Acres	County	Acres
Alameda	83,922	**Madera**	41,190	**San Joaquin**	28,214
Alpine	50,861	**Marin**	24,696	**San Luis Obispo**	733,458
Amador	97,686	**Mariposa**	228,533	**San Mateo**	32,801
Butte	88,320	**Mendocino**	855,474	**Santa Barbara**	28,657
Calaveras	124,320	**Merced**	12,030	**Santa Clara**	43,054
Colusa	39,975	**Modoc**	2,853	**Santa Cruz**	40,770
Contra Costa	28,731	**Mono**	130,547	**Shasta**	381,315
Del Norte	10,802	**Monterey**	92,667	**Sierra**	35,361
El Dorado	184,442	**Napa**	169,772	**Siskiyou**	508,754
Fresno	51,792	**Nevada**	146,358	**Solano**	55,831
Glenn	2,085	**Orange**	151,777	**Sonoma**	57,738
Humboldt	78,482	**Placer**	122,653	**Stanislaus**	14,179
Imperial	710,020	**Plumas**	60,257	**Sutter**	2,369
Inyo	246,441	**Riverside**	1,065,179	**Tehama**	84,053
Kern	1,014,386	**Sacramento**	75,501	**Trinity**	116,464
Kings	8,907	**San Benito**	8,877	**Tulare**	6,847
Lake	82,544	**San Bernardino**	1,734,287	**Tuolumne**	70,255
Lassen	180,689	**San Diego**	522,630	**Ventura**	31,804
Los Angeles	911,564	**San Francisco**	4,245	**Yolo**	40,856
Total					**11,788,962**

Figure 4-8. Buildable Lands



4.4. EQUITY PRIORITY COMMUNITIES

In addition to assessing the impacts of hazard events on State assets and lands, the Risk Assessment for this SHMP estimates hazard impacts on equity priority communities. For hazard risk analysis in this Plan, equity priority communities are defined as all locations with a Social Vulnerability Index (SVI) of 0.7 or greater; federal grant programs commonly establish thresholds in the range of 0.60 to 0.75 to prioritize communities with a greater need for funding. Equity priority communities may face additional barriers and challenges that increase vulnerability to hazards. This includes lower quality housing, which increases the risk to floodwater infiltration and mold growth and exposure; limited access to transportation, resulting in delayed evacuation or inability to evacuate; increased mental health impacts from exposure to hazards; and more. Additional details of the barriers and challenges that may lead to increased vulnerability within equity priority communities are discussed in Appendix B. The baseline condition for equity priority communities across the State is presented in Section 0.

EARTHQUAKE

Climate Impacts:
Unknown

Equity Impacts:
36.7% of the exposed population (those living on NEHRP D or E soils) identified as residing in equity priority communities

State Facilities Exposed:
$28 billion total replacement cost value for facilities on NEHRP D or E soils; $5.9 billion total replacement cost value for facilities in liquefaction zones (this number represents a minimum value because liquefaction zones are not yet mapped for the entire State); $16.4 billion total replacement cost value for facilities in significant shaking areas

Community Lifelines Exposed:
412 lifelines on NEHRP D or E soils; 149 lifelines in liquefaction zones; 241 lifelines in significant shaking areas

Impact Rating: High (45)

5. EARTHQUAKE

Earthquake has been identified as a high-impact natural hazard of interest based on the hazard impact rating protocol applied for this SHMP. Earthquakes happen frequently in California and can impact all State-owned or -leased facilities, community lifelines, and large percentages of the State's population. The potential impacts of earthquakes will influence future development in the State. Climate change is not expected to affect the frequency of earthquakes.

5.1. HAZARD OVERVIEW

An earthquake occurs when the ground shakes because rock beneath the Earth's surface suddenly breaks and shifts. In California, two of the massive plates that make up the crust of the Earth—the Pacific and North American plates— slide past each other in opposite directions at a rate of about 1.5 inches per year. Friction between the plates causes some parts to stick, then break free in sudden movements. The sudden movements release energy that travels through the ground as waves, causing shaking at the surface in the form of earthquakes (DOC 2022).

California has a long history of damaging earthquakes, and earthquake forecasts indicate a 93 percent chance that one or more major earthquakes (magnitude 7 or greater) will happen in the State in the 30 years following 2014 (USGS 2015).

5.1.1. Ways of Measuring Earthquakes

Magnitude

An earthquake's magnitude is a measurement of the energy radiated by the earthquake. Typically, a particular earthquake recorded at a particular distance is defined as a "standard" earthquake and assigned a magnitude of 1. An earthquake that causes ground motion at a seismic station 10 times larger than the standard earthquake is magnitude 2. An earthquake causing motion 10 times larger than a magnitude 2 is a magnitude 3, and so on. To achieve each tenfold increase in recorded amplitude requires about 32 to 33 times the energy. That means the energy released by an earthquake of magnitude 6 is about 33 times that of the energy released by a magnitude 5 earthquake (Pacific Northwest Seismic Network n.d.).

Magnitude is commonly expressed by ratings on the moment magnitude scale (Mw), the most common scale in use today. This scale is based on the total distance a fault moved and the force required to move it. The scale is as follows:

- Great—Mw > 8
- Major—Mw = 7.0 – 7.9
- Strong—Mw = 6.0 – 6.9
- Moderate—Mw = 5.0 – 5.9
- Light—Mw = 4.0 – 4.9
- Minor—Mw = 3.0 – 3.9
- Micro—Mw < 3

Ground Acceleration

The ground experiences acceleration as it shakes during an earthquake. The peak ground acceleration (PGA) is the largest acceleration that a recording monitoring station at the ground surface records during an earthquake. PGA measures how hard the earth shakes in a given geographic area. It is expressed as a percentage of the acceleration due to gravity (g). Horizontal and vertical PGA varies with soil or rock type. One approach to earthquake hazard assessment involves estimating the annual probability that certain ground accelerations will be exceeded, and then calculating the annual probabilities over a time period of interest using probability models.

Intensity

Intensity is a measure of how strong an earthquake feels at any one location. It can vary widely across the range where an earthquake is experienced. The most commonly used intensity scale is the modified Mercalli intensity scale. Ratings of the scale and the perceived shaking and damage potential for structures are shown in Figure 5-1 and Table 5-1. The range of ground shaking depends on the distance from the earthquake, the rock and soil conditions of the impacted area, and complexities in the structure of the earth’s crust that affect how the seismic waves radiate from the earthquake source and propagate to the site.

Figure 5-1. Modified Mercalli Intensity Scale

CIIM Intensity	People's Reaction	Furnishings	Built Environment	Natural Environment
I	Not felt			Changes in level and clarity of well water are occasionally associated with great earthquakes at distances beyond which the earthquakes felt by people.
II	Felt by a few.	Delicately suspended objects may swing.		
III	Felt by several; vibration like passing of truck.	Hanging objects may swing appreciably.		
IV	Felt by many; sensation like heavy body striking building.	Dishes rattle.	Walls creak; window rattle.	
V	Felt by nearly all; frightens a few.	Pictures swing out of place; small objects move; a few objects fall from shelves within the community.	A few instances of cracked plaster and cracked windows with the community.	Trees and bushes shaken noticeably.
VI	Frightens many; people move unsteadily.	Many objects fall from shelves.	A few instances of fallen plaster, broken windows, and damaged chimneys within the community.	Some fall of tree limbs and tops, isolated rockfalls and landslides, and isolated liquefaction.
VII	Frightens most; some lose balance.	Heavy furniture overturned.	Damage negligible in buildings of good design and construction, but considerable in some poorly built or badly designed structures; weak chimneys broken at roof line, fall of unbraced parapets.	Tree damage, rockfalls, landslides, and liquefaction are more severe and widespread wiht increasing intensity.
VIII	Many find it difficult to stand.	Very heavy furniture moves conspicuously.	Damage slight in buildings designed to be earthquake resistant, but severe in some poorly built structures. Widespread fall of chimneys and monuments.	
IX	Some forcibly thrown to the ground.		Damage considerable in some buildings designed to be earthquake resistant; buildings shift off foundations if not bolted to them.	
X			Most ordinary masonry structures collapse; damage moderate to severe in many buildings designed to be earthquake resistant.	

Source: (USGS 2022h)

Table 5-1. Modified Mercalli Intensity and PGA Equivalents

Modified Mercalli Intensity	PGA (% gravitational acceleration)	Perceived Shaking	Potential Damage
I	<0.17	Not Felt	None
II	0.17 – 1.4	Weak	None
III	0.17 – 1.4	Weak	None
IV	1.4 – 3.9	Light	None
V	3.9 – 9.2	Moderate	Very Light
VI	9.2 – 18	Strong	Light
VII	18 – 34	Very Strong	Moderate
VIII	34 – 65	Severe	Moderate to Heavy

Source: (USGS 2022h)

The modified Mercalli intensity scale is generally represented visually using ShakeMaps, which shows the expected ground shaking at any given location produced by an earthquake with a specified magnitude and epicenter. A ShakeMap shows the variation of ground shaking in a region immediately following significant earthquakes.

5.1.2. Mapping the Earthquake Hazard

CGS Seismic Hazards Program Mapping

The California Geological Survey (CGS) Seismic Hazards Program delineates areas prone to multiple earthquake-related hazards:

- Soil liquefaction (when saturated soil loses its strength and stiffness)
- Earthquake-induced landslides
- Surface fault rupture (visible offset of the ground surface due to a rupture along a fault, an underground fracture in the Earth's crust)
- Tsunami inundation

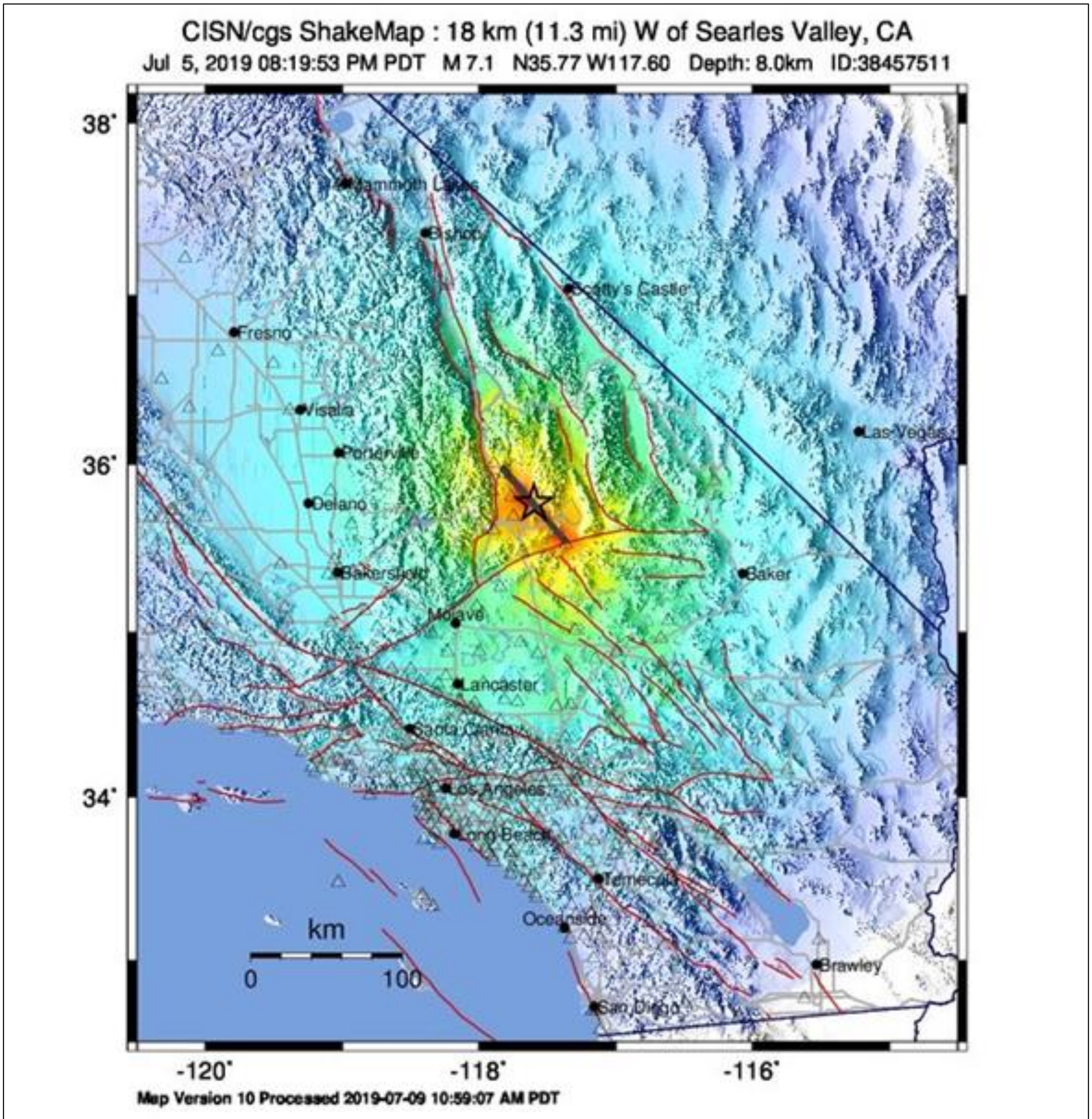
Areas that are prone to these hazards are called seismic hazard zones. Cities and counties are required to use the program's maps in land-use planning and building permitting so that these hazards are identified and mitigated for development projects. The Seismic Hazards Program works with the U.S. Geological Survey (USGS) to produce earthquake maps that are used to develop building codes and estimate earthquake damage and loss (DOC 2019a).

ShakeMaps

The California Integrated Seismic Network is a partnership between CGS, Cal OES, the Seismology Lab at UC Berkeley, the California Institute of Technology's Seismological Laboratory, and the USGS. The Network operates instruments across the State to measure earthquake shaking. It converts the recorded data into maps called ShakeMaps that provide near-real-time pictures of ground motion and shaking intensity following significant earthquakes (CISN n.d.). Figure 5-2 is an example ShakeMap generated for the 2019 M7.1 Ridgecrest Earthquake.

Emergency responders use ShakeMaps to evaluate shaking in areas affected by an earthquake and send resources to areas that most likely sustained heavy damage. ShakeMaps have also been prepared to model the effects of scenario earthquakes. They are the basis for loss estimates following earthquakes in FEMA's Hazus model.

Figure 5-2. ShakeMap for 2019 M7.1 Ridgecrest Earthquake



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.1	0.5	2.4	6.7	13	24	44	83	>156
PEAK VEL.(cm/s)	<0.07	0.4	1.9	5.8	11	22	43	83	>160
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Source: (USGS 2019d)

National Earthquake Hazards Reduction Program Soil Maps

The National Earthquake Hazards Reduction Program (NEHRP) maps soil types that define the potential for significant impact from an earthquake. The soil type determines how an earthquake's energy is amplified as it moves out from the fault. Type A has the least amplification, and Type E has the most. The soil types are generally described as follows:

- Type A—Hard rock
- Type B—Rock
- Type C—Dense soil/soft rock
- Type D—Stiff soil
- Type E—Soft soil
- Type F—Special soils requiring special evaluation

Liquefaction Maps

Liquefaction occurs when loosely packed, water-logged sediments at or near the ground surface lose their strength in response to strong ground shaking. This makes the materials behave like a liquid, damaging building foundations and causing pipes to leak or break and paved surfaces to buckle. Liquefaction beneath buildings and other structures can cause significant damage during earthquakes (USGS 2022d).

Soil liquefaction maps are valuable tools to assess potential damage from earthquakes. Areas susceptible to liquefaction include places where sandy sediments have been deposited by rivers along their course or by wave action along beaches. If there is a dry soil crust, excess water will sometimes come to the surface through cracks in the confining layer, bringing liquefied sand with it, creating sand boils. CGS has only evaluated and mapped about 5 percent of the State for liquefaction hazards. This represents a gap in the capability to assess the risk from earthquakes. Closing that gap has been identified as a high-priority action in this Plan.

Landslide Maps

CGS evaluates earthquake-induced landslide hazard potential by analyzing geologic material strength, slope gradient, and anticipated ground shaking. Resulting landslide hazard maps are useful tools to identify where slopes are more likely to fail during an earthquake. Landslide hazards are discussed in detail in Section 12.

Shaking Potential Mapping

Models of earthquake shaking hazards for a given place consider the potential for all future earthquakes on surrounding faults and their related ground motion affecting that place. Integrating all the potential for ground motion statewide produces maps that show the long-term probabilistic seismic hazard anywhere in the State. Such maps help identify particularly vulnerable areas.

CGS and the USGS have prepared mapping that shows the relative intensity of ground shaking in California from earthquakes (DOC 2022b). The shaking potential is calculated as the level of ground motion that has a 2 percent chance of being exceeded in 50 years. This equates to ground-shaking with about a 2,500-year average repeat time. Where the ground movement defined by the shaking potential has an acceleration that exceeds the acceleration of gravity (1 g), it is considered to be violent to extreme shaking (see Figure 5-2).

The mapping shows relatively long-period (1.0 second) earthquake shaking, which affects tall, relatively flexible buildings, and correlates well with overall earthquake damage. The ground-shaking mapping is used in the earthquake Risk Assessment for this Plan, indicating areas of the State that could experience significant shaking.

California Earthquake Clearinghouse

Following a large and damaging earthquake in California, critical information is rapidly needed to assess ground deformation, damaged buildings, and disrupted utilities and highways. When an earthquake of this extent occurs, the California Earthquake Clearinghouse is authorized to activate and establish a location close to the epicenter (California Public Resources Code, Div. 2, Ch. 2, Sec. 2201(c)). The Clearinghouse is managed jointly by CGS, the Earthquake Engineering Research Institute, Cal OES, the USGS, and the California Seismic Safety Commission (SSC). Its principal function is to promptly gather information from significant seismic events, coordinate the response, and share information with State and federal disaster response managers and the scientific and engineering communities.

Engineers, geologists, seismologists, sociologists, economists, and other professionals who arrive in the affected area share information, findings, and data through the Clearinghouse to maximize its availability. Information is shared through evening briefings and posting of preliminary findings, including data, maps, photos, and reports on the ***Learning from Earthquakes*** Clearinghouse event website hosted by the Earthquake Engineering Research Institute.

With both State and federal managing partners, the Clearinghouse supports the NEHRP directive for state and federal agencies to coordinate the collection of post-earthquake information through a clearinghouse. In addition to emergency response, the Clearinghouse supports pre-event preparedness planning and regional earthquake resilience to promote more rapid recovery.

5.2. HAZARD LOCATION

5.2.1. Fault Locations

California has many faults with the potential to produce damaging earthquakes. In general, faults that slip the fastest over geologic time are more likely to produce earthquakes in the near future (Figure 5-3). More than 70 percent of California's population lives within 30 miles of a known fault where strong ground shaking could occur in the next 30 years (Southern California Earthquake Center 2017).

Faults offshore of California are also capable of producing damaging earthquakes. The Cascadia Subduction Zone—a sizeable offshore fault system extending from Northern California to British Columbia—can produce great earthquakes (magnitudes greater than 8.0) north of Cape Mendocino (Cal OES 2018a). An event on this offshore fault system can increase the tsunami risk.

5.2.2. Areas Susceptible to Earthquake Damage

For the earthquake Risk Assessment in this plan, three data sets were used to map susceptibility to damage from earthquakes. These data sets account for the primary causes of damage from earthquakes:

- NEHRP **Soils Data**—Earthquake vulnerability based on the presence of NEHRP Type D, E, and F soils (see Figure 5-4).
- **Liquefaction Mapping**—Earthquake vulnerability based on liquefaction susceptibility (see Figure 5-5). Liquefaction mapping data currently is not available statewide. However, where this data is available, it can provide increased resolution on the risk associated with earthquakes.
- **Earthquake Shaking Potential**—Earthquake vulnerability based on having more than a 2 percent chance in 50 years of shaking that exceeds 1 g (see Figure 5-6).
- **Earthquake-Induced Landslide Hazard Zones**—Mapping of areas with a higher probability of earthquake-induced landslides, within which specific actions are mandated by California law prior to any development. See Chapter 12.
- Mapping indicates that the entire State is at risk of earthquakes, particularly along the coastline and the San Andreas Fault.

Figure 5-3. Significant Faults in California

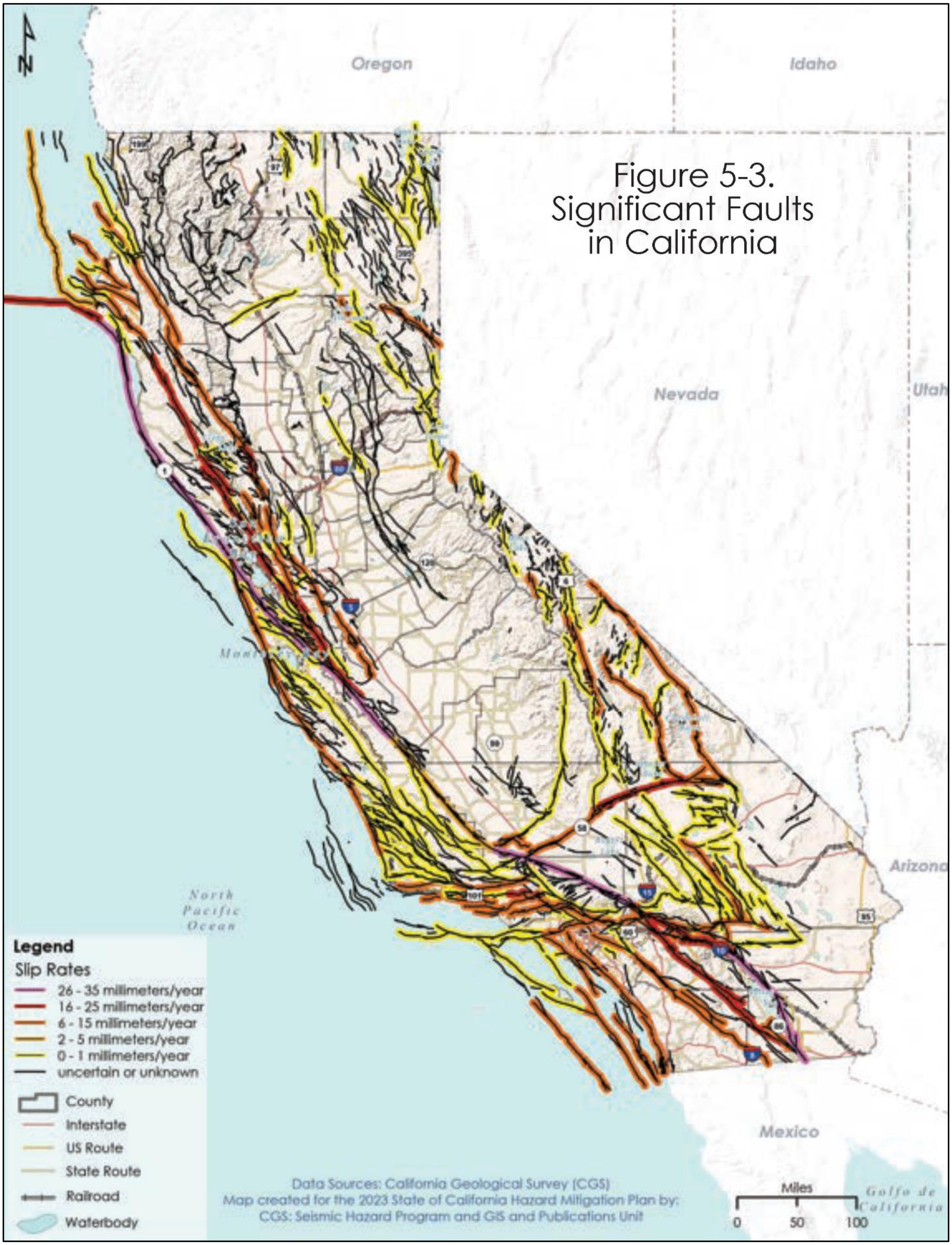


Figure 5-4. NEHRP Type D and E Soils

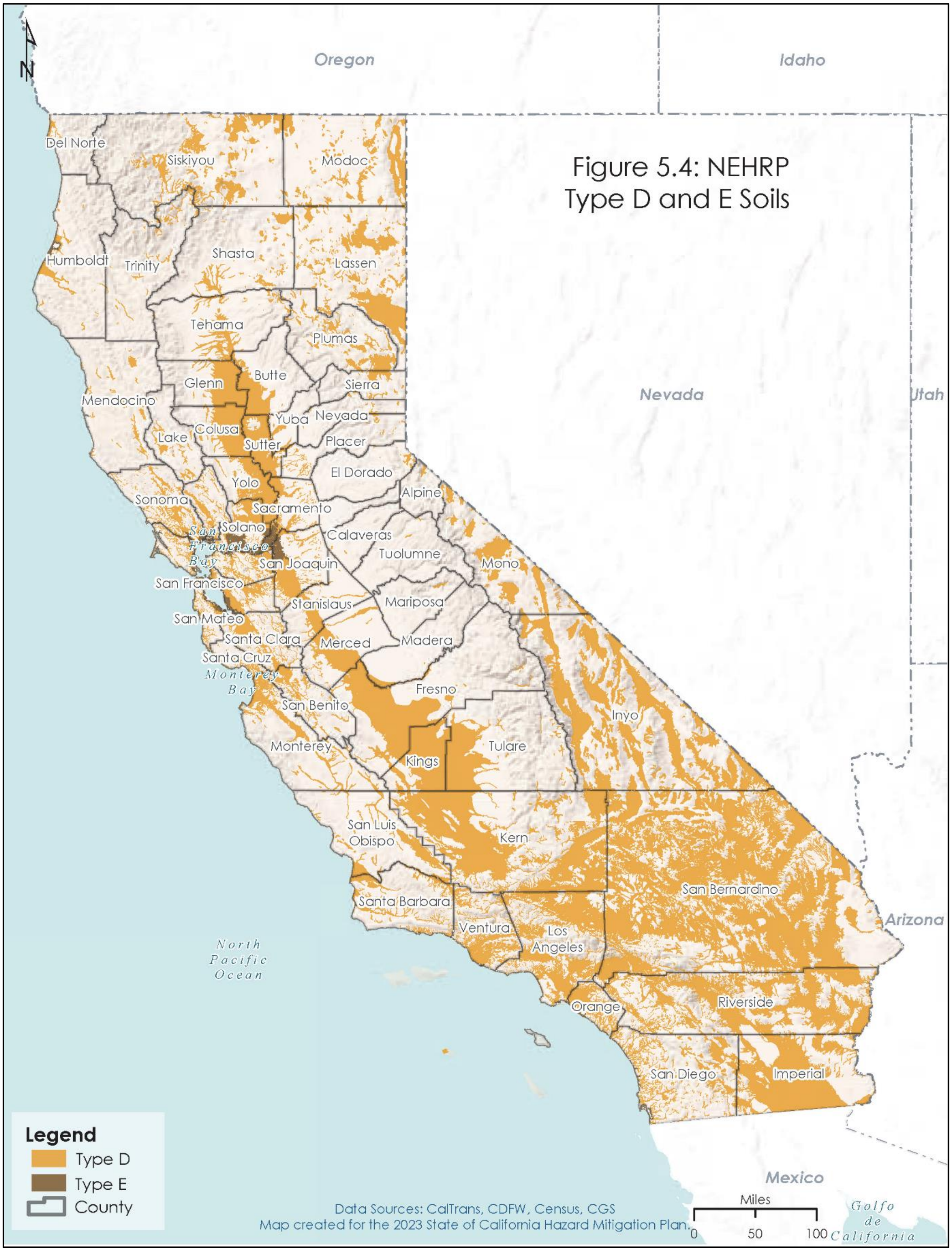


Figure 5-5. Liquefaction Zones

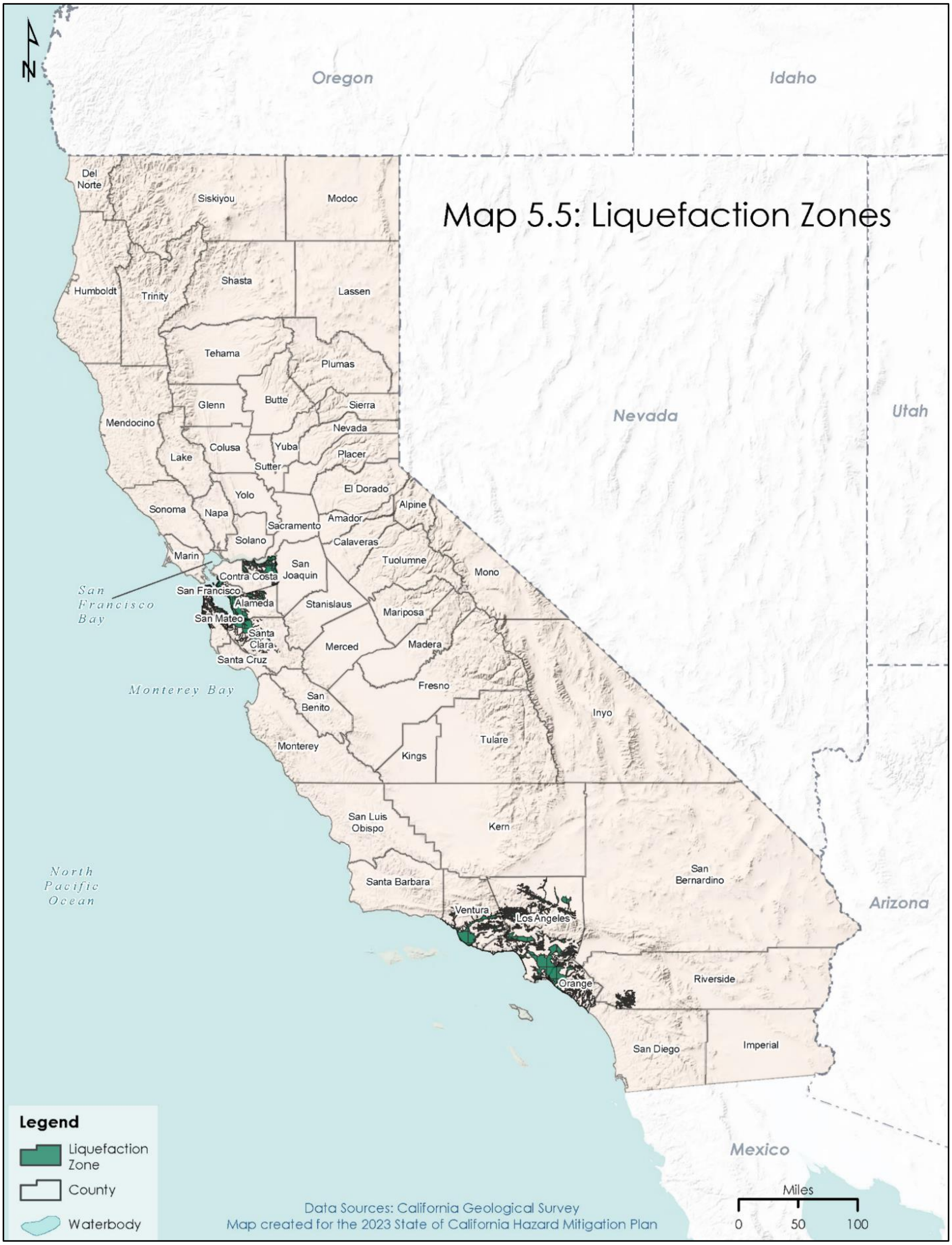
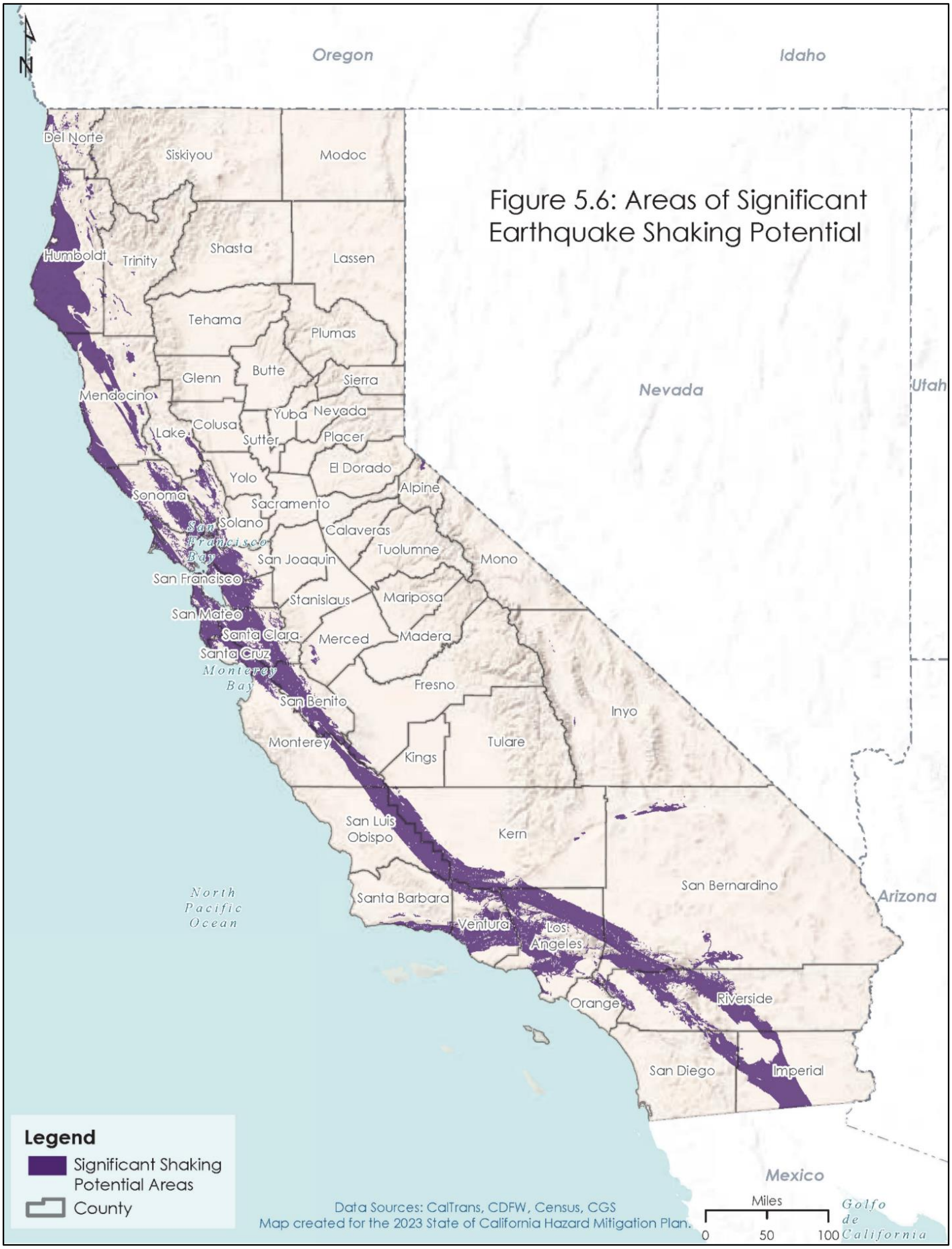


Figure 5-6. Areas of Significant Earthquake-Shaking Potential



5.3. PREVIOUS HAZARD OCCURRENCES

5.3.1. Disaster and Emergency Declarations

The following disaster declarations or emergency proclamations related to earthquakes have been issued for California (see Appendix F for details):

- Federal Major Disaster (DR) or Federal Emergency (EM) declaration, 1953 – 2022: 13 events, classified as earthquake
- California Emergency Proclamations, 1950 – 2022: 23 events, classified as earthquake
- USDA agricultural disaster declarations, 2012 – 2022: none

5.3.2. Event History

The 2018 SHMP discussed specific earthquake events in California through 2018. This SHMP update summarizes earthquake events of magnitude 5 or greater between 2018 and 2023, as listed in Table 5-2.

Table 5-2. Earthquake Events in California With a Magnitude 5 or Greater, 2018 to 2022

Date	Magnitude	Location (recorded epicenter)
April 5, 2018	5.3	19 miles southwest of Santa Cruz Island (E end), CA
June 23, 2019	5.6	4 miles south-southwest of Petrolia, CA
July 4, 2019	6.4	Ridgecrest Earthquake Sequence
July 5, 2019	5.4	10 miles west of Searles Valley, CA
July 6, 2019	7.1	11 miles west of Searles Valley, CA
July 6, 2019	5.5	9 miles east-southeast of Little Lake, CA
July 6, 2019	5.4	12 miles east of Little Lake, CA
March 18, 2020	5.2	9 miles west of Petrolia, CA
April 11, 2020	5.2	19 miles southeast of Bodie, CA
June 4, 2020	5.5	11 miles south of Searles Valley, CA
June 24, 2020	5.8	11 miles south-southeast of Lone Pine, CA
June 5, 2021	5.3	7 miles west of Calipatria, CA
July 8, 2021	6.0	Antelope Valley, CA
July 8, 2021	5.0	20 miles southeast of Markleeville, CA
July 18, 2021	5.1	7 miles west of Petrolia
December 20, 2021	6.2	4 miles north of Petrolia, CA
October 25, 2022	5.1	9 miles east-southeast of East Foothills, CA
December 20, 2022	6.4	9 miles southwest of Ferndale, CA
January 2, 2023	5.4	30 miles south of Eureka and 9 miles southeast of Rio Dell

Sources: (USGS 2023a), (SCEDC 2023)

5.4. PROBABILITY OF FUTURE HAZARD EVENTS

5.4.1. Overall Probability

Probability Based on Previous Events

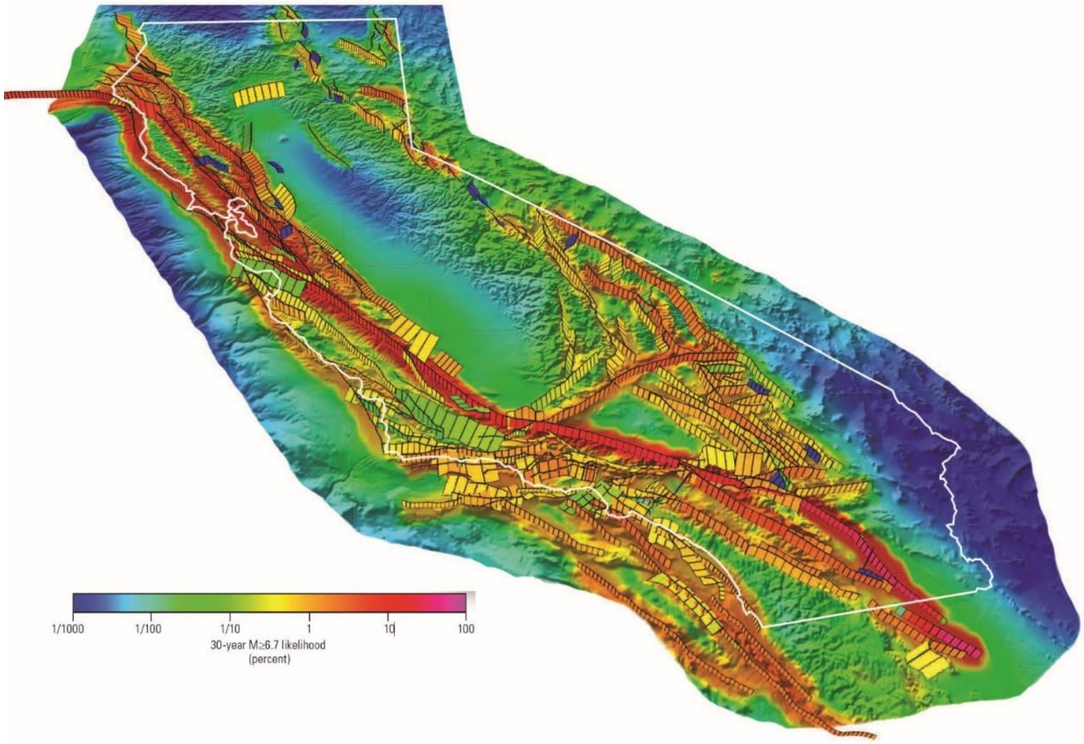
According to the USGS earthquake database, California experienced 285 earthquakes, magnitude 5 and greater, between 1950 and 2021. Based on these statistics, the State can expect at least four earthquakes with a magnitude of 5 or greater each year.

Uniform California Earthquake Rupture Forecast

The sliding movement of rock on either side of a fault is called fault rupture. The fault rupture is responsible for causing the resulting shaking. Scientists have developed an earthquake forecast model for California called the Third Uniform California Earthquake Rupture Forecast (UCERF3) (Field, et al. 2013). The model estimates the magnitude, location, and likelihood of earthquake fault rupture throughout the State. Figure 5-7 shows the model's estimate of the likelihood over the 30 years following 2014 of an earthquake of magnitude 6.7 or greater at locations across the State.

Overall, the results of the UCERF3 modeling confirm previous findings but with some significant changes. For example, compared to the previous forecast model version, the likelihood of moderate-sized earthquakes (magnitude 6.5 to 7.5) is lower, whereas that of larger events is higher. This model serves as a reminder that damaging earthquakes are inevitable in California.

Figure 5-7. Likelihood of a Magnitude 6.7 or Larger Earthquake in the Next 30 Years



Source: (WGCEP 2021)

5.4.2. Climate Change Impacts

The potential direct impacts of climate change on earthquake probability are unknown. Climate change can increase the risk of cascading hazards related to earthquakes, including landslides. Rising air temperatures can facilitate soil breakdown, allowing more water to penetrate soils and affecting erosion rates, sediment control, and the likelihood of landslides. Climate change may also increase the probability of more frequent, intense rainstorms. This can result in more significant erosion, higher sediment transport in rivers and streams, and a higher probability of landslides, primarily from higher water content.

5.5. IMPACT ANALYSIS

5.5.1. Severity

Ground shaking from earthquakes can cause buildings and bridges to collapse; disrupt utility services; and trigger landslides, avalanches, flash floods, fires, and tsunamis. Collapsing buildings and infrastructure during earthquake events produced eight of the 10 costliest disasters In California in the last 100 years (CEA 2020).

State infrastructure (roads, highways, dams, and State water projects) located in areas with liquefaction zones or on NEHRP Soil Types D, E, and F can experience extensive cracking, rip apart, settle, and slough during an earthquake.

As shown in Table 5-2, in just a five-year period, California has experienced numerous earthquakes exceeding magnitude 5, several more exceeding magnitude 6, and one exceeding magnitude 7. The last major rupture in the Cascadia Subduction Zone in 1700 caused what was likely an earthquake in the magnitude 9 range (Oregon Department of Emergency Management n.d.). Figure 5-1 and Table 5-1 describe potential observed effects for ranges of magnitude to associate with the severity of the events cited in Table 5-2.

5.5.2. Warning Time

Researchers are studying potential earthquake warning systems to give critical seconds' notice before damaging levels of shaking arrive. The warning time could allow someone to get under a desk, step away from a hazardous material, or shut down a computer system.

Cal OES's Earthquake Early Warning California (MyShake), developed in partnership with UC Berkeley and USGS ShakeAlert, is the country's first publicly available, statewide warning system that provides seconds or tens of seconds to take cover or other preventive measures before shaking occurs, depending on the location of the event. The system uses data from motion sensors and Global Navigation Satellite System across the State to detect earthquakes before humans can feel them and to notify Californians of an earthquake in advance. Individuals can download the MyShake App on their phones to receive earthquake warnings.

5.5.3. Cascading Impacts

Cascading impacts are the impacts that result when one type of hazard event triggers one or more other hazard events, which may, in turn, trigger still others. The following are notable cascading impacts associated with earthquakes beyond the hazards associated with ground shaking:

- **Surface Fault Rupture—**When a fault rupture extends to the earth's surface, the displacement can catastrophically damage structures or utilities. Fissuring, settlement, and permanent horizontal and vertical ground shifting often accompany large earthquakes. Such displacement can significantly increase damage and may be a contributing cause of damage. Studies after the 1972 San Fernando Earthquake showed that incidents of moderate to severe damage were significantly elevated near the fault zone. Because of its geographic extent and the tendency for it to be buried, networked infrastructure such as water, power, communication, and transportation infrastructure is particularly vulnerable to surface fault rupture.

- **Fires—**Fires following earthquakes may result from multiple causes, including overturned burning candles, sparking from downed power lines, and broken gas pipelines (Scawthorn and Schiff 2005). Fires following the 1906 San Francisco Earthquake led to more damage than was caused by ground shaking. Significant fires also occurred in San Francisco following the 1989 Loma Prieta Earthquake and in Los Angeles following the 1994 Northridge Earthquake. Fires after earthquakes may severely strain fire departments that must respond to multiple simultaneous ignitions. Impaired communications, water supply, transportation, and other demands such as structural collapses, hazardous materials releases, or medical emergencies affect fire department response. Several computer programs (e.g., Hazus, URAMP, SERA, and RiskLink) are available to assess the fire-following-earthquake vulnerability of a community in future earthquakes (Scawthorn and Schiff 2005).
- **Liquefaction—**Ground settlement during liquefaction can cause damage when the amount of settlement varies significantly across the length of a structure. Liquefaction can occur in susceptible soils below bodies of water. It can severely damage dams, bridges, wharves, piers, and other structures at ports and harbors, as well as underwater utility lines.
- **Landslides—**Landslides caused by earthquakes can be widespread over the area of the highest shaking intensity and at greater distances if hillsides are susceptible. Earthquake-induced landslides can significantly damage structures and transportation and utility lifelines.
- **Tsunami—** Fault rupture and earthquake-induced landslides along the coast and offshore can trigger tsunamis that can cause flooding in low-lying coastal areas.
- **Dam or Levee Failure—**Earthquake ground shaking in and around dams and levees can affect the performance of these structures. The type of foundation

the dam or levee is constructed on (such as peat or alluvium) will influence its performance during a seismic event or under certain static loading conditions.

- **Power Outages—**Earthquakes can cause significant impacts associated with loss of power. Earthquakes of all sizes can damage electrical facilities and power lines, impacting community lifelines that rely on power to maintain their critical functions.
- **Hazardous Materials Release—**Earthquakes can result in collapsed buildings and severed pipelines, leading to the release of hazardous materials, which may include oil spills, the release of gases, and runoff of hazardous materials (Young, Balluz and Malilay 2004).

5.5.4. Environmental Impacts

Environmental problems from earthquakes can be numerous. Earthquake-induced landslides can significantly damage the surrounding habitat. It is also possible for earthquakes to reroute streams, which can change the water quality, possibly damaging habitat and feeding areas. Streams fed by groundwater or springs may dry up because of changes in underlying geology.

Another threat to the environment from earthquakes is the potential release of hazardous materials caused by any of the following:

- The toppling of elevated tanks or overturning of horizontal tanks
- Structural failures
- Dislodging of asbestos
- Sloshing from open-topped containers
- Falling containers or shelves, especially in laboratories
- Storage container failures
- Under- or above-ground pipeline breaks
- Structural fire in industrial facilities following earthquake events

5.5.5. Impacts on Agriculture

California agriculture is large, diverse, and complex, and agricultural impacts from earthquakes can be significant. Earthquakes can cause damage and the loss of infrastructure that supports agricultural production, storage, and transport. Damage to major hubs, including ports, may have more substantial impacts. A 2014 report for SCC found that significant losses are a concern for rural food and agricultural industries and concluded the following:

- Large areas of California agriculture—along the Mexican border, along the central and southern coast, and near the Sacramento-San Joaquin Delta—are especially vulnerable to seismic activity.
- The California produce industry may be more vulnerable to seismic disruptions than any other agricultural sector because of its location and the high levels of perishability.
- The most important dairy production and processing regions, in the Southern San Joaquin Valley, are less prone to seismic events than the coastal counties and Imperial County. Nonetheless, given extreme perishability and animal welfare concerns, dairies need to be aware of seismic risks.

5.5.6. Local Hazard Impacts

LHMP Rankings

All but one of the hazard mitigation plans prepared for California's 58 counties list earthquake as a hazard of concern, and 46 counties rank it as a high-impact hazard:

- Alameda
- Amador
- Butte
- Contra Costa
- Del Norte
- El Dorado
- Fresno
- Humboldt
- Imperial
- Inyo
- Kern
- Kings
- Lake
- Lassen
- Los Angeles
- Madera
- Marin
- Mendocino
- Merced
- Modoc
- Monterey
- Napa
- Nevada
- Orange
- Placer
- Plumas
- Riverside
- Sacramento
- San Benito
- San Bernardino
- San Diego
- San Francisco
- San Luis Obispo
- San Mateo
- Santa Barbara
- Santa Clara
- Santa Cruz
- Shasta
- Sierra
- Solano
- Sonoma
- Stanislaus
- Sutter
- Tuolumne
- Yolo
- Yuba

An additional eight counties identified earthquake as a medium-impact hazard.

LHMP Estimates of Potential Loss

Table 5-3 summarizes potential losses to vulnerable structures based on estimates from the local risk assessments (as called for in FEMA's Standard State Mitigation Planning Requirement S6.b). Due to variances in approaches to assessing risk at the local level as well as the hazards assessed and the age of each assessment reviewed, this data is considered approximate.

Table 5-3. Earthquake Risk Exposure Analysis for LHMP Reviews

Estimated Total Population Exposed	39,538,232*
Estimated Number of Structures at Risk	8,361,028
Estimated Value of Structures at Risk	$319.6 billion

* Assumed to be the entire State population

5.6. VULNERABILITY ANALYSIS

The earthquake vulnerability assessment for State-owned or -leased assets and critical facilities/community lifelines looked at NEHRP soil types D and E, liquefaction zones (where mapping is available; liquefaction zones are not yet mapped for most of the State), and exposure to ground shaking. The assessment determined the exposure to State assets, critical facilities, and community lifelines to these hazard areas.

5.6.1. Exposure of State-Owned or -Leased Facilities

Table 5-4 and Table 5-5 summarize the number and replacement cost value of State assets on NEHRP Type D or E soils, in liquefaction zones (where data are available) and in areas of potential significant shaking.

Figure 5-8, Figure 5-9, and Figure 5-10 summarize the exposed assets as a percentage of total assets statewide. Appendix I provides detailed results by county.

Table 5-4. State-Owned or -Leased Facilities Exposed to the Earthquake Hazard

Type of Facility	Number of Structures	Total Area (sq. ft.)	Replacement Cost Value		
			Structure	Content	Total
State Facilities on NEHRP Soil Types D & E					
State-Leased Facilities	1,037	—	$5,436,392,749	$5,526,604,492	$10,962,997,241
State-Owned Facilities					
Facilities Housing Vulnerable Populations					
Correctional Facility	2,176	23,629,348	$2,106,526,246	$1,290,776,135	$3,397,302,381
Development Center	0	0	$0	$0	$0
Hospital	2	119,500	$6,114,574	$4,531,982	$10,646,556
Migrant Center	14	818,733	$606,765,693	$311,004,919	$917,770,612
Special School	64	510,744	$10,729,356	$9,928,709	$20,658,065
All Other Facilities	7,155	79,325,222	$6,333,510,634	$6,447,416,272	$12,780,926,905
Total State-Owned	***9,411***	***104,403,547***	***$9,063,646,503***	***$8,063,658,016***	***$17,127,304,519***
Total Facilities	**10,448**	**N/A***	**$14,500,039,252**	**$13,590,262,508**	**$28,090,301,760**
State Facilities in the Mapped Liquefaction Zone (zones are not yet mapped for the entire State)					
State-Leased Facilities	235	—	$1,185,108,167	$1,189,440,868	$2,374,549,035
State-Owned Facilities					
Facilities Housing Vulnerable Populations					
Correctional Facility	68	482,198	$33,750,554	$26,291,181	$60,041,735
Development Center	0	0	$0	$0	$0
Hospital	1	71,500	$5,669,649	$3,864,595	$9,534,245
Migrant Center	0	0	$0	$0	$0
Special School	64	510,744	$10,729,356	$9,928,709	$20,658,065
All Other Facilities	927	17,569,418	$1,709,473,964	$1,793,595,177	$3,503,069,141
Total State-Owned	***1,060***	***18,633,860***	***$1,759,623,523***	***$1,833,679,663***	***$3,593,303,186***
Total Facilities	**1,295**	**N/A***	**$2,944,731,690**	**$3,023,120,530**	**$5,967,852,220**

Type of Facility	Number of Structures	Total Area (sq. ft.)	Replacement Cost Value		
			Structure	Content	Total
State Facilities in Mapped Areas Exposed to Ground Shaking					
State-Leased Facilities	468	—	$2,357,525,251	$2,376,797,602	$4,734,322,853
State-Owned Facilities					
Facilities Housing Vulnerable Populations					
Correctional Facility	150	1,707,566	$71,675,721	$54,920,790	$126,596,511
Development Center	0	0	$0	$0	$0
Hospital	308	2,866,825	$95,505,290	$114,662,785	$210,168,075
Migrant Center	3	231,750	$515,052,873	$257,526,437	$772,579,310
Special School	64	510,744	$10,729,356	$9,928,709	$20,658,065
All Other Facilities	4,830	66,335,481	$5,183,127,033	$5,426,765,460	$10,609,892,493
Total State-Owned	***5,355***	***71,652,366***	***$5,876,090,273***	***$5,863,804,181***	***$11,739,894,454***
Total Facilities	**5,823**	**N/A***	**$8,233,615,524**	**$8,240,601,783**	**$16,474,217,306**

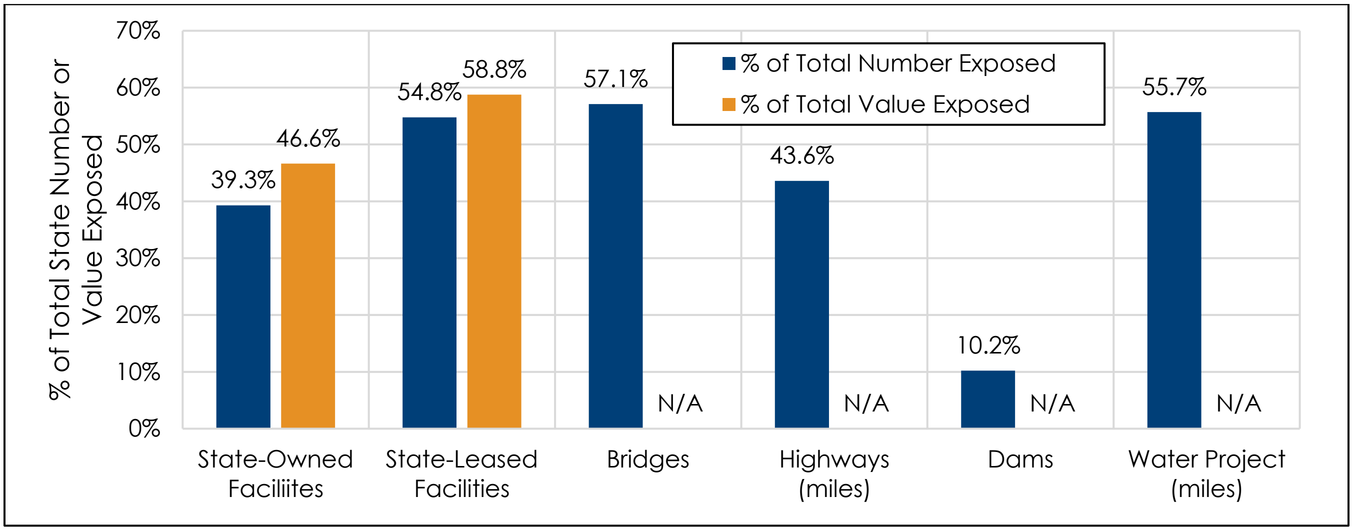
* The inventory of State assets does not include building area for State-leased facilities, so no total area for all State facilities is provided; the building area of vulnerable assets is shown for State-owned facilities only.

Table 5-5. State-Owned Infrastructure Exposed to the Earthquake Hazard

Type of Facility	State-Owned Infrastructure in the Mapped Hazard Area		
	NEHRP Soil Types D & E	Liquefaction Zones*	Exposure to Ground Shaking
Bridges	7,538	2,276	4,642
Highway (miles)	13,120.8	1,601.9	6,364.1
Dams	5	1	9
Water Project (miles)	398.0	7	225.7

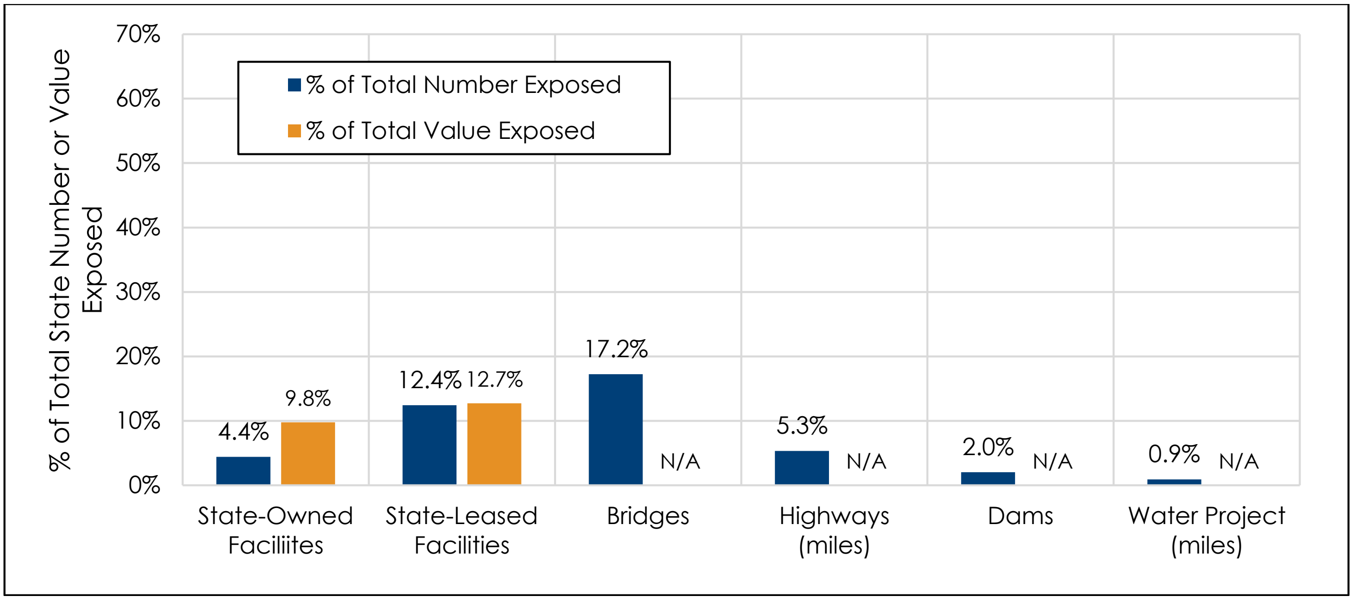
* Liquefaction hazard zones are not yet mapped for the entire State.

Figure 5-8. State Assets on NEHRP Type D or E Soils, as % of Statewide Total



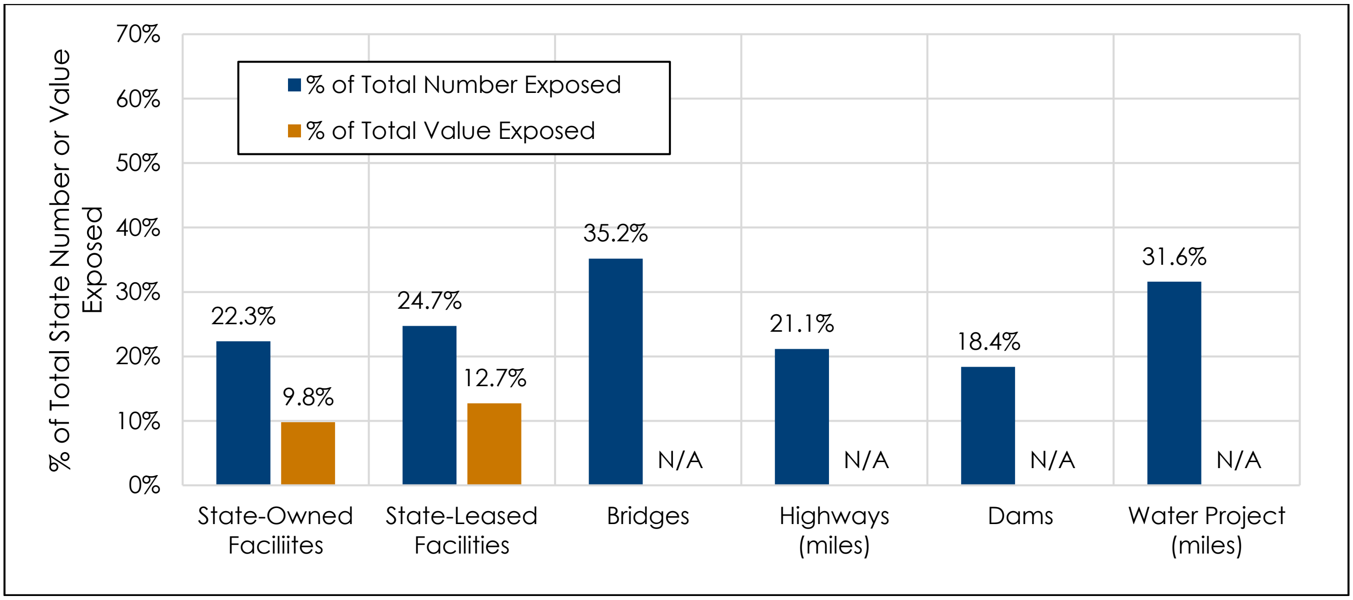
N/A: Values not defined for bridges, highways, dams, and water project

Figure 5-9. State Assets in Mapped Liquefaction Hazard Zones, as % of Statewide Total



N/A: Values not defined for bridges, highways, dams, and water project

Figure 5-10. State Assets in Areas with Significant Ground Shaking Potential, as % of Statewide Total



N/A: Values not defined for bridges, highways, dams, and water project

The following are significant results of the analysis of State-owned or -leased assets in the earthquake hazard areas:

- For State-owned facilities in areas with NEHRP Soil Types D and E, the average area is 1,800,061 square feet, with an average replacement cost value of

$295 million (structure and contents). In mapped liquefaction areas, the average area is 321,273 square feet, with an average replacement cost value of $61.9 million (structure and contents). In areas susceptible to significant ground shaking, the average area is 13,380 square feet, with an average replacement cost value of $2.2 million (structure and contents).

- The average replacement cost value for State-leased facilities (structure and contents) is $189 million on NEHRP Soil Types D and E, $40.9 million in mapped liquefaction zones, and $10.1 million in areas susceptible to significant ground shaking.
- The five State agencies with the most State-owned or -leased facilities in earthquake hazard areas are as follows:
  - **NEHRP Types D and E soils**—CDCR (2,223), State Parks (2,021), UC (1,234), Caltrans (1,073), and California Department of Fish and Wildlife (CDFW) (695).
  - **Mapped Liquefaction zones**—State Parks (280), California State University (CSU) (210), Caltrans (194), California Department of Education (CDE) (79), and CDCR (78).
  - **Significant ground shaking areas**— State Parks (1,924), UC (616), Caltrans (562), CSU (537), and CAL FIRE (463).
- The State agency with the highest total replacement cost for State-owned or -leased facilities in areas of NEHRP Soil Types D and E and areas susceptible to significant ground shaking is CSU, at $3.8 billion.

5.6.2. Exposure of Critical Facilities and Community Lifelines

Functional downtime is the most significant earthquake impact on critical facilities and community lifelines. The severity of this impact is based on the amount of time it takes to restore damaged facilities to operational status. Hazus estimates damage and functional downtime for earthquake scenarios. Local governments are encouraged to use Hazus or similar tools when developing LHMPs.

Transportation routes, including bridges and highways, are vulnerable to earthquakes, especially in NEHRP Soil Types D and E and liquefaction zones. Aging infrastructure and those already in poor condition are most vulnerable.

Interruption of utility infrastructure services may impact vulnerable populations and facilities that need to be in operation during a disaster. Table 5-6 summarizes the total number of critical facilities, by community lifeline, located in earthquake hazard areas statewide. Food, water, and shelter facilities have the largest number located in these hazard areas. Appendix I provides detailed results by county.

Table 5-6. Critical Facilities and Community Lifelines Exposure to Earthquake Hazard Areas

Lifeline Category	Total Number of Facilities	Number of Facilities in Hazard Area			% of Total Facilities		
		NEHRP D & E	Liquefaction *	Significant Ground Shaking	NEHRP D & E	Liquefaction *	Significant Ground Shaking
Communications	42	30	13	24	71.4%	31.0%	57%
Energy	176	92	32	51	52.3%	18.2%	18%
Food, Water, Shelter	257	131	37	73	51.0%	14.4%	28%
Hazardous Material	56	35	12	8	62.5%	21.4%	14%
Health & Medical	47	20	9	23	42.6%	19.1%	49%
Safety & Security	46	20	6	16	43.5%	13.0%	35%
Transportation	131	84	40	46	64.1%	30.5%	35%
Total	**755**	**412**	**149**	**241**	**54.6%**	**19.7%**	**32%**

* Liquefactions zones are not yet mapped for the entire State.

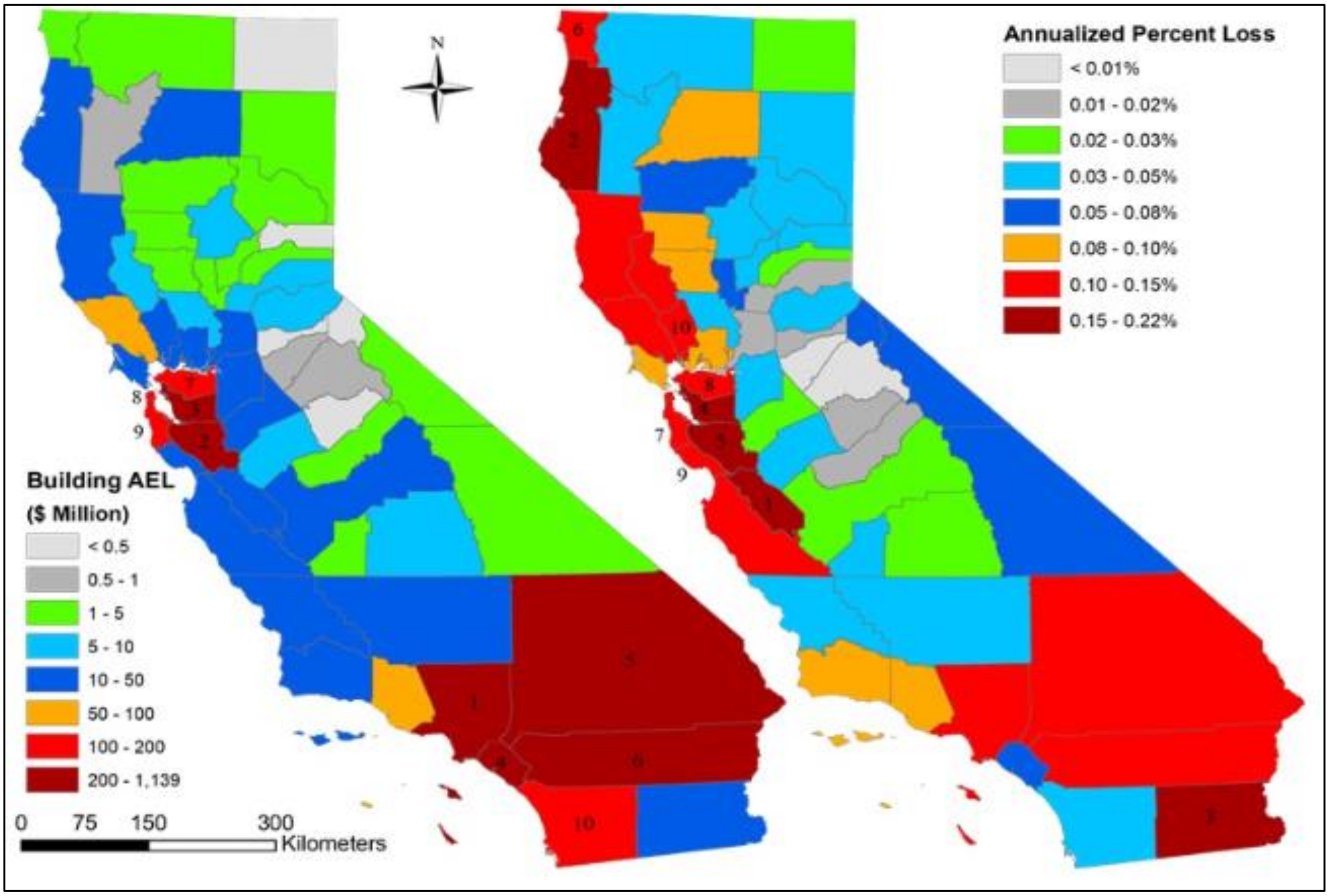
5.6.3. Estimates of Loss

Earthquake loss estimation quantifies seismic risk based on exposure and vulnerability of the built environment. Such studies need to be frequently updated because of the continuing development of the built environment and evolving technology in seismic hazard assessments. CGS has participated in the development of many planning scenarios since 1980. CGS also updates its scenario- and probabilistic-based loss estimations when significant developments occur in ground motion hazard analyses and the built environment (DOC 2019b).

In 2016, CGS calculated the annualized earthquake loss for California. The annualized earthquake loss provides a long-term average yearly loss in a geographic area. It indicates relative regional earthquake risk and facilitates comparison of earthquake risk among different communities. The 2016 analysis estimates the annualized loss to be $3.7 billion for California. This is 11 percent higher than the 2010 estimates due to the combined effects of increased building inventory value and differences in velocity maps (Chen and Wils 2016).

Figure 5-11 shows the building annualized earthquake loss and annualized percent earthquake loss. The five counties with the highest estimated loss are Los Angeles, Santa Clara, Alameda, Orange, and San Bernardino. The five counties with the highest annualized percent earthquake loss are San Benito, Humboldt, Imperial, Alameda, and Santa Clara.

Figure 5-11. Distribution of Annualized Earthquake Losses and Annualized Percent Earthquake Loss



Source: (Chen and Wils 2016)

5.6.4. Buildable Land

Of 11.7 million acres of land available for development statewide, 143,890 acres (1.2 percent) are located in the liquefaction zones that have been mapped so far, 3,714,106 acres (31.5 percent) are located in areas with NEHRP Type D or E soils, and 1,800,765 acres are located in areas susceptible to significant ground shaking. Appendix G provides a detailed assessment of exposed buildable lands by county.

5.6.5. Equity Priority Communities

The risk analysis for earthquakes found the following vulnerability of equity priority communities (a breakdown by county is included in Appendix I):

- 36.7 percent of people living on NEHRP Type D or E soils live in equity priority communities (6,898,652 people)
- 35.6 percent of people living in liquefaction areas that have been mapped live in equity priority communities (2,707,505 people)
- 27.8 percent of people living in areas of significant shaking potential live in equity priority communities (4,083,116 people)

5.6.6. NRI Scores

According to the NRI, all the State's counties have earthquake risk, rated from relatively low to very high. Table 5-7 shows scores for the six counties with the highest rating. See Section 4.1.3 for a description of the components of the NRI.

Table 5-7. NRI Scoring of Counties for Earthquake

County	Expected Annual Loss	Social Vulnerability Rating	Community Resilience Rating	Community Risk Factor	Risk Value	Score
Los Angeles	$3.8 billion	Very High	Very Low	1.36	$5.2 billion	100
Santa Clara	$1.2 billion	Relatively Low	Relatively High	1.34	$1.33 billion	99.97
Alameda	$1.2 billion	Relatively Moderate	Very High	1.13	$1.33 billion	99.94
San Bernardino	$964 million	Very High	Relatively Moderate	1.34	$1.32 billion	99.90
Orange	$926 million	Relatively Moderate	Very Low	1.26	$1.2 billion	99.87
Riverside	$838 million	Very High	Relatively Low	1.34	$1.1 billion	99.84

5.7. MITIGATING THE HAZARD

5.7.1. Existing Measures for Mitigating the Hazard

Earthquake mitigation measures are typically intended to reduce damage and fatalities from earthquakes. Common mitigation measures include:

- Structural mitigation measures to improve the capacity of a building to resist seismic forces
- Nonstructural mitigation measures to restrain, brace, anchor, or otherwise improve the seismic resistance of nonstructural building components
- Replacement of an existing building with substantial seismic deficiencies with a new current code building
- Design and construction of a new facility to be higher than the minimum seismic standards required by building codes

The State of California has invested significantly in seismic mitigation efforts. The State developed a method to mitigate ground failure-related hazards caused by earthquakes. Through the Alquist-Priolo Earthquake Fault Zoning Act of 1972, which addresses hazards associated with surface fault rupture, and the Seismic Hazards Mapping Act of 1990, addressing hazards from soil liquefaction and earthquake-induced landslides, CGS delineates regulatory earthquake zones over the State's most populated areas and most hazardous faults. These earthquake zones promote mitigation activities before or during construction, making new developments resilient to future earthquakes, saving lives, and reducing earthquake recovery costs. In 2018, CGS launched the California Earthquake Hazards Zone Application, also called EQZapp, an online mapping tool that allows anyone to check whether a property is in an earthquake hazard zone (DOC 2019a).

5.7.2. Opportunities for Mitigating the Hazard

In addition to the mitigation actions described above, Table 5-8 provides a range of potential alternatives for mitigating the earthquake hazard (see Section 1.2.3 for a description of the different types of alternatives).

Table 5-8. Potential Opportunities to Mitigate the Earthquake Hazard

Community-Scale	Organizational -Scale	Government-Scale
Manipulate the hazard: ▪ Apply engineering solutions that minimize or eliminate the hazard **Reduce exposure and vulnerability:** ▪ Locate outside of the hazard area (off soft soils) ▪ Retrofit structure (anchor house structure to the foundation) ▪ Secure household items that can cause injury or damage (such as water heaters, bookcases, and other appliances) ▪ Build to higher design **Build local capacity:** ▪ Practice "drop, cover, and hold" ▪ Develop household mitigation plan, such as creating a retrofit savings account, communication capability with outside, 72-hour self-sufficiency during an event ▪ Keep cash reserves for reconstruction	**Manipulate the hazard:** ▪ Apply engineering solutions that minimize or eliminate the hazard **Reduce exposure and vulnerability:** ▪ Locate or relocate mission-critical functions outside hazard areas where possible ▪ Build redundancy for critical functions and facilities ▪ Retrofit critical buildings and areas housing mission-critical functions **Build local capacity:** ▪ Adopt a higher standard for new construction; consider "functional recovery-based design" when building new structures ▪ Keep cash reserves for reconstruction ▪ Inform employees about the possible impacts of earthquakes and how to deal with them at work	**Manipulate the hazard:** ▪ Apply engineering solutions that minimize or eliminate the hazard **Reduce exposure and vulnerability:** ▪ Locate critical facilities or functions outside the hazard area where possible ▪ Harden infrastructure ▪ Provide redundancy for critical functions ▪ Adopt higher regulatory standards ▪ Encourage and invest in renewable energy and backup and storage, such as microgrids, for vital systems redundancy during power outages and interruptions **Build local capacity:** ▪ Provide better hazard maps ▪ Provide technical information and guidance ▪ Enact tools to help manage development in hazard areas (e.g., tax incentives, information) ▪ Include retrofitting and replacement of critical system elements in the capital improvement plan ▪ Develop a strategy to take advantage of post-disaster opportunities ▪ Warehouse critical infrastructure components such as pipes, power lines, and road repair materials ▪ Develop and adopt a continuity of operations plan ▪ Initiate triggers guiding improvements (such as >50% substantial damage or improvements)

Community-Scale	Organizational -Scale	Government-Scale
▪ Become informed on the hazard and risk reduction alternatives available ▪ Develop a post-disaster action plan for your household ▪ Consider the purchase of earthquake insurance	▪ Develop a continuity of operations plan ▪ Consider the purchase of earthquake insurance	▪ Further enhance seismic risk assessment to target high-hazard buildings for mitigation opportunities ▪ Develop a post-disaster action plan that includes grant funding and debris removal components ▪ Evaluate earthquake insurance as an option ▪ Expand data collection capabilities of the California Earthquake Clearinghouse ▪ Broaden application of lessons learned from California Earthquake Clearinghouse ▪ Establish Local Assistance Centers
Nature-based opportunities: ▪ None identified		

5.7.3. Selected Actions to Mitigate the Hazard

The mitigation strategy developed for this SHMP includes the following actions that address the earthquake hazard:

- Action 2023-002: Conduct both structural and non-structural assessments of State-owned facilities that identify vulnerabilities and feasible alternatives to retrofit those vulnerabilities.
- Action 2023-003: Develop a Hazus repository for both earthquake and flood hazards where local planning efforts that create these models can share this information with the State once the models have been developed.
- Action 2023-004: Leverage existing State programs to develop and support programs for the assessment and retrofit of structures identified with soft-story construction.
- Action 2023-005: Coordinate planning efforts for aquifer storage and recharge actions within areas of known liquefaction risk (note that not all liquefaction areas in the State have yet been mapped) so that the risk is addressed if potentially increased by the storage basin mitigation action.

An Example Success Story for Earthquake Mitigation:

The California Residential Mitigation Program's Earthquake Brace + Bolt Program

Two homes after the 2022/2023 Ferndale Earthquakes – The house on the left fell off its foundation without retrofitting. The house on the right remained on its foundation due to retrofitting.

Problem: The California Earthquake Authority (CEA) estimates more than 1.2 million houses in high-seismic-hazard areas in California are vulnerable to earthquakes because of their construction types. Many of these homes were built before 1980, are wood-framed with a raised foundation, and may have a cripple wall in the crawl space. A 6.4 magnitude earthquake on December 20, 2022, followed by a 5.3 magnitude earthquake on January 1, 2023, damaged many wood-framed homes in Humboldt County that would have benefited from a retrofit.

Solution: Bolting the home to its foundation and bracing its cripple walls reduces the likelihood that these older homes will slide off their foundation during an earthquake. The California Residential Mitigation Program's Earthquake Brace + Bolt (EBB) program addresses this vulnerability. Retrofits must adhere to the California Existing Building Code. Since 2014 when the first EBB retrofit was completed, EBB grants have helped more than 19,000 homeowners retrofit their homes.

Cost and Funding: The California Residential Mitigation Program administers the EBB program, a Joint Exercise of Powers Agreement between CEA and Cal OES. The program provides up to $3,000 to qualifying homeowners to help pay for code-compliant seismic retrofits in 521 high-risk zip codes. To ensure that equity remains a guiding principle of the program, income-eligible homeowners may also qualify for supplemental grants to help cover up to 100 percent of the cost of a code-compliant seismic retrofit. The amounts vary depending on the region and type of retrofit completed and are available for households with an income at or below $72,080. Grants are contingent upon meeting eligibility requirements and available funds.

Benefits: Retrofitting a home help ensure a lower risk of damage and reduces the risk of injury to its occupants. Retrofitting more homes today will help prevent the current housing crisis from becoming far more acute after a damaging earthquake, as preserving the existing housing supply is critical. Completing an EBB seismic retrofit provides peace of mind to homeowners by knowing they have done what they can to protect their homes and family. After a damaging earthquake, more families will be able to stay in their homes and more communities will be able to rebuild faster because of EBB. The EBB Program has provided nearly $59 million in grants to homeowners and poured millions of dollars into California's construction industry.

RIVERINE, STREAM, AND ALLUVIAL FLOODING

Climate Impacts:
Frequent, larger rain events and snowmelt leading to more flooding
Equity Impacts:
35.9% of the population living in the 1% annual chance flood hazard area and 41.2% of the population living in the 0.2% annual chance flood hazard area) are identified as living in equity priority communities
State Facilities Exposed:
1,824 facilities in 1% annual chance flood hazard areas
Community Lifelines Exposed:
65 lifelines in the 1% annual chance flood hazard areas

Impact Rating: High (42)

6. RIVERINE, STREAM, AND ALLUVIAL FLOODING

Riverine, stream, and alluvial flooding has been identified as a high-impact natural hazard of interest based on the hazard impact rating protocol applied for this SHMP. Such flooding happens frequently in the State; over 15 percent of State-owned or -leased facilities and community lifelines are exposed. Approximately 15 percent of the State's population is exposed (living in the 1% and 0.2% annual chance flood hazard areas), and over 41 percent of that population has been identified as living in equity priority communities. Over 7 percent of the identified buildable lands within the State intersect mapped riverine, stream, or alluvial floodplains. The frequency and severity of riverine, stream, and alluvial flooding is anticipated to increase over the next 30 years due to the impacts from climate change.

6.1. HAZARD OVERVIEW

6.1.1. Types of Flooding

In terms of recent disasters and the probability of future destruction at increasing magnitudes, floods represent one of California's most destructive sources of hazard, vulnerability, and risk. This chapter assesses the State's risks associated with the following flood hazards (DWR 2019):

- **Riverine flooding** occurs when rivers, streams, and lakes overflow their banks. Areas adjacent to local streams and creeks can experience flooding due to excessive runoff from heavy rainfall and accumulation of water flowing over broad flat areas. Riverine flooding can be widespread, with floodwaters persisting for just a few hours or several weeks.

- A **flash flood** is a sudden, rapid flooding of low-lying areas, typically caused by intense rainfall. Flash flooding can quickly roll boulders, tear out trees, and destroy buildings and bridges. Flash floods can also occur from the collapse of a structure built by people. Rapidly rising water can reach heights of 30 feet or more.
- **Localized flooding** occurs during or after a storm when rainfall and subsequent runoff overwhelm drainage systems. When the system backs up, pooling water can flood streets, yards, and even the lower floors of homes and businesses. Even less intense storms can cause this type of flooding when leaves, sediment, and debris plug storm drains.
- **Alluvial fan flooding** is sudden and unpredictable flooding on alluvial fans – fan-shaped landforms created by sediment erosion from an upland water source. It is characterized by relatively shallow depths, high velocity, and moving soil and sediment, creating uncertainty on where rising water will travel.

6.1.2. Flood Zones

FEMA conducts flood studies that use historical records to determine the probability of occurrence for different flood levels in a community. Flood Insurance Rate Maps (FIRMs) show flood zones for rainfall flooding, riverine flooding, coastal flooding, and shallow flooding and distinguish areas where detailed studies have been conducted to determine flood elevations. The federal government started regulatory floodplain mapping on a nationwide basis in the late 1960s. FEMA's mapping reflects the risk from coastal and major inland flooding but does not generally reflect the risk of localized urban flooding. There is no statewide system for mapping risk from urban flooding. The location, extent, and vulnerability of such flooding are analyzed using the Special Flood Hazard Areas (SFHA) depicted on each county's FIRM.

6.1.3. Flood Frequency

The recurrence interval of a flood, or frequency, is the average number of years between floods of a certain size. Riverine flooding is measured using a discharge probability, the probability that a certain river discharge (flow) level will be equaled or exceeded in a given year. Flood studies use historical records to determine the probability of occurrence for the different discharge levels.

The number of years between floods of any given size varies because of the natural variations in climate and weather events. FEMA FIRMs identify the flood hazard area as the area that would be inundated by a flood with a 1 percent chance of occurring in any given year (the 1% annual chance flood). FIRMs also typically show the extent of the flood with a 0.2 percent chance of occurring in any given year (0.2% annual chance flood). These measurements reflect statistical averages only, and it is possible for two or more floods with a 1% annual chance to occur in a short time period (USGS 2022i). Table 6-1 summarizes the concept of recurrence intervals and probabilities.

Table 6-1. Recurrence Intervals and Probabilities of Occurrence

Recurrence Interval (in years)	Probability of Being Equaled or Exceeded in Any Given Year	Percent Chance of Being Equaled or Exceeded in Any Given Year
100	1 in 100	1%
50	1 in 50	2%
25	1 in 25	4%
10	1 in 10	10%
5	1 in 5	20%
2	1 in 2	50%

Source: (USGS 2023b)

6.1.4. Repetitive Loss Properties and Areas

FEMA defines a repetitive loss (RL) property as a property insured through the National Flood Insurance Program (NFIP) that has experienced any of the following since 1978:

- Four or more paid losses of more than $1,000
- Two paid losses of more than $1,000 within any rolling 10-year period
- Three or more paid losses that equal or exceed the current value of the insured property

FEMA designates as severe repetitive loss (SRL) any NFIP-insured single-family or multi-family residential building for which either of the following is true:

- The building has incurred flood-related damage for which four or more separate claims payments have been made, with the amount of each claim (including building and contents payments) exceeding $5,000 and with the cumulative amount of such payments exceeding $20,000.
- At least two separate claims payments (building payments only) have been made under NFIP coverage, with the cumulative amount of claims exceeding the market value of the building.

To qualify as an SRL property, at least two of the claims must be within 10 years of each other (claims made within 10 days of each other are counted as one). In determining SRL status, FEMA considers the loss history since 1978 or from the building's construction if it was built after 1978, regardless of any changes in the ownership of the building.

FEMA encourages communities to identify and mitigate the causes of repetitive losses. FEMA-sponsored programs such as the Community Rating System (CRS) require participating communities to identify RL areas. A RL area is the portion of a floodplain holding structures that FEMA has identified as meeting the definition of RL. Identifying RL areas helps to identify structures at risk but not on FEMA's list of RL structures because no flood insurance policy was in force at the time of loss.

6.2. HAZARD LOCATION

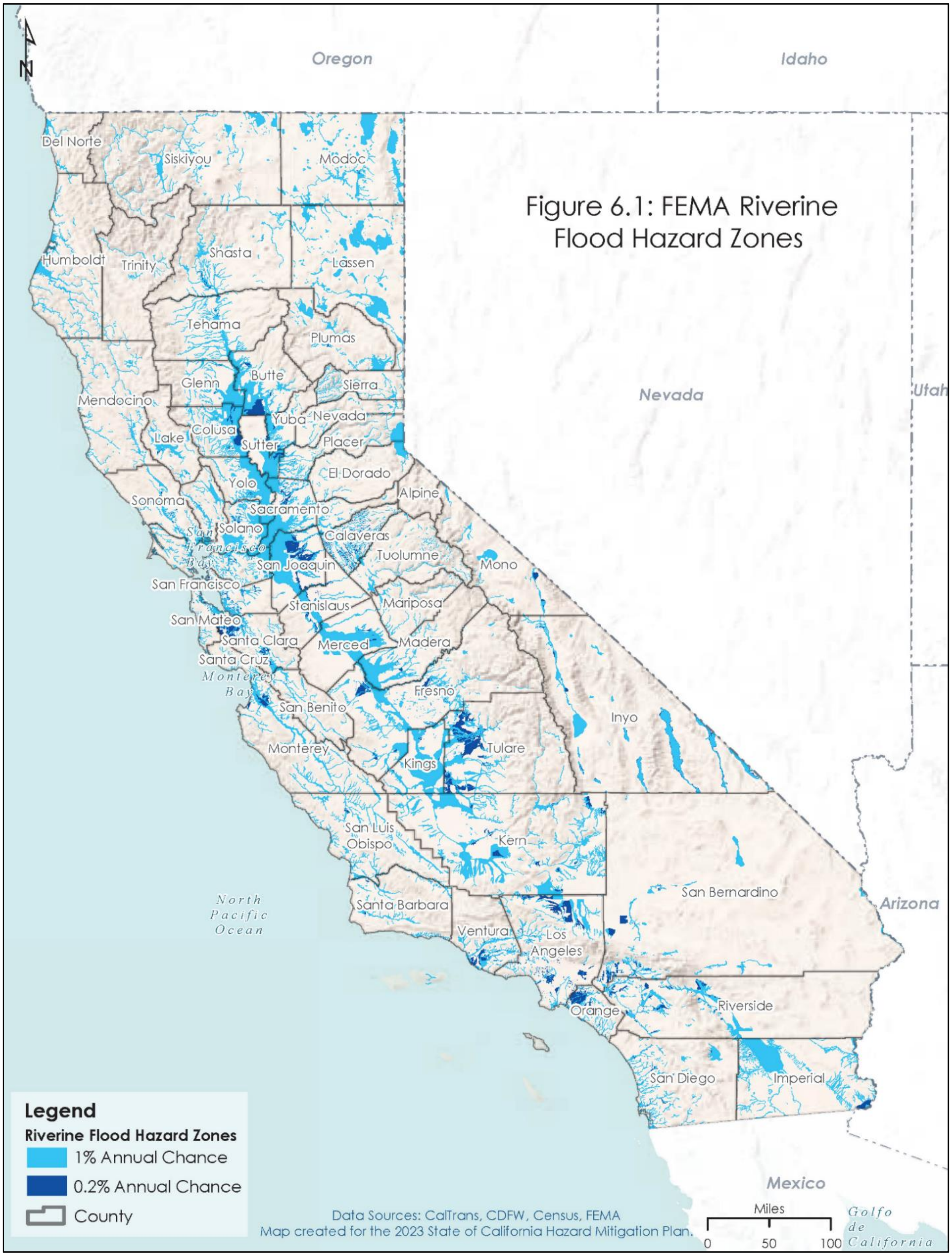
California faces widespread flooding. Figure 6-1 shows SFHAs in the State. FEMA FIRMs do not provide complete coverage of California and contain inaccuracies due to changes in development and infrastructure since the original surveying. FEMA has mapped a portion of California but has substantial areas yet to map. Efforts have been underway to update some FIRMs in the State through FEMA's Risk MAP (Mapping, Assessment, and Planning) Strategy.

All regions of California are susceptible to flooding at different times of the year and in different forms—ranging from alluvial fan flooding at the base of hillsides to fast-moving flash floods to slow-rise deep flooding in valleys. Flood risk varies across the State, generally increasing with development in floodplains (DWR 2022f).

Existing FIRMs for areas across the State show that flood hazard zones are common in populated areas. Every county in the State experiences floods, although the nature of flood events varies due to the State's diverse climatology and geography (DWR 2019):

- Riverine flooding can occur along any streams, creeks, or rivers. Of particular concern in California are the deep floodplains of the Central Valley, which are subject to periodic riverine flooding.
- Flash flooding can occur anywhere in the State.
- Localized flooding typically occurs in urban areas.
- Alluvial flooding occurs in mountainous areas, the foothills, or the coast. Alluvial fans are common in parts of Central and Southern California.

Figure 6-1. FEMA Riverine Flood Hazard Zones



6.3. PREVIOUS HAZARD OCCURRENCES

6.3.1. Disaster and Emergency Declarations

The following disaster declarations or emergency proclamations related to flooding have been issued for California (see Appendix F for details):

- Federal DR or EM declaration, 1953 – 2022: 37 events, classified as flood, flash flooding, severe storms, erosion, rain/snow/windstorms, landslides/mudslides, high tides, levee break, or coastal storm
- California Emergency Proclamations, 1950 – 2022: 124, classified as flood
- USDA agricultural disaster declarations, 2012 – 2022: None

From 2018 through September 2022, the following counties experienced 24 or more declared disasters:

- Kern, Los Angeles, Riverside, San Bernardino, Orange, and San Diego in Southern California
- Contra Costa, Alameda, San Mateo, Marin, Napa, and Santa Cruz in the San Francisco Bay Area
- Sacramento, Yolo, Sutter, El Dorado, and Yuba in the Sacramento/Sierra foothill area
- Humboldt, Trinity, Butte, and Mendocino in Northern California

6.3.2. Event History

Table 6-2 describes major riverine, flash, and alluvial fan flooding events (those that cause $25,000 or more in property damage) that impacted California between 2018 and 2022. Appendix K lists events before 2018.

Table 6-2. Major Flood Event History

<table>
<tr><th>Date</th><th>Event Type</th><th>FEMA Declaration Number</th><th>USDA Declaration Number</th><th>Counties Impacted</th></tr>
<tr><td>January 9, 2018</td><td>Debris Flow, Flash Flood</td><td>N/A</td><td>N/A</td><td>Riverside</td></tr>
<tr><td colspan="5">Gusty winds, mountain snow, and heavy rainfall in Southern California. Rainfall totals of 1-2 inches occurred over the coast and valleys, with isolated amounts of 6-8 inches along coastal slopes. About 10 swift water rescues were reported in the Inland Empire and San Bernardino County Mountains. Several vehicles were stuck in the mud and flooded out. Urban flooding was reported elsewhere in the Inland Empire. Approximately $25,000 in property damage was reported.</td></tr>
<tr><td>March 21-22, 2018</td><td>Flash Flood</td><td>N/A</td><td>N/A</td><td>Nevada, El Dorado, Tuolumne, Mariposa</td></tr>
<tr><td colspan="5">Rain brought flash flooding to portions of the northern Sierra and Motherlode foothills. The heaviest flooding was in Groveland, where 4-5 inches of rain fell, combining with 8-9 inches in higher elevations.

In Nevada County, Combie Road flooded, resulting in $100,000 in property damage.
In El Dorado County, street flooding in Cameron Park Estates resulted in $100,000 in property damage.

In Tuolumne County, 3 inches of rain in 4 hours upstream of Moccasin Dam led to erosion and at least one landslide. Water and debris ran down into the Moccasin Reservoir. The water level rose to 3 times the normal reservoir capacity, and the emergency spillway was used. There was severe erosion of the spillway and the potential for the dam to fail. Sewer systems were inundated with water and debris. Roads damaged included State Highways 49 and 132—approximately $43 million in damage.

In Mariposa County, several homes flooded near Lake Don Pedro, Hornitos, and the City of Mariposa, and roadways washed out across the northwestern county. Approximately $2 million in property damage was reported, and two fatalities were recorded.</td></tr>
<tr><td>July 12, 2018</td><td>Flash Flood</td><td>N/A</td><td>N/A</td><td>Inyo</td></tr>
<tr><td colspan="5">Thunderstorms across the Mojave Desert and southern Great Basin produced severe weather and flash flooding. In Inyo County, several off-highway vehicle roads were flooded and had sinkholes, and a stretch of Highway 168 was closed. Approximately $125,000 in property damage was reported.</td></tr>
</table>

Date	Event Type	FEMA Declaration Number	USDA Declaration Number	Counties Impacted
September 30, 2018	Flash Flood	N/A	N/A	Riverside
Moisture from Tropical Storm Rosa brought rain and thunderstorms to Southern California. Runoff from 2 to 4 inches of rain in Box Canyon near I-10 destroyed a dike operated by Coachella Valley Water District. A vehicle traveling on Box Canyon Road was swept away in a flash flood, and the driver drowned. $200,000 in property damage was reported. Significant damage to Box Canyon Road forced the road to be closed for days, resulting in $50,000 in damage.				
October 3, 2018	Flash Flood	N/A	N/A	Riverside, San Bernardino
Moisture from Tropical Storm Sergio brought heavy rain to Southern California. In Riverside County mountains and the Coachella Valley, some areas saw more than 1 inch of rainfall. The Coachella Valley Water District dike was blown out, resulting in $100,000 in property damage. Flash flooding across Joshua Tree National Park caused most of the paved and dirt roads to become closed. $25,000 in property damage was reported. In San Bernardino County, major flash flooding occurred in the Morongo Basin. Many roads were flooded, and numerous vehicles were washed off roads or stuck in floodwaters or mud. Three water lines were broken, leaving customers without water for up to 36 hours. $500,000 in property damage was reported.				
December 6, 2018	Flood	N/A	N/A	San Diego
A moisture plume brought showers and thunderstorms to Southern California, especially Orange and San Diego Counties. All mountains, coast, and valleys areas received 1-3 inches of rain, and some spots over higher terrain received over 4 inches. In Carlsbad County, five businesses in the Shoppes at Carlsbad reported flood damage. A roof collapsed at a childcare center. $50,000 in property damage was reported. The Alpha Project Bridge Shelter in East Village San Diego closed for a week due to flooding. $25,000 in property damage was reported.				

Date	Event Type	FEMA Declaration Number	USDA Declaration Number	Counties Impacted
January 16-17, 2019	Flash Flood	N/A	N/A	Riverside County
An atmospheric river brought heavy rain and snow to Southern California. Seal Beach reported 2 inches of rain in 2 hours, which caused extensive flash flooding. Water was up to doorways outside of homes, and the Pacific Coast Highway was closed for over a day in Huntington Beach. Swift water rescues occurred on the Santa Ana River in Riverside. Rainfall rates exceeded flash flooding thresholds for the Holy Fire burn scar. Highway 60 had lane closures due to heavy rain. Swift water rescues on the Santa Ana River included helicopter extractions along Fleetwood and Via Ricardo. $10,000 in property damage and $1,000 in crop damage were reported. Flash flooding from heavy rainfall over Holy Fire scar in Trilogy Parkway and Glen Eden resulted in water going around homes. $20,000 in property damage and $10,000 in crop damage were reported.				
February 2, 2019	Flash Flood	N/A	N/A	San Bernardino
A storm brought heavy rain and isolated flash flooding to San Bernardino County. Roads and intersections were flooded in Yucca Valley and Joshua Tree, at least four homes were flooded, at least four vehicles were stranded, and at least six swift water rescues occurred. One man was killed when flood waters swept away his vehicle. $100,000 in property damage was reported.				
February 13-14, 2019	Flood, Flash Flood	N/A	N/A	Lake, Sacramento, Orange, San Diego, San Bernardino, Riverside, Butte, Calaveras
▪ In Lake County, Heavy rain caused widespread road flooding. $20,000 in property damage was reported. ▪ In Sacramento County, $20,000 in property damage was reported. ▪ In Orange County, storm channels were inundated by flash flooding. Streets were closed, and homes were threatened. $80,000 in property damage was reported. ▪ In San Diego County, flooding occurred in Ramona with up to 2 feet of standing water—severely damaging portions of Highways 78 and 79. $100,000 in property damage was reported. Flooding in Mission Valley included Fashion Valley Mall. The San Diego River reached 12.1 feet. $100,000 in property damage was reported. Flash flooding in Pala resulted in road damage. $40,000 in property damage was reported. ▪ Big Bear City received 6 inches of rain in 24 hours. Flash flooding occurred with up to 1 foot of moving water and 2 feet of standing water. $100,000 in property damage was reported. Flash flooding closed Mt. Baldy Road and caused debris flows. $30,000 in property damage was reported. Emergency road repairs were needed. $5 million in property damage was reported.				

Date	Event Type	FEMA Declaration Number	USDA Declaration Number	Counties Impacted
▪ In Riverside County, heavy rainfall of 3-6 inches occurred. The Holy Fire scar flooded and sent debris flows through Temescal Canyon Road and into homes. Riverside County reported up to $70 million in flood control structure damage. Roads in Morongo Valley and Yucca Valley were flooded, and water entered at least one home, resulting in $50,000 in property damage. Flooding severely damaged Highway 111, causing a weeklong closure. $3 million in property damage was reported. Debris flows and heavy runoff into San Jacinto Creek caused widespread damage to State highway 74, including complete washouts at Strawberry Creek below the Cranston Burn Scar. $10 million in property damage was reported. ▪ A flash flood on Palm Springs Tram Road destroyed the road. The tram and the road were closed through April 2. 3-5 inches of rain occurred on the dry side of Mt. San Jacinto. $1 million in property damage was reported. Widespread flooding and flash flooding were reported in Coachella Valley and tributaries to the Whitewater River. Palm Springs airport set a daily record for rainfall with 3.6 inches. The City of Indio reported $1 million in roadway damage from flooding, with $3 million in property damage. Debris flows and heavy runoff into San Jacinto Creek caused widespread damage to Highway 74, resulting in $10 million in property damage. ▪ The Butte County Sheriff evacuated the Nord Cana Highway and Wilson Landing Road area south of Rock Creek after a levee breached and the creek flooded, resulting in $100,000 in property damage. Butte County firefighters located a truck and horse trailer underwater that were swept 150 feet off the roadway in the area of Lower Honcut Road and Highway 70. ▪ In Calaveras County, floodwaters over Pool Station Road caused a bridge to crack, resulting in $500,000 in property damage.				
February 26, 2019	Flood	N/A	N/A	Butte, Kern
An atmospheric river brought heavy precipitation across interior Northern California. Evacuation of all residences was required on Taffee Avenue, Reavis Avenue, and Chico Avenue due to flooding from Little Chico Creek. $100,000 in property damage was reported. Swift water rescue occurred for six people in four cars stuck in a flooded roadway. $80,000 in property damage was reported. In Kern County, roads were washed out by heavy rain, resulting in $50,000 in property damage.				
March 27, 2019	Flash Flood	N/A	N/A	Shasta
Thunderstorms brought flooding to Shasta County. There were 8 inches of water over Dry Creek and Deschutes Road in Bella Vista. Water was over a small bridge by a post office. A fire station flooded out, and 1-2 inches of water flowed through the station. $25,000 in property damage was reported.				
April 5, 2019	Flash Flood	N/A	N/A	Shasta
Thunderstorms brought road flooding and a minor debris flow. Rock Creek jumped its banks, occupied portions of the floodplain along Rock Creek Road, and overtopped several crossings, resulting in $50,000 in property damage.				

Date	Event Type	FEMA Declaration Number	USDA Declaration Number	Counties Impacted
September 1, 2019		N/A	N/A	Riverside
Thunderstorms across far eastern Riverside County generated locally heavy rainfall with peak rain rates of over 1 inch per hour. Flash flooding along the lower Colorado River Valley north of Blythe affected motorists on Highway 95. Seven to eight vehicles became stuck in flooded portions of Highway 95. The highway was closed at Wind River Road due to flash flooding. $75,000 in property damage was reported.				
September 25, 2019	Flash Flood	N/A	N/A	Imperial
Thunderstorms across the eastern portion of Imperial County generated peak rain rates in excess of 1 inch per hour. Flash flooding resulted in a vehicle being washed out along Ogilby Road south of State Route 78. The driver was not injured. However, 30 more vehicles were stuck before a flowing wash in the vicinity. $40,000 in property damage was reported.				
November 19, 2019	Flash Flood	N/A	N/A	San Bernardino
Due to widespread rain and flooding in the Mojave Desert in San Bernardino County, Highways 95 and 62 were closed, there was at least one swift water rescue when a vehicle was washed away, and about 100 vehicles were stuck in the closures. $700,000 in property damage was reported.				
November 28, 2019	Flash Flood	N/A	N/A	Riverside, San Diego, San Bernardino
Riverside County saw 1 to 3 inches of rainfall at the coast and in the valleys. San Diego River reached 9.5 feet with flooding. Roadways were flooded. An RV Park in La Mesa experienced flash flooding. A sinkhole opened on the shoulder of I-10 in Redlands due to heavy rain. The total cost to repair the sinkhole was $760,000. Flash flooding resulted in a car becoming flooded and floating near the intersection of 6th Avenue and Highway 95. The driver was rescued through the roof of the vehicle. $30,000 in property damage was reported. In San Diego County, a driver was rescued after driving through 2 feet of water in Sorrento Valley. $30,000 in property damage was reported. In San Bernardino County, Highway 95 was completely washed out south of the Nevada state line, resulting in $50,000 in property damages.				
December 4, 2019	Flash Flood	N/A	N/A	Riverside
In Riverside County, heavy rain resulted in flooding of the San Diego River. Water levels at Fashion Valley peaked at 9 feet. Roads around Fashion Valley Mall were closed due to flooding. The Tijuana River flooded, closing roads and trapping cars in floodwaters. A search and rescue worker died during a search for a missing hiker. Interstate 10 in Redlands had a large sinkhole on the shoulder of the interstate. The cost to repair the damage was $759,000. Hollister Street flooded in the Tijuana River Valley. Cars stalled in 2 feet of water, some requiring water rescues. $40,000 in property damage was reported.				

Date	Event Type	FEMA Declaration Number	USDA Declaration Number	Counties Impacted
March 12, 2020	Flash Flood	N/A	N/A	Imperial
Rainfall that exceeded 1 inch in some places resulted in flooding and flash flooding over central Imperial County. Flowing water led to road closures. Flooding northeast of Brawley resulted in local traffic impacts. A vehicle was swept away in a flash flood on State Route 78 south of Palo Verde. All of the people were rescued. Multiple vehicles were stuck in or near flood waters at the intersection of State Route 78 and Milpitas Wash Road. $60,000 in property damage was reported.				
April 6-10, 2020	Flash Flood	N/A	N/A	Orange, San Diego
In Orange County, rainfall rates over 0.70 inches per hour caused 8 inches of swift-moving water to flood Lakeview Avenue north of Miraloma Avenue, resulting in $25,000 in property damage. In San Diego County, the City of Oceanside had significant damage to the wastewater treatment plant. Up to 2 million gallons spilled as the plant was inundated by flash flooding of Buena Vista Creek. $250,000 in property damage was reported. Twelve incidents of flooding and flash flooding were reported in Encinitas. People were evacuated from homes in the Encinitas Blvd/Quail Gardens Road area. Twenty persons were evacuated from a nursing home. $70,000 in property damage was reported.				
January 10, 2021	Flash Flood	N/A	N/A	Imperial
Isolated thunderstorms caused moderate to heavy rain rates and flash flooding east of the Imperial Valley. Flooding on Highway 78 resulted in vehicles being stranded about 5 miles east of Glamis. $30,000 in property damage was reported.				
January 27, 2021	Flood	N/A	N/A	San Benito
An atmospheric river caused flooding and 15 to 20 inches of rain in the Santa Lucia Mountains. In San Benito County, damage was reported to Cienega Road, resulting in $2.5 million in property damage; Union Road resulting in $250,000 in property damage; Southside Road resulting in $2 million in property damage; and Salinas Grade Road resulting in $2 million in property damage. New Idria Road was completely washed out from Panoche Valley to 20 miles south, resulting in $3.5 million in property damage. King City Road was damaged from SR 25 to Monterey County, resulting in $2 million in property damage. Coalinga Road was damaged from SR 25 to Fresno County, resulting in $3 million in property damage. Roadway flooding at Fairview Road and Mansfield Road resulted in $250,000 in property damage.				
January 29, 2021	Flood	N/A	N/A	Riverside
A weak atmospheric river brought flooding across Southern California. In Riverside County, a vehicle was stuck in water on San Jacinto and Murrieta Road in Perris, where a water rescue was conducted. $1 million in property damage was reported.				
March 10, 2021	Flash Flood	N/A	N/A	Orange
A storm brought widespread rain, snowfall, and areas of flooding. In Orange County, six homes had mud and water damage. Swift water rescues were performed. $75,000 in property damage was reported.				

Date	Event Type	FEMA Declaration Number	USDA Declaration Number	Counties Impacted
August 29-31, 2021	Flash Flood	N/A	N/A	San Bernardino, Imperial
A round of thunderstorms brought severe winds and flash flooding. In San Bernardino County, 30 low water crossings on Highway 95 between Needles and Havasu Lake Road were covered in mud and debris, resulting in $50,000 in property damage. In Imperial County, 7 inches of rain fell in 5 hours, and extensive flooding occurred along SR 78 from Palo Verde south, leading to extended closure for repairs and $1 million in property damage.				
October 21, 2021	Flash Flood	N/A	N/A	Trinity
Heavy rain across the River Complex burn scar in Trinity County caused one or more debris flows. Removal, protective measures, and repair costs from this debris flow were estimated to be $3.2 million.				
December 23, 2021	Flash Flood	N/A	N/A	Orange County
An atmospheric river moved into Southern California. In Orange County, Santiago Creek Road was blocked by high water and mud. Jackson Creek Road was flooded with mud and debris. $800,000 in property damage was reported.				

6.4. PROBABILITY OF FUTURE HAZARD EVENTS

6.4.1. Overall Probability

Flooding is common in California and can take place any time of the year. Based on historical flood events, the State has a high probability of future riverine, flash, localized, and alluvial fan flood events.

According to FEMA, USDA, and the National Oceanic and Atmospheric Administration (NOAA), California experienced 631 flash flood events and 510 flood events between 1996 and 2022—an average of more than 20 flash flood events and just under 20 flood events per year. Some areas in the State are more prone to flooding than others, and the frequency and size of flood events will vary.

6.4.2. Climate Change Impacts

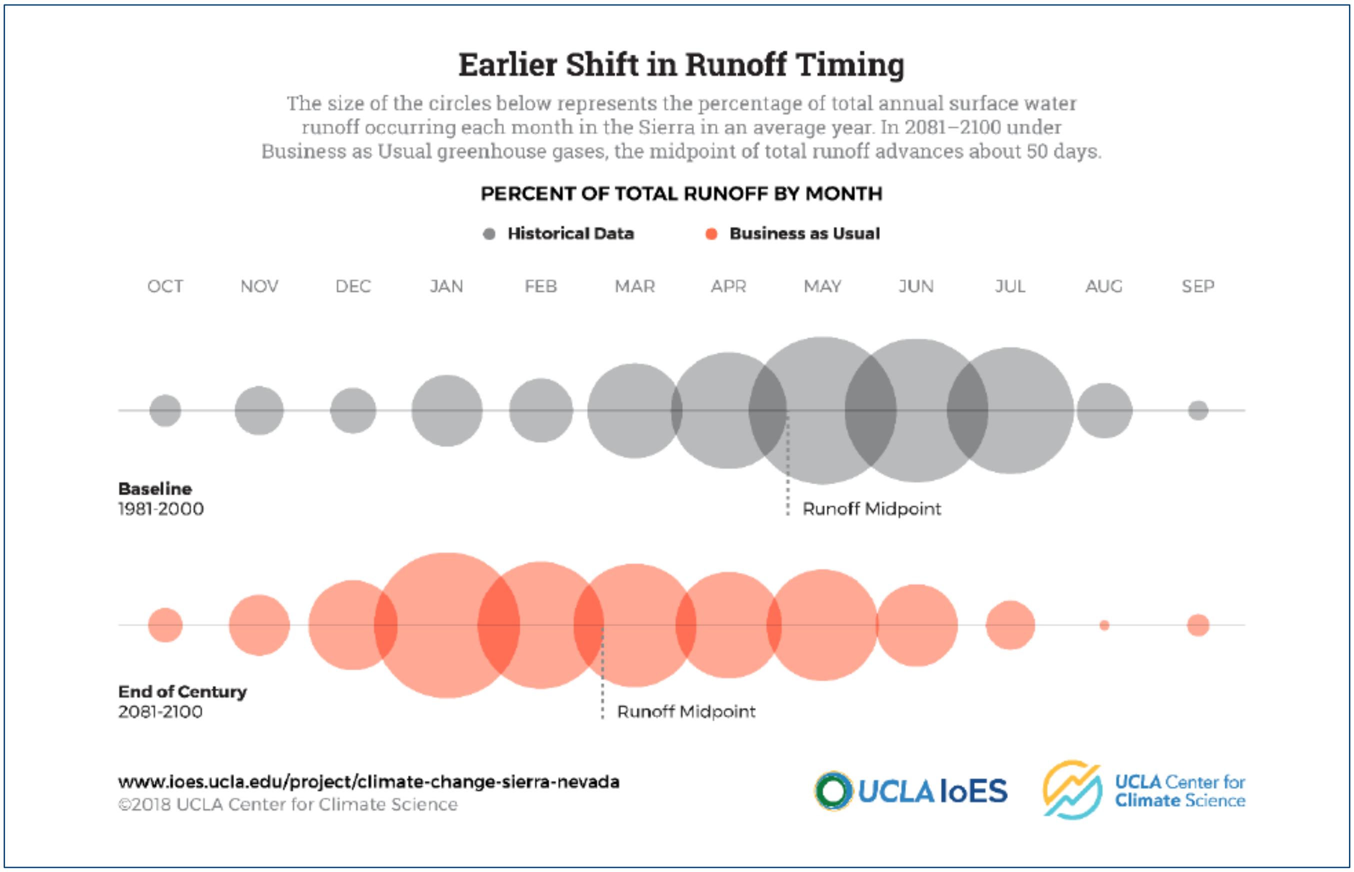
Current projections indicate the following climate change trends that may affect flood hazards.

Precipitation

Cal-Adapt mapping indicates a shift of precipitation events away from southern and inland regions toward central and northern regions (CEC 2017). However, decreases in annual precipitation in southern and inland regions may not be accompanied by a reduction in flooding. An increase in climate variance may result in these regions experiencing heavier, more intense episodic rainfall and flooding events due to the transport of warmer, moisture-laden air from the ocean (CNRA, CalEMA 2012).

The timing of precipitation and subsequent runoff is important for determining when stream flow occurs and how much is available for supply. Most precipitation in California falls during the wet season (generally October to April, depending on the region). Runoff peaks in winter and spring, when demand is lowest. Climate studies project that precipitation patterns will increasingly shift peak runoff earlier in the winter and spring as more precipitation falls as rain instead of snow, and snow melts off earlier. This is projected to be especially true in rain-dominated watersheds, with runoff peaking earlier and higher. In snow-dominated watersheds, relatively little change in seasonality or peak runoff is expected by mid-century (2050), but large April-to-July decreases in peak runoff are expected by 2100. Figure 6-2 shows the projected shift in the runoff by month from the historical baseline to 2081 through 2100.

Figure 6-2. Projected Shift in Runoff by Month From Historical Baseline to 2081-2100.



Source: (Schwarz, et al. 2020)

Snowpack

Snowpack in northern and coastal mountains and the Sierra Nevada mountains is projected to be reduced and accompanied by earlier rainfall with subsequent runoff downstream, particularly in the Sacramento River and San Joaquin River watersheds that converge in the California Delta. These trends suggest the potential for increased incidence of intense flooding in the Central Valley and the San Francisco Bay region.

Sea-Level Rise

The Sea-Level Rise Guidance 2018 Update prepared by the California Ocean Protection Council (OPC) provides sea-level rise projections by decade based on greenhouse gas (GHG) emissions scenarios (CNRA, OPC 2018). An extreme scenario included in the guidance, labeled as H++, projects a 10.2-foot sea-level rise by 2100 and a 21.9-foot rise by 2150. This increase will result in coastal areas experiencing increased inundation and may increase the extent of floodplains near the mouths of streams and rivers. Sea-level rise combined with high tides will increase the frequency and severity of flood events for areas adjoining places where coastal streams and rivers empty to the ocean.

Summary

In California, changing temperature, precipitation, runoff, and snowpack records have already altered annual runoff patterns (DWR 2015). A change from snowfall to rainfall may also contribute to an increased number and severity of flood events.

Climate change impacts on multiple natural hazards interact in ways that can exacerbate the severity and frequency of flood events. For example, larger and more frequent wildfires brought on by climate change can reduce the ability of a landscape to retain rainfall, which can lead to flooding and mudflows. Examples include the catastrophic mudflows that occurred in early 2018 in Santa Barbara County following heavy rainfall in an area where the 2017 Thomas Fire had denuded slopes of vegetation.

The Impact of Wildfire on Flooding

Flooding, erosion, and debris flows can also occur in California in the months and years following large hot fires. High-severity wildfires significantly reduce the amount of vegetation, which can reduce the amount of rainwater absorption, allowing excessive water runoff that often includes large amounts of debris. Structures located anywhere near a severe burn area are susceptible to flooding. Periods of high-intensity rainfall are of particular concern, but post-fire flooding can also occur during a normal rainy season.

Source: (USGS 2018a)

6.5. IMPACT ANALYSIS

Floods have the potential for numerous severe impacts (Cal OES 2018):

- Injuries and deaths occur
- Residences, businesses, and personal property are damaged
- Critical infrastructure is damaged and could be out of service for long periods
- Vital services become isolated or are closed
- Jobs are lost or put at risk when businesses are dislocated or closed
- The local and national economy can be disrupted due to damage to commercial and industrial buildings
- Water supplies and water quality are affected
- Vulnerable communities are displaced
- Natural resources and public access are damaged or eliminated
- Usable land is lost through erosion, contamination, or other flood-related means
- The transport of hazardous materials and debris could impact human and animal health and the environment

6.5.1. Severity

California has a chronic and destructive flooding history. All 58 counties have experienced at least one significant flood event in the past 25 years, resulting in loss of life and billions of dollars in damage. As seen in Table 6-2, California experienced 26 flood events over just a four-year period, with damage of at least $25,000 and up to many millions of dollars. Since 1950, floods have accounted for the second-highest combined losses of all natural hazard events in California (after earthquake) and the largest number of deaths.

Floods can be long-term events that may last for several days to weeks, and their severity depends on the amount of water that accumulates and the land's ability to manage this water. When the ground is saturated or frozen, infiltration into the soil slows, and any more accumulated water must flow as runoff (Harris 2008). Additional key factors in determining the severity of a flood are the depth of the floodwater at a particular point of interest and the velocity at which the floodwaters are moving.

Based on FEMA mapping, flood depths range from 0 feet to greater than 15 feet in zones mapped as A, AE, AH, and AO throughout the State. U.S. Army Corps of Engineers' (USACE) depth-damage curves indicate no more than 16 feet of flood depth for residential structures with or without basements, so any damage associated with depths greater than 16 feet would be considered substantial. The curves also do not account for damage associated with flood velocities. Per the National Weather Service (NWS):

- Six inches of water will reach the bottom of most passenger cars, causing loss of control and possible stalling.
- A foot of water will float many vehicles.
- Two feet of rushing water can carry away most vehicles, including sport utility vehicles and pickups.

Flooding and the Many Faces of California Climate

The chance of heavy flooding and flash flooding is greatest during California’s rainy season from November to April. However, the diversity of climate patterns in California makes flooding more than a seasonal risk. The following are some of the weather and climate conditions that have a significant impact on the occurrence of flooding:

- El Niño conditions
- La Niña conditions
- Desert monsoons
- Tropical storms
- Gulf of Alaska storms
- Atmospheric river patterns

Source: (Cal OES 2018)

6.5.2. Warning Time

The NWS uses four categories to determine impending flood threats. Each category has a definition based on property damage and public threat (NWS 2011):

- ***Action Stage***—When reached by a rising stream, lake, or reservoir, this stage represents the level where the NWS or a partner needs to take some type of mitigation action in preparation for possible significant hydrologic activity.
- ***Minor Flooding***—Minimal or no property damage, but possibly some public threat or inconvenience.

- ***Moderate Flooding***—Some inundation of structures and roads near streams. Some evacuations of people or transfer of property to higher elevations are necessary.
- ***Major Flooding***—Extensive inundation of structures and roads. Significant evacuations of people or transfer of property to higher elevations.

6.5.3. Cascading Impacts

Cascading impacts are the impacts that result when one type of hazard event triggers one or more other hazard events, which may, in turn, trigger still others. The following are the most significant cascading impacts associated with riverine, stream, and alluvial flooding:

- Riverine flooding causes bank erosion, especially in the upper courses of rivers with steep gradients, where floodwaters can pass quickly without much flooding but scour the banks, edging properties closer to the floodplain or causing them to fall in.
- Flooding can cause landslides when high flows over-saturate soils on steep slopes, causing them to fail.
- Hazardous materials spills can result from flooding if storage tanks rupture and spill into streams, rivers, or drainage sewers.
- Flooding can result in the failure of critical infrastructure (i.e., roads, bridges, levees, etc.).

6.5.4. Environmental Impacts

Negative Environmental Impacts From Floods

Flooding can impact the environment in negative ways. Migrating fish can wash into roads or over dikes into flooded fields, with no possibility of escape. Pollution from roads, such as oil and hazardous materials, can wash into rivers and streams. During floods, these can settle onto normally dry soils, polluting them for agricultural uses. Human development, such as bridge abutments, levees, or logjams from timber harvesting, can increase stream bank erosion, causing rivers and streams to migrate into non-natural courses.

Many species of mammals, birds, reptiles, amphibians, and fish live in plant communities dependent on streams, wetlands, and floodplains. Wildlife and fish are impacted when plant communities are eliminated or fundamentally altered to reduce habitat. Since water supply is a major limiting factor for many animals, riparian communities are of special importance.

Floodwater can also alter the landscape, for instance, by eroding riverbanks and causing them to collapse. As floodwater carries material from the eroded banks, it suspends sediment in the water, which can degrade water quality and lead to harmful algae blooms. Suspended sediment eventually settles out of the water in a process called sedimentation, which can clog riverbeds and streams, smother aquatic organisms, and destroy habitats. Erosion and sedimentation have a more negative impact on ecosystems that are already degraded or heavily modified.

Floods are the leading cause of weather-related infectious disease outbreaks. Flooding increases the chance of spreading waterborne diseases such as hepatitis A and cholera. Receding floodwater can create stagnant pools of water, which provide a breeding ground for mosquitoes that can transmit malaria and other diseases. Floodwater that infiltrates buildings and homes can harbor mold, which can be inhaled and cause or exacerbate respiratory conditions. Furthermore, floods can lead to the release of toxic waste from facilities where it is stored. This can expose nearby communities in low-lying areas to dangerous runoff if floodwaters infiltrate those facilities.

Positive Environmental Impacts From Flooding

While floods bring hazards, they also bring nutrients and essential components for life. Seasonal floods can renew ecosystems. Floods transport nutrients such as nitrogen, phosphorus, and organic material to the surrounding land. When the water recedes, it leaves sediment and nutrients behind on the floodplain. This rich, natural fertilizer improves soil quality and has a positive effect on plant growth, thus increasing productivity in the ecosystem. Ancient civilizations first arose along the deltas of seasonally flooded rivers, such as the Nile in Egypt, because they provided fertile soil for farmland.

Floods can replenish underground water sources. Floodwater gets absorbed into the ground and then percolates through layers of soil and rock, eventually reaching underground aquifers. These aquifers supply clean freshwater to springs, wells, lakes, and rivers. Ecosystems rely heavily on groundwater during dry spells when it may be the only freshwater supply. A good groundwater supply positively impacts soil health and leads to more productive crop and pasture lands.

Floods can trigger breeding events, migrations, and dispersal in some species. In 2016, thousands of water birds flocked to the Macquarie Marshes in the Australian state of New South Wales. Flooding had filled their wetland habitat for the first time in years, triggering a mass breeding event (ANSTO 2016).

Small seasonal floods can be beneficial to native fish stocks and can help those fish outcompete invasive species that are not adapted to the river's cycles. Sediment deposited on riverbeds during floods can provide a nursery site for small fish. Nutrients carried by floodwater can support aquatic food webs by boosting productivity.

6.5.5. Local Hazard Impacts

LHMP Rankings

All but one of the hazard mitigation plans prepared for California's 58 counties list flood as a hazard of concern, and 38 counties rank it as a high-impact hazard.

- Amador
- Butte
- Colusa
- El Dorado
- Fresno
- Glenn
- Imperial
- Inyo
- Kern
- Kings
- Lake
- Lassen
- Madera
- Mendocino
- Merced
- Monterey
- Napa
- Nevada
- Placer
- Plumas
- Sacramento
- San Bernardino
- San Diego
- San Joaquin
- San Luis Obispo
- Santa Barbara
- Santa Clara
- Santa Cruz
- Shasta
- Sierra
- Siskiyou
- Solano
- Stanislaus
- Sutter
- Trinity
- Tulare
- Yolo
- Yuba

An additional 16 counties identified flood as a medium-impact hazard.

LHMP Estimates of Potential Loss

Table 6-3 summarizes potential losses to vulnerable structures based on estimates from the local risk assessments (as called for in FEMA's Standard State Mitigation Planning Requirement S6.b). Due to variances in approaches to assessing risk at the local level as well as the hazards assessed and the age of each assessment reviewed, this data is considered approximate.

Table 6-3. Riverine Stream and Alluvial Flood Risk Exposure Analysis for LHMP Reviews

Estimated Total Population Exposed	1,354,364*
Estimated Number of Structures at Risk	382,339
Estimated Value of Structures at Risk	$48.04 billion

* Population estimated within the FEMA-mapped 1% annual chance floodplain

6.6. VULNERABILITY ANALYSIS

To assess the State's risk to the riverine flood hazard, a spatial analysis was conducted in which mapped hazard areas (the 1% annual chance flood hazard zone and the 0.2% annual chance flood hazard zone) were overlaid with State assets to determine the total number and replacement cost values located in the hazard areas. If the asset is in the hazard area, it is deemed exposed to the hazard and potentially vulnerable to loss.

6.6.1. Exposure of State-Owned or -Leased Facilities

Table 6-4 and Table 6-5 summarize the numbers of State assets within the mapped 1% annual chance and 0.2% annual chance flood hazard zones. Figure 6-3 and Figure 6-4 summarize the exposed assets as a percentage of total assets statewide. Appendix I provides detailed results by county.

Table 6-4. State-Owned or -Leased Facilities Exposed to the Riverine or Stream Flood Hazard

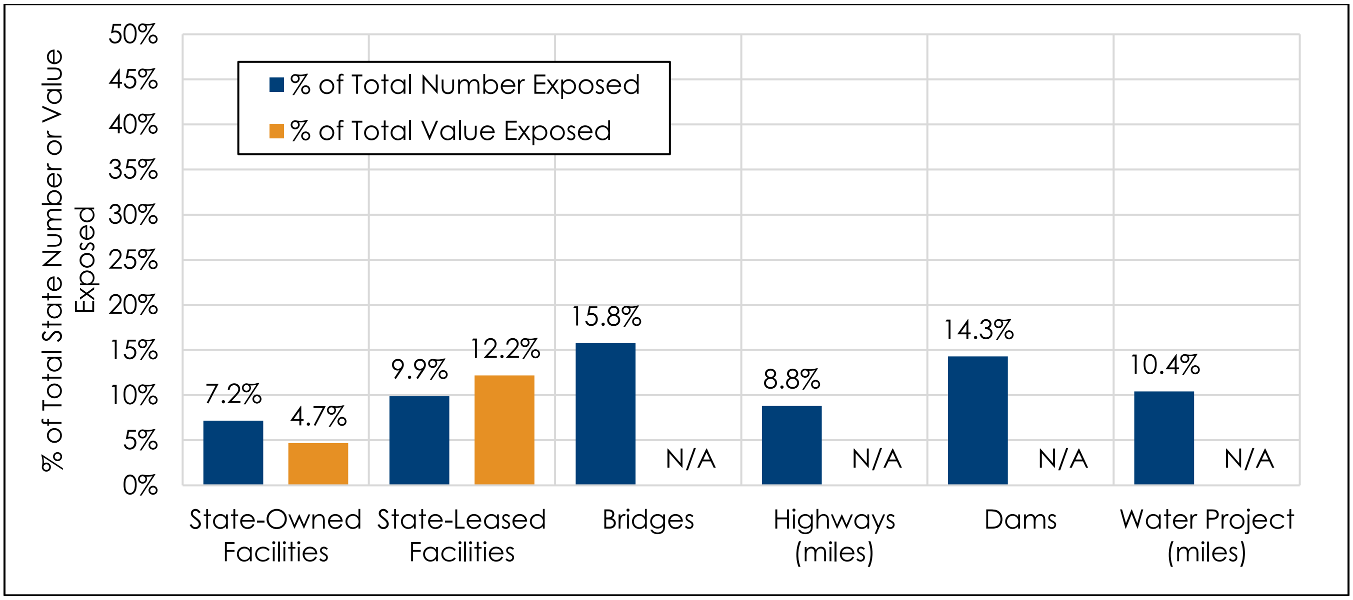
Type of Facility	Number of Structures	Total Area (sq. ft.)	Replacement Cost Value		
			Structure	Content	Total
State Facilities in the Mapped 1% Annual Chance Floodplain					
State-Leased Facilities	182	--	$839,048,220	$870,586,030	$1,709,634,251
State-Owned Facilities					
Facilities Housing Vulnerable Populations					
Correctional Facility	266	3,405,313	$107,785,327	$107,785,327	$215,570,654
Development Center	0	0	$0	$0	$0
Hospital	0	0	$0	$0	$0
Migrant Center	5	329,500	$555,472,024	$280,239,085	$835,711,109
Special School	0	0	$0	$0	$0
All Other Facilities	1371	3,133,297	$613,992,207	$599,693,859	$1,213,686,066
Total State-Owned	***1642***	***6,868,110***	***$1,277,249,558***	***$987,718,271***	***$2,264,967,829***
Total Facilities	***1,824***	**N/A***	**$2,116,297,778**	**$1,858,304,301**	**$3,974,602,079**
State Facilities in the Mapped 0.2% Annual Chance Floodplain					
State-Leased Facilities	352	—	$1,845,598,009	$1,883,536,951	$3,729,134,960
State-Owned Facilities					
Facilities Housing Vulnerable Populations					
Correctional Facility	308	3,720,744	$141,535,881	$134,076,508	$275,612,389
Development Center	0	0	$0	$0	$0
Hospital	0	0	$0	$0	$0
Migrant Center	9	512,233	$569,777,234	$290,194,941	$859,972,175
Special School	0	0	$0	$0	$0
All Other Facilities	2,134	13,157,442	$1,450,103,729	$1,503,938,251	$2,954,041,981
Total State-Owned	***2,451***	***17,390,419***	***$2,161,416,844***	***$1,928,209,700***	***$4,089,626,545***
Total Facilities	***2,803***	**N/A***	**$4,007,014,854**	**$3,811,746,651**	**$7,818,761,505**

* The inventory of State assets does not include building area for State-leased facilities, so no total area for all State facilities is provided; the building area of vulnerable assets is shown for State-owned facilities only.

Table 6-5. State-Owned Infrastructure Exposed to the Riverine or Stream Flood Hazard

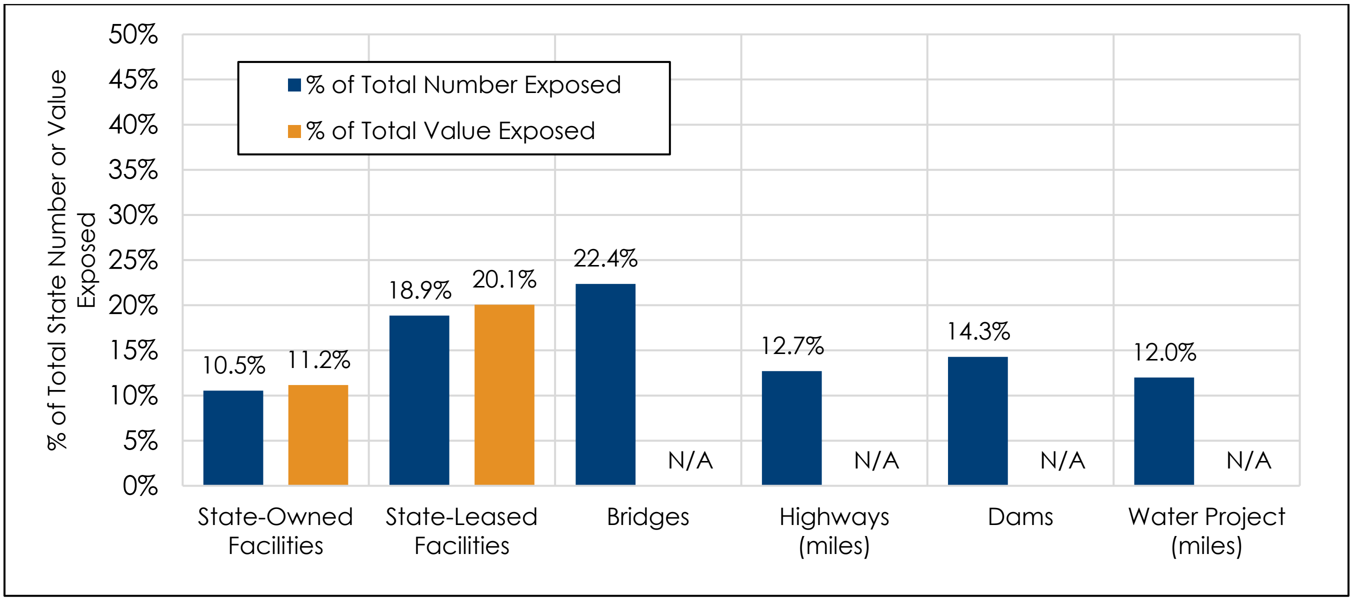
	State-Owned Infrastructure in the Mapped Hazard Area	
Type of Facility	1% annual Chance Floodplain	0.2% annual Chance Floodplain
Bridges	2,079	2,959
Highway (miles)	2,627	3,801.2
Dams	7	7
Water Project (miles)	74.4	85.7

Figure 6-3. State Assets Exposed to 1% annual Chance Floodplain, as % of Statewide Total



N/A: Values not defined for bridges, highways, dams, and water project

Figure 6-4. State Assets Exposed 0.2% annual Chance Floodplain, as % of Statewide Total



N/A: Values not defined for bridges, highways, dams, and water project

The following are significant results of the analysis of State-owned assets in mapped flood hazard areas:

- For facilities that the State owns within the 1% annual chance floodplain, the average building area is 4,183 square feet, with an average replacement cost value of $1.4 million.
- For facilities that the State owns within the 0.2% annual chance floodplain, the average building area is 7,095 square feet, with an average replacement cost value of $1.7 million.
- The average replacement cost value for State-leased facilities within the 1% annual chance floodplain is $9.4 million.
- The Average replacement cost value for State-leased facilities within the 0.2% annual chance floodplain is $10.6 million.
- The five State agencies with the most State-owned or -leased facilities within the 1% annual chance floodplain are as follows:
  - State Parks (580)
  - CDFW (318)
  - CDCR (268)
  - District Agricultural Associations (257)
  - Caltrans (158)

- The five State agencies with the most State-owned or -leased facilities within the 0.2% annual chance floodplain are as follows:
  - State Parks (669)
  - District Agriculture Associations (393)
  - CDFW (382)
  - Caltrans (351)
  - CDCR (324)
- The State agency with the highest total replacement cost for State-owned or lease facilities within the 1% annual chance floodplain is the District Agriculture Association, at $909 million.
- The State agency with the highest total replacement cost for State-owned or lease facilities within the 0.2% annual chance floodplain is the District Agriculture Association, at $1.2 billion.

6.6.2. Exposure of Critical Facilities and Community Lifelines

The Risk Assessment identified 65 critical facility and community lifelines within the 1% annual chance floodplain. The "food, water, shelter" lifeline category accounts for 42 percent of these, the "transportation" category accounts for 23 percent, and "energy" accounts for 16 percent. The County with the largest percentage of these facilities is Sacramento (8.7 percent), followed by Inyo and Kern Counties with 7.25 percent each.

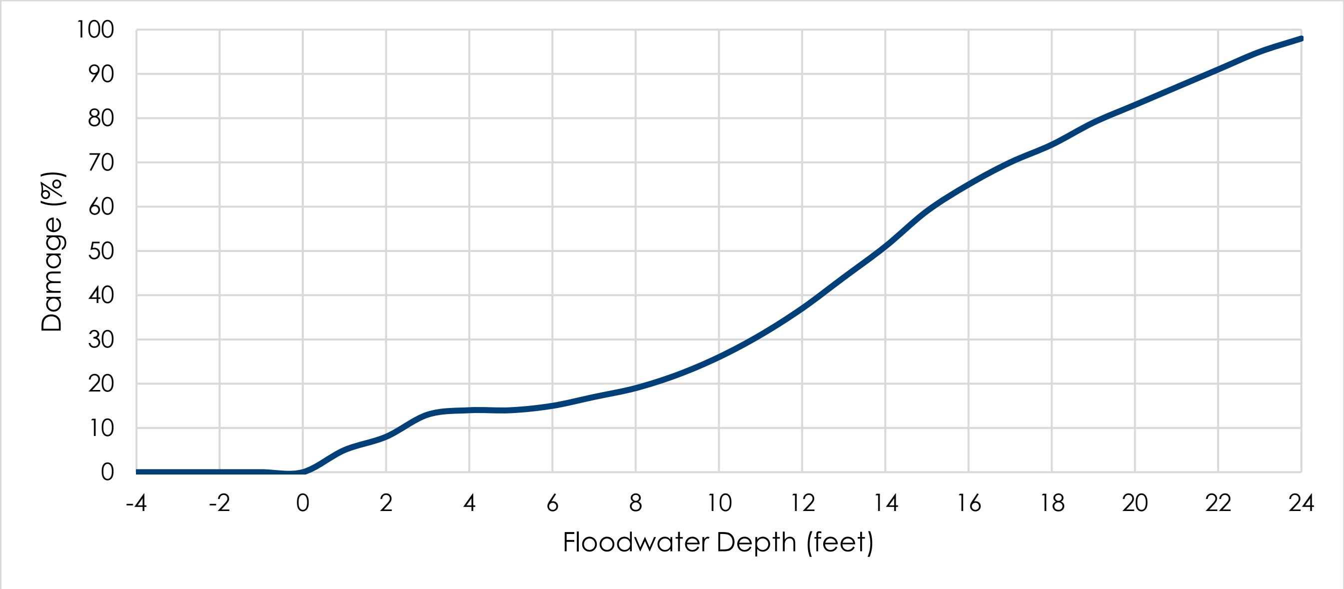
The Risk Assessment identified 125 critical facility and community lifelines within the 0.2% annual chance floodplain. The "food, water shelter" lifeline category accounts for 34 percent of these, the "transportation" category accounts for 21 percent, and "energy" accounts for 19 percent. The County with the largest percentage of these facilities is Santa Clara (9.3 percent), followed by San Bernardino (8.5 percent) and Fresno (7.8 percent). For a detailed breakdown of facility counts by County, see Appendix I.

Critical facilities and community lifelines exposed to the riverine flood hazard are likely to experience functional downtime following a flood event, which could increase the net impact of the event. Local governments are encouraged to use Hazus or similar tools when developing LHMPs.

6.6.3. Estimates of Loss

Loss estimations for hazard events that cause flooding typically use an approach that correlates damage to the depth of flood water at a structure and the time of inundation. USACE has established depth/damage correlations based on analysis of historical flood events. The assessment of potential loss associated with riverine flooding for this SHMP used the USACE depth-damage curve for facilities with "average government function" (see Figure 6-5).

Figure 6-5. Depth/Damage Curve for "Average Government Function" Occupancy



Source: Data taken from Hazus model developed for this SHMP

Table 6-6 shows the resulting estimates of potential damage to State-owned or -leased facilities in the 1% annual chance flood hazard zone per foot of flood depth up to the flood depth that would trigger substantial damage (50 percent of replacement cost value).

6.6.4. Buildable Lands

Of the 11.7 million acres of land available for development in California, 7.1 percent (834,480 acres) is within the 1% annual chance flood hazard zone, and 8.5 percent (997,939 acres) is within the 0.2% annual chance flood hazard zone.

Table 6-6. Estimates of Flood Loss for Facilities in the 1% annual Chance Flood Hazard Zone

Flood Depth (feet)	Estimates of Flood Loss*		
	State-Owned	State-Leased	Total
1	$200,350,743	$190,587,333	$390,938,075
2	$320,561,188	$304,939,732	$625,500,920
3	$520,911,931	$495,527,065	$1,016,438,996
4	$560,982,080	$533,644,531	$1,094,626,611
5	$560,982,080	$533,644,531	$1,094,626,611
6	$601,052,228	$571,761,998	$1,172,814,226
7	$681,192,525	$647,996,931	$1,329,189,456
8	$761,332,822	$724,231,864	$1,485,564,686
9	$881,543,268	$838,584,263	$1,720,127,531
10	$1,041,823,862	$991,054,129	$2,032,877,991
11	$1,242,174,605	$1,181,641,462	$2,423,816,066
12	$1,482,595,496	$1,410,346,261	$2,892,941,757
13	$1,763,086,536	$1,677,168,526	$3,440,255,062
14	$2,043,577,575	$1,943,990,792	$3,987,568,367

* Structure Losses only. Does not include contents losses.

Any development in these areas will be susceptible to damage associated with a riverine, stream, or alluvial flood event. Future development could increase flooding due to increased impervious surfaces and subsequent stormwater runoff. The population occupying these future-developed areas may also face increased exposure due to transportation networks located within hazard-prone areas to support increased development.

Not all flood risk in the State has been mapped, and the scope of regulatory oversight of new development is limited to known or mapped floodplains. However, the State's regulatory capabilities—such as growth management, participation in the NFIP, and general building codes and standards—position the State to manage future development in a manner to avoid adverse impacts and unintended consequences. It will be important to continually improve the understanding of flood risk within these buildable land areas so that the regulatory capacity of the State can be effective.

6.6.5. Repetitive Loss Analysis

As of August 31, 2022, the State of California has 3,660 FEMA-identified RL properties, of which 576 have been identified as SRL properties. Table 6-7 provides a breakdown of these properties by County.

Table 6-7. RL Data for California

	Numbers of Properties					Number of Losses	Loss Value	
County	RL	SRL	Mitigated	NFIP-Insured	Outside SFHA		Cumulative	Average
Alameda	15	2	3	1	10	30	$625,526	$20,851
Alpine	0	0	0	0	0	0	$0	$0
Amador	5	0	0	1	1	11	$368,102	$33,464
Butte	35	6	0	11	11	102	$2,257,357	$22,131
Calaveras	5	0	0	2	3	17	$773,829	$45,519
Colusa	22	3	0	4	20	59	$1,627,461	$27,583
Contra Costa	76	9	6	20	34	208	$4,827,616	$23,210
Del Norte	2	0	0	0	1	4	$139,395	$34,489
El Dorado	8	0	0	0	4	16	$749,000	$46,816
Fresno	9	1	4	1	7	22	$396,750	$18,034
Glenn	21	1	0	6	7	51	$876,897	$17,194
Humboldt	14	4	1	2	3	38	$1,173,181	$30,873
Imperial	14	0	0	0	2	31	$240,897	$7,771
Inyo	0	0	0	0	0	0	$0	$0
Kern	3	0	0	1	1	8	$109,573	$13,697
Kings	0	0	0	0	0	0	$0	$0
Lake	167	28	9	30	28	508	$9,336,350	$18,379
Lassen	1	0	0	0	0	2	$36,094	$18,047
Los Angeles	479	39	41	86	293	1,164	$19,809,904	$17,019
Madera	2	0	0	1	0	8	$138,759	$17,345
Marin	234	28	3	69	63	684	$14,185,977	$20,740
Mariposa	0	0	0	0	0	0	$0	$0
Mendocino	3	1	0	0	0	8	$288,771	$28,596
Merced	15	0	0	9	1	33	$759,710	$23,021
Modoc	0	0	0	0	0	0	$0	$0
Mono	1	0	0	0	0	2	$377,751	$18,876
Monterey	123	8	4	27	18	261	$8,501,845	$32,574
Napa	126	27	29	40	21	357	$11,974,973	$33,543
Nevada	4	0	0	1	2	10	$426,733	$42,673
Orange	126	9	29	30	62	257	$5,463,031	$21,257
Placer	63	7	36	26	26	145	$4,881,887	$33,668

	Numbers of Properties					Number of Losses	Loss Value	
County	RL	SRL	Mitigated	NFIP-Insured	Outside SFHA		Cumulative	Average
Plumas	3	1	0	0	1	9	$322,046	$35,783
Riverside	80	3	16	16	41	105	$3,037,681	$28,930
Sacramento	238	40	70	99	127	567	$14,882,503	$26,248
San Benito	11	0	0	4	2	33	$1,197,590	$36,291
San Bernardino	36	2	4	4	15	73	$1,198,615	$16,419
San Diego	150	17	13	35	88	264	$7,977,113	$30,216
San Francisco	4	0	0	0	1	11	$112,901	$1,173
San Joaquin	8	2	3	1	6	17	$428,304	$25,194
San Luis Obispo	38	2	0	9	17	91	$1,534,574	$16,863
San Mateo	48	6	3	14	28	129	$4,090,052	$31,709
Santa Barbara	78	5	1	27	40	171	$3,972,781	$23,233
Santa Clara	35	9	6	10	8	111	$2,748,422	$24,761
Santa Cruz	102	13	18	27	44	309	$5,262,348	$17,030
Sierra	0	0	0	0	0	0	$0	$0
Shasta	20	2	0	6	8	53	$824,884	$15,564
Siskiyou	2	0	0	0	1	4	$9,299	$2,325
Solano	57	5	1	17	21	144	$4,984,634	$34,616
Sonoma	951	268	87	215	113	3,262	$86,700,101	$26,579
Stanislaus	18	2	0	6	6	45	$1,311,715	$29,149
Sutter	11	0	1	0	4	31	$367,715	$11,861
Tehama	42	6	2	7	18	104	$1,572,825	$15,123
Tuolumne	0	0	0	0	0	0	$0	$0
Trinity	0	0	0	0	0	0	$0	$0
Tulare	12	2	0	3	3	25	$400,603	$16,024
Ventura	91	12	5	24	50	236	$5,547,420	$23,506
Yolo	40	6	11	7	10	99	$1,603,262	$16,195
Yuba	12	0	1	2	6	27	$705,260	$26,121
Total	**3,660**	**576**	**407**	**901**	**1,276**	**9,956**	**$241,140,017**	**$24,221**

Source: FEMA PIVOT Database (August 31, 2022)

The following is a summary analysis of RL statistics:

- 15.7 percent of the 3,660 RL properties have been identified as SRL by FEMA
- The county with the most SRL properties is Sonoma County, with 268 (28.2 percent of its total RL properties)
- 34.8 percent of the 3,660 RL properties in the State are outside of the SFHA

- The county with the most RL properties outside the SFHA is Los Angeles County (61.2 percent of its total RL properties)
- 24.6 percent of the 3,660 RL properties are insured under the NFIP
- 11.1 percent of the 3,660 RL properties have been identified as mitigated
- The county with the most mitigated RL properties is Sonoma County (87), followed by Sacramento County (70) and Los Angeles County (41)
- The 3,660 identified RL properties have accounted for 9,956 total losses, with a total value of $241 million in claims paid by the NFIP: this amounts to an average claim of $24,241. This is below the national average flood insurance claim under the NFIP of just over $31,000 per claim
- 50 of the 58 counties in the State (86.2 percent) have identified RL properties
- The top five RL counties in the State are:
    - Sonoma County (951 properties)
    - Los Angeles County (479 properties)
    - Sacramento County (238 properties)
    - Marin County (234 properties)
    - Lake County (167 properties)
- The county with the highest average loss per claim is El Dorado County at $46,816

6.6.6. Equity Priority Communities

The risk analysis for riverine flooding found the following vulnerability of equity priority communities (a breakdown by county is included in Appendix I):

- 35.9 percent of people living in the 1% annual chance flood hazard zone live in equity priority communities (486,048 people)
- 41.2 percent of people living in the 0.2% annual chance flood hazard zone live in equity priority communities (2,153,503 people)

6.6.7. NRI Scores

According to the NRI, all the State's counties have riverine flood risk, rated from very low to very high. Table 6-8 shows scores for the six counties with the highest rating. See Section 4.1.3 for a description of the components of the NRI.

Table 6-8. NRI Scoring of Counties for Riverine Flood

County	Expected Annual Loss	Social Vulnerability Rating	Community Resilience Rating	Community Risk Factor	Risk Value	Score
Kern	$47,867,304	Very High	Very Low	1.41	$72,069,983	99.59
Ventura	$42,303,163	Relatively High	Relatively Moderate	1.22	$54,069,269	99.52
San Bernardino	$30,907,939	Very High	Relatively Moderate	1.34	$42,775,664	99.36
Marin	$28,231,043	Relatively Low	Very High	1.02	$30,230,864	98.98
Riverside	$18,804,063	Very High	Relatively Low	1.34	$27,982,149	98.92
Fresno	$16,491,298	Very High	Relatively Low	1.53	$25,232,318	98.82

6.7. MITIGATING THE HAZARD

6.7.1. Existing Measures to Mitigate the Hazard

The National Flood Insurance Program

The NFIP provides flood insurance to homeowners, renters, and business owners in participating communities. For most such communities, FEMA has prepared a detailed Flood Insurance Study that shows flood data for specific water courses, lakes, and coastal areas. The study report contains detailed flood elevation data in flood profiles and data tables. FEMA produces FIRMs as part of the NFIP.

As of this plan update, 528 California communities participate in the NFIP (FEMA 2022s). Five communities in the State are eligible but do not participate. One community has been suspended from the program. The status of all 528 participating NFIP communities in California can be seen on FEMA's website. As of August 31, 2022, 191,488 flood insurance policies were in force in the participating communities, with a total coverage of $58 billion and a total annual premium of $161 million (FEMA n.d.).

The Community Rating System

The CRS is an extension of the NFIP that provides insurance premium discounts of up to 45 percent based on a community's enforcement of higher regulatory standards. The CRS is a voluntary incentive program that encourages community floodplain management activities that exceed the minimum NFIP requirements. Participating communities' flood insurance premium rates are discounted to reflect the reduced risk.

Currently, California has 89 communities participating in the CRS. This accounts for 66 percent of the NFIP policy base statewide. The CRS benefits more than 167,000 policyholders and saves property owners and businesses over $14.5 million annually.

Climate Change Information

California offers a variety of resources, including the California Climate Change Assessments and Cal-Adapt, that aggregate peer-reviewed climate projection data and allow users to assess exposure and vulnerability across the local, State, and regional scales. While medium and long-term climate projections are subject to changing dynamics, assessing vulnerability under changing climate conditions plays a critical role in planning and anticipating risk.

6.7.2. Opportunities for Mitigating the Hazard

Flood hazards can be mitigated using both structural and non-structural solutions. A range of potential opportunities for mitigating the riverine stream and alluvial flood hazard is provided in Table 6-9. See Section 1.2.3 for a description of the different types of alternatives.

6.7.3. Selected Actions to Mitigate the Hazard

The mitigation strategy developed for this SHMP includes the following actions that address riverine flooding:

- Action 2023-003: Develop a Hazus repository for both earthquake and flood hazards where local planning efforts that create these models can share this information with the State once the models have been developed.
- Action 2023-009: Implement the 2022 Central Valley Flood Protection Plan (CVFPP).
- Action 2023-012: Continue to support programs that promote the mitigation of FEMA-identified RL and SRL properties.

Table 6-9. Potential Opportunities to Mitigate the Flood Hazard

Community-Scale	Organizational Scale	Government-Scale	
Manipulate the hazard: ▪ Clear storm drains and culverts ▪ Use green infrastructure **Reduce exposure and vulnerability:** ▪ Locate outside of the hazard area ▪ Elevate utilities above base flood elevation ▪ Use low-impact development ▪ Raise structures above base flood elevation ▪ Elevate items in the house above the	**Manipulate the hazard:** ▪ Clear storm drains and culverts ▪ Use low-impact development **Reduce exposure and vulnerability:** ▪ Locate outside the hazard area ▪ Use low-impact development ▪ Build redundancy for critical functions or retrofit critical buildings ▪ Provide flood-proofing when new critical infrastructure must be	**Manipulate the hazard:** ▪ Maintain drainage system ▪ Institute low-impact development techniques on property ▪ Dredging, levee construction, and providing regional retention areas ▪ Use structural flood control (levees, etc.) only when no nature-based option is feasible ▪ Stormwater management regulations and master planning ▪ Acquire vacant land or promote open space uses in developing watersheds to control runoff **Reduce exposure and vulnerability:** ▪ Locate or relocate critical facilities outside the hazard area ▪ Acquire or relocate identified RL properties ▪ Promote open space uses in identified high-hazard areas via planned unit developments, easements, setbacks, greenways, sensitive area tracks, etc. ▪ Adopt land development criteria such as clustering, planned unit developments, density transfers ▪ Institute low impact development techniques on property	▪ Facilitate retreat from or upgrade of at-risk areas ▪ Require accounting of sea-level rise in applications for new shoreline development ▪ Implement Assembly Bill (AB) 162 requiring flood information in local general plans **Build local capacity:** ▪ Produce better hazard maps ▪ Provide technical information and guidance ▪ Enact tools to help manage development in hazard areas (stronger controls, tax incentives, and information) ▪ Incorporate retrofitting or replacement of critical system elements in the capital improvement plan ▪ Develop a strategy to take advantage of post-disaster opportunities ▪ Warehouse critical infrastructure components ▪ Develop and adopt a continuity of operations plan

Community-Scale	Organizational Scale	Government-Scale	
base flood elevation ▪ Build new home above base flood elevation ▪ Flood-proof structures **Build local capacity:** ▪ Buy flood insurance ▪ Develop a household plan, such as retrofit savings, communication with the outside, 72-hour self-sufficiency during and after an event	located in floodplains **Build local capacity:** ▪ Keep cash reserves for reconstruction ▪ Support and implement hazard disclosure for the sale of property in risk zones ▪ Solicit cost-sharing through partnerships with others on projects with multiple benefits.	▪ Acquire vacant land or promote open space uses in developing watersheds to control runoff ▪ Preserve undeveloped and vulnerable shoreline ▪ Restore existing flood control and riparian corridors, including the removal of invasive species in the floodplain to reduce bulk flows and infrastructure impacts ▪ Harden infrastructure, bridge replacement program ▪ Provide redundancy for critical functions and infrastructure ▪ Adopt regulatory standards such as freeboard standards, substantial improvement or damage, substantial damage threshold, compensatory storage, and non-conversion deed restrictions ▪ Stormwater management regulations and master planning ▪ Adopt "no-adverse impact" floodplain management policies to limit increases in the flood risk on downstream communities	▪ Consider participation in the CRS ▪ Maintain and collect data to define risks and vulnerability ▪ Train emergency responders ▪ Create an elevation inventory of structures in the floodplain ▪ Develop and implement a public information strategy ▪ Charge hazard mitigation fee ▪ Integrate floodplain management policies into other planning mechanisms within the planning area ▪ Consider the probable impacts of climate change on the risk associated with the flood hazard ▪ Consider the residual risk associated with structural flood control in future land use decisions ▪ Enforce NFIP requirements ▪ Adopt a stormwater management master plan ▪ Develop an adaptive management plan to address the long-term sea-level rise

Community-Scale	Organizational Scale	Government-Scale
Nature-based opportunities: ▪ Restore and reconnect floodplains that have been degraded by development and structural flood control. ▪ Use soft approaches for stream bank restoration and hardening (e.g., introducing large woody debris into a system). ▪ Set back levees on systems that rely on levee protection to allow the river channel to meander, which reduces erosion and scour potential. ▪ Acquire property within the floodplain, remove or relocate structures, and preserve these areas as open space in perpetuity. ▪ Preserve floodplain storage capacity by limiting or prohibiting the use of fill in the floodplain. ▪ Incorporate green infrastructure into stormwater management facilities ▪ Protect or restore riparian buffers		

An Example Success Story for Riverine Flood Mitigation:

Sonoma County Flood Elevation Program, Russian River

Russian River flooding, 2019

Elevated living spaces stay above floodwaters

The Russian River in Sonoma and Mendocino Counties poses a substantial threat of flooding for adjacent communities. The 110-mile river is a critical resource and provides potable water to communities in Sonoma, Mendocino, and Marin Counties

Problem: Sonoma County has one of the country's highest concentrations of repetitive flood loss properties due to flooding along the Russian River. Since 1940, Sonoma County has sustained more than $5 billion in damage from severe storms and flooding and received 14 presidential flood disaster declarations. During the same period, the town of Guerneville flooded 38 times.

Solution: In 1995, Sonoma County established the Sonoma County Flood Elevation Program to elevate flood-prone structures. The projects consisted of elevating structures to a minimum of 1 foot above the base flood elevation.

Cost and Funding: Sonoma County has elevated 290 structures for $20,380,443, funded through FEMA's Hazard Mitigation Grant Program (HMGP) and Flood Mitigation Assistance (FMA) Program, administered by Cal OES.

Benefits: In February 2019, torrential rainfall caused the Russian River to swell to its highest levels in 25 years. The river crested 15 feet above flood level. Guerneville and Monte Rio were cut off from land travel. More than 2,600 homes across the County were affected, and hundreds of residents were displaced. Of the 290 structures elevated, 197 were impacted by the 2019 flood. Cal OES conducted a loss avoidance study to quantify the damage prevented from that flood as a result of the home elevation projects. The loss avoidance study found the following:

- Completed Structure Elevation Costs – $20,380,443
- Structure and Content Value – $136,059,075
- Pre-Mitigation Flood Losses – $51,946,012
- Post-Mitigation Flood Losses – $1,280,447
- Total Losses Avoided – $50,665,565

The avoided losses divided by the project cost represent a return on investment of 249 percent.

Extreme Heat

Climate Impacts:
More frequent and intense events
Equity Impacts:
30.4% of the exposed population (all persons in the State are exposed) identified as living in equity priority communities
State Facilities Exposed:
All facilities exposed
Community Lifelines Exposed:
All lifelines exposed

Impact Rating: High (39)

7. EXTREME HEAT

Extreme heat has been identified as a high-impact natural hazard of interest based on the hazard impact rating protocol applied for this SHMP. Extreme heat events frequently happen in the State, and all State-owned or -leased facilities and community lifelines are exposed to this hazard but have a limited risk of damage. The exposure of and impacts on the general population and equity priority communities poses a serious risk. While some portions of the State may get hotter than others, all populations in the State can experience extreme heat events relative to their area. These events are likely to impact equity priority communities more than the general populations due to many factors. Exposure to extreme heat events could increase if all buildable lands were developed. The frequency and severity of extreme heat events is anticipated to increase over the next 30 years due to impacts from climate change.

7.1. HAZARD OVERVIEW

Extreme heat is defined as temperatures that hover 10 °F or more above the average high temperatures for a region for several days or weeks. Extreme heat events can lead to an increase in heat-related illnesses and deaths, worsen drought, and impact water supplies and other infrastructure such as transportation, agriculture, and energy.

7.1.1. Impacts on Human Health

Extreme heat is one of the leading causes of weather-related deaths in the United States, killing an average of more than 702 people per year from 2004–2018, more than all other weather hazards (except hurricanes) combined. The Billion Dollar Weather Disasters database compiled by NOAA lists heat waves as six of the top 10 deadliest U.S. disasters since 1980 (NOAA 2023b).

Heat-related illness includes a spectrum of illnesses ranging from heat cramps to severe heat exhaustion and life-threatening heat stroke. Table 7-1 describes common heat-related illnesses are listed.

Table 7-1. Typical Heat-Related Illnesses

Definition	Symptoms	First Aid
Heat Stroke		
Heat stroke occurs when the body can no longer control its temperature: the body's temperature rises rapidly, the sweating mechanism fails, and the body is unable to cool down. When heat stroke occurs, the body temperature can rise to 106 °F or higher within 10 to 15 minutes.	Confusion, altered mental status, slurred speech; loss of consciousness (coma); hot, dry skin or profuse sweating; seizures; very high body temperature; fatal if treatment delayed	▪ Call 911 ▪ Stay with sufferer until help arrives ▪ Move sufferer to a shaded, cool area and remove outer clothing ▪ Circulate air to speed cooling ▪ Place cold wet cloths or ice on head, neck, armpits, and groin
Heat Exhaustion		
Heat exhaustion is the body's response to an excessive loss of water and salt, usually through excessive sweating. Heat exhaustion is most likely to affect older adults, infants and children, people with chronic medical conditions, athletes, pregnant women, and those working outdoors or in a hot environment.	Headache; nausea; dizziness; weakness; irritability; thirst; heavy sweating; elevated body temperature; decreased urine output	▪ Take sufferer to a clinic or emergency room for medical evaluation and treatment ▪ Call 911 if medical care is unavailable ▪ Stay with sufferer until help arrives ▪ Remove sufferer from hot area and give liquids to drink ▪ Remove unnecessary clothing ▪ Cool the sufferer with cold compresses or cold water ▪ Encourage frequent sips of cool water
Rhabdomyolysis		
Rhabdomyolysis is a medical condition associated with heat stress and prolonged physical exertion. It causes the rapid breakdown, rupture, and death of muscle. When muscle tissue dies, electrolytes and large proteins are released into the bloodstream. This can cause irregular heart rhythms, seizures, and damage to the kidneys.	Muscle cramps/pain; abnormally dark urine; weakness; exercise intolerance	▪ Stop activity ▪ Drink more liquids (water preferred) ▪ Seek immediate care at the nearest medical facility ▪ Ask to be checked for rhabdomyolysis

Definition	Symptoms	First Aid
Heat Syncope		
Heat syncope is a fainting (syncope) episode or dizziness that usually occurs when standing for too long or suddenly standing up after sitting or lying. Factors that may contribute to heat syncope include dehydration and lack of acclimatization.	Fainting (short duration); dizziness; light-headedness from standing too long or suddenly rising from a sitting or lying position	▪ Sit or lie down in a cool place ▪ Slowly drink water, clear juice, or a sports drink
Heat Cramps		
Heat cramps usually affect workers who sweat a lot during strenuous activity. This sweating depletes the body's salt and moisture levels. Low salt levels in muscles cause painful cramps. Heat cramps may also be a symptom of heat exhaustion.	Muscle cramps, pain, or spasms in the abdomen, arms, or legs	▪ Drink water and have a snack or drink that replaces carbohydrates or electrolytes every 15 to 20 minutes ▪ Avoid salt tablets ▪ Get help if the sufferer has heart problems, is on a low-sodium diet, or has cramps that do not subside within 1 hour
Heat Rash		
Heat rash is a skin irritation caused by excessive sweating during hot, humid weather.	Red clusters of pimples or small blisters, usually on the neck, upper chest, groin, under the breasts, and in elbow creases	▪ Work in a cooler, less humid environment if possible ▪ Keep rash area dry ▪ Apply powder to increase comfort ▪ Do not use ointments or creams

Source: (CDC 2022e)

Heat-related illness results from the body's inability to dissipate heat produced by metabolic activity, often as a result of increased ambient temperature (State of California 2022j). Heat waves do not strike victims immediately, but their cumulative effects slowly cause harm to vulnerable populations. Elevated nighttime temperatures are likely key ingredients in causing heat-related illness and mortality. When there is no break from the heat at night, it can cause discomfort and lead to health problems, especially for those who lack access to cooling and health care, which are often people who have low incomes or are experiencing homelessness. Other groups that are particularly vulnerable to heat stress include older adults, infants and children, people with chronic health conditions, people with disabilities, outdoor workers, and others within identified equity priority communities.

Some studies have indicated that extreme heat has negative impacts on mental health. A study in New York found that hot days were associated with a higher risk of emergency room visits for substance abuse, mood and anxiety disorders, schizophrenia, and dementia. Extreme heat is also associated with increases in depression, suicide, aggression, and domestic violence. Those with severe mental illnesses or currently on psychiatric medications may be more vulnerable to exacerbated mental or physical health impacts of extreme heat (Clayton, et al. 2017, Dodgen, et al. 2016).

7.1.2. Impacts on Infrastructure

Cascading impacts on urban systems can result from extreme heat stress applied on water, power, and transportation systems (UCLA Luskin Center for Innovation 2021). Heat can compromise infrastructure safety and reliability; it can cause issues such as train track buckling and road material softening. Extreme heat can also prevent aircraft from taking off as it reduces the density of air mass, making it more difficult for aircraft to lift, in addition to possibly softening tarmac materials (UCLA Luskin Center for Innovation 2021).

7.1.3. Urban Heat Islands

Large urban areas often experience higher temperatures in summer than more rural communities—a phenomenon known as the urban heat island effect. Heat islands are created by a combination of heat-absorptive surfaces (such as dark pavement and roofing), heat-generating activities (such as engines and generators), and the absence of vegetation (which provides evaporative cooling) (CalEPA 2022). In certain urban settings where conditions create heat islands, occupants face a greater risk of heat-related diseases (UCAR Center for Science Education 2022).

Heat island effects can occur in urban areas when natural surfaces and materials such as grass, trees, and soil, which dissipate heat, are replaced by roads and buildings with materials that increase absorption (and reduce dissipation) of heat. As a result of building and road construction and other human activities, more heat is generated and retained, and air temperatures in urban heat island areas are consistently higher than in surrounding areas (CalEPA 2022). Increased temperatures also add to the heat load of buildings in urban areas, adding to the risk of high ambient temperatures.

The transportation sector, with its roads, highways, and pavements, is both a major contributor to the urban heat island effect and vulnerable to its effects. As heat increases, pavement begins to deteriorate and rail and bridge joints are more likely to buckle, increasing maintenance costs (Sacramento Metropolitan Air Quality Management District 2017).

7.1.4. The Heat Index

The heat index is a measure of how temperature feels to the human body when combined with relative humidity. When the body gets hot, it begins to perspire to cool itself. When perspiration evaporates off the body, it effectively reduces the body's temperature. When the atmospheric moisture content (i.e., relative humidity) is high, the rate of evaporation from the body decreases. When relative humidity decreases, the rate of evaporation increases, so the body actually feels cooler in arid conditions. Figure 7-1 shows heat index ratings based on humidity and temperature.

Figure 7-1. Heat Index

Temperature (°F)

Relative Humidity (%)	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	128	136					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

Likelihood of Heat Disorders with Prolonged Exposure or Strenuous Activity

Caution   Extreme Caution   Danger   Extreme Danger

Source: (NWS 2023a)

7.2. HAZARD LOCATION

California has a diversity of climates, and statewide provisions to the California Energy Code account for these variations using a set of 16 climate zones (CEC n.d.-a). Extreme heat impacts the entire State of California.

7.3. PREVIOUS HAZARD OCCURRENCES

7.3.1. Disaster and Emergency Declarations

The following disaster declarations or emergency proclamations related to energy shortage have been issued for California (see Appendix F for details):

- Federal DR or EM declaration, 1953 – 2022: none
- California Emergency Proclamations, 1950 – 2022: 2 events, classified as heat wave
- USDA agricultural disaster declarations, 2012 – 2022: 50 events

7.3.2. Event History

California has experienced many extreme heat events. The 2018 SHMP did not chronicle past extreme heat events. Table 7-2 lists prominent events since 2018 that resulted in property damage, crop damage, or casualties.

2021 Western Heat Wave

During June and July 2021, the western United States experienced a record-breaking heat wave for several days. Based on a comparison of health records from the period June 26–July 10, 2020, to those from the same period in 2021, heat-related deaths increased from 2 to 145 in Washington, 0 to 119 in Oregon, and 12 to 25 in California. These estimates were provided by the California Department of Public Health (CDPH), Oregon Health Authority, and Washington State Department of Health. An increase in heat-related emergency room visits was observed during the heatwave. According to a Centers for Disease Control and Prevention (CDC) report, the mean daily number of emergency room visits due to heat-related illnesses in Alaska, Idaho, Oregon, and Washington was 69 times higher from June 25–30, 2021 than for the same period in 2019.

Table 7-2. Extreme Heat Events in the State of California (2018 to 2022)

<table>
<tr><th>Date</th><th>Event Type</th><th>FEMA Declaration Number</th><th>USDA Declaration Number</th><th>Counties/Areas Impacted</th></tr>
<tr><td>June 12 – 13, 2018</td><td>Extreme Heat</td><td>N/A</td><td>N/A</td><td>Death Valley National Park</td></tr>
<tr><td colspan="5">Temperatures reached Excessive Heat Warning levels on June 12 and 13. One hiker suffering from dehydration and heat exposure was rescued from Death Valley National Park on the 15.</td></tr>
<tr><td>July 6 – 7, 2018</td><td>Extreme Heat</td><td>N/A</td><td>N/A</td><td>San Diego County Valley, Coachella Valley, San Bernardino County, Riverside County, Orange County Inland Zone</td></tr>
<tr><td colspan="5">Extreme hot temperatures and dry conditions impacted southern California. Inland Orange County, San Diego Valleys, Inland Empire, and the deserts. Thermal and Chino reached 120 °F and San Bernardino and Riverside Airport reached 118 °F. San Diego Public Health and 211 services reported a large number of heat-related calls. One fatality and 50 injuries were reported as a result of this event.</td></tr>
<tr><td>August 2 – 5, 2019</td><td>Extreme Heat</td><td>N/A</td><td>N/A</td><td>Coachella Valley, San Diego County, San Bernardino County, Riverside County</td></tr>
<tr><td colspan="5">Between August 2 and 4, temperatures ranged from 98 °F in the Inland Empire to 115 °F in Palm Springs. Between August 5 and 6, temperatures ranged from 103 °F in the Inland Empire cities to 121 °F at Palm Springs. Approximately $1.5 million in property damage was recorded.</td></tr>
<tr><td>July 5, 2020</td><td>Extreme Heat</td><td>N/A</td><td>N/A</td><td>San Diego County, Orange County</td></tr>
<tr><td colspan="5">A hiker required medical rescue due to heat-related illness near doghouse Junction on Otay Mountain. Around 1:15 pm, temperature at Otay Mountain was 87 °F.</td></tr>
<tr><td>August 13 – 20, 2020</td><td>Extreme Heat</td><td>N/A</td><td>N/A</td><td>Joshua Tree National Park, Salton Sea, Imperial County</td></tr>
<tr><td colspan="5">Strong high pressure caused excessive heat for multiple days across southeast California. A heat-caused fatality was reported in Joshua Tree National Park on August 20 after an individual's vehicle became disabled along an unmaintained road.</td></tr>
<tr><td>August 14 – 18, 2020</td><td>Extreme Heat</td><td>N/A</td><td>N/A</td><td>Tulare County, Kern County</td></tr>
<tr><td colspan="5">A high-pressure center over central California caused oppressive heat for several days. An Excessive Heat Warning was posted for the San Joaquin Valley and Sierra Foothills for five days and for the Kern County Deserts for seven days. New records were set for afternoon high temperatures and overnight high minimum temperatures. Several locations reported highs above 110 °F and lows above 80 °F. Several cities opened cooling centers. Local emergencies were declared in Fresno, Tulare, and Kings Counties due to an unusually high rate of livestock fatalities.</td></tr>
<tr><td>September 4 – 7, 2020</td><td>Excessive Heat</td><td>N/A</td><td>N/A</td><td>Joshua Tree National Park, Salton Sea, Chuckwalla Mountains, Imperial County, Palo Verde Valley, Chiriaco Summit</td></tr>
<tr><td colspan="5">High pressure led to excessive heat across southeast California during the Labor Day weekend. Temperatures across the region reached around 115 to 120 °F. A young person died from the heat after setting out on a hike in Joshua Tree National Park during the afternoon of September 5.</td></tr>
</table>

Date	Event Type	FEMA Declaration Number	USDA Declaration Number	Counties/Areas Impacted
September 2022	Heat Dome	Declaration Requested	N/A	All Counties
In early September 2022, a long-lasting heat dome settled over the U.S. West and brought scorching temperatures that set all-time record highs. The extreme heat fueled wildfires and stressed the power grid before an eastern Pacific tropical storm moved into the region and broke the warm spell. On September 7, 2022, more than 61 million people were under active extreme heat advisories, watches, and warnings, according to the National Weather Service.				

Source: (NCEI 2022)

7.4. PROBABILITY OF FUTURE HAZARD EVENTS

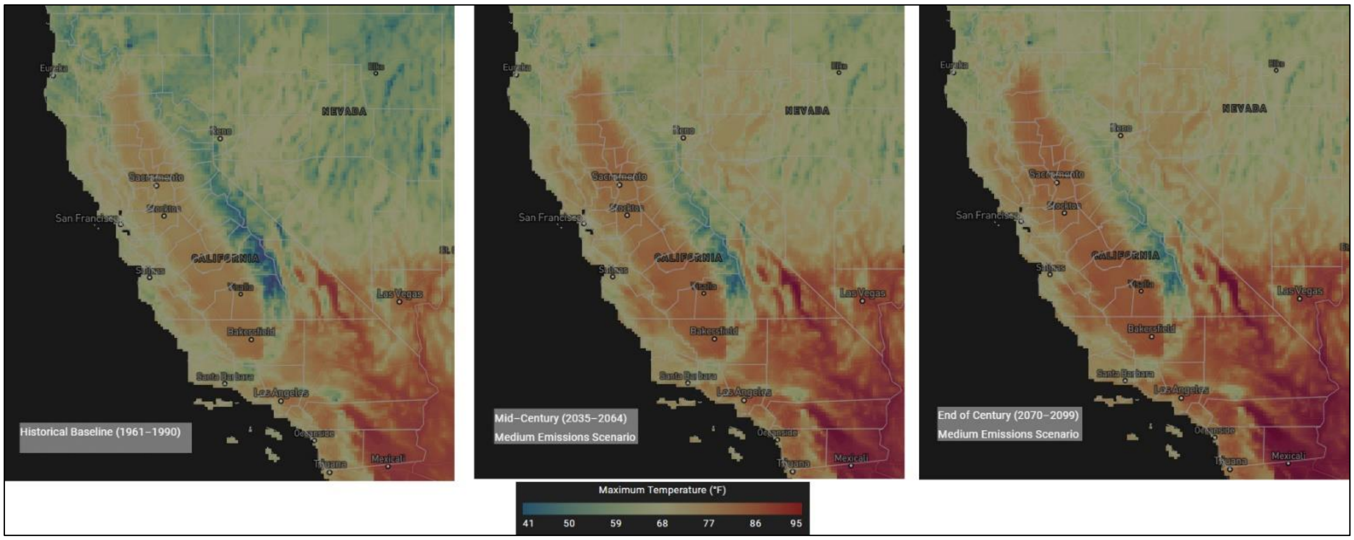
7.4.1. Overall Probability

California's 990 recorded extreme heat events between 1953 and 2022 represent an average of almost 15 events per year (NCEI 2022). The State expects to continue experiencing a similar number of extreme heat events per year on average, or possibly more due to climate change.

7.4.2. Climate Change Impacts

California is already experiencing the impacts of climate change. When comparing average annual temperatures from 1901–1960 to those of 1986 – 2016, most of California has experienced increases exceeding 1°F, with some areas exceeding 2°F (OPR 2022). The daily maximum average temperature, an indicator of extreme temperature shifts, is expected to rise 4.4 °F to 5.8 °F by 2050 and 5.6 °F to 8.8 °F by 2100 (State of California 2022j). Figure 7-2 illustrates the statewide temperature increase trend.

Figure 7-2. California Historical and Projected Temperature, 1961-2099



Source: (Cal-Adapt 2022)

Different regions of the State experience extreme heat differently – some areas accustomed to hot temperatures are experiencing very hot conditions and some that have been historically cool are experiencing warmer temperatures (State of California 2022j). Climate models project that by mid-century, Los Angeles County will experience an average of nine days of extreme heat per year, growing to 12 days per year by the final decades of the century (LAO 2022). Sacramento County is projected to experience 20 days per year of extreme heat by mid-century and 28 days annually by the end of the century (LAO 2022). These trends will be even more severe in some inland counties. In Fresno County, the historical trends of five days of extreme heat per year are projected to increase to 29 days annually between 2035 and 2064 and to 43 days annually between 2070 and 2099 (LAO 2022).

With rising temperatures, the State of California will experience more extreme heat events with greater severity and for longer periods of time. This trend is accentuated specifically for humid heat waves, which are expressed very strongly in nighttime temperatures (Gershunov, Cayan and Jacobellis 2009) (Gershunov and Guirguis 2012).

For many cities in the State, extreme heat days—daily high temperatures that used to occur about four times a summer—will occur 40 to 70 days during the summer by 2050, according to an analysis based on Cal-Adapt (CalEPA n.d.). Without appropriate preparation, communities unaccustomed to repeated heat events will be unprepared to address the health consequences of extreme heat.

Heat waves that result in public health impacts, also referred to as heat-health events, are also projected to worsen throughout the State. By 2050, average heat-health events are projected to last two weeks longer in the Central Valley and four to 10 times more often in the Northern Sierra region (State of California 2022j).

7.5. IMPACT ANALYSIS

7.5.1. Severity

According to the California Climate Adaptation Strategy, heat waves have claimed more lives in California than all other declared disaster events combined.

Several regions have seen record-breaking temperatures in recent years. In 2020, parts of Los Angeles County hit 121 °F, while the Coachella Valley hit its all-time high of 123°F in 2021 (Carpenter 2022).

7.5.2. Warning Time

The NWS heat risk forecast (see Figure 7-3) provides a quick view of heat risk potential over the upcoming seven days. The heat risk is portrayed in a numeric scale (0-4) and a color scale (green/yellow/orange/red/magenta). It provides one value each day that indicates the approximate level of heat risk concern for any location, along with identifying the groups who are most at risk.

Figure 7-3. NWS Heat Risk Forecasting System

Category	Level	Meaning
Green	0	No Elevated Risk
Yellow	1	Low Risk for those extremely sensitive to heat, especially those without effective cooling and/or adequate hydration
Orange	2	Moderate Risk for those who are sensitive to heat, especially those without effective cooling and/or adequate hydration
Red	3	High Risk for much of the population, especially those who are heat sensitive and those without effective cooling and/or adequate hydration
Magenta	4	Very High Risk for entire population due to long duration heat, with little to no relief overnight

Source: (NWS 2023)

The NWS issues excessive heat watches, excessive heat warnings and heat advisories to warn of an extreme heat event (a “heat wave”) within the next 36 hours.

If forecasters predict an excessive heat event in the three- to seven-day timeframe, then the NWS issues messaging in the form of a special weather statement, emails, and social media. The NWS uses the Heat Risk Forecasting System to determine if an excessive heat watch/warning or heat advisory is warranted:

- **Heat Advisory**—Heat Risk output is on the orange/red (Level 2-3) thresholds (orange will not be an automatic heat advisory).
- **Excessive Heat Watch/Warning**—Heat Risk output is on the red/magenta (Level 3-4) thresholds.

An excessive heat watch warns the public and emergency officials that extreme temperatures are expected. If significantly hot temperatures remain in the forecast for 24 to 28 hours, the excessive heat watch is upgraded to an excessive heat warning, indicating that extreme heat has arrived or is expected soon.

7.5.3. Cascading Impacts

Cascading impacts are the impacts that result when one type of hazard event triggers one or more other hazard events, which may in turn trigger still others. The following are notable cascading impacts associated with extreme heat events:

- Poor air quality, which can occur when stagnant atmospheric conditions trap humid air and pollutants near the ground. Ozone, a major component of smog, is created in the presence of sunlight via reactions between chemicals in gasoline vapors and industrial smokestacks. Hot weather can increase ozone levels. High ozone levels often cause or worsen respiratory problems (EPA 2022b).
- Climate change-influenced heat events may also create a conducive environment for vector-borne diseases. Extended heat events can result in the emergence of vectors that can carry infectious diseases—such as dengue, Zika, yellow fever, and chikungunya—in areas of California that have not historically experienced their occurrence. Recent surges in Zika and dengue fever infections present an example. For these two pathogens, an increase in temperature allows mosquitoes to feed more frequently, breed more prolifically, and live longer, which ultimately results in their ability to travel farther to spread carried viruses (CDPH 2022b).
- Air conditioning used during extreme heat events increases energy demand and could increase the risk of energy shortages. In the summer of 2020, the demand for electricity during heat waves in California contributed to the State's

first rolling blackout in nearly 20 years (Kim, et al. 2021). The three largest utilities—Pacific Gas & Electric, Southern California Edison and San Diego Gas & Electric—turned off power to more than 410,000 homes and businesses for about an hour at a time until the Emergency Declaration ended after several hours (Har and Beam 2020).

- PSPSs are cascading hazards associated with extreme heat events. Under certain severe weather conditions, including extreme heat, utility service providers shut off power to help prevent wildfire and keep communities safe. A PSPS may be called in response to a combination of dry vegetation and high winds that can uproot trees, blow branches onto power lines or create sparks if power lines contact one another.
- Extreme heat contributes to more severe wildfires in a longer wildfire season and increases the health and safety risk experienced by wildland firefighters and populations near wildfires due to additional reductions in air quality. Wildfire can also further exacerbate worsening air quality caused by extreme heat, placing all vulnerable populations at risk of new or worsened respiratory conditions.
- Heat evaporation can lead to loss of stored water in reservoirs and aqueducts. The amount of water lost depends largely on local climate conditions. High air temperatures, low humidity, strong winds and sunshine will increase evaporation.
- Power outages are associated with extreme heat events, which could impact critical facilities infrastructure.
- Ozone can impact plant health, by interfering with plants' ability to produce and store food. This can lead to reduction in agricultural yields of many crops, from wheat and cotton to soybeans (Avnery, et al. 2011, Ainsworth 2017).

7.5.4. Environmental Impacts

Extreme heat events, especially when accompanied by drought conditions, can lead to environmental consequences. Increasing temperatures can lead to exacerbated risk of wildfire; drought and its effects on the health of watersheds; and increased stress, migration, and death in plants and animals. These shifts result in significant cultural impacts on Tribal Nations, where plants and animals that have been used as traditional food, medicine, or materials, or in ceremony are no longer present (State of California 2022j). Alpine trees are vulnerable to temperature changes, resulting in mass tree deaths and a loss of habitat for animals (Mooney and Zavaleta 2016).

7.5.5. Impacts on Agriculture

Increased extreme heat events will likely impact California's agriculture sector negatively. Although heatwaves are usually considered a summer problem, warm winter and spring temperatures can also be a problem for fruit and nut trees. For example, many of California's perennials require exposure to cool temperatures during the winter in order to bloom and develop correctly in the spring. When crops do not receive enough winter chill, the timing of bloom may be delayed, which can cause problems for pollination. In 2015 a warm winter and a lack of chill devastated California's pistachio crop and caused more than $180 million in crop damage.

In the future, warming winter temperatures are expected to reduce the exposure of perennials to needed cool temperatures. This reduction in winter chill could effectively eliminate the production of some fruits and nuts in California by the end of the 21st century. For example, by the mid-21st century, up to 75 percent of California's Central Valley may be too warm for crops that need more than 700 chill hours. As much as 98 percent of the region may be too warm by the end of the century.

7.5.6. Local Hazard Impacts

LHMP Rankings

County hazard mitigation plans often identify "severe weather" as a hazard of concern without separating hot or cold temperatures from each other or from other weather types. Of the 58 counties in California, 54 assessed severe weather as a hazard of concern in their hazard mitigation plans: 17 specified extreme temperature (hot or cold). None ranked extreme temperature as high risk; 13 ranked it as medium risk, and 4 ranked it as low risk. The following counties listed extreme temperature as a medium-risk hazard:

- Amador
- Butte
- Calaveras
- El Dorado
- Fresno
- Lake
- Madera
- Modoc
- Mono
- Monterey
- Nevada
- Placer
- San Benito
- Tulare

LHMP Estimates of Potential Loss

A review of the LHMPs in the counties (as called for in FEMA's Standard State Mitigation Planning Requirement S6.b) found no quantitative risk analysis that identifies population or structures exposed to this hazard. This can be attributed to the lack of extent and location hazard mapping to use for such an analysis. Therefore, no summary of risk for local plan reviews is provided for this hazard.

7.6. VULNERABILITY ANALYSIS

7.6.1. Exposure of State-Owned or -Leased Facilities, Critical Facilities, and Community Lifelines

All State-owned or -leased assets, as listed in Table 4-1 and Table 4-2, are exposed to extreme heat. This includes 23,961 State-owned facilities, and 1,893 State-leased facilities. All 755 State critical facilities and community lifelines, as listed in Table 4-3, are exposed to this hazard as well.

Functional downtime associated with power interruption is the most significant impact on critical facilities and community lifelines from extreme heat events. The level of impact depends on the amount of time it takes to restore power to operational status at impacted facilities.

7.6.2. Estimates of Loss

Extreme heat events do not typically impact buildings; however, losses may be associated with the urban heat island effect and overheating of heating, ventilation, and air conditioning systems. This can impact power and cooling dependent upon power, which could impact infrastructure that needs temperature control, such as information technology equipment. There are no standard generic formulas for estimating associated losses. Instead, loss estimates were developed representing 10 percent, 30 percent, and 50 percent of the replacement cost value of the contents all State-owned facilities (see Table 7-3). This allows the State to select a range of potential economic impacts based on an estimate of the percentage of damage.

Table 7-3. Loss Potential of State-Owned Asset Contents for Extreme Heat

Type of Facility	Total Replacement Cost Value (contents only)	Estimated Loss Potential Based on % Damage		
		10% Damage	30% Damage	50% Damage
Facilities Housing Vulnerable Populations				
Correctional Facility	$2,254,012,157	$225,401,216	$676,203,647	$1,127,006,079
Development Center	$390,885,847	$39,088,585	$117,265,754	$195,442,924
Hospital	$454,638,764	$45,463,876	$136,391,629	$227,319,382
Migrant Center	$341,691,270	$34,169,127	$102,507,381	$170,845,635
Special School	$63,904,858	$6,390,486	$19,171,457	$31,952,429
All Other Facilities	**$14,057,592,693**	**$1,405,759,269**	**$4,217,277,808**	**$7,028,796,347**
Total	**$17,562,725,589**	**$1,756,272,559**	**$5,268,817,677**	**$8,781,362,795**

Increased extreme heat events will likely impact California's agriculture sector negatively. Although heatwaves are usually considered a summer problem, warm winter and spring temperatures can also be a problem for fruit and nut trees. For example, many of California's perennials require exposure to cool temperatures during the winter in order to bloom and develop correctly in the spring. When crops do not receive enough winter chill, the timing of bloom may be delayed, which can cause problems for pollination. In 2015 a warm winter and a lack of chill devastated California's pistachio crop and caused more than $180 million in crop damages (USDA n.d.).

Extreme heat threatens the State's fish and wildlife, ecosystems, and native plants, contributing to biodiversity loss. It is estimated that 45 to 56 percent of the natural vegetation in California will be climatically stressed by 2100 under current emission levels (State of California 2018).

In the future, warming winter temperatures are expected to reduce the exposure of perennials to needed cool temperatures. This reduction in winter chill could effectively eliminate the production of some fruits and nuts in California by the end of the 21st century. For example, up to 75 percent of California's Central Valley may be too warm for crops that need more than 700 chill hours by the mid-21st century. As much as 98 percent of the region may be too warm by the end of the century (USDA n.d.).

7.6.3. Buildable Land

An estimated 11.7 million acres of land is available for development in California. Because the entire State is vulnerable to extreme heat, any type of development of any of this land will be susceptible to damage and impacts from this hazard.

7.6.4. Equity Priority Communities

Extreme heat conditions can impact the entire population of the State; however, for equity priority communities these conditions can be dangerous and deadly, as heat risk is associated and correlated with physical, social, political, and economic factors (State of California 2022j). Older populations, infants and children, pregnant people, and people with chronic illness can be especially sensitive to heat exposure. Combining these characteristics and existing health inequities with additional factors, such as poverty, linguistic isolation, housing insecurity, limited to no access to cooling or shade, and the legacy of racist redlining policies, can put individuals at disproportionately high risk of heat-related illness and death (State of California 2022j).

Low-income individuals are more likely to live in poorly ventilated dwellings, lack air conditioning, or be unable to afford cooling; people experiencing homelessness lack shelter, cooling apparatus, and consistent access to water to minimize heat impacts (Center for Climate and Energy Solutions 2021). Indigenous, Black, Latina/e/o, Asian, Hawaiian and Pacific Islander, and other populations of color are vulnerable to extreme heat impacts due to underinvestment in their communities, leaving many with inadequate housing, infrastructure, and health services to manage extreme heat days (Center for Climate and Energy Solutions 2021).

Because the entire population of the State of California is exposed and vulnerable to extreme heat, the exposed population in equity priority communities is equal to the statewide percentage: 30.4 percent of the total population (12 million people).

7.6.5. NRI Scores

According to the NRI, all of the State's counties have heat wave risk, rated from very low to very high. Table 7-4 shows scores for the six counties with the highest rating. See Section 4.1.3 for a description of the components of the NRI.

Table 7-4. NRI Scoring of Counties for Heat Wave

County	Expected Annual Loss	Social Vulnerability Rating	Community Resilience Rating	Community Risk Factor	Risk Value	Score
Tulare	$19,484,740	Very High	Very Low	1.55	$30,585,603	99.65
Fresno	$12,873,728	Very High	Relatively Low	1.53	$19,280,399	99.46
Sacramento	$12,434,271	Relatively High	Relatively High	1.22	$15,543,423	99.24
Merced	$7,593,791	Very High	Very low	1.55	$11,815,569	99.01
Madera	$7,522,714	Very High	Very Low	1.41	$11,138,740	98.95
Riverside	$7,651,092	Very High	Relatively Low	1.34	$10,323,436	98.76

7.7. MITIGATING THE HAZARD

7.7.1. Existing Measures to Mitigate the Hazard

New legislation in California has been introduced to rank heat waves similarly to hurricanes. Assembly Bill (AB) 2238 and AB 2076 each propose solutions designed to protect people from heat and improve heat resilience and mitigation efforts. Among the ideas proposed, the bills would establish a Chief Heat Officer role, an interagency heat task force, and an extreme heat advisory council.

7.7.2. Opportunities for Mitigating the Hazard

Table 7-5 provides a range of potential alternatives for mitigating extreme heat.

7.7.3. Selected Actions to Mitigate the Hazard

The mitigation strategy developed for this SHMP includes the following actions that address the extreme heat hazard:

- Action 2018-008: Develop a database containing a description of the specific natural hazard event for which each project was designed to mitigate.
- Action 2018-090: Extreme Heat Vulnerability: Identify areas of the State most vulnerable to climate impacts.
- Action 2018-091: Extreme Heat Vulnerability: Identify vulnerable populations (e.g., people experiencing homelessness, lower-income households, older adults).

Table 7-5. Potential Opportunities to Mitigate the Extreme Heat Hazard

<table>
<tr><th>Community-Scale</th><th>Organizational Scale</th><th>Government-Scale</th></tr>
<tr>
<td>Manipulate the hazard:
▪ Plant trees to create shade in urban areas
▪ Remove concrete and other hard surfaces and replace them with native vegetation
Reduce exposure and vulnerability:
▪ Insulate residential and non-residential structures to provide greater thermal efficiency
▪ Provide redundant power sources
▪ Get air conditioning installed
▪ Plant appropriate trees near home and power lines (“Right tree, right place” National Arbor Day Foundation Program)
Build local capacity:
▪ Promote 72-hour self-sufficiency
▪ Obtain a NOAA weather radio</td>
<td>Manipulate the hazard:
▪ Plant trees in urban areas experiencing urban heat island effects or with below average tree canopy coverage
▪ Remove concrete and other hard surfaces and replace them with native vegetation
Reduce exposure and vulnerability:
▪ Relocate critical infrastructure (such as power lines) underground
▪ Reinforce or relocate critical infrastructure such as power lines meet resiliency expectations against all-hazard impacts
▪ Install tree wire
▪ Provide cooling centers for employees
▪ Install “cool roofs” and “green roofs.”
Build local capacity:
▪ Create redundancy in power supply
▪ Equip facilities with a NOAA weather radio</td>
<td>Manipulate the hazard:
▪ Plant trees in urban areas experiencing urban heat island effects or with below average tree canopy coverage
▪ Remove concrete and other hard surfaces and replace them with native vegetation
Reduce exposure and vulnerability:
▪ Harden infrastructure such as locating utilities underground
▪ Trim trees back from power lines
▪ Install “cool roofs,” “green roofs,” and other green infrastructure
▪ Use the best available technology to enhance the warning systems for all severe weather events
Build local capacity:
▪ Increase communication alternatives
▪ Enhance public awareness campaigns to address actions to take during extreme heat events
▪ Coordinate severe weather warning capabilities and the dissemination of warning among agencies with the highest degree of capability
▪ Modify land use and environmental regulations to support vegetation management activities that improve reliability in utility corridors
▪ Modify landscape and other ordinances to encourage appropriate planting near overhead power, cable, and phone lines
▪ Provide NOAA weather radios to the public
▪ Review and update heat response plan in light of climate change projections
▪ Promote programs that support community-scale microgrids
▪ Evaluate and revise, as needed, building codes to address and mitigate extreme heat impacts on residents</td>
</tr>
</table>

Community-Scale	Organizational Scale	Government-Scale
▪ Obtain an emergency generator or community microgrid	▪ Equip vital facilities with emergency power sources	

Nature-based opportunities

- Green roofs can be up to 40 °F cooler than typical roofs and reduce community temperatures by up to 5 °F. They can reduce building air conditioning costs by up to 75 percent. Green roofs provide benefits up to $14 more per square foot than traditional roofs
- Tree can lower surface temperatures by providing shade and through evapotranspiration, which can reduce peak local summer temperatures by 2 °F to 9° F. Shady areas can be between 20 °F and 45 °F cooler than sunny areas, providing safe resting places outside. A study found cities see benefits equivalent to $1.50 to $3 for every $1 invested in tree planting
- The Planting of native plants—including along parking lots, streets, and in yards—can provide cooling effects. Vertical gardens, also referred to as green or living walls, involve planting on walls to provide shade for buildings. This helps to cool the building and surrounding area
- Any solutions that convert built environments to natural environments such as forests, wetlands, and vegetation can aid in lowering temperatures. Natural environments and green vegetation provide more shade, moisture, and evaporation than built environments, all of which help reduce temperatures. These systems sequester carbon, helping to minimize future warming

Extreme Cold or Freeze

Climate Impacts:
More frequent and intense events
Equity Impacts:
30.4% of exposed population (all persons in the State are exposed) identified as living in equity priority communities
State Facilities Exposed:
All facilities exposed
Community Lifelines Exposed:
All lifelines exposed

Impact Rating: High (39)

8. EXTREME COLD OR FREEZE

Extreme cold or freeze has been identified as a high-impact natural hazard of interest based on the hazard impact rating protocol applied for this SHMP. Extreme cold events happen frequently in the State and all State-owned or -leased facilities and community lifelines are exposed to this hazard, although the damage caused would be limited. While some portions of the State may get colder than others, all populations in the State could experience extreme cold or freeze events relative to their area. These events are likely to impact equity priority communities more than the general populations due to many factors. Exposure to extreme cold or freeze events could increase if all buildable lands are developed, but the vulnerability of that exposure is considered low because it would be new development subject to codes and standards. The frequency and severity of extreme cold or freeze events is anticipated to increase over the next 30 years due to the impacts from climate change.

8.1. HAZARD OVERVIEW

Extreme cold events are when temperatures drop well below the temperatures that are normal in an area. Depending on what is normal, this may mean temperatures around the freezing point (32 °F) or below 0 °F. Freeze events are when temperatures remain below freezing for a sustained period.

The impact of extreme cold and freezing temperatures on people is generally measured through the wind chill temperature index. The wind chill temperature is the temperature that people feel when outside. It is based on the rate of heat loss from exposed skin due to the effects of wind and cold. As the wind increases, the body is cooled at a faster rate, causing the skin's temperature to drop. The wind chill temperature index includes a frostbite indicator, showing the temperature, wind speed, and exposure time that will produce frostbite to humans, as shown on Figure 8-1 (NWS 2022b).

Figure 8-1. NWS Wind Chill Index

Wind (mph)	Temperature (°F)																	
Calm	40	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45
5	36	31	25	19	13	7	1	-5	-11	-16	-22	-28	-34	-40	-46	-52	-57	-63
10	34	27	21	15	9	3	-4	-10	-16	-22	-28	-35	-41	-47	-53	-59	-66	-72
15	32	25	19	13	6	0	-7	-13	-19	-26	-32	-39	-45	-51	-58	-64	-71	-77
20	30	24	17	11	4	-2	-9	-15	-22	-29	-35	-42	-48	-55	-61	-68	-74	-81
25	29	23	16	9	3	-4	-11	-17	-24	-31	-37	-44	-51	-58	-64	-71	-78	-84
30	28	22	15	8	1	-5	-12	-19	-26	-33	-39	-46	-53	-60	-67	-73	-80	-87
35	28	21	14	7	0	-7	-14	-21	-27	-34	-41	-48	-55	-62	-69	-76	-82	-89
40	27	20	13	6	-1	-8	-15	-22	-29	-36	-43	-50	-57	-64	-71	-78	-84	-91
45	26	19	12	5	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-79	-86	-93
50	26	19	12	4	-3	-10	-17	-24	-31	-38	-45	-52	-60	-67	-74	-81	-88	-95
55	25	18	11	4	-3	-11	-18	-25	-32	-39	-46	-54	-61	-68	-75	-82	-89	-97
60	25	17	10	3	-4	-11	-19	-26	-33	-40	-48	-55	-62	-69	-76	-84	-91	-98

Frostbite Times: 30 minutes, 10 minutes, 5 minutes

Source: (NWS 2021a)

8.2. HAZARD LOCATION

The entire State is at risk for extreme cold and freeze events. California has a diversity of climates, and statewide provisions to the California Energy Code account for these variations using a set of 16 climate zones (CEC n.d.-a). Much of the impact of this hazard will be seen in the central and northern portions of the State, though areas in Southern California can also experience extreme cold events.

Extreme cold temperature events are typically isolated to more mountainous communities. Bodie State Park in Mono County is considered the coldest place in California (Bartell 2019).

8.3. PREVIOUS HAZARD OCCURRENCES

Many sources provided historical information regarding previous occurrences and losses associated with extreme temperatures throughout the State of California; therefore, the loss and impact information for many events could vary depending on the source. The accuracy of monetary figures discussed is based only on the available information in cited sources.

8.3.1. Disaster and Emergency Declarations

The following disaster declarations or emergency proclamations related to extreme cold, or freeze have been issued for California (see Appendix F for details):

- Federal DR or EM declaration, 1953 – 2022: 3 events, classified as "severe freeze" or "citrus crop damage"
- California Emergency Proclamations, 1950 – 2022: 9 events, classified as "freeze"
- USDA agricultural disaster declarations, 2012 – 2022: 1 event

8.3.2. Event History

Most extreme cold and freeze events in California take place in the winter, primarily between December and February. According to the NOAA National Centers for Environmental Information Storm Events Database, there have been over 500 extreme cold and freeze events in the State since 2000, most of them occurring between November and March. Refer to Appendix K for the history of cold/freeze events since 1969.

The 2018 SHMP discussed cold/freeze events that occurred in the State from 1969 to 2017. An additional event since then occurred February 20 – 21, 2018, in the San Joaquin Valley, which experienced its coldest morning in several years at many locations. Many weather stations reported several hours of subfreezing temperatures. Numerous crops experienced significant damage from the cold. The snap pea crop was nearly wiped out and the almond crop was also hit hard. Damage to citrus was mitigated by the fact that much of the crop had already been harvested. About $150 million in crop damage resulted.

8.4. PROBABILITY OF FUTURE HAZARD EVENTS

8.4.1. Overall Probability

California's 1,373 recorded extreme cold/freeze events between 1953 and 2022 represent an average of almost 20 events per year. The State expects to continue experiencing a similar number of extreme cold/freeze events each year.

8.4.2. Climate Change Impacts

When comparing average annual temperatures from 1901–1960 to those of 1986 – 2016, most of California has experienced increases exceeding 1°F, with some areas exceeding 2°F (OPR 2022). This general warming trend has the potential to reduce the occurrence and range of anticipated intensities of extreme cold or freeze events in the future.

8.5. IMPACT ANALYSIS

Extreme cold and freeze events can have significant impacts on the State. This includes loss of life, illnesses, and economic costs in transportation, agriculture, energy, and infrastructure. The State faces the following risks associated with extreme cold or freeze events, which can last several days (Rand 2018):

- Extremely cold temperatures often accompany winter weather. which can cause power failures and icy roads.
- People may have inadequate heat in their homes because of a power failure, because of an inadequate heating system or no heating system at all, or because the household cannot afford to operate the heating system.
- The use of space heaters and fireplaces to keep warm increases the risk of household fires and carbon monoxide poisoning.
- Sustained temperatures below freezing can cause life loss and health risks to vulnerable populations in areas where such temperatures are not common.
- Freezing temperatures occurring during winter and spring growing seasons can cause extensive crop damage.

8.5.1. Severity

The coldest temperature on record in California is –45 °F, recorded January 20, 1937, in the community of Boca in Nevada County (Western Regional Climate Center n.d.) Bodie State Park in Mono County is considered the coldest place in California overall. During the 2018 – 2019 winter, the average observed temperature in the park was -7 °F (Bartell 2019).

8.5.2. Warning Time

Meteorologists can accurately forecast the timing and severity of extreme temperature events with several days' lead time. These forecasts provide an opportunity for public health and other officials to notify vulnerable populations.

Currently, the only way to headline very cold temperatures is with the use of the NWS-designated Wind Chill Advisory or Warning products. When actual temperatures reach Wind Chill Warning criteria with little to no wind, extreme cold warnings may be issued (NWS 2021a).

8.5.3. Cascading Impacts

Cascading impacts are the impacts that result when one type of hazard event triggers one or more other hazard events, which may in turn trigger still others. The following are notable cascading impacts associated with extreme cold or freeze events:

- Cold temperatures can freeze pipes, causing them to burst and create water leaks and water supply issues. Infrastructure such as roads and utilities are at risk to freezing temperatures, causing failures and hazardous road conditions (OTS 2022) (Center for Disaster Philanthropy 2022).
- Exposure to cold temperatures can cause hypothermia and frostbite. Infants and older adults are particularly at risk, but anyone can be affected (CDC 2005). Slip and fall risk increases during extreme cold events (BLS 2016). Carbon monoxide exposures and poisonings occur more often during fall and winter when people are using gas furnaces and heaters (CDC 2008).

8.5.4. Environmental Impacts

Freezing and warming weather patterns create changes in natural processes. An excess amount of snowfall followed by early warming periods may affect natural processes such as flow of water resources.

8.5.5. Local Hazard Impacts

LHMP Rankings

County hazard mitigation plans often identify “severe weather” as a hazard of concern without separating hot or cold temperatures from each other or from other weather types. Of the 58 counties in California, 54 assessed severe weather as a hazard of concern in their hazard mitigation plans: 17 specified extreme temperature (hot or cold). None ranked extreme temperature as high risk; 13 ranked it as medium risk, and 4 ranked it as low risk. The following counties listed extreme temperature as a medium-risk hazard:

- Amador
- Butte
- Calaveras
- El Dorado
- Fresno
- Lake
- Madera
- Modoc
- Mono
- Monterey
- Nevada
- Placer
- San Benito
- Tulare

LHMP Estimates of Potential Loss

A review of the LHMPs in the counties (as called for in FEMA’s Standard State Mitigation Planning Requirement S6.b) found no quantitative risk analysis that identifies population or structures exposed to this hazard. This can be attributed to the lack of extent and location hazard mapping to use for such an analysis. Therefore, no summary of risk for local plan reviews is provided for this hazard.

8.6. VULNERABILITY ANALYSIS

8.6.1. Exposure of State-Owned or -Leased Facilities, Critical Facilities, and Community Lifelines

All State-owned or -leased assets, as listed in Table 4-1 and Table 4-2, are exposed to extreme cold or freeze. This includes 23,961 State-owned facilities, and 1,893 State-leased facilities. All 755 State critical facilities and community lifelines, as listed in Table 4-3, are exposed to this hazard as well.

Functional downtime associated with power interruption is the most significant impact on critical facilities and community lifelines from extreme cold or freeze events. The level of impact depends on the amount of time it takes to restore power to operational status at impacted facilities. Water supply infrastructure (pipes, pumps, and wells) can also be subject to impacts from freezing if they are shallow subsurface elevations or not protected from the elements.

8.6.2. Estimates of Loss

State assets could be damaged by extreme cold or freeze events, but there are no standard generic formulas for estimating associated losses. Instead, loss estimates were developed representing 10 percent, 30 percent, and 50 percent of the replacement cost value of all State-owned facilities (see Table 8-1). This allows the State to select a range of potential economic impacts based on an estimate of the percentage of damage. Damage in excess of 50 percent is considered to be substantial by most building codes and typically requires total reconstruction of the structure.

Table 8-1. Loss Potential of State-Owned Assets for Extreme Cold or Freeze

Type of Facility	Total Replacement Cost Value (contents only)	Estimated Loss Potential Based on % Damage		
		10% Damage	30% Damage	50% Damage
Facilities Housing Vulnerable Populations				
Correctional Facility	$5,673,743,477	$567,374,348	$1,702,123,043	$2,836,871,738
Development Center	$696,669,418	$69,666,942	$209,000,825	$348,334,709
Hospital	$837,461,197	$83,746,120	$251,238,359	$418,730,598
Migrant Center	$996,980,976	$99,698,098	$299,094,293	$498,490,488
Special School	$128,610,363	$12,861,036	$38,583,109	$64,305,182
All Other Facilities	**$28,392,185,985**	**$2,839,218,598**	**$8,517,655,796**	**$14,196,092,992**
Total	**$36,725,651,416**	**$3,672,565,142**	**$11,017,695,425**	**$18,362,825,708**

8.6.3. Buildable Land

An estimated 11.7 million acres of land is available for development in California. Because the entire State is vulnerable to extreme cold or freeze, any type of development of any of this land will be susceptible to damage and impacts from this hazard.

8.6.4. Equity Priority Communities

Because the entire population of the State of California is exposed and vulnerable to extreme cold or freezing, the exposed population in equity priority communities is equal to the statewide percentage: 30.4 percent of the total population (12 million people). Cold temperatures most immediately impact populations who lack the resources to access a warm environment during the cold weather event.

8.6.5. NRI Scores

According to the NRI, six of the State's counties have cold wave risk, rated from very low to relatively moderate. Table 8-2 shows scores for these six counties. See Section 4.1.3 for a description of the components of the NRI.

Table 8-2. NRI Scoring of Counties for Cold Wave

County	Expected Annual Loss	Social Vulnerability Rating	Community Resilience Rating	Community Risk Factor	Risk Value	Score
Modoc	$98,176	Relatively High	Relatively Low	1.35	$133,771	60.48
Siskiyou	$58,958	Relatively High	Relatively Moderate	1.39	$92,996	55.2
Shasta	$0	Relatively High	Relatively Moderate	1.26	$0	27.65
Lassen	$0	Relatively High	Relatively Moderate	1.14	$0	27.46
Mono	$0	Relatively Moderate	Relatively High	1.17	$0	27.33
Inyo	$0	Relatively Moderate	Relatively Low	1.31	$0	26.92

8.7. MITIGATING THE HAZARD

8.7.1. Opportunities for Mitigating the Hazard

Table 8-3 provides a range of potential alternatives for mitigating the extreme cold and freeze hazard. See Section 1.2.3 for a description of the different types of alternatives.

Table 8-3. Potential Opportunities to Mitigate the Extreme Cold or Freeze Hazard

<table>
<tr><th>Community-Scale</th><th>Organizational Scale</th><th>Government-Scale</th></tr>
<tr>
<td>Manipulate the hazard:
None
Reduce exposure and vulnerability:
Insulate residential and non-residential structures to provide greater thermal efficiency and reduce heat loss
Provide redundant heat and power
Ensure natural gas input/release valves do not get covered in snow and ice, leading to freezing
Build local capacity:
Prepare emergency food and supplies to be self-sufficient for at least 72 hours in the event of severe winter weather
Obtain an emergency generator</td>
<td>Manipulate the hazard:
None
Reduce exposure and vulnerability:
Relocate critical infrastructure (such as power lines) underground
Reinforce or relocate critical infrastructure such as power lines to meet performance expectations
Provide warming centers for employees
Build local capacity:
Create redundancy
Equip facilities with a NOAA weather radio
Equip vital facilities with emergency power sources</td>
<td>Manipulate the hazard:
None
Reduce exposure and vulnerability:
Harden infrastructure such as locating utilities underground
Provide backup power sources at vital critical facilities
Establish warming centers
Build local capacity:
Enhance public awareness. campaigns to address issues of warnings and actions to take during extreme cold events
Use the best available technology to enhance the warning systems for all severe weather events
Coordinate severe weather warning capabilities and the dissemination of warning amongst agencies with the highest degree of capability
Provide NOAA weather radios to the public
Retrofit above-ground utilities to underground facilities if appropriate
Create a salt reserve or research alternates to stretch salt reserve
Evaluate and revise, as needed, building codes to address and mitigate extreme cold and freeze impacts on residents</td>
</tr>
<tr><td colspan="3">Nature-based opportunities
Where available, take advantage of geothermal resources for heating assets subject to extreme cold or freeze.</td></tr>
</table>

8.7.2. Selected Actions to Mitigate the Hazard

The mitigation strategy developed for this SHMP includes the following actions that address the extreme cold/freeze hazard:

- Action 2023-006: Prohousing Designation Program: Promote the Program to encourage cities and counties to apply for this designation to receive points or preference in competitive housing, community development, and infrastructure programs.
- Action 2018-006: Enhance Collaboration on the Development and Sharing of Data Systems and geographic information systems (GIS) modeling.
- Action 2018-008: Develop a database containing a description of the specific natural hazard event for which each project was designed to mitigate.

WILDFIRE

Climate Impacts:

If GHG emissions continue to rise, California is likely to see a 50% increase in fires larger than 25,000 acres as well as a 77% increase in average area burned by 2100

Equity Impacts:

7% of exposed population (those living in high and very high fire hazard severity zones) identified as living in equity priority communities

State Facilities Exposed:

5,038 State facilities in high and very high fire hazard severity zones; $1.9 billion in total replacement cost values for facilities in high and very high fire hazard severity zones

Community Lifelines Exposed:

71 community lifelines in high and very high fire hazard severity zones

Impact Rating: High (36)

9. WILDFIRE

Wildfire has been identified as a high-impact natural hazard of interest based on the hazard impact rating protocol applied for this SHMP. Wildfires happen frequently in the State. About 21 percent of State-owned or -leased facilities and 10 percent of community lifelines are exposed to this hazard. Approximately 9 percent of the State's population is exposed this hazard, and over 7 percent of that population has been identified as living in equity priority communities. Over 45 percent of identified buildable lands in the State intersect identified high fire severity zones. The frequency and severity of wildfire is anticipated to increase over the next 30 years due to the impacts of climate change.

9.1. HAZARD OVERVIEW

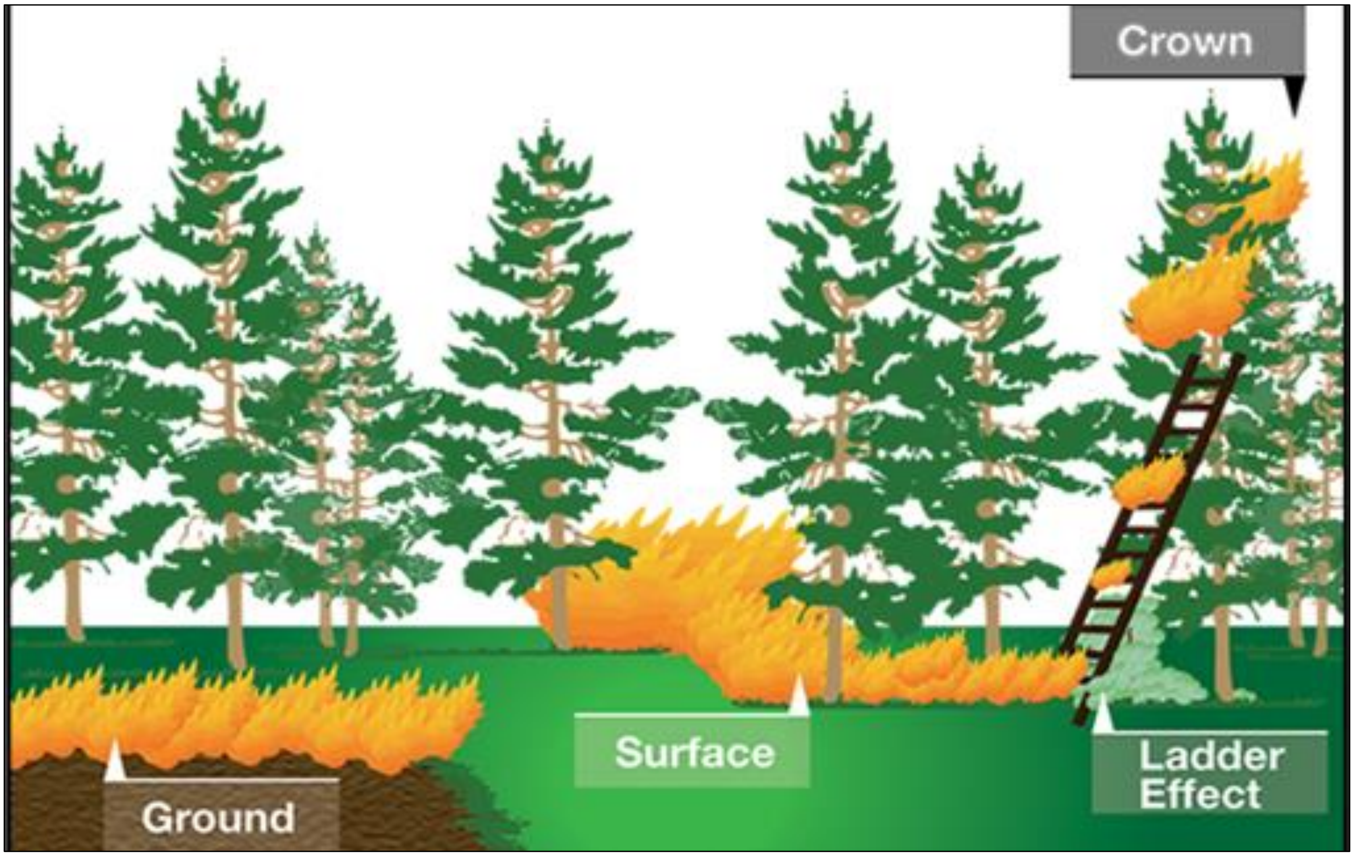
Wildfire has been among the three greatest sources of hazard to California. With the catastrophic wildfire events from 2017 through 2022, fire has emerged as an annual threat roughly comparable to floods and surpassed in risk level only by earthquakes, which occur less frequently but can be more destructive. The final impact rating for wildfire in this Plan differs from the initial estimate determined through the risk ranking. However, both rate wildfire in California as "high."

In California, wildfire is common due to the combination of complex terrain, Mediterranean climate that annually facilitates several month-long rain-free periods, productive natural plant communities that provide ample fuels, and ample natural and anthropogenic ignition sources (UC n.d.). The State has an extensive history of severe wildfire events and faces the probability of future events that are even more destructive than those of the past. Wildfires are the most frequent source of declared disasters and account for the third highest combined losses of natural hazards in the State.

9.1.1. General Wildfire Types

Flammable expanses of brush, diseased timberland, overstocked forests, hot and dry summers, extreme topography, intense fire weather wind events, summer lightning storms, and human acts all contribute to California's wildfire threat. Wildfires can generally be classified as follows (see Figure 9-1):

Figure 9-1. Types of Wildfires



Source: (Haygot Technologies 2020)

- Ground fires occur when fuels ignite and burn underground. Ground fires may eventually burn through the ground surface and become surface fires.
- Surface fires burn on the surface of the ground and are primarily fueled by low-lying vegetation.
- Ladder fuels are vegetation that allow surface fires to climb into the tree canopy and become crown fires (National Wildfire Coordinating Group 2021).
- Crown fires spread from treetop to treetop spread at a rapid pace. Crown fires are often pushed by wind and can be extremely intense (De La Torre 2021).

What is a Wildfire?

In general, the following characteristics define a wildfire:

- A free-burning (unplanned) vegetative fire
- Started by an unplanned ignition that may be either natural (e.g., lightning) or human-caused (e.g., power lines, mechanical equipment, discarded cigarettes, escaped prescribed fires, or intentionally set fires)
- With a management objective of full suppression.

Source: (National Wildfire Coordinating Group 2021)

9.1.2. Factors Affecting Fire Behavior

Fire behavior is based on factors such as the following (CAL FIRE 2021):

- **Fuel**—Fuel may include living and dead vegetation on the ground, along the surface as brush and small trees, and above the ground in tree canopies. Lighter fuels such as *Arundo donax* and other grasses, leaves, and needles quickly expel moisture and burn rapidly, while heavier fuels such as tree branches, logs, and trunks take longer to warm and ignite. Trees killed or defoliated by forest insects and diseases are more susceptible to wildfire.
- **Weather**—Relevant weather conditions include temperature, relative humidity, wind speed and direction, cloud cover, precipitation amount and duration, and the stability of the atmosphere. Conditions are very favorable for extensive and severe wildfires when the temperature is high, relative humidity is low, wind speed is increasing and coming from the east (offshore flow), and there has been little or no precipitation, so vegetation is dry. These conditions occur more frequently inland where temperatures are higher, and fog is less prevalent.
- **Terrain**—The slope and elevation of a region influences the amount and moisture of fuel; the impact of weather conditions such as temperature and wind; potential barriers to fire spread, such as highways and lakes; and elevation and slope of landforms (fire spreads more easily uphill than downhill).

9.1.3. Wildland Fire vs. Wildland Urban Interface Fires

Fire science distinguishes between wildland fires, which burn predominately in undeveloped areas, and wildland urban Interface (WUI) fires (USFS 2019). Mitigation actions, response actions and damage associated with the two types of fire may differ significantly (McCaffrey, et al. 2020).

Wildland Fires

Wildland fires that burn in undeveloped settings are part of a natural fire regime and may be beneficial to the landscape if they burn within the historical range of variability for fire size and intensity. Many species are adapted to California's natural fire regimes and flourish after a low or mixed severity burn. These fires also enhance ecosystem function by creating landscapes that have more variation, are more resilient to other disturbances, and are better suited to withstand extremes in precipitation (UC 2017). However, wildland fires still pose a threat and can have catastrophic impacts on wildlife and habitat.

A wildland fire may result in secondary negative impacts in the form of air pollution, including GHG emissions, soil erosion (resulting in siltation of streams and lakes), post-fire flooding, or mudslides. The impacts can even extend beyond State borders. In 2020, wildfire smoke not only blanketed large swaths of California, but also worsened air quality across the United States (Saldanha, et al. 2021).

Unless wildland fires or their related cascading hazards occur in or near developed areas, they are rarely classified as disasters because they do not pose severe risk to life or widescale damage to the environment. Wildland fires that burn primarily on federally managed lands are only rarely classified as disasters. For example, the 2007 Zaca Fire (240,207 acres) and 2009 Station Fire (160,577 acres), both of which burned on U.S. Forest Service lands, were enormous in size but did not result in federal disaster status. Those fires stand in contrast to the October 2017 Northern California Wildfires, which were smaller in area but much more destructive, due to their proximity to larger urbanized areas.

WUI Fires

The WUI has been defined as "the area or zone where structures and other human development meet or intermingle with undeveloped wildland or vegetative fuels" (U.S. Fire Administration 2022a). The WUI can be configured in many ways including a classic "interface" (e.g., a community that abuts a National Forest at a distinct boundary), an "intermix" (e.g., vegetative fuels distributed between buildings throughout a subdivision between buildings), or an "occlusion" (e.g., a community that completely surrounds a designated open space area) (Federal Register 2001). The combination of natural and human-made fuels that are burned in WUI fires may lead to the formation or release of toxic emissions not found in purely wildland fires (Committee on the Chemistry of Urban Wildfires 2022).

WUI fires represent an increasingly significant concern for California. California has a chronic and destructive WUI fire history with significant losses of life, structures, infrastructure, agriculture, and businesses (USFS 2019). Most local governments that have prepared LHMPs have identified fire and WUI fires as specific hazards. Even relatively small WUI fires may result in disastrous damage (Li and Banerjee 2021).

Most WUI fires are suppressed before they exceed 100 acres (Li and Banerjee 2021). The remainder usually occur during episodes of hot, windy conditions that exceed initial attack capabilities and are more likely to cause heightened losses to the built environment. Many WUI fires occur in areas that have a historical pattern of wildland fires that burn under extreme conditions. The pattern of increased damage is directly related to increased urban spread into areas that have historically had wildfire as part of the natural ecosystem (Doumar 2018).

California has a strong statewide approach toward WUI planning and regulatory requirements, including minimum WUI building code requirements, Fire Safe regulations, and State land use planning guidance from the California Governor's Office of Planning and Research (OPR) (Community Wildfire Planning Center 2021).

9.1.4. The Role of Wildfire in Broader Ecosystems

Fire is a natural part of California's diverse landscapes and is vital to many ecosystems across the State. For centuries, many California Native American Tribal Nations recognized the interdependence between fire, communities, culture, and the environment and used prescribed burning—the intentional ignition of small, low-intensity fires—to maintain and restore environmental health and promote resilience against catastrophic wildfires (Cal OES 2018b).

While wildfires can lead to benefits to an ecosystem if within the range of natural variability for a given geographical area, they can also lead to harmful effects to the natural and built environment (CAL FIRE n.d.-a).

Research into the century-old policies of fire exclusion and suppression has provided better understanding of the importance of fire in the natural cycle of some ecotypes, particularly mixed-conifer forests (National Park Service 2015). As a result, prescribed fires have been used more extensively as a land management tool to replicate natural fire cycles. Unfortunately, a century of fire exclusion has led to a significant buildup of fuels in many mixed-conifer forests, which historically experienced frequent, low-intensity surface fires. Thus, there are significant areas where prescribed fires, in conjunction with mechanical thinning, may be appropriate to restore more natural forest conditions (California Wildfire & Forest Resilience Task Force 2022).

9.1.5. Firefighting Responsibility in California

Across California, many agents provide firefighting functions. There are three land classifications to identify the agency with primary financial responsibility for preventing and suppressing wildfire at any given location in the State:

- Local Responsibility Area is primarily the responsibility of the local jurisdiction (local fire departments and districts)
- State Responsibility Area is primarily the responsibility of the State (CAL FIRE).
- Federal Responsibility Area is primarily the responsibility of a federal government agency (U.S. Forest Service, Bureau of Land Management, etc.)

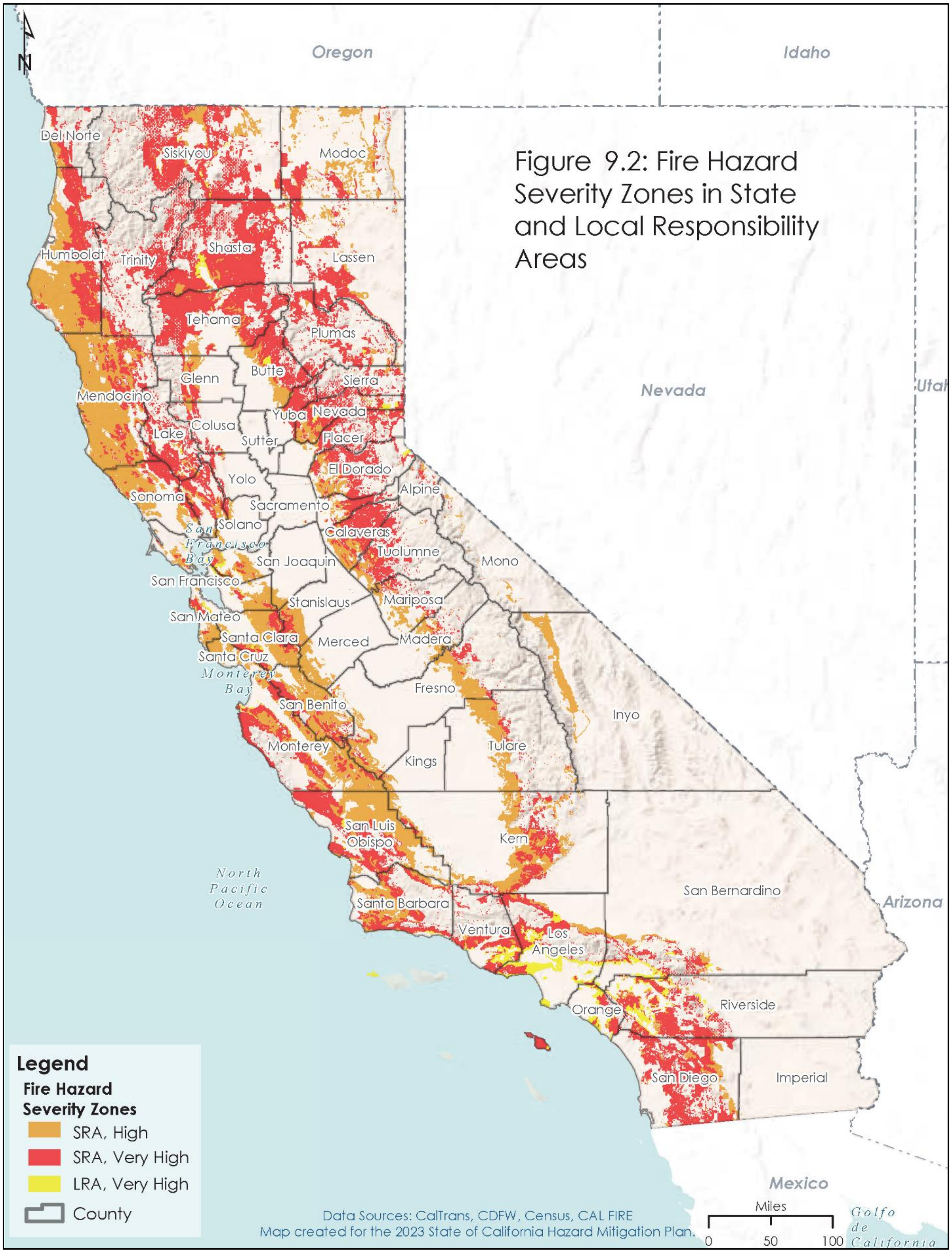
9.2. HAZARD LOCATION

Every county in California is susceptible to wildfire. Fuel-dominated wildfires are common in the timber-rich forests of the Sierra Nevada Mountain Range that contain large fuel loads due to successful fire suppression and timber harvesting. Counties west of the Sierra Nevada Mountains are more susceptible to wind-dominated wildfires. In the northern part of the State, north winds drive wildfires, while Santa Ana Winds drive wildfires in southern California (Keeley and Syphard 2019). The most common extreme fire behavior factor is high, dry, warm winds, such as Santa Ana or Diablo winds, which occur in a predictable location and seasonable pattern (Ekwurzel 2018).

9.2.1. Fire Hazard Severity Zone Mapping

CAL FIRE has mapped wildfire hazard zones using a model that designates moderate, high, or very high Fire Hazard Severity Zones (FHSZ), based on how a fire would behave in an area and the probability of flames and embers threatening buildings. For wildland areas, the FHSZ model uses burn probability and fire behavior based on weather, fuel, and terrain. For urban areas, hazard levels are based on vegetation density, distance from wildlands, and the levels assigned to surrounding zones. Each area gets a score for flame length, embers, and the likelihood of burning. Scores of smaller areas are averaged over larger zones that encompass them. Figure 9-2 shows the moderate, high, and very high FHSZs for State and local responsibility areas.

Figure 9-2. Fire Hazard Severity Zones in State and Local Responsibility Areas

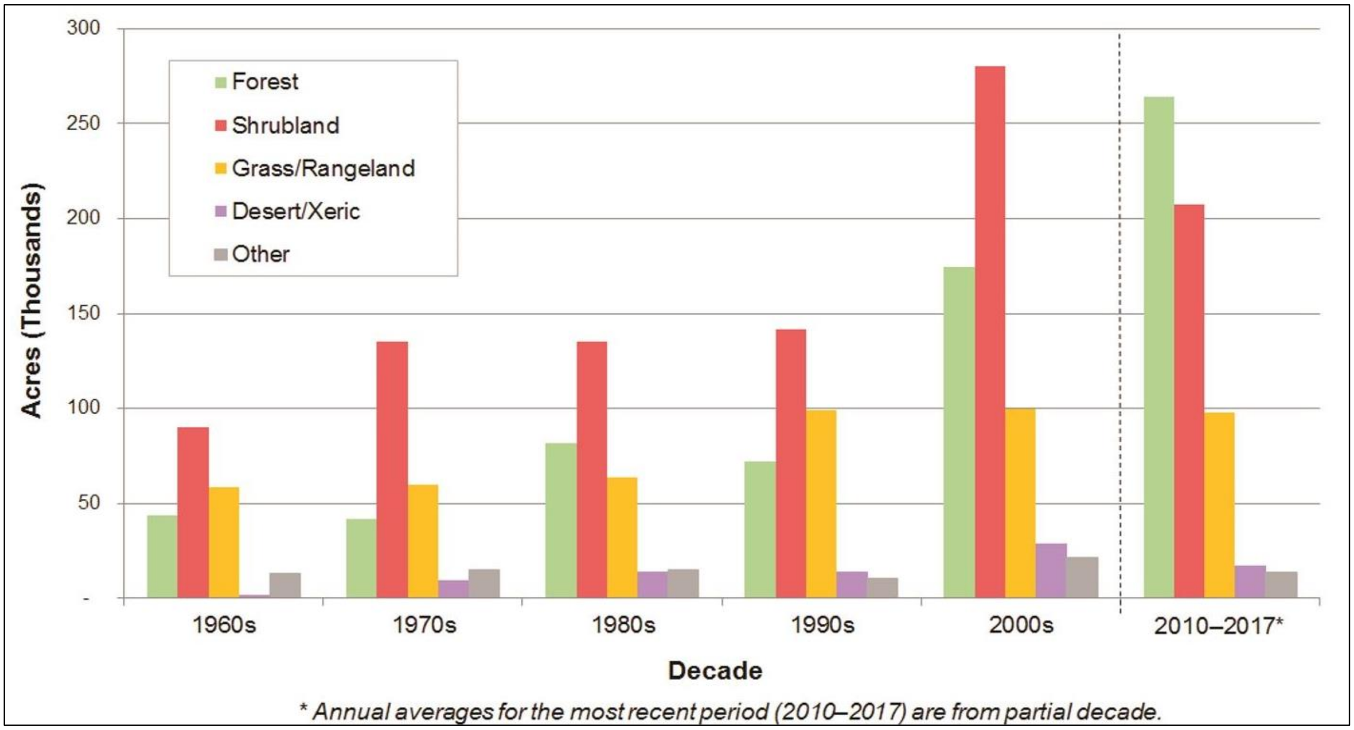


FHSZ ratings are derived from a combination of fire frequency (how often an area burns) and expected fire behavior under severe weather conditions. CAL FIRE's model derives fire frequency from 50 years of fire history data. It also is based on frequency of fire weather, ignition patterns, and expected rate-of spread. It accounts for flying ember production, which is the principal driver of the wildfire hazard in densely developed areas. A related concern in built-out areas is the relative density of vegetative fuels that can start new fires and spread to adjacent structures. The model refines the zones to account for fire exposure mechanisms that cause ignitions to structures. Significant land-use changes are accounted for through periodic model updates.

9.2.2. Historical Fire Locations

Figure 9-3 shows that shrublands have historically experienced the greatest number of acres burned in California. Shrublands are commonly found near higher urban populations, resulting in an increased number of human ignitions. Coniferous forests are burning in larger acreages in recent decades, which may be due to increased fuel loading, or build-up of burnable debris, or "fuel," in a general area.

Figure 9-3. Annual Acres Burned by Vegetation Type and Decade, 1960-2017



Source: (CAL FIRE 2017)

Figure 9-4 shows fire frequency from 1950 to 2017 across the State, based on datasets prepared by CAL FIRE. Historic fire perimeters indicate a pattern that many wildfires occur in the foothills of the coastal and interior mountain ranges, especially in mountainous regions near populated areas of Southern California. The 2018 Camp Fire burned 18,804 structures, making it the most destructive wildfire in California history (CAL FIRE 2022b). The 2020 August Complex fire burned 1,032,648 acres, making it the largest wildfire in the State's history (CAL FIRE 2022b).

An analysis of repeat fires in a given area, as shown in Figure 9-5, illustrates that some areas in California are prone to burn with greater regularity than other areas. This is of special concern in the South and Central Coast regions, which show the highest frequencies. These regions have significant amounts of shrubland plant communities where wildfires typically occur as high-intensity, stand-replacement fires.

9.2.3. Areas Susceptible to WUI Fires

Wildfire vulnerability in California is found chiefly in WUI communities, located largely on the periphery of suburban areas in Southern California, coastal mountains, and heavily wooded areas of Northern California and the Sierra Nevada. Some areas burn frequently, particularly the hills surrounding Los Angeles, San Diego, and Big Sur, as well as more isolated mountains in the Coast Ranges and Sierra Nevada.

As populations increase and communities continue to expand into the WUI throughout the State, more areas are expected to become vulnerable to wildfires. This is in part because human-caused wildfires are responsible for most of the wildfires in the WUI (Silvis Lab 2021). Figure 9-6, based on CAL FIRE's Fire and Resource Assessment Program, or FRAP, data, shows an increasing pattern of projected development encroaching into previously wildland area. The California State Forester manages a list of Communities at Risk, currently numbering 1,333 in all 58 counties (CAL FIRE 2022).

Figure 9-4. Fire Frequency (Number of Times Burned), 1950-2017

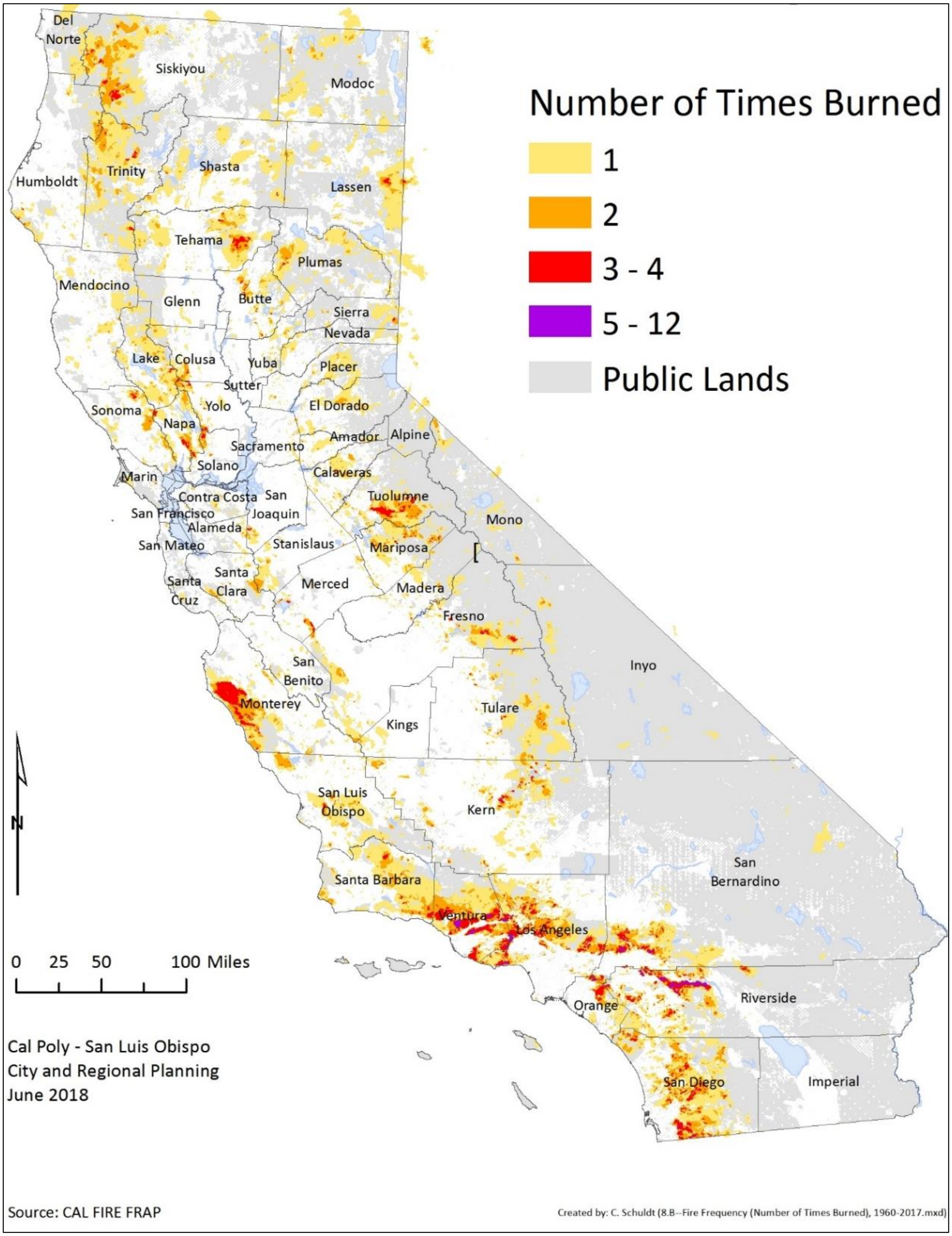


Figure 9-5. State and Federal Declared Fire Disasters, 1993 – Present

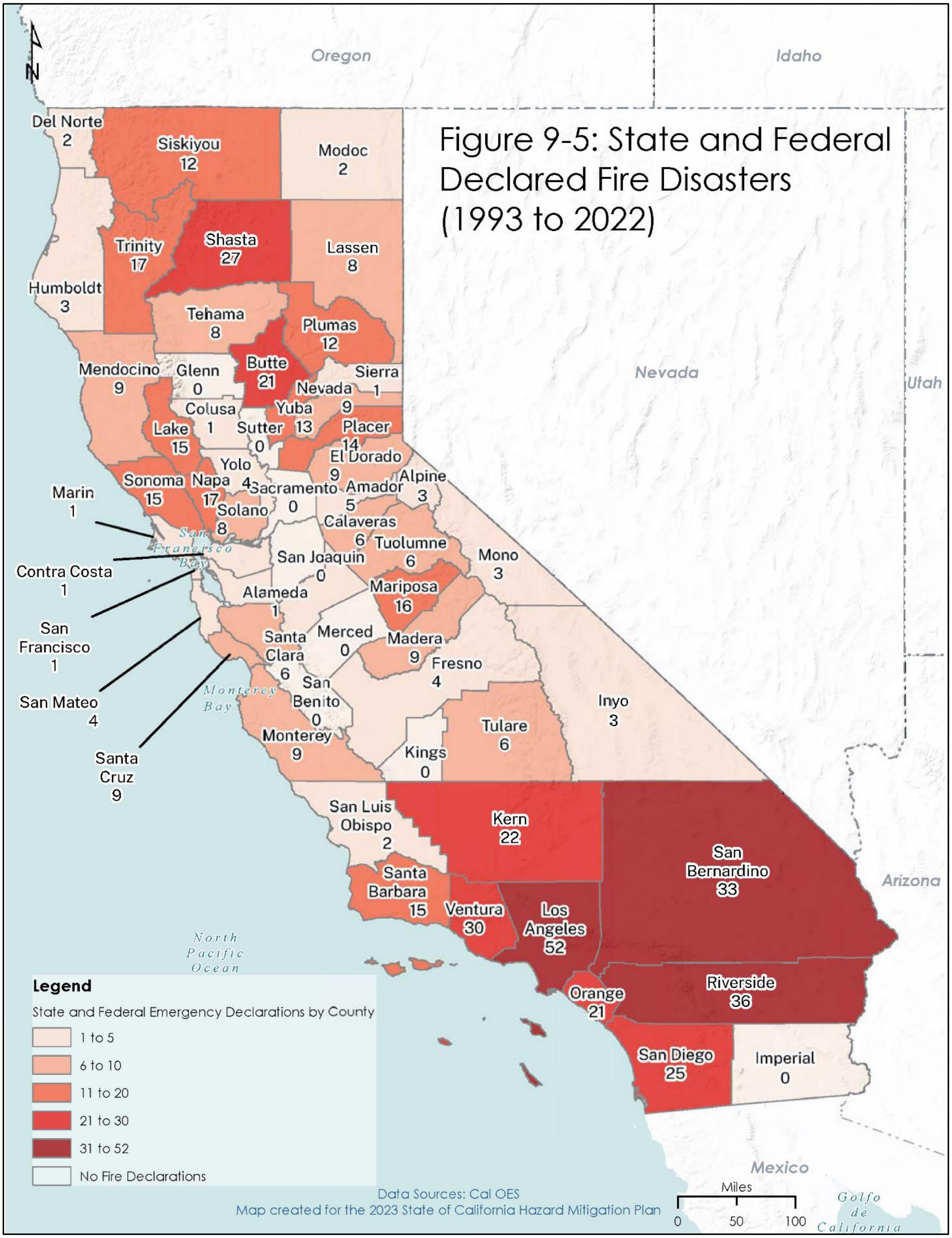
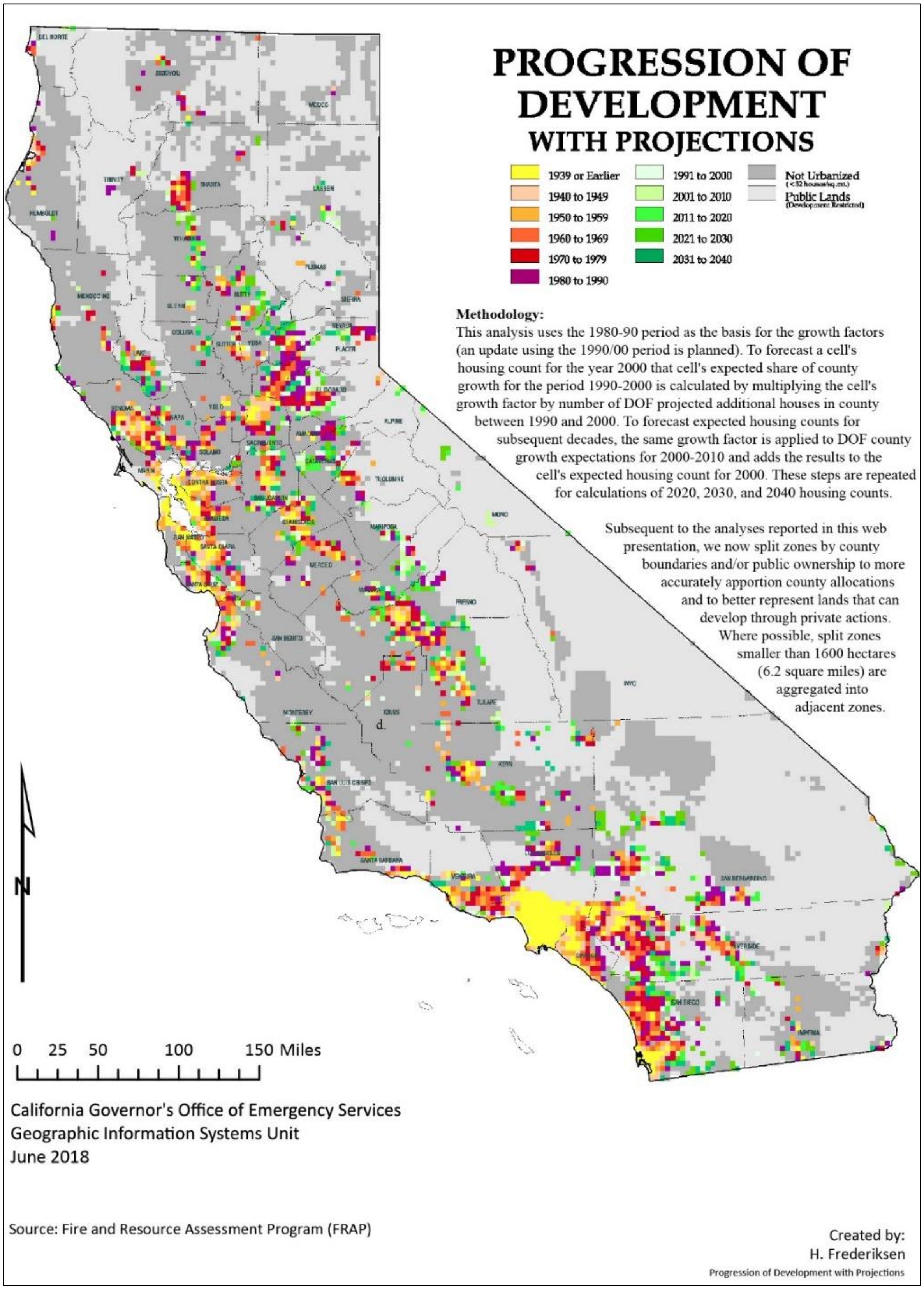


Figure 9-6. California's Projection of Development Based on Historical Factors



9.2.4. Northward Trend

Most FEMA wildfire declarations in California have covered Southern California—due to its large, exposed population base and annually occurring Santa Ana winds. However, there are growing concerns about wildfire in Northern California. These concerns have been substantiated by a series of catastrophically destructive fires between 2017 and 2021, including the following (CAL FIRE 2022d):

- 2017 Northern California fires in Sonoma, Napa, and Solano Counties
- 2018 Carr Fire in Shasta and Trinity Counties
- 2018 Mendocino Complex in Mendocino, Lake, Glenn, and Colusa Counties
- 2018 Camp Fire in Butte County; the 2020 North Complex in Butte, Plumas, and Yuba Counties
- 2020 LNU Lightning Complex in Napa, Solano, Sonoma, Yolo, Lake, and Colusa Counties
- 2020 CZU Lightning Complex in Santa Cruz and San Mateo Counties
- 2020 August Complex in Mendocino, Humboldt, Trinity, Tehama, Glenn, Lake, and Colusa Counties
- 2020 Glass Fire in Napa and Sonoma Counties
- 2021 Dixie Fire in Butte, Plumas, Lassen, and Tehama Counties
- 2021 Caldor Fire in Alpine, Amador, and El Dorado Counties

9.3. PREVIOUS HAZARD OCCURRENCES

California is susceptible to thousands of wildfires every year, impacting all 58 counties. In the past, fire season was mainly from May through October. With climate change as a contributing factor, fire season begins earlier and ends later each year; wildfires are now taking place year-round (Frontline 2022).

9.3.1. Disaster and Emergency Declarations

The following disaster declarations or emergency proclamations related to wildfire have been issued for California (see Appendix F for details):

- Federal DR, EM, Fire Management Assistance (FM), or Fire Suppression Authorization (FS) declarations, 1953 – 2022: 274 events, classified as forest fire, brush fire, timber fire, urban fire, grass fire, wildlands fire, fire storm or complex fire
- California Emergency Proclamations, 1950 – 2022: 134 events, classified as wildfire
- USDA agricultural disaster declarations, 2012 – 2022: 50 events

Of the 274 FEMA declarations for fire events between 1953 and 2022, 142 were issued since 2010. FEMA declaration of a wildfire event as a federal disaster is based on thresholds of monetary damage. Some wildfires, while significant in size and destruction of natural resources, may be in remote areas with minimal development and result in relatively low dollar value of losses to structures or infrastructure.

9.3.2. Event History

California has long been recognized as one of the most fire-prone natural landscapes in the world. Between 1987 and July 2022, California annually averaged 8,650 fires that burned 772,817 acres. The average number of fires per year has declined since 1987, but the number of acres burned annually is highly variable between years. In some years with drought and high winds larger single fires burn larger areas.

Twenty fires larger than 177,000 acres have burned in California since 1932. While modern fires still burn far fewer acres than in the past, in general, large, destructive wildfires are becoming common in California, even with increased firefighting personnel, equipment, technology, and training.

As shown in Table 9-1, 18 of the largest wildfires in California history have occurred since 2003, with 8 of them occurring within the last 5 years, including the largest ever recorded, the August Complex Fire which was ignited in August 2020 (CAL FIRE 2022d).

Table 9-1. Largest California Wildfires by Acres Burned

Fire Name (Cause)	Ignition Date	County	Number of Acres Burned*	Structures Destroyed	Deaths
August Complex (Lightning)	August 2020	Mendocino, Humboldt, Trinity, Tehama, Glenn, Lake, Colusa	1,032,648	935	1
Dixie (Powerlines)	July 2021	Butte, Plumas, Lassen, Shasta, Tehama	963,309	1,329	1
Mendocino Complex (Human Related)	July 2018	Mendocino, Lake, Colusa, Glenn	459,123	280	1
SCU Lightning Complex (Lightning)	August 2020	Stanislaus, Santa Clara, Alameda, Contra Costa, San Joaquin	396,624	222	0
Creek (Undetermined)	September 2020	Fresno, Madera	379,895	853	0
LNU Lightning Complex (Lightning/ Arson)	August 2020	Napa, Solano, Sonoma, Yolo, Lake, Colusa	363,220	1,491	6
North Complex (Lightning)	August 2020	Butte, Plumas, Yuba	318,935	2,352	15
Thomas (Powerlines)	December 2017	Ventura, Santa Barbara	281,893	1,063	2
Cedar (human related)	October 2003	San Diego	273,246	2,820	15
Rush (Lightning)	August 2012	Lassen	271,911	0	0
RIM (Human related)	August 2013	Tuolumne	257,314	112	0
Zaca (Human related)	July 2007	Santa Barbara	240,207	1	0
Carr Fire (Human related)	July 2018	Shasta, Trinity	229,651	1,614	8
Monument (Lightning)	July 2021	Trinity	223,124	50	0
Caldor (Human Related)	August 2021	Alpine, Amador, El Dorado	221,835	1,003	1
Matilija (Undetermined)	September 1932	Ventura	220,000	0	0
River Complex (Lightning)	July 2021	Siskiyou, Trinity	199,343	122	0
Witch (Powerlines)	October 2007	San Diego	197,990	1,650	2

Fire Name (Cause)	Ignition Date	County	Number of Acres Burned*	Structures Destroyed	Deaths
Klamath Theater Complex (Lightning)	June 2008	Siskiyou	192,038	0	2
Marble Cone (Lightning)	July 1977	Monterey	177,866	0	0

* Area burned in California only; burned area in other states not included for fires that crossed State lines.

Source: (CAL FIRE 2022d)

This increase in destructive fires is due to a number of factors:

- Increased fuel loading following a century of fire exclusion policies
- More human-caused ignitions
- Climate change, which is influencing drought and extreme heat events
- Greater silvicultural insect and disease impacts
- Increased tree mortality
- Lengthening of the "fire season," or annual time frame during which vegetative fuels are receptive to combustion

California has a long history of destructive WUI fires, beginning with the 1923 Berkeley Fire that destroyed 584 buildings while burning only 123 acres (Burress 1998). Many geographic areas have experienced repetitive WUI fires. For example, the area burned in the 1923 Berkeley Fire burned again in the 1991 Tunnel Fire, which is the third most destructive fire in State history (Krans 2021). Similarly, the 2007 Witch Creek Fire (1,650 structures burned) in San Diego County reburned portions of the 2003 Cedar Fire area (2,820 structures burned).

Table 9-2 shows the most disastrous WUI fires based on number of structures destroyed. As of June 2022, 92.7 percent of the most damaging WUI fires (as measured by number of structures burned) have occurred in the last two decades.

Table 9-3 summarizes, by year, the number of wildfires, structures burned, acres burned, and deaths, along with descriptions of significant events, between 2017 and 2022. The events during this timeframe have been the most destructive and deadliest wildfires in recent California history. For events prior to 2017, refer to Appendix K.

Table 9-2. Top 20 Most Destructive Wildfires in California, by Structures Destroyed

Fire name (cause)	Ignition Date	County	Acres Burned	Structures Destroyed	Deaths
Camp (Powerlines)	November 2018	Butte	153,336	18,804	85
Tubbs (Electrical)	October 2017	Sonoma	36,807	5,636	22
Tunnel (Rekindle)	October 1991	Alameda	1,600	2,900	25
Cedar (Human Related)	October 2003	San Diego	273,246	2,820	15
North Complex (Lightning)	August 2020	Butte, Plumas, Tuba	318,935	2,352	15
Valley (Electrical)	September 2015	Lake, Napa, Sonoma	76,067	1,955	4
Witch (Powerlines)	October 2007	San Diego	197,990	1,650	2
Woolsey (Electrical)	November 2018	Ventura	96,949	1,643	3
Carr (Human Related)	July 2018	Shasta, Trinity	229,651	1,614	8
Glass (Undetermined)	September 2020	Napa, Sonoma	67,484	1,520	0
LNU Lightning Complex (Lightning/Arson)	August 2020	Napa, Solano, Sonoma, Yolo, Lake, Colusa	363,220	1,491	6
CZU Lightning Complex (Lightning)	August 2020	Santa Cruz, San Mateo	86,509	1,490	1
Nuns (Powerline)	October 2017	Sonoma	54,382	1,355	2
Dixie (Under Investigation)	July 2021	Butte, Plumas, Lassen, Tehama	963,309	1,329	1
Thomas (Powerline)	October 2017	Ventura, Santa Barbara	281,893	1,063	2
Caldor (Human Related)	September 2021	Alpine, Amador, El Dorado	221,835	1,003	1
Old (Human Related)	October 2003	San Bernardino	91,281	1,003	6
Jones (Undetermined)	October 1999	Shasta	26,200	954	1
August Complex (lightning)	August 2020	Mendocino, Humboldt, Trinity, Tehama, Glenn, Lake Colusa	1,032,648	935	1
Butte (Powerlines)	September 2015	Amador, Calaveras	70,868	921	2

Source: (CAL FIRE 2022b)

Table 9-3. Wildfire Events in the State of California (2017 to 2022)

Year	Number of Wildfires	Structures Burned	Acres Burned	Number of Deaths
2017	9,270	10,280	1,548,429	47
▪ Northern California Wildfire Complex in October—started by lightning strikes and driven by extreme weather and drought conditions in the WUI ▪ Thomas Fire in December—started by power lines coming into contact during high winds and driven by extreme weather and drought conditions in the WUI ▪ Tubbs Fire in October—started by a private electrical system failure, destroyed over 5,000 structures and took the lives of 22 people ▪ Nuns Fire in October—started by electrical equipment				
2018	7,948	24,226	1,975,086	100
▪ Mendocino Complex Fire in July—started by a spark from a hammer driving a metal stake into the ground, burned over 450,000 acres ▪ Carr Fire in July—started by an auto accident and driven by high winds destroyed over 1,600 structures, caused multiple fatalities, and burned 229,651 acres ▪ Camp Fire in November—caused by electrical transmission lines destroyed over 18,800 structures and resulted in 85 deaths ▪ Woolsey Fire in November—started by electrical and communication equipment burned nearly 198,000 acres and took the lives of 3 people				
2019	7,860	732	259,823	3
▪ Kincade Fire in October—started by an electrical transmission line failure during a high wind event ▪ Walker Fire in September—started by lightning strikes				
2020	8,648	11,116	4,304,379	33
▪ August Complex in August—started by lightning strikes burned over 1 million acres and 935 structures ▪ SCU Complex in August—started by lightning strikes burned nearly 400,000 acres and 222 structures ▪ North Complex in August—started by lightning strikes burned nearly 319,000 acres, 2,352 structures, and resulted in 15 deaths ▪ LNU Complex in August—started by lightning strikes burned 363,220 acres and nearly 1,500 structures ▪ CZU Complex in August—started by lightning strikes burned 1,490 structures ▪ Creek Fire in September—started by lightning strikes ▪ Glass Fire in September burned 1,520 structures				

Year	Number of Wildfires	Structures Burned	Acres Burned	Number of Deaths
2021	8,835	3,629	2,568,948	3
▪ Dixie Fire in July—started by an electrical distribution line burned over 963,000 acres and 1,329 structures ▪ River Complex in July—started by lightning strikes ▪ Monument Fire in July—started by lightning strikes burned 223, 124 acres and 50 structures ▪ Caldor Fire in August—started by a firearm projectile burned 221,835 acres and over 1,000 structures				
2022	4,026	2	27,848	0
▪ Oak Fire in July (Figure 9-7)—cause under investigation and driven by extreme heat, drought, and dry fuel from mass tree fatality ▪ McKinney Fire in July (Figure 9-8)—started by lightning strikes still burning at 60,392 acres, 185 structures, and 4 fatalities				

Sources: (CAL FIRE 2022c), (Cal OES 2018a), (Jacobo 2022)

Figure 9-7. Helicopter Water-Drop Efforts During the Oak Fire in July 2022

Source: (Berger 2022)

Figure 9-8. 2022 McKinney Fire Burns Along California Highway 96

Source: (Berger 2022)

Figure 9-9 is based on CAL FIRE datasets of fire perimeters from 1985 to 2017. Fires are shown by 10-year period, overlaid on public lands. The most significant 2017 fires—the Thomas Fire, which at that time burned the largest number of acres ever recorded, and the fires that make up the Northern California Wildfire Complex, which at that time burned the largest number of structures on record—are delineated with special coloring on the map.

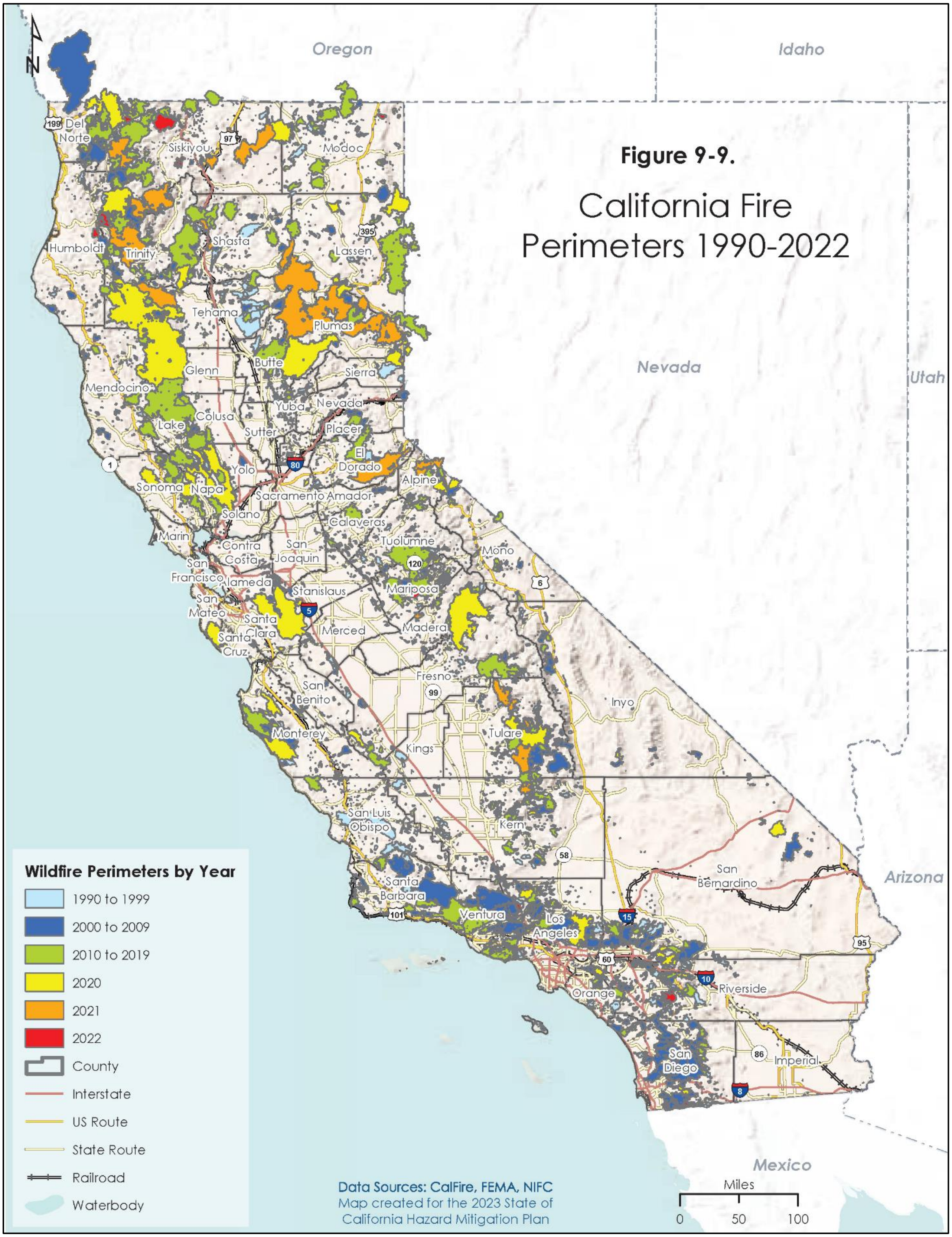
9.4. PROBABILITY OF FUTURE HAZARD EVENTS

9.4.1. Overall Probability

According to CAL FIRE, the State of California experienced 77,518 wildfire events between 2013 and July 9, 2022. Based on these statistics, the State can expect about 8,000 wildfires each year.

Due to fuel buildup following a century of fire exclusion, a lengthened fire season predicted by many climate change models, forest management practices which removed many of the older, larger trees, and massive tree die-off following epidemic bark beetle infestations, fires in mixed-conifer forests are likely to continue to grow in both size and intensity (Steel, Safford and Viers 2015) (Wayman and Safford 2021).

Figure 9-9. California Fire Perimeters 1990 – 2022



9.4.2. Climate Change Impacts

According to California's Fourth Climate Change Assessment, if GHG emissions continue to rise, California is likely to see a 50 percent increase in fires larger than 25,000 acres and a 77 percent increase in average area burned by 2100. Numerous climactic drivers will influence wildfire risk differently between California regions:

- *Increasing Temperatures:* Wildfire risk in the San Francisco Bay Area is rising in tandem with increasing temperatures. Further upstate, in the Sacramento, Sierra Nevada, and North Coast regions, forests that experience drought are also more susceptible to wildfire. High heat not only influences fire risk directly but can also produce indirect impacts. For instance, in the San Joaquin Valley, where fire hazard is typically low, warming temperatures will likely worsen air quality due to extended agriculture fallowing. This, in turn, can exacerbate health impacts from wildfire smoke.
- *Shifting Wind Patterns:* The Santa Ana, Sundowner, and Diablo winds will continue to shape wildfire activity across Southern, Central, and Northern California, respectively. Modelers are still working to determine how these wind events will be impacted by climate change.
- *Shifting Water Patterns*: Climate change will cause shifting water patterns that can impact wildfire risk across the State. In the inland desert, the potential weakening of the North American Monsoon signal could reduce the threat of fire starts due to lightning. Changing patterns of rainfall will impact plant growth in the desert, thereby altering the amount of fuel for fires. Mediterranean ecosystems along the central coast have a similar response to water availability since they are situated in a transition zone. In Southern California and San Diego, meanwhile, changing precipitation will factor heavily into post-fire risk assessments since these landscapes are especially vulnerable to post-fire flooding and landslides.
- *Shifting Insect Habitat*: Bark beetle infestations are rising in response to the changing climate, increasing tree mortality—particularly in the southern Sierra Nevada —and reducing carbon storage.
- *Human Impacts:* Across all of California's landscapes human factors, such as development patterns and risk mitigation strategies, will have a direct impact on communities' ability to mitigate and adapt to the impacts of climate change. Local decisions are a large factor in determining the future health of a community.

9.5. IMPACT ANALYSIS

9.5.1. Severity

The August Complex in 2020 was California's largest wildfire complex to date, with 1,032,648 acres burned. The Camp Fire of 2018 resulted in the loss of 18,804 structures, the most destroyed in any California wildfire. The Camp Fire also caused the most deaths of any other wildfire with 85 human lives lost due to flames. An estimated 3,652 lives were lost due to smoke from wildfires in 2018 (Wang, et al. 2022).

9.5.2. Warning Time

Of the largest and most destructive fires listed in Table 9-1 and Table 9-2, the majority (61 percent) were caused by humans and power lines. There is no way to predict when a human-caused wildfire will break out. Prolonged drought and severe winds can greatly increase the likelihood of a wildfire event (Goss, et al. 2020). Severe weather can be predicted, so special attention can be paid during weather events that may increase wildfire events, such as lightning storms.

If a wildfire breaks out and spreads rapidly, residents may need to evacuate immediately. According to the U.S. Forest service, a fire's peak burning period generally is between 10 a.m. and sundown (USFS n.d.-a). Once a fire has started, fire alerting is reasonably rapid in most cases. The rapid spread of cellular and two-way radio communications in recent years has further contributed to significant improvements in warning time. Residents in many communities can sign up for local emergency alerts (DHS 2022).

Both hazard and extent scales have been developed to estimate wildfire danger. The State uses these scales to predict when wildfires are likely to occur and how a wildfire will behave based on air and fuel moisture content, lighting events, and wind conditions. The sections below describe the metrics currently available.

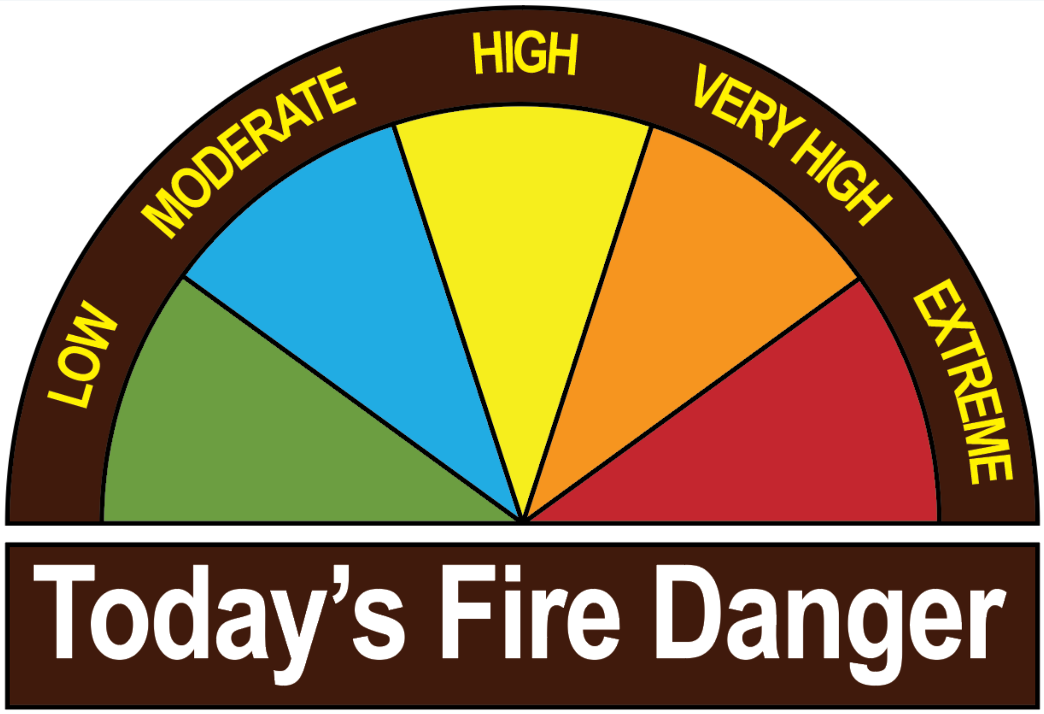
WUI Hazard Scale

The WUI Hazard Scale assigns a measure of severity to embers and fire from 1 (no exposure) to 4 (most severe exposure) (National Institute of Standards and Technology 2012). To implement the WUI Hazard Scale, the National Institute of Standards and Technology, CAL FIRE, and the Insurance Institute for Business & Home Safety published a document called the WUI Structure/Parcel/Community Fire Hazard Mitigation Methodology.

National Fire Danger Rating System

The National Fire Danger Rating System is used for determining fire danger for a given area. Based on that determination, restrictions or closures to public land may be imposed, and fire managers will plan for staff and equipment to fight fires and decide whether to suppress or allow fires to burn under prescribed conditions (National Park Service 2021). The rating system uses five color-coded levels (see Figure 9-10) indicating fire potential (USFS 2022); (National Park Service 2021):

Figure 9-10. National Fire Danger Rating System



Source: (USFS 2022)

- **Fire Danger Level: Low (Green)**—When the fire danger is "low" it means that fuels do not ignite easily from small embers, but a more intense heat source, such as lightning, may start fires in duff or dry rotten wood. Fires in open, dry grasslands may burn easily a few hours after a rain, but most wood fires will spread slowly, creeping or smoldering. Control of fires is generally easy.
- **Fire Danger Level: Moderate (Blue)**—When the fire danger is "moderate" it means that fires can start from most accidental causes, but the number of fire starts is likely to be pretty low. If a fire does start in an open, dry grassland, it will

burn and spread quickly on windy days. Most wood fires will spread slowly to moderately. Average fire intensity will be moderate except in heavy concentrations of fuel, which may burn hot. Fires are still not likely to become serious and are often easy to control.

- **Fire Danger Level: High (Yellow)**—When the fire danger is "high," fires can start easily from most causes and small fuels (such as grasses and needles) will ignite readily. Unattended campfires and brush fires are likely to escape. Fires will spread easily, with some areas of high-intensity burning on slopes or concentrated fuels. Fires can become serious and difficult to control unless they are put out while they are still small. Outdoor burning should be restricted to early mornings and late evenings.
- **Fire Danger Level: Very High (Orange)**—When the fire danger is "very high," fires will start easily from most causes. The fires will spread rapidly and have a quick increase in intensity, right after ignition. Small fires can quickly become large fires and exhibit extreme fire intensity, such as long-distance spotting and fire whirls. These fires can be difficult to control and will often become much larger and longer-lasting fires. Outdoor burning is not recommended.
- **Fire Danger Level: Extreme (Red)**—When the fire danger is "extreme," fires of all types start quickly and burn intensely. All fires are potentially serious and can spread very quickly with intense burning. Small fires become big fires much faster than at the "very high" level. Spot fires are probable, with long-distance spotting likely. These fires are very difficult to fight and may become very dangerous and often last for several days. No outdoor burning should take place in areas with extreme fire danger.

National Weather Service Fire Weather Criteria—Red Flag Program

The NWS issues red flag warnings and fire weather watches to alert land management agencies about the onset, or possible onset, of weather and fuel moisture conditions that could lead to wildfire (NWS 2022d). Fire Weather Watches and Red Flag Warnings are issued when the combination of fuels and weather conditions support extreme fire danger and/or fire behavior:

- A fire weather watch is used to alert agencies to the potential for development of a Red Flag event in the 18- to 96-hour time frame (at least 50 percent confidence). The watch may be issued for all or selected portions of a fire weather zone or zones.

- A red flag warning is used to inform agencies of impending or occurring red flag conditions. A red flag warning is issued when there is high confidence that red flag criteria will be met within the next 48 hours or are already being met. Longer lead times are allowed when confidence is very high, or the fire danger situation is critical. The warning may be issued for all or selected portions of a fire weather zone or zones.

Fire weather watches and red flag warnings are included in all affected forecasts. All NWS fire weather web pages also highlight any watch or warning issuances.

NWS offices normally call affected dispatch offices and affected agencies as well as their respective Geographic Area Coordination Centers when red flag warnings and fire weather watches are issued or updated. Watches and warnings are available on the internet via the California Fire Weather web page, the web sites of the issuing NWS offices, the NWS National Fire Weather Page and www.weather.gov/fire.

NWS weather forecast offices serving California have the option to use the phrase "Particularly Dangerous Situation" within the red flag warning headline and body of the product (this is not a new red flag warning product). The objective is to highlight exceptional fire weather conditions (combination of meteorological and fuels) considered rare or especially impactful to the public and firefighting community. Where appropriate, inclusion of the Particularly Dangerous Situation language must be coordinated between adjacent offices prior to product issuance and messaging.

Lower Atmosphere Stability Index (Haines Index)

The Haines Index is used to indicate the potential for wildfire growth by measuring the stability and dryness of the air over a fire. It is calculated by combining the stability and moisture content of the lower atmosphere into a number that correlates well with large fire growth. The stability term is determined by the temperature difference between two atmospheric layers; the moisture term is determined by the temperature and dew point difference.

This index has been shown to be correlated with large fire growth on initiating and existing fires where surface winds do not dominate fire behavior (USFS n.d.-b). The Haines Index can range between 2 and 6.

- 2—Very Low Potential (Moist Stable Lower Atmosphere)
- 3—Very Low Potential
- 4—Low Potential

- 5—Moderate Potential
- 6—High Potential (Dry Unstable Lower Atmosphere)

The drier and more unstable the lower atmosphere is, the higher the index.

Burning Index

The Burning Index is an estimate of the potential difficulty of fire containment related to the flame length at the head of a fire. It is a relative number related to the contribution that fire behavior makes to the amount or effort needed to contain a fire in a specified fuel type. Doubling the burning index indicates that twice the effort will be required to contain a fire in that fuel type as was previously required, providing all other parameters are held constant (National Wildfire Coordinating Group 2021).

9.5.3. Cascading Impacts

Cascading impacts are the impacts that result when one type of hazard event triggers one or more other hazard events, which may in turn trigger still others. The following are notable cascading impacts associated with wildfires:

- Wildfires strip slopes of vegetation, exposing them to greater amounts of runoff. This in turn can weaken soils and cause failures on slopes (USGS 2021a). Major landslides can occur several years after a wildfire (DOC 2019d).
- Most wildfires burn hot and for long durations that can bake soils, especially those high in clay content, thus increasing the imperviousness of the ground (California Ecosystems Climate Solutions 2020). This increases the runoff generated by storm events, thus increasing the chance of flooding (NWS n.d.-d).
- Flooding after fire is often more severe, as debris and ash left from the fire can form mudflows. As rainwater moves across charred and denuded ground, it can also pick up soil and sediment and carry it in a stream of floodwaters. These mudflows can cause significant damage.
- Fire weather conditions pre-event can cause power interruptions due to PSPS scenarios initiated by public utility service providers. PSPS events are addressed in Chapter 24.
- Critical infrastructure disruptions or delays can be triggered by wildfire events.
- Fires can contaminate drinking water supplies.
- Fires can negatively affect air quality.

9.5.4. Impacts of Smoke

Wildfire smoke has grown significantly as a hazard in recent years. The number of people in the Western U.S. experiencing at least one extreme smoke day with serious impacts increased by a factor of 27 over the last decade (Childs, et al. 2022). Over 30 million Californians experienced significant wildfire smoke in 2020 alone (Rosenthal, et al. 2022). Wildfire smoke typically kills many times as many people as wildfire flames (see Table 9-4).

Table 9-4. Deaths From Flames and Smoke for Select Heavy Wildfire Before 2020

Fire Year (Region)	Counties Evaluated	Deaths From Flames	Deaths From Smoke
2003 (Southern California)	Los Angeles, Riverside, San Bernardino, San Diego, Santa Barbara, Ventura	24	133
2018 (Statewide)	Statewide	104	3,652

Sources: (Kochi, et al. 2012); (Wang, et al. 2022)

The danger of wildfire smoke comes primarily from particulate matter (PM), consisting of fine particles that are 2.5 micrometers (about a ten-thousandth of an inch) or less in diameter ($PM_{2.5}$). On a given day, California wildfires can produce 10 times more $PM_{2.5}$ air pollution than is produced by all other pollution sources combined (Associated Press 2020). The small particles in $PM_{2.5}$ pollution are capable of reaching deep into the lungs, causing a host of complications, including significantly increased risks of heart disease, respiratory disease, asthma, and premature mortality. Health problems related to wildfire smoke exposure can be as mild as eye and respiratory tract irritation and as serious as worsening of heart and lung disease, including asthma, and even death. Smoke from wildfires that burn homes and other structures can additionally contain toxic materials such as asbestos and heavy metals. Studies indicate that wildfire smoke is up to 10 times more harmful than other forms of $PM_{2.5}$ pollution (Aguilera, et al. 2021).

Not all individuals are equally exposed to the hazard of wildfire smoke, nor are they equally vulnerable. Outdoor workers and unhoused individuals have especially high exposure to outdoor air, and younger individuals are especially vulnerable to unhealthy air. On November 15, 2018, over 1 million California children had classes canceled due to wildfires and wildfire smoke (Holm, Miller and Balmes 2020). Because $PM_{2.5}$ pollution affects the immune and cardiovascular systems, other vulnerable populations include people with medical conditions, including diabetes and heart and lung conditions. These vulnerable populations together represent a significant fraction of the California population and indicate inequity in impacts.

At least 95 percent of Californians suffered unhealthy levels of particle pollution due to wildfires in 2020 (Los Angeles Times 2020). Worse air quality leads to illnesses, emergency room visits, and hospitalizations for chronic health conditions, including chronic obstructive pulmonary disease, asthma, chronic bronchitis, and other respiratory and cardiovascular conditions as well as increased risk for respiratory infections, which all result in greater health costs to the State (Romley, Hackbarth and Goldman 2010, Wang, Aaron and Madrigano 2019, Inserro 2018).

9.5.5. Environmental Impacts

Fire is a natural process in most terrestrial ecosystems, affecting the types, structure, and spatial extent of native vegetation. Fire can act as a catalyst for promoting biological diversity and healthy ecosystems, reducing buildup of organic debris, releasing nutrients into the soil, and triggering changes in vegetation community composition (CDFW 2022d). However, in some circumstances it can also cause severe negative environmental impacts, such as the following:

- **Soil Erosion**—The protective covering provided by foliage and dead organic matter is removed, leaving the soil fully exposed to wind and water erosion. Accelerated soil erosion occurs, causing landslides and threatening aquatic habitats (California Ecosystems Climate Solutions 2020).
- **Reduced Agricultural Resources**—Wildfire can have disastrous consequences on agricultural resources, removing them from production and necessitating lengthy restoration programs (Philip 2019).
- **Spread of Invasive Plant Species**—Non-native woody plant species frequently invade burned areas. When weeds become established, they can dominate the plant cover over broad landscapes, and become difficult and costly to control (U.S. Department of the Interior, Office of Wildland Fire 2022).
- **Disease and Insect Infestations**—Unless diseased or insect-infested trees are swiftly removed, infestations and disease can spread to healthy forests and private lands. Timely active management actions are needed to remove diseased or infested trees (The White House n.d.).
- **Destroyed Endangered Species Habitat**—Wildfire can have negative consequences on endangered species by degrading their habitat (Butcher, Kristin 2019).

- **Soil Sterilization**—Some wildfires burn so hot that they can sterilize the soil. Topsoil exposed to extreme heat can become water repellant, and soil nutrients may be lost (FireSafe Sonoma 2020).
- **Damaged Fisheries**—Fisheries can suffer from increased water temperatures, sedimentation, and changes in water quality (NASA Jet Propulsion Laboratory, California Institute of Technology 2022); (Beakes, et al. 2014).
- **Damaged Cultural and Historical Resources**—The destruction of cultural and historic resources may occur, scenic vistas can be damaged, and access to recreational areas can be reduced (National Park Service 2021).

9.5.6. Local Hazard Impacts

LHMP Rankings

All but one of the hazard mitigation plans prepared for California's 58 counties list wildfire as a hazard of concern, and 45 counties rank it as a high-impact hazard:

- Alameda
- Alpine
- Amador
- Butte
- Calaveras
- Colusa
- El Dorado
- Fresno
- Glenn
- Humboldt
- Inyo
- Kern
- Kings
- Lake
- Lassen
- Los Angeles
- Madera
- Marin
- Mariposa
- Mendocino
- Modoc
- Mono
- Monterey
- Napa
- Nevada
- Placer
- Plumas
- Riverside
- Sacramento
- San Bernardino
- San Diego
- San Luis Obispo
- Santa Barbara
- Santa Cruz
- Shasta
- Sierra
- Siskiyou
- Solano
- Sonoma
- Tehama
- Trinity
- Tulare
- Tuolumne
- Yolo
- Yuba

An additional 10 counties identified wildfire as a medium-impact hazard.

LHMP Estimates of Potential Loss

Table 9-5 summarizes potential losses to vulnerable structures based on estimates from the local risk assessments (as called for in FEMA's Standard State Mitigation Planning

Requirement S6.b). Due to variances in approaches to assessing risk at the local level as well as the hazards assessed and the age of each assessment reviewed, this data is considered approximate.

Table 9-5. Wildfire Risk Exposure Analysis for LHMP Reviews

Estimated Total Population Exposed	3,629,974
Estimated Number of Structures at Risk	848,115
Estimated Value of Structures at Risk	$232 billion

9.6. VULNERABILITY ANALYSIS

To assess the vulnerability of State assets to the wildfire hazard, GIS software was used to overlay CAL FIRE's fire hazard severity zones with State assets. The analysis included only very high and high hazard zones in the State responsibility areas and local responsibility areas combined. The areas used are shown in Figure 9-2.

9.6.1. Exposure of State-Owned or -Leased Facilities

Table 9-6 and Table 9-7 summarize the number and replacement cost value of State assets located in high and very fire hazard severity zones. Figure 9-11 summarizes the exposed assets as a percentage of total assets statewide. Appendix I provides detailed results by county.

9.6.2. Exposure of Critical Facilities and Community Lifelines

The Risk Assessment identified 71 community lifelines in the "high" or "very high" wildfire hazard severity zones. The "food, water, shelter" lifeline category accounts for 44 percent of these, the "energy" category accounts for 35 percent, and "transportation" accounts for 10 percent. For a detailed breakdown of facility counts by County see Appendix I. Critical facilities and community lifelines that are exposed to the wildfire hazard are likely to experience functional downtime following these events that could increase the net impact of these events in a region.

Table 9-6. State-Owned or -Leased Facilities Exposed to High or Very High FHSZ

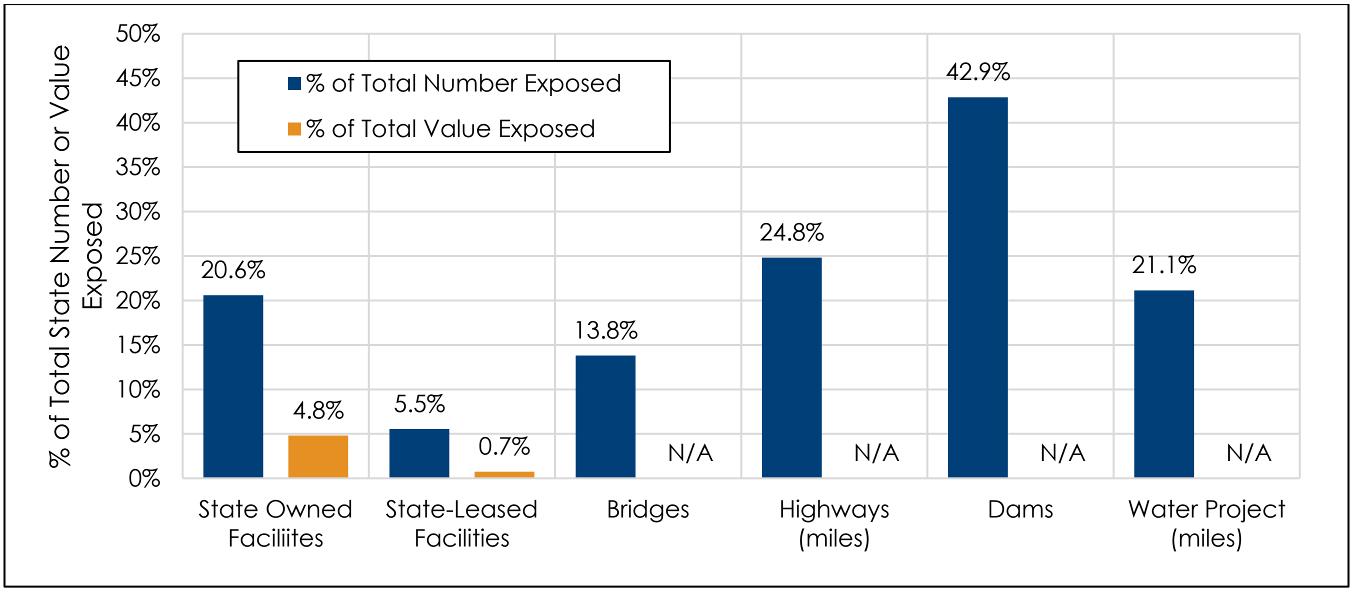
Type of Facility	Number of Structures	Total Area (sq. ft.)	Replacement Cost Value		
			Structure	Content	Total
State-Leased Facilities	105	—	$69,044,243	$70,725,927	$139,770,170
State-Owned Facilities					
Facilities Housing Vulnerable Populations					
Correctional Facility	105	633,339	$38,317,982	$38,317,982	$76,635,964
Development Center	0	0	$0	$0	$0
Hospital	0	0	$0	$0	$0
Migrant Center	0	0	$0	$0	$0
Special School	0	0	$0	$0	$0
All Other Facilities	4,828	10,580,124	$831,982,506	$858,576,850	$1,690,559,356
Total State-Owned	***4,933***	***11,213,463***	***$870,300,488***	***$896,894,832***	***$1,767,195,320***
Total Facilities	**5,038**	**N/A***	**$939,344,732**	**$967,620,759**	**$1,906,965,490**

* The inventory of State assets does not include building area for State-leased facilities, so no total area for all State facilities is provided; the building area of vulnerable assets is shown for State-owned facilities only.

Table 9-7. State-Owned Infrastructure Exposed to High or Very High FHSZ

Type of Facility	State-Owned Infrastructure in the Mapped Hazard Area
Bridges	1,823
Highway (miles)	7,469.1
Dams	21
Water Project (miles)	151

Figure 9-11. State Assets in High or Very High Fire Hazard Severity Zones, as % of Statewide Total



N/A: Values not defined for bridges, highways, dams, and water project

9.6.3. Estimates of Loss

State assets can be damaged by wildfire, but there are no established damage curves or functions for estimating associated losses. Instead, loss estimates were developed representing 10 percent, 30 percent, and 50 percent of the replacement cost value of exposed State-owned facilities in the mapped wildfire hazard areas (see Table 9-8). This allows the State to select a range of potential economic impacts based on an estimate of the percentage of damage to these assets. Damage in excess of 50 percent is considered to be substantial by most building codes and typically requires total reconstruction of the structure.

Table 9-8. Loss Potential of State-Owned Assets for Wildfire

Type of Facility	Total Replacement Cost Value (contents only)	Estimated Loss Potential Based on % Damage		
		10% Damage	30% Damage	50% Damage
Facilities Housing Vulnerable Populations				
Correctional Facility	$76,635,964	$7,663,596	$22,990,789	$38,317,982
Development Center	$0	$0	$0	$0
Hospital	$0	$0	$0	$0
Migrant Center	$0	$0	$0	$0
Special School	$0	$0	$0	$0
All Other Facilities	**$1,690,559,356**	**$169,055,936**	**$507,167,807**	**$845,279,678**
Total	**$1,767,195,320**	**$176,719,532**	**$530,158,596**	**$883,597,660**

In addition to impacting State assets, wildfire events can have major economic impacts on a community from the initial loss of structures and subsequent economic losses.

9.6.4. Buildable Land

Of 11.7 million acres of land available for development statewide, 5.3 million acres (45.1percent) is located in the evaluated fire hazard severity zones. Appendix G provides a detailed assessment of exposed buildable lands by county. Any type of development in these areas will be susceptible to damage associated with wildfires.

9.6.5. Equity Priority Communities

Many communities and populations are especially vulnerable to wildfires, including low-income communities, migrant populations, populations whose primary language is not English, Indigenous, Black and Latina/e/o populations, communities of older adults, those with respiratory and other health concerns, and those with access or functional needs. Members of immigrant communities may be concerned about impacts to their immigration status and do not seek help. When a wildfire impacts an area with high rents where multiple families live in one structure, it may be difficult for those not listed on the lease to prove that they were affected by the fire. This could result in a lack of access to services.

Additionally, fires quickly increase housing prices and rent prices, further displacing people already affected by the fire and increasing the number of individuals experiencing homelessness. The underlying driver of housing affordability often means that the populations pushed into these peripheral regions are also the ones who can least afford the cost of wildfire damage and relocation, setting up social and economic complications to one-size-fits all solutions for wildfire resilience.

It can take days to translate information into languages other than English, hindering communication about evacuations and health and safety alerts. Indigenous populations may lose sacred sites; fisheries and hunting and gathering grounds may be degraded (National Academies Press 2020). Older adults do not have the mobility many others have, which can slow or prevent evacuation. More than one-third of the long-term care facilities in California are located in risky areas (Bénichou, Peterson and Pickoff-White 2020). WUI wildfire events can threaten economic security through loss of property, work, or life and disruption of food production. This can impact human health and increase stress, anxiety, depression, and mental health disorders for those within the equity priority communities who have greater risk of exposure and harm.

The risk analysis for wildfire found that 7.0 percent of people living in the fire hazard severity zones live in equity priority communities (253,461 people). A breakdown of exposed equity priority communities by county is included in Appendix I.

9.6.6. NRI Scores

According to the NRI, all of the State's counties have wildfire risk, rated from very low to very high. Table 9-9 shows scores for the six counties with the highest rating. See Section 4.1.3 for a description of the components of the NRI.

Table 9-9. NRI Scoring of Counties for Wildfire

County	Expected Annual Loss	Social Vulnerability Rating	Community Resilience Rating	Community Risk Factor	Risk Value	Score
San Diego	$381,629,724	Relatively High	Very Low	1.20	$445,037,091	100
Riverside	$319,123,716	Very High	Relatively Low	1.34	$398,534,350	99.97
San Bernardino	$134,371,346	Very High	Relatively Moderate	1.34	$147,460,270	99.94
Los Angeles	$108,835,472	Very High	Very Low	1.36	$110,453,363	99.90
Ventura	$48,353,567	Relatively High	Relatively Moderate	1.22	$53,155,787	99.81
Orange	$49,545,003	Relatively Moderate	Very Low	1.26	$45,718,477	99.78

9.7. MITIGATING THE HAZARD

9.7.1. Existing Measures for Mitigating the Hazard

Once thought of as a seasonal hazard, wildfires are an almost everyday occurrence in California today. However, much of the State's approach to dealing with wildfire is still seasonal in nature. Some past management practices have failed to address the full nature of the human/wildfire conflict and have exacerbated conditions that can lead to more damaging fires.

The State is improving its fire preparedness and mitigation efforts. The State has invested over $2.9 billion for wildfire prevention and forest resilience—first in the 2021-22 State budget and the Early Action Wildfire Package, and then in the passage of Senate Bill (SB) 155. The Early Action Wildfire Package includes $536 million in 2020-21 for roughly two dozen programs managed by 14 departments. SB 155 continuously appropriates $200 million from the Greenhouse Gas Reduction Fund annually until 2028-29 and provides more funding for research and incentives.

The State is also working toward long-term wildfire prevention and forest health through the implementation of vegetation management projects. In response to the Governor's Emergency Proclamation on March 22, 2019, CAL FIRE has identified 35 priority projects that can be implemented immediately to help reduce public safety risk for over 200 of California's most wildfire-vulnerable communities. Project examples include removal of hazardous dead trees, vegetation clearing, creation of fuel breaks and community defensible spaces, and creation of safer ingress and egress corridors.

Tools exist to predict and manage fire response. The Wildfire Forecast & Threat Intelligence Integration Center serves as California's integrated central organizing hub for wildfire forecasting, weather information, threat intelligence gathering, analysis, and dissemination. It provides information that government agencies can use to plan for upcoming fires. The Fire Integrated Real-time Intelligence System is a program that provides real-time intelligence data and analysis on emerging disaster incidents. Funding supports aircraft, a common operating picture, and near-real-time fire modeling that is available at the onset of emerging incidents. The goal of these programs is to provide fire crews and governing bodies with quick, real-time information for informed decision making.

General Wildfire Mitigation Approaches

Approaches to mitigate wildfires can include:

- An informed, educated public that takes responsibility for its own decisions relating to wildfire protection.
- Land use policies and standards that protect life, property, and natural resources.
- Building and fire codes that reduce structural ignitions from windblown embers and flame contact from WUI fires and impede or halt fire spread within the structure once ignited.
- Construction and property standards that provide defensible space.
- Forest management commitments to manage for more natural forest conditions.
- An effective regulatory mechanism for permitting an aggressive hazardous fuels management program.
- An effective wildfire suppression program.

Source: (FEMA 2013a)

9.7.2. Opportunities for Mitigating the Hazard

In addition to the work the State is already doing to mitigate wildfire risk, Table 9-10 provides a range of potential alternatives for mitigating the wildfire hazard. See Section 1.2.3 for a description of the different types of alternatives. Additional mitigation alternatives are available in the *Wildfire Smoke Considerations for California's Public Health Officials* (CDPH 2022k).

Table 9-10. Potential Opportunities to Mitigate the Wildfire Hazard

Community-Scale	Organizational Scale	Government-Scale
Manipulate the hazard: ▪ Clear potential fuels on property such as dry overgrown underbrush and diseased trees **Reduce exposure and vulnerability:** ▪ Create and maintain defensible space around structures ▪ Locate outside of hazard area ▪ Mow regularly ▪ Create and maintain defensible space around structures and provide water on site ▪ Use fire-resistant building materials ▪ Create defensible spaces around home ▪ Home hardening	**Manipulate the hazard:** ▪ Clear potential fuels on property such as dry underbrush and diseased trees **Reduce exposure and vulnerability:** ▪ Create and maintain defensible space around structures and infrastructure ▪ Locate outside of hazard area ▪ Create and maintain defensible space around structures and infrastructure and provide water on site ▪ Use fire-resistant building materials ▪ Use fire-resistant plantings in buffer areas of high wildfire threat	**Manipulate the hazard:** ▪ Clear potential fuels on property such as dry underbrush and diseased trees ▪ Remove invasive non-native hazardous fuels in riparian areas and restore native habitat ▪ Implement best management practices on public lands **Reduce exposure and vulnerability:** ▪ Create and maintain defensible space around structures and infrastructure ▪ Locate outside of hazard area ▪ Enhance building code to include use of fire-resistant materials in high-hazard area ▪ Create and maintain defensible space around structures and infrastructure ▪ Use fire-resistant building materials ▪ Use fire-resistant plantings in buffer areas of high wildfire threat ▪ Consider higher regulatory standards (such as Class A roofing) ▪ Establish biomass reclamation initiatives ▪ Reintroduce fire (controlled or prescribed burns) to fire-prone ecosystems while also protecting critical native habitat resilience, such as chaparral and sage scrub ▪ Manage fuel load through thinning and brush removal ▪ Establish integrated performance standards for new development to harden homes ▪ Create and manage multi-benefit greenbelts for resilience (also known as wildfire risk reduction buffers zones), or other ecosystem-appropriate land use strategies, such as SOAR (Save Open Space & Agricultural Resources)-designated and wildlife corridors

Community-Scale	Organizational Scale	Government-Scale
Build local capacity: ▪ Employ techniques from the National Fire Protection Association's Firewise USA program to safeguard home ▪ Identify alternative water supplies for fire fighting ▪ Install/replace roofing material with non-combustible roofing materials and implement other strategies to harden homes from embers and flame impingement	**Build local capacity:** ▪ Support Firewise USA community initiatives ▪ Create/establish stored water supplies to be utilized for firefighting	**Build local capacity:** ▪ More public outreach and education efforts, including an active Firewise USA program ▪ Possible weapons of mass destruction funds available to enhance fire capability in high-risk areas ▪ Identify fire response and alternative evacuation routes and establish where needed ▪ Seek alternative water supplies ▪ Become a Firewise USA community ▪ Use academia to study impacts/solutions to wildfire risk ▪ Establish/maintain mutual aid agreements between fire service agencies ▪ Develop, adopt, and implement integrated plans for mitigating wildfire impacts in wildland areas bordering on development ▪ Consider the probable impacts of climate change on the risk associated with the wildfire hazard in future land use decisions ▪ Establish a management program to track forest and rangeland health ▪ Provide incentives for existing structures to be hardened against wildfire ▪ Use tools to detect, forecast, and take action ahead of wildfire
Nature-based opportunities ▪ Manage invasive species (e.g., lodgepole pines) that are susceptible to increased wildfire risk ▪ Create riparian corridors in wildfire hazard areas as fire breaks ▪ Incorporate nature-based wildfire risk reduction buffers into existing ecosystem-friendly land uses (e.g., green space, trails, or community parklands) ▪ Implement and fund ecological thinning and prescribed fire and cultural fire and, where appropriate, manage wildfire for resource benefit		

9.7.3. Selected Actions to Mitigate the Hazard

The mitigation strategy developed for this SHMP includes the following actions that address the wildfire hazard:

- Action 2018-064: Legislation for Local Wildfire Hazard Planning: Incorporate wildfire hazards into development and land use planning as stated in California Government Code 65302.g.3 66474.02. and the California Environmental Quality Act (CEQA).
- Action 2018-065: Fire Hazard Severity Zones: Map areas of significant fire hazards based on fuels, terrain, weather, and other relevant factors to define the application of various mitigation strategies to reduce risk.
- Action 2018-068: Fire Safe Councils: Increase awareness, knowledge, and actions implemented by individuals and communities to reduce human loss and property damage from wildland fires, such as defensible space, fire risk reduction and fire safe building standards.
- Action 2018-070: Community Wildfire Protection Plans: Identify hazardous fuel reduction treatment priorities, recommend measures to reduce structural ignitability and address issues such as wildfire response, hazard mitigation, community preparedness and structure protection.

An Example Success Story for Wildfire Mitigation:

Wildfire Reduction at the Lick Observatory in Santa Clara County

The Lick Observatory is an active center for astronomical research founded in 1888. It is visited by approximately 35,000 people annually and serves as a resource for providing educational and cultural opportunities.

Problem: Wildfires pose an increasing threat to the Observatory, which is at the summit of Mount Hamilton and surrounded by forests.

Solution: UC Santa Cruz implemented a hazard mitigation project in 2007 to create defensible space around the observatory and remove combustible fuels. The work included vegetation management on 48 acres. The project brought the campus into compliance with California Public Resource Code, PRC 4291-Defensible Space, which requires 100 feet of reduced wildfire fuels around structures, along with treatments to reduce hazardous fuels.

Cost and Funding: The program, funded through FEMA Hazard Mitigation Assistance (HMA) grants, was completed in 2017 for a cost of $864,330.

Benefits: On August 16, 2020, a lightning storm in Santa Clara County led to one of the most destructive wildfires in California history, the Santa Clara Unit Lightning Complex Fire. The defensible space protected the Observatory structures and allowed CAL FIRE to safely remain at the observatory to protect the facility. The Observatory, valued at $77 million, experienced only $3.7 million in damage. CAL FIRE's suppression costs at the Observatory totaled $360,000.

Cal OES conducts loss avoidance studies after past mitigation projects are tested by the hazard they are meant to mitigate, in order to quantify the damage prevented by the projects. The following are key findings of the avoidance study for the Lick Observatory after the August 2020 fire:

- Without the mitigation action, the Observatory would have been completely lost by this fire
- Observatory Structure and Content Value: $77,152,670
- Observatory Structure and Content Damage: $3,769,707
- CAL FIRE Suppression Costs: $360,000
- Total Losses Avoided: $73,022,963

For the project cost of $864,330, this represents a return on investment of 8,448 percent.

SEVERE WIND, WEATHER, AND STORMS

Climate Impacts:
Increase in frequency and severity of severe weather events
Equity Impacts:
30.4% of exposed population (all persons in the State are exposed) identified as living in equity priority communities
State Facilities Exposed:
All facilities exposed
Community Lifelines Exposed:
All lifelines exposed

Impact Rating: High (36)

10. Severe Wind, Weather, and Storms

The severe wind, weather, and storm hazard has been identified as a high-impact natural hazard of interest based on the hazard impact rating protocol applied for this SHMP. Such events happen frequently in the State and all State-owned or -leased facilities and community lifelines are exposed to the hazard, although damage would be limited. All populations in the State could experience severe wind, weather, and storm events. These events are likely to impact equity priority communities more than the general populations due to many factors. Exposure to these events could increase if all buildable lands are developed, but the vulnerability of that exposure is considered low because it would be new development subject to codes and standards. The frequency and severity of severe wind, weather, and storm events is anticipated to increase over the next 30 years due to the impacts of climate change.

10.1. HAZARD OVERVIEW

Severe weather events in California are very common and can occur at any time of the year. For this SHMP, the severe weather profile includes coastal storms (including El Niño and La Niña), windstorms, hail, thunderstorms, tornadoes, and winter weather (including snow and ice storms).

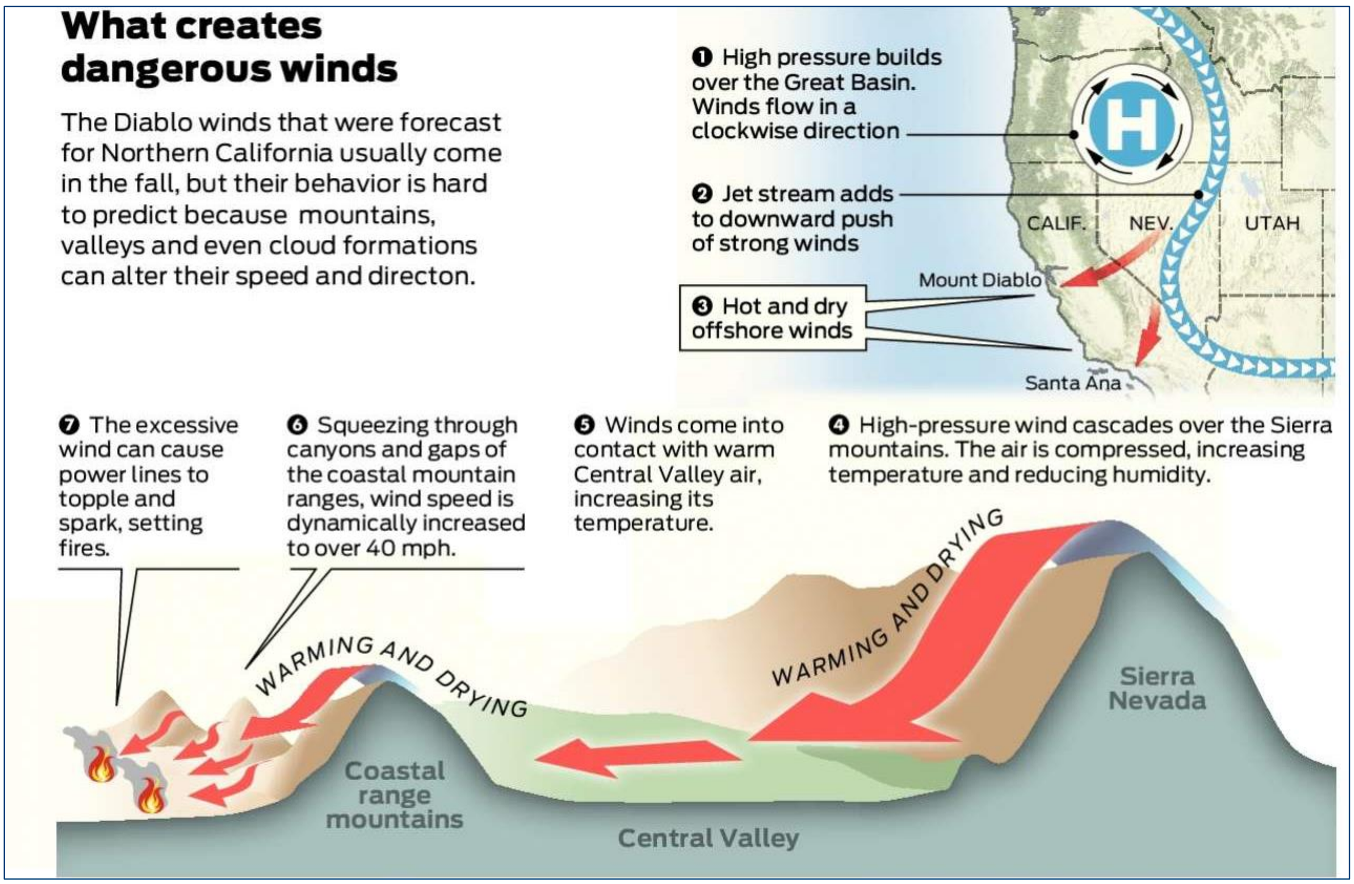
10.1.1. Windstorm

Wind occurs at all scales, from local breezes lasting a few minutes to global winds resulting from solar heating of the earth. High winds are often associated with other severe weather events such as thunderstorms, tornadoes, or tropical storms (NWS 2022h).

Santa Ana winds are warm, dry winds that blow during the Southern California cool season (October to March). They form when high pressure builds over the Great Basin—the geographic area bound by the Rocky Mountains to the east and the Sierra Nevada to the west—and when low pressure sits over the California coast. As air moves west from the Great Basin toward California, where pressure is lower (air flows from high to low pressure), it gains speed as it whips through mountain valleys and passes. The resulting airflow can reach speeds upwards of 30 mph, and gusts of more than twice this speed. The windstorms can last for several days at a time (Means 2021).

Diablo wind is a name that is sometimes used for hot, dry wind from the northeast that typically occurs in the San Francisco Bay Area during the spring and fall. The Diablo wind is created by the combination of strong inland high pressure at the surface, strongly sinking air aloft, and lower pressure off the California coast (see Figure 10-1. The air descending from aloft as well as from the Coast Ranges compresses as it sinks to sea level, where it warms as much as 20 °F and loses relative humidity.

Figure 10-1. Diablo Winds



Source: (San Francisco Chronicle 2020)

Because of the elevation of the coastal ranges in north-central California, the thermodynamic structure that occurs with the Diablo wind pattern favors the development of strong ridge-top and lee-side downslope winds associated with a phenomenon called the "hydraulic jump." While hydraulic jumps can occur with Santa Ana winds, the same thermodynamic structure that occurs with them typically favors "gap" flow more frequently. Santa Ana winds are gravity-driven winds draining air off the high deserts, while the Diablo wind originates mainly from strongly sinking air from aloft, pushed toward the coast by higher inland pressure. Thus, Santa Ana winds are the strongest in canyons, whereas a Diablo wind is first noted and blows strongest atop and on the western slopes of mountain peaks and ridges around the Bay Area.

10.1.2. Hail

Hail is a form of precipitation that occurs when updrafts in thunderstorms carry raindrops upward into extremely cold areas of the atmosphere, where they freeze into ice. Hail can damage aircrafts, homes, cars, and infrastructure, and can be deadly to livestock and people (NOAA National Severe Storms Laboratory 2022).

10.1.3. Thunderstorm

A thunderstorm is a local rainstorm produced by a cumulonimbus cloud and accompanied by lightning and thunder (NOAA n.d.-a). Such storms form from a combination of moisture, rapidly rising warm air, and a force capable of lifting air, such as a warm front, cold front, or mountain.

Although thunderstorms generally affect a small area, they have the potential to become dangerous due to their ability to generate tornadoes, hailstorms, strong winds, flash flooding, landslides, and lightning.

Roads may become impassable from flooding, downed trees or power lines, or a landslide. Downed power lines can lead to loss of utility services, such as water, phone, and electricity. Typical thunderstorms are 15 miles in diameter and last an average of 30 minutes.

Lighting is a flash of electrical energy produced by a thunderstorm. The resulting clap of thunder is the result of a shock wave created by the rapid heating and cooling of the air in the lightning channel. Lightning kills approximately 50 people in the United States each year and injures hundreds. Lightning can be cloud to air, cloud to cloud, or cloud to ground. Cloud to ground strikes can also be the cause of wildfires.

10.1.4. Tornadoes

A tornado is a rotating, funnel-shaped cloud that extends from a thunderstorm to the ground with whirling winds that can reach 250 mph or greater. Tornadoes typically move at speeds between 30 and 125 mph. Their damage paths can be more than a mile wide and 50 miles long. Tornadoes typically develop from either a severe thunderstorm or hurricane as cool air rapidly overrides a layer of warm air. The lifespan of a tornado rarely is longer than 30 minutes (FEMA 2022w); (NWS 2022). Tornadoes can occur at any time of the year, with peak seasons at different times for different states (NOAA National Severe Storms Laboratory 2022). According to the NWS, tornadoes in California occur mainly in the spring and fall, and their magnitudes usually do not exceed EF-3 strength, that is, 165 mph.

10.1.5. Winter Weather

Winter weather consists of storm events in which the main types of precipitation are snow, sleet, or freezing rain. California experiences its rainiest season during the winter, making winter precipitation more likely to occur (Kennedy 2022). For the purposes of this SHMP update, winter weather includes the following (NWS 2009):

- **Snowstorms—**Snow is precipitation in the form of ice crystals and forms directly from the freezing of water vapor in the air. Snowstorms are winter events that last several hours and see snow accumulation of more than 2 inches an hour.
- **Ice Storms—**An ice storm is a storm that results in the accumulation of at least 0.25 inches of ice on exposed surfaces. This creates hazardous driving and walking conditions. Tree branches and powerlines can easily snap under the weight of the ice.

10.1.6. El Niño and La Niña

El Niño is characterized by unusually warm water temperatures in the central and eastern portions of the topical Pacific Ocean. El Niño’s impacts can affect the location of jet streams. Instead of coming ashore in the Pacific Northwest, the southern jet stream hits California with increased rainfall that is typically accompanied by floods, landslides, and coastal erosion. El Niño tends to make atmospheric rivers stronger.

La Niña is characterized by a cooling of the ocean surface in the central and eastern tropical Pacific Ocean. La Niña winters typically result in dry conditions, particularly for

Southern California. La Niña results in cold ocean water developing off the West coast of the Americas, which pushes the jet stream north. In a La Niña winter, the storm track tends to hit the Pacific Northwest with heavier rain and flooding, sometimes dipping into Northern California. The American Southwest, meanwhile, is left drier than normal (Water Education Foundation 2022).

10.2. HAZARD LOCATION

The entire State of California is susceptible to the severe weather hazard; however, some areas of the State are more susceptible to different types of severe weather than others:

- Coastal storms typically occur along the central and northern coasts of the State. Hurricanes are a rare occurrence because tropical storm winds generally blow from east to west, but when they do occur, they tend to impact the southern part of the State.
- Windstorms impact the entire State.
- Hailstorms impact the entire State.
- Thunderstorms impact the entire State.
- Tornadoes impact the entire State.
- Winter weather typically impacts the northern and central parts of the State between October and March.
- El Niño and La Niña can impact the entire State.

10.3. PREVIOUS HAZARD OCCURRENCES

Severe weather occurs frequently in the State of California and poses a threat to people and property.

10.3.1. Disaster and Emergency Declarations

The following disaster declarations or emergency proclamations related to severe weather have been issued for California (see Appendix F for details):

- Federal DR or EM declaration, 1953 – 2022: 17 events, classified as coastal storms, tornadoes, mudslides, flooding, severe winter storm, rain, snow, wind, high tides, or landslides
- California Emergency Proclamations, 1950 – 2022: 32 events, classified as monsoon, severe storm, snow, tornado, or windstorm
- USDA agricultural disaster declarations, 2012 – 2022: none

10.3.2. Event History

Table 10-1 lists significant severe weather events that impacted the State of California between 2018 and 2022. Due to the significant number of events, the table includes only events that caused at least $250,000 in property or crop damage. For events prior to 2018, please refer to Appendix K.

Table 10-1. Severe Weather Events in the State of California (2018 to 2022)

Date	Event Type	FEMA Declaration Number	USDA Declaration Number	Counties/Areas Impacted
March 15 – 17, 2018	Winter Storm	N/A	N/A	Shasta, Tehama
A series of cool storms brought travel impacts in the mountains from heavy snow. Thunderstorms in the Sacramento Valley had dime-sized hail. The event caused an estimated $300,000 in damages.				
July 13, 2018	Thunderstorm Wind	N/A	N/A	San Bernardino, Inyo
A substantial push of monsoon moisture helped trigger widespread thunderstorms across the Mojave Desert and southern Great Basin. Many storms produced severe weather and flash flooding. Thunderstorm winds derailed 15 train cars, blocking Highway 95. This event caused an estimated $666,000 in property damage.				
December 6, 2018	Winter Weather	N/A	N/A	Kern and Los Angeles
Several reports of 1-3 inches of snow were reported in the Kern County Mountains above 4,000 feet. The snow resulted in several roads being closed for a portion of the day including Interstate 5 from south of Grapevine in Kern County to Castaic in Los Angeles County after several vehicles became either stuck or were involved with accidents. This event caused approximately $250,000 in property damage.				

<table>
<tr><th>Date</th><th>Event Type</th><th>FEMA Declaration Number</th><th>USDA Declaration Number</th><th>Counties/Areas Impacted</th></tr>
<tr><td>January 17, 2019</td><td>Tornado</td><td>N/A</td><td>N/A</td><td>Mariposa, Kern, Tulare, Fresno</td></tr>
<tr><td colspan="5">A strong low-pressure system with deep moisture fetch pushed into central California during the afternoon of January 16 and brought moderate to heavy precipitation along with strong winds to much of the area through the afternoon of January 17. Several reports of roadway flooding were received during the morning of January 17 when the heaviest precipitation occurred. Flash flooding and debris flows were reported in the Ferguson Fire burn area in Mariposa County and State Route 140 was closed for over 11 hours. One thunderstorm produced a tornado east of Clovis which was rated as EF-1 following a storm survey of the damage it produced. There were also several reports of post-frontal wind gusts exceeding 50 mph in the Kern County Mountains and Deserts while low-impact indicator sites had gusts exceeding 65 mph.</td></tr>
<tr><td>February 2, 2019</td><td>Thunderstorm Wind</td><td>N/A</td><td>N/A</td><td>Mariposa, Fresno, Tulare, Kern</td></tr>
<tr><td colspan="5">A strong upper low-pressure system approached the central California coast during the morning of February 2. Ahead of the low, strong southerly winds impacted the Grapevine area along Interstate 5 for much of the morning. By late morning, the strong winds spread northward into the Bakersfield area where there were numerous reports of downed trees and wind damage. As the main low moved inland during the day, moderate to heavy precipitation spread into the area and produced several instances of roadway and nuisance flooding. Scattered thunderstorms brought additional rainfall and small hail to the San Joaquin Valley and southern Sierra foothills during the late afternoon. One thunderstorm produced a brief small tornado south of Mariposa. $257,000 in property was damaged.</td></tr>
<tr><td>February 14, 2019</td><td>Strong Wind</td><td>N/A</td><td>N/A</td><td>Santa Cruz Mountains</td></tr>
<tr><td colspan="5">Strong wind gusts downed trees and caused power outages and structural damage. A tree fell on a car causing one fatality and one injury on Highway 17 while another tree caused a multi-car accident.</td></tr>
<tr><td>February 17 – 18, 2019</td><td>Winter Storm</td><td>N/A</td><td>N/A</td><td>Kern City Mountains, S. Sierra Foothills</td></tr>
<tr><td colspan="5">Interstate 5 was closed by California Highway Patrol (CHP) between Grapevine and Castaic for several hours between the early evening of February 17 to the late morning of February 18 due to refreezing of rain and wet snow which led to the formation of black ice on several roads in the Kern County Mountains. Several vehicles spun out or crashed due to the black ice on Interstate 5. $250,000 in property was damaged.</td></tr>
</table>

Date	Event Type	FEMA Declaration Number	USDA Declaration Number	Counties/Areas Impacted
February 24 – March 1, 2019	Severe Winter Storms and Flooding	DR-4434	N/A	Amador, Butte, Calaveras, Colusa, Colusa, Del Norte, El Dorado, Glenn, Humboldt, Lake, Marin, Marin, Mariposa, Mendocino, Modoc, Monterey, Napa, Riverside, Santa Barbara, Shasta, Sonoma, Tehama, Trinity, Tuolumne, and Yolo
A series of heavy precipitation, snow, flooding, and winds impacted northern California. Numerous downed trees were reported, causing power outages and closed roadways. Property damage was estimated at over $1 million.				
May 19, 2019	Hail	N/A	N/A	Fresno
A strong upper-level low pressure system moved into central California during the afternoon of May 18. A cold front associated with this system pushed across the area overnight bringing periods of moderate to locally heavy precipitation to the area with much of the area picking up between 0.75 and 2 inches of liquid precipitation. There were several reports of small hail and locally heavy rainfall from areas impacted by these thunderstorms. One strong cell produced a small EF0 tornado near Huron as well as some wind damage. $75,000 in property damage and $16 million in crop damage resulted from this event.				
July 23 – 24, 2019	Thunderstorm Wind	N/A	N/A	Riverside, San Bernardino, San Diego
Strong thunderstorms led to microbursts in Riverside County, downing 20 utility poles and causing power outages. The winds also damaged cars, buildings, and infrastructure. Approximately $8 million in property damages was reported for this event.				
September 16-18, 2019	Severe Storms/ Winter Weather	N/A	N/A	Yuba, Tehama, Butte, Nevada
A series of cold, upper-level disturbances tracked across northern California, bringing showers, thunderstorms, and snow to higher elevations. Flooding and wind damage were the main impacts from this storm. Approximately $4 million in property damage and $2.5 million in crop damage resulted from this event.				

Date	Event Type	FEMA Declaration Number	USDA Declaration Number	Counties/Areas Impacted
August 22, 2020	Hail	N/A	N/A	San Bernardino
Thunderstorms developed over the Mojave Desert causing isolated flash flooding and hail damages. In San Bernardino, golf ball sized hail accumulated on I-15 at Mountain Pass and damaged vehicles. Approximately $250,000 in property damage was reported.				
January 18-19, 2021	High Wind	N/A	N/A	Sierra
A series of high wind events impacted the southern portion of the State, bringing strong winds over the Sierra Nevada and adjacent foothills. Wind gusts exceeded 60 mph for an 8-to-12-hour period. The strong winds downed power lines and caused extended power outages. Estimated 100 mph gusts near Yosemite Valley toppled several trees knocking out power to nearly all of Yosemite Park for several days. In addition, several structures were damaged by the winds and the park was closed for several days. Damages were estimated at $200 million.				
January 27, 2021	High Wind/Heavy Rain	N/A	N/A	Bakersfield
Heavy rain fell over northern and central California, causing flooding and wind damage. Wind gusts of up to 60 mph were measured. Rainfall totals ranged from 1-7 inches. Heavy snow fell in the Sierra Nevada as well. The storm led to extensive tree damage and approximately $250,000 in property damage.				
August 31, 2021	Thunderstorm Wind	N/A	N/A	Imperial
Rainfall occurred in northeast Imperial County along SR 78, where nearly 7 inches of rain was estimated to have fallen within a 5-hour period. An unbridged crossing along SR 78 at Milpitas Wash became flooded with swiftly flowing water due to the heavy rainfall. A vehicle attempting to cross through the flooded portion of the highway was swept off the roadway before overturning in the wash. Both occupants perished in the flash flood. Strong to severe thunderstorms across the Imperial Valley led to damaging wind gusts that resulted in numerous downed power poles. According to the Imperial Irrigation District, extensive damage sustained to the power infrastructure on both the 30th and 31st would cost the district more than $8 million.				

While California has tornadoes, such storms represent a relatively low risk for most areas, compared to states in the Midwestern and Southern United States where risk exposure is severe, and many lives and millions of dollars are lost annually due to this hazard. On average, the State of California experiences 11 tornadoes a year (The Weather Channel 2022).

El Niño events in 1982-1983 and 1997-1998 drenched the West Coast with record rain. The last El Niño, a weak one, occurred in 2018-2019 (Water Education Foundation 2022).

10.4. PROBABILITY OF FUTURE HAZARD EVENTS

10.4.1. Overall Probability

According to FEMA, NOAA, and the 2018 SHMP, the State of California experienced over 2,500 severe weather events between 1950 and 2022, as summarized in Table 10-2. This equates to an average of 35 severe weather events each year. Overall, the State can expect to experience at least a similar average frequency of these events in the future, with the possibility of an increase in frequency due to the impacts from climate change.

Table 10-2. Probability of Future Severe Weather Events in California

Hazard Type	Events Between 1950 and 2022	Average Frequency
Coastal Storms and Hurricanes	10	About 1 per 7 years
Windstorm	>500	More than 7 per year
Hailstorm	>500	More than 7 per year
Thunderstorm and Lightning	>500	More than 7 per year
Tornado	466	About 7 per year
Winter Weather (snow and ice)	>500	More than 7 per year

Source: (FEMA 2022o), (NCEI 2022b), and (Cal OES 2018)

10.4.2. Climate Change Impacts

A key theme in the California Climate Adaptation Strategy is the likelihood of more extreme weather-related events. Because the science is new, however, little is yet known about some of the potential effects of climate change on weather. For example, the California Adaptation Strategy does not include an in-depth assessment of the possibility of increasing numbers and intensities of windstorms.

While a specific event is difficult to project for a particular location, planners should be familiar with local weather patterns and be able to identify which events meet or go beyond the historically observed range that would pose the greatest risk to a community. This could be intense rainfall, wind, heat, powerful hurricanes, or any other climate change-influenced event. Communities should include the potential for these events in their planning process. For example, severe coastal storms may increase in frequency and severity. This potential should be incorporated into coastal community plans for land use and emergency response.

10.5. IMPACT ANALYSIS

10.5.1. Severity

Coastal Storms

Only two tropical storms have had a landfall in California. The first was on September 24, 1939. This storm approached the Los Angeles area but lost hurricane strength just before making landfall at San Pedro as a tropical storm (Sistek 2022). The second was Tropical Storm Kay, in September 2022 (State of California 2022m).

Windstorms

Table 10-3 provides the description of winds used by the NWS during wind-producing events.

Table 10-3. NWS Wind Descriptions

Description	Sustained Wind Speed (mph)
Strong, dangerous, or damaging	≥40
Very Windy	30-40
Windy	20-30
Breezy, brisk, or blustery	15-25
None	5-15 or 10-20
Light or light and variable wind	0-5

Source: (NWS 2022a)

One of the first scales to estimate wind speeds and effects was created by Sir Francis Beaufort (1774-1857). He developed a scale in 1805 to help sailors estimate winds via visual observations. The scale starts with 0 and goes to a force of 12. The Beaufort scale is still used today to estimate wind strengths. Table 10-4 shows the Beaufort Wind Scale ratings.

Hailstorms

Hail size is often estimated by comparing it to a known object, as shown in Figure 10-2. Most hailstorms are made up of a mix of different sizes, and only the very largest hail stones pose serious risk to people caught in the open (NWS 2022g).

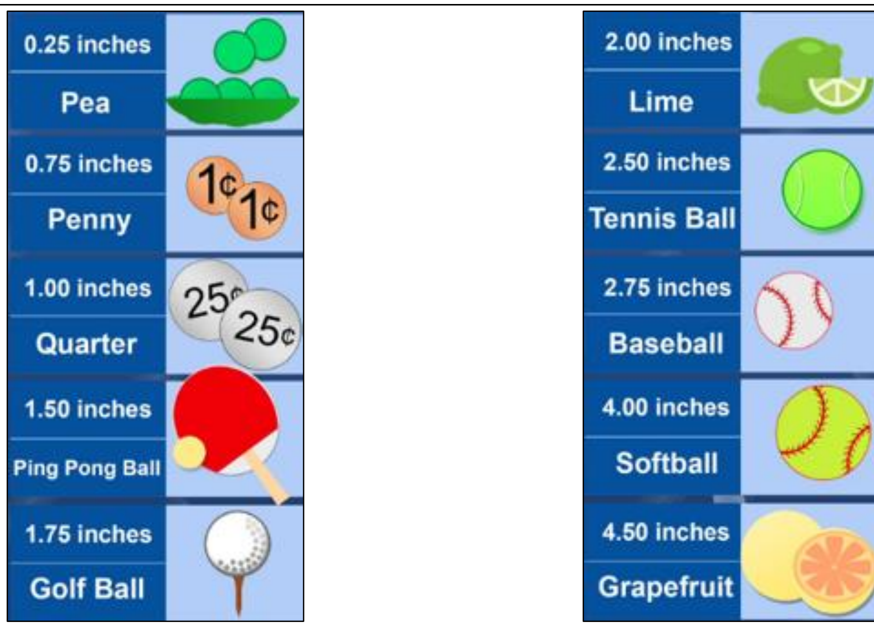
Table 10-4. Beaufort Wind Scale

Force	Speed (mph)	Speed (knots)	Description	Specifications for use at sea / Specifications for use on land
0	0-1	0-1	Calm	Sea like a mirror. Calm: smoke rises vertically.
1	1-3	1-3	Light Air	Ripples with the appearance of scales are formed, but without foam crests. Direction of wind shown by smoke drift, but not by wind vanes.
2	4-7	4-6	Light Breeze	Small wavelets, still short, but more pronounced. Crests have a glassy appearance and do not break. Wind felt on face; leaves rustle; ordinary vanes moved by wind.
3	8-12	7-10	Gentle Breeze	Large wavelets. Crests begin to break. Foam of glassy appearance. Perhaps scattered white horses. Leaves and small twigs in constant motion; wind extends light flag.
4	13-18	11-16	Moderate Breeze	Small waves, becoming larger; frequent white horses. Raises dust and loose paper; small branches are moved.
5	19-24	17-21	Fresh Breeze	Moderate waves, taking a more pronounced long form; many white horses are formed. Small trees in leaf begin to sway; crested wavelets form on inland waters.
6	25-31	22-27	Strong Breeze	Large waves begin to form; the white foam crests are more extensive everywhere. Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty.
7	32-38	28-33	Near Gale	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind. Whole trees in motion; inconvenience felt when walking against the wind.
8	39-46	34-40	Gale	Moderately high waves of greater length; edges of crests begin to break into spindrift. The foam is blown in well-marked streaks along the direction of the wind. Breaks twigs off trees; generally, impedes progress.
9	47-54	41-47	Severe Gale	High waves. Dense streaks of foam along the direction of the wind. Crests of waves begin to topple, tumble, and roll over. Spray may affect visibility Slight structural damage occurs (chimney pots and slates removed)

Force	Speed (mph)	Speed (knots)	Description	Specifications for use at sea / Specifications for use on land
10	55-63	48-55	Storm	Very high waves with long overhanging crests. The resulting foam, in great patches, is blown in dense white streaks along the direction of the wind. Overall, the surface of the sea takes on a white appearance. The tumbling of the sea becomes heavy and shock-like. Visibility affected.
				Seldom experienced inland; trees uprooted; considerable structural damage occurs.
11	64-72	56-63	Violent Storm	Exceptionally high waves (small and medium-size ships might be for a time lost to view behind the waves). The sea is completely covered with long white patches of foam lying in the direction of the wind. Everywhere the edges of the wave crests are blown into froth. Visibility affected.
				Very rarely experienced; accompanied by wide-spread damage.
12	72-83	64-71	Hurricane	The air is filled with foam and spray. Sea completely white with driving spray; visibility very seriously affected.
				See Saffir-Simpson Hurricane Scale

Source: (NWS n.d.-a)

Figure 10-2. Hail Size Chart

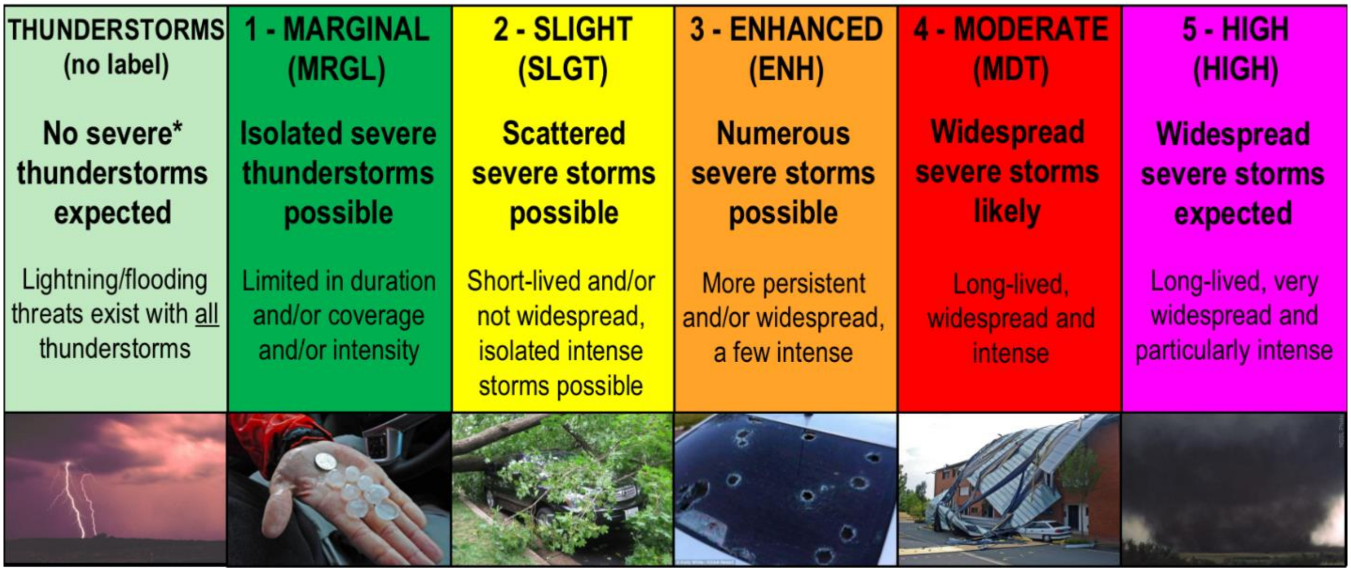


Source: (NWS 2020)

Thunderstorms

The National Weather Service Storm Prediction Center (SPC) issues severe thunderstorm risk maps based on the likelihood of different severities of thunderstorms. Figure 10-3 shows the SPC's severe thunderstorm risk categories (SPC 2020).

Figure 10-3. Severe Thunderstorm Risk Categories



Source: (SPC 2020)

Lightning severity is determined by the frequency of lightning strikes during a storm. Multiple devices are available to track and monitor the frequency of lightning, including NOAA's nowCOAST weather tracking tool (NOAA 2023).

Tornadoes

The severity of a tornado is categorized using the Enhanced Fujita Tornado Intensity Scale (EF Scale), which compares wind speed and actual damage. Figure 10-4 illustrates the relationship between EF ratings, wind speed, and expected tornado damage.

Figure 10-4. Explanation of EF-Scale Ratings

EF Rating	Wind Speeds	Expected Damage
EF-0	65-85 mph	'Minor' damage: shingles blown off or parts of a roof peeled off, damage to gutters/siding, branches broken off trees, shallow rooted trees toppled.
EF-1	86-110 mph	'Moderate' damage: more significant roof damage, windows broken, exterior doors damaged or lost, mobile homes overturned or badly damaged.
EF-2	111-135 mph	'Considerable' damage: roofs torn off well constructed homes, homes shifted off their foundation, mobile homes completely destroyed, large trees snapped or uprooted, cars can be tossed.
EF-3	136-165 mph	'Severe' damage: entire stories of well constructed homes destroyed, significant damage done to large buildings, homes with weak foundations can be blown away, trees begin to lose their bark.
EF-4	166-200 mph	'Extreme' damage: Well constructed homes are leveled, cars are thrown significant distances, top story exterior walls of masonry buildings would likely collapse.
EF-5	> 200 mph	'Massive/incredible' damage: Well constructed homes are swept away, steel-reinforced concrete structures are critically damaged, high-rise buildings sustain severe structural damage, trees are usually completely debarked, stripped of branches and snapped.

Source: (NWS n.d.-e)

Winter Weather

The Sperry-Piltz Ice Accumulation (SPIA) Index predicts the projected footprint, total ice accumulation, and resulting potential damage from incoming ice storms. The SPIA Index, shown in Figure 10-5, is based on three parameters: storm total rainfall, converted to ice accumulation; wind; and temperatures during the event period (SPIA Index n.d.).

Figure 10-5. Sperry-Piltz Ice Accumulation

Ice Damage Index	Damage and Impact Descriptions
0	Minimal risk of damage to exposed utility systems; no alerts or advisories needed for crews, few outages.
1	Some isolated or localized utility interruptions are possible, typically lasting only a few hours. Roads and bridges may become slick and hazardous.
2	Scattered utility interruptions expected, typically lasting 12 to 24 hours. Roads and travel conditions may be extremely hazardous due to ice accumulation.
3	Numerous utility interruptions with some damage to main feeder lines and equipment expected. Tree limb damage is excessive. Outages lasting 1 – 5 days.
4	Prolonged & widespread utility interruptions with extensive damage to main distribution feeder lines and some high voltage transmission lines/structures. Outages lasting 5 – 10 days.
5	Catastrophic damage to entire exposed utility systems, including both distribution and transmission networks. Outages could last several weeks in some areas. Shelter needed.

Source: (SPIA Index n.d.)

10.5.2. Warning Time

Coastal Storms

The Coastal Storm Modeling System (CoSMoS) provides emergency responders and coastal planners with critical storm-hazard information such as flood extent, flood depth, duration of flooding, wave height, and currents that can be used to increase public safety, mitigate physical damages, and more effectively manage complex coastal settings. The Coastal and Marine Hazards and Resources Program initially developed CoSMoS in collaboration with Deltares, and later in partnership with the National Oceanic and Atmospheric Administration, the National Park Service, and non-governmental organizations (NGOs) (USGS 2019e).

Windstorms

NWS issues advisories and warnings for winds, which are normally site-specific. High wind advisories, watches, and warnings are issued by the NWS when wind speeds may pose a hazard or may be life threatening. The criteria for each of these varies from state to state.

Thunderstorms

Severe thunderstorm watches and warnings are issued by the local NWS office and the SPC. A severe thunderstorm warning is issued when thunderstorms are producing hail equal to or greater than 1 inch in diameter or wind gusts of at least 58 mph are occurring or imminent. The local NWS office and the SPC update watches and warnings and notify the public when they are no longer in effect.

10.5.3. Cascading Impacts

Cascading impacts are the impacts that result when one type of hazard event triggers one or more other hazard events, which may in turn trigger still others. The following are notable cascading impacts associated with severe wind, weather, and storms:

- The most significant cascading hazards associated with severe local storms are floods, mudslides, landslides, sinkholes, and power failures.
- PSPS events associated with severe weather events.
- Rapidly melting snow combined with heavy rain can overwhelm both natural and constructed drainage systems, causing overflow and property destruction.
- Landslides occur when the soil on slopes becomes oversaturated and fails.
- Lightning can start wildfires.
- Road closures caused by weather can restrict the movement of people and goods.

10.5.4. Environmental Impacts

Severe weather that creates long periods of rainfall can erode natural banks along waterways and degrade soil stability for terrestrial species. Tornadoes can tear apart habitats, causing fragmentation across ecosystems. Researchers believe that a greater number of diseases can spread across ecosystems because of impacts that severe weather and climate change have on water supplies (CDC 2022b). The residual impacts of a community’s methods to maintain its infrastructure through winter weather (such as road salting) may also have an impact on the environment. Reduced snowpack in the mountainous regions can worsen both drought and wildfire (National Integrated Drought Information System n.d.).

10.5.5. Local Hazard Impacts

LHMP Rankings

County hazard mitigation plans often identify "severe weather" as a hazard of concern without separating specific weather types from each other. Of the 58 counties in California, four assessed tornado as a hazard of concern. All four ranked it as low risk. Severe weather was assessed as a hazard of concern in 54 counties' hazard mitigation plans. The following 31 counties listed severe weather as a high-risk hazard:

- Alpine
- Amador
- Butte
- Calaveras
- El Dorado
- Humboldt
- Imperial
- Inyo
- Kern
- Lake
- Madera
- Mendocino
- Merced
- Modoc
- Mono
- Monterey
- Napa
- Nevada
- Placer
- San Benito
- San Diego
- San Joaquin
- Santa Barbara
- Santa Clara
- Shasta
- Siskiyou
- Solano
- Stanislaus
- Trinity
- Tulare
- Yolo

LHMP Estimates of Potential Loss

A review of the LHMPs in the counties (as called for in FEMA's Standard State Mitigation Planning Requirement S6.b) found no quantitative risk analysis that identifies population or structures exposed to this hazard. This can be attributed to the lack of extent and location hazard mapping to use for such an analysis. Therefore, no summary of risk for local plan reviews is provided for this hazard.

10.6. VULNERABILITY ANALYSIS

To understand risk, the assets exposed to hazards must be identified. For severe weather, the entire State of California is exposed. However, certain areas are more vulnerable to specific severe weather events than others due to geographic location and local weather patterns.

10.6.1. Exposure of State-Owned or -Leased Facilities

All State-owned or -leased assets, as listed in Table 4-1 and Table 4-2, are exposed to severe weather and storms. This includes 23,961 State-owned facilities, and 1,893 State-leased facilities.

10.6.2. Exposure of Critical Facilities and Community Lifelines

All 755 State critical facilities and community lifelines, as listed in Table 4-3, are exposed to the severe weather hazard. Loss of utilities and closed roadways are the most common issue with severe weather events. Impacts on transportation lifelines affect both short-term (e.g., evacuation activities) and long-term (e.g., day-to-day commuting and goods transport) transportation needs. The utility infrastructure can also suffer damage, resulting in widespread power outages. The interruption of power, water, wastewater, hospital services, and other emergency services has cascading impacts on the State's population and all forms of economic activity.

Critical facilities and community lifelines that are exposed to severe wind, weather, and storms are likely to experience functional downtime associated with loss of power following these events, which could increase the net impact of these events. Additionally, the impacts of road closures during severe storm events can cause functional downtime due to inaccessibility of locations and/or ability of employees to come to work.

10.6.3. Estimates of Loss

Depending on the severity and duration of the severe weather event, damage to State assets can include roof damage from wind, structural damage from downed trees, and power outages. State infrastructure can be impacted by debris and downed trees/power lines, causing road closures, power outages, and limiting access to emergency personnel.

Loss estimations for the severe weather hazards profiled in this assessment are not based on damage functions, because no such damage functions have been generated. Instead, loss estimates were developed representing 10 percent, 30 percent, and 50 percent of the replacement cost value of all State-owned facilities (see Table 10-5). This allows the State to select a range of potential economic impacts based on an estimate of the percentage of damage to these assets. Damage in excess of 50 percent is considered to be substantial by most building codes and typically requires total reconstruction of the structure.

Table 10-5. Loss Potential of State-Owned Facilities for Severe Wind, Weather, and Storms

Type of Facility	Total Replacement Cost Value	Estimated Loss Potential Based on % Damage		
		10% Damage	30% Damage	50% Damage
Facilities Housing Vulnerable Populations				
Correctional Facility	$5,673,743,477	$567,374,348	$1,702,123,043	$2,836,871,738
Development Center	$696,669,418	$69,666,942	$209,000,825	$348,334,709
Hospital	$837,461,197	$83,746,120	$251,238,359	$418,730,598
Migrant Center	$996,980,976	$99,698,098	$299,094,293	$498,490,488
Special School	$128,610,363	$12,861,036	$38,583,109	$64,305,182
All Other Facilities	**$28,392,185,985**	**$2,839,218,598**	**$8,517,655,796**	**$14,196,092,992**
Total	**$36,725,651,416**	**$3,672,565,142**	**$11,017,695,425**	**$18,362,825,708**

10.6.4. Buildable Land

An estimated 11.7 million acres of land is available for development in California. Because the entire State is vulnerable to severe weather, any type of development of any of this land will be susceptible to damage and impacts from this hazard.

10.6.5. Equity Priority Communities

Because the entire population of the State of California is exposed and vulnerable to severe weather, the exposed population in equity priority communities is equal to the statewide percentage: 30.4 percent of the total population (12 million people).

Priority populations include older adults, people with disabilities, people with low income or linguistically isolated populations, people with chronic conditions and life-threatening illnesses, individuals experiencing homelessness, and residents living in areas that are isolated from major roads. Power outages can be life-threatening to those dependent on electricity for assistive technology and life-sustaining medical devices and is a significant concern. These populations face isolation and exposure during severe weather events and are likely to suffer more secondary effects of the hazard.

10.6.6. NRI Scores

Strong Wind

According to the NRI, all of the State's counties have strong wind risk, rated from very low to very high. Table 10-6 shows scores for the six counties with the highest rating. See Section 4.1.3 for a description of the components of the NRI.

Table 10-6. NRI Scoring of Counties for Strong Wind

County	Expected Annual Loss	Social Vulnerability Rating	Community Resilience Rating	Community Risk Factor	Risk Value	Score
Los Angeles	$569,654	Very High	Very Low	1.36	$795,169	73.46
Riverside	$260,521	Very High	Relatively Low	1.34	$342,928	46.2
San Diego	$275,332	Relatively High	Very Low	1.20	$334,902	45.53
San Bernardino	$233,745	Very High	Relatively Moderate	1.34	$314,175	43.46
Imperial	$156,546	Very High	Very Low	1.70	$253,897	36.84
Orange	$201,184	Relatively Moderate	Very Low	1.26	$251,692	36.68

Hail

According to the NRI, all of the State's counties have hail risk, rated from very low to relatively moderate. Table 10-7 shows scores for the six counties with the highest rating. See Section 4.1.3 for a description of the components of the NRI.

Table 10-7. NRI Scoring of Counties for Hail

County	Expected Annual Loss	Social Vulnerability Rating	Community Resilience Rating	Community Risk Factor	Risk Value	Score
Fresno	$1,341,822	Very High	Relatively Low	1.53	$2,045,009	94.65
Tulare	$624,358	Very High	Very Low	1.55	$993,965	88.51
Kern	$292,913	Very High	Very Low	1.41	$431,559	77.63
Madera	$197,348	Very High	Very Low	1.41	$292,345	70.44
San Bernardino	$131,055	Very High	Relatively Moderate	1.34	$171,618	61.06
San Joaquin	$114,293	Very High	Relatively High	1.32	$151,064	57.08

Thunderstorm

According to the NRI, all of the State's counties have thunderstorm risk, rated from very low to relatively high. Table 10-8 shows scores for the six counties with the highest rating. See Section 4.1.3 for a description of the components of the NRI.

Table 10-8. NRI Scoring of Counties for Thunderstorm

County	Expected Annual Loss	Social Vulnerability Rating	Community Resilience Rating	Community Risk Factor	Risk Value	Score
Los Angeles	$774,547	Very High	Very Low	1.36	$1,104,747	95.01
Contra Costa	$552,279	Relatively Moderate	Relatively High	1.11	$630,520	89.32
Stanislaus	$370,800	Very High	Relatively Moderate	1.43	$519,711	87.00
Kern	$367,329	Very High	Very Low	1.41	$515,940	86.81
Butte	$254,470	Very High	Relatively High	1.25	$329,057	79.89
San Joaquin	$237,850	Very High	Relatively High	1.32	$320,007	79.50

Tornado

According to the NRI, all of the State's counties have tornado risk, rated from very low to relatively high. Table 10-9 shows scores for the six counties with the highest rating. See Section 4.1.3 for a description of the components of the NRI.

Table 10-9. NRI Scoring of Counties for Tornado

County	Expected Annual Loss	Social Vulnerability Rating	Community Resilience Rating	Community Risk Factor	Risk Value	Score
Los Angeles	$16,313,687	Very High	Very Low	1.36	$21,880,211	97.61
Riverside	$5,237,380	Very High	Relatively Low	1.34	$6,816,650	89.47
Orange	$4,799,429	Relatively Moderate	Very Low	1.26	$5,847,332	87.40
San Bernardino	$3,398,026	Relatively Moderate	Very Low	1.34	$4,548,618	83.17
San Diego	$2,054,719	Relatively High	Very Low	1.20	$2,466,557	70.73
Alameda	$2,198,340	Relatively Moderate	Very High	1.13	$2,408,097	70.12

Winter Weather

According to the NRI, 52 of the State's counties have winter weather risk, rated from very low to relatively high. Table 10-10 shows scores for the six counties with the highest rating. See Section 4.1.3 for a description of the components of the NRI.

Table 10-10. NRI Scoring of Counties for Winter Weather

County	Expected Annual Loss	Social Vulnerability Rating	Community Resilience Rating	Community Risk Factor	Risk Value	Score
Mono	$317,625	Relatively Moderate	Relatively High	1.17	$370,412	88.51
Alpine	$106,849	Relatively Moderate	Relatively Moderate	1.35	$144,225	72.96
El Dorado	$103,764	Relatively Low	Relatively High	1.02	$112,264	66.59
Nevada	$79,943	Relatively Low	Relatively High	0.98	$78,097	57.14
Tuolumne	$58,693	Relatively Moderate	Relatively Moderate	1.16	$62,138	50.72
Los Angeles	$46,516	Very High	Very Low	1.36	$56,395	48.55

10.7. MITIGATING THE HAZARD

10.7.1. Existing Measures to Mitigate the Hazard

Storm-related mitigation activities that occur during storm season in California include clearing culverts, marshaling heavy equipment, training crews in flood-fighting techniques, and sharing weather-related information with the public.

10.7.2. Opportunities for Mitigating the Hazard

Planners should be familiar with local weather patterns and be able to identify which events meet or go beyond the historically observed range that would pose the greatest risk to a community. This could be any climate change-influenced event. Communities should include the potential for these events in their planning process. For example, severe coastal storms may increase in frequency and severity. This potential should be incorporated into coastal community plans for land use and emergency response. A range of alternatives by scale to mitigate the severe wind, weather, and storms hazards is provided in Table 10-11.

Table 10-11. Potential Opportunities to Mitigate the Severe Weather Hazards

Community-Scale	Organizational Scale	Government-Scale
Manipulate the hazard: ▪ None **Reduce exposure and vulnerability:** ▪ Insulate residential and non-residential structures ▪ Provide redundant heat and power ▪ Plant appropriate trees near home and power lines ("Right tree, right place" National Arbor Day Foundation Program) **Build local capacity:** ▪ Trim or remove trees that could affect power lines ▪ Promote 72-hour self-sufficiency ▪ Obtain a NOAA weather radio ▪ Obtain an emergency generator	**Manipulate the hazard:** ▪ None **Reduce exposure and vulnerability:** ▪ Relocate critical infrastructure (such as power lines) underground ▪ Reinforce or relocate critical infrastructure such as power lines to meet performance expectations ▪ Install tree wire **Build local capacity:** ▪ Trim or remove trees that could affect power lines ▪ Create redundancy ▪ Equip facilities with a NOAA weather radio ▪ Equip vital facilities with emergency power sources	**Manipulate the hazard:** ▪ None **Reduce exposure and vulnerability:** ▪ Harden infrastructure such as locating utilities underground ▪ Trim trees back from power lines ▪ Designate snow routes and strengthen critical roads and bridges ▪ Use the best available technology to enhance the warning systems for all severe weather events **Build local capacity:** ▪ Support programs such as "Tree Watch" that proactively manage problem areas through the use of selective removal of hazardous trees, tree replacement, etc. ▪ Establish and enforce building codes that require all roofs to withstand snow loads ▪ Increase communication alternatives ▪ Enhance public awareness campaigns to address actions to take during severe weather events ▪ Coordinate severe weather warning capabilities and the dissemination of warning among agencies with the most capability ▪ Modify land use and environmental regulations to support vegetation management activities that improve reliability in utility corridors ▪ Modify landscape and other ordinances to encourage appropriate planting near overhead power, cable, and phone lines ▪ Provide NOAA weather radios to the public ▪ Consider the probable impacts of climate change on risk associated with the severe weather hazard ▪ Evaluate and revise, as needed, building codes to address severe weather impacts on residents
Nature-based opportunities ▪ No nature-based solutions have been identified to mitigate severe wind, weather, and storms.		

10.7.3. Selected Actions to Mitigate the Hazard

The mitigation strategy developed for this SHMP includes the following actions that address severe weather:

- Action 2018-001: Support Legislative Efforts that Formalize California's Comprehensive Mitigation Program.
- Action 2018-006: Enhance Collaboration on the Development and Sharing of Data Systems and GIS modeling.
- Action 2018-008: Develop a database containing a description of the specific natural hazard event for which each project was designed to mitigate.

Sea-Level Rise, Coastal Flooding, and Erosion

Climate Impacts:
Shoreline erosion, coastal flooding, water pollution, degraded or disturbed coastal ecosystems, and impacts to human-made structures

Equity Impacts:
Sea-Level Rise – 11.4% of population living in the 6-foot sea-level rise hazard area identified as living in equity priority communities
Coastal Flooding – 3% of population living in the 1% annual chance coastal flood hazard area identified as living in equity priority communities

State Facilities Exposed:
Sea-Level Rise – 42 facilities in the 6-foot hazard area
Coastal Flooding – 81 facilities in the 1% percent chance flood hazard areas (coastal)

Community Lifelines Exposed:
Sea-Level Rise – 1 lifeline in the 6-foot hazard area
Coastal Flooding – 4 lifelines in the 1% annual chance flood hazard areas (coastal)

Impact Rating: High (33)

11. SEA-LEVEL RISE, COASTAL FLOODING, AND EROSION

The sea-level rise, coastal flooding, and erosion hazard has been identified as a high-impact natural hazard of interest based on the hazard impact rating protocol applied for this SHMP. Events associated with this hazard happen frequently in the State. About 14 percent of State-owned or -leased facilities and community lifelines are exposed to the hazard. Approximately 5 percent of the State's population is exposed to these hazards, and over 30 percent of that population has been identified as living in equity priority communities. About 7 percent of the identified buildable lands in the State intersect mapped sea-level rise, coastal flood, and erosion hazard areas. The frequency and severity of this hazard is anticipated to increase over the next 30 years due to the impacts of climate change.

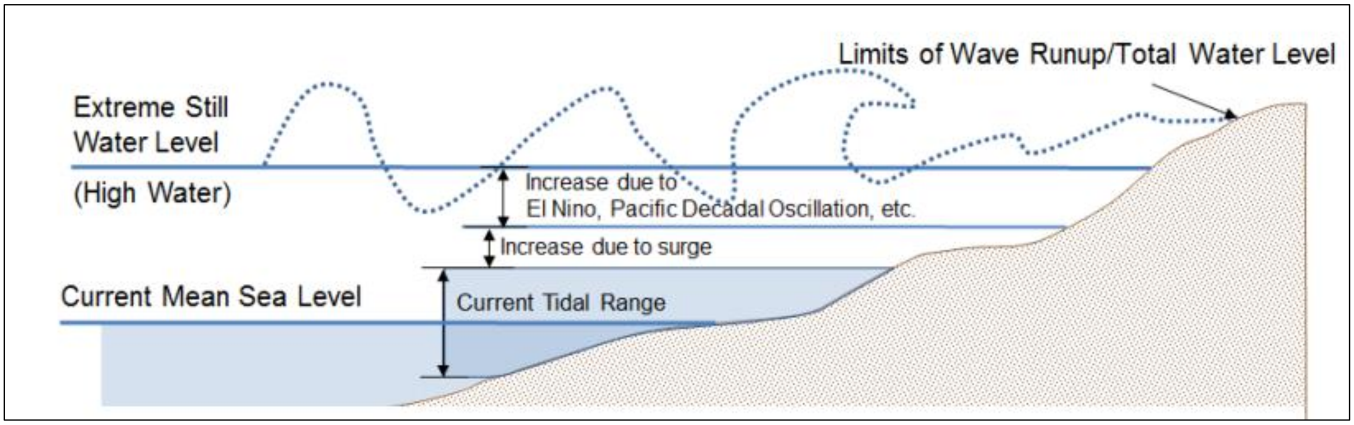
11.1. HAZARD OVERVIEW

California has more than 1,100 miles of outer coast featuring bluffs, beaches, and wetlands, in addition to bay shorelines and the Sacramento-San Joaquin River Delta. The San Francisco Bay shoreline alone is approximately 300 miles, not including the Delta. The coast supports varying levels of development and land use, including recreational, agricultural, industrial, commercial, and residential uses. These coastal areas are exposed to coastal flooding and erosion. Changes to sea level will increase the occurrence and severity of coastal flooding and erosion events (Cal OES 2018a).

11.1.1. Sea-Level Rise

Sea-level rise is an increase in the average level of the ocean. Generally, sea-level rise progressively worsens the impact of high tides and wind-driven waves associated with severe storms. Coupled with increased frequency, severity, and duration of high tide and storm events related to climate change, sea-level rise will exacerbate these extreme events along the coast. El Niño events exacerbate storms and coastal inundation above that already occurring due to sea-level rise and normal coastal weather and tidal patterns (Barnard 2017). The additive effects of high tides, storm surge, atmospheric patterns (e.g., El Niño) and sea-level rise are shown in Figure 11-1.

Figure 11-1. Additive Effects of Sea-Level Rise



Source: (California Coastal Commission 2018)

Increases in global sea level result from three primary causes: ocean expansion caused by warming water; the melting of land-based ice, including mountain glaciers, ice caps, and the polar ice sheets of Greenland and Antarctica; and land-water storage changes. Since 2006, the melting of land ice from glaciers and ice sheets has become the most important contributor to sea-level rise, with mountain glaciers contributing 20 percent and ice sheets 33 percent (IPCC 2019). If the current rate of loss for these ice sheets continues, their contribution will become the dominant source of sea-level rise (OPC 2017).

While global mean sea level is rising, it is relative sea level—the local difference in elevation between the height of the sea surface and the height of the land surface at any particular location—that affects coastal communities and ecosystems at risk from coastal flooding.

Future changes in relative sea level will vary along the length of the California coastline and can be influenced by factors such as the following:

- Fluctuating ocean and atmospheric patterns (e.g., El Niño, which usually causes regional sea level to rise along the California coast for several months)
- Vertical land movement from tectonic forces, sediment compaction, or extraction of water or hydrocarbon

- Changes in river flows that affect runoff
- Weather such as storm surge and wave runup during severe storm conditions

11.1.2. Coastal Flooding

Coastal flooding is the rising of tidally influenced waters due to high astronomical tides or storm surge. Most locations in California experience two high and two low tides daily. Storm surge is the abnormal rise in seawater level during a storm, measured as the height of the water above the normal predicted astronomical tide. The surge is caused primarily by a storm's winds pushing water onshore. The amplitude of the storm surge at any given location depends on the orientation of the coastline relative to the storm track; the intensity, size, and speed of the storm; and the local underwater topography (NOAA 2022a). When astronomical high tides and storm surge occur at the same time, the risk for coastal flooding is much greater.

High-tide flooding, often referred to as "nuisance" or "sunny day" flooding, is increasingly common due to years of relative sea-level increases. It occurs when tides reach anywhere from 1.75 to 2 feet above the daily average high tide and start spilling onto streets or bubbling up from storm drains. Overall, coastal flooding is more likely during El Niño conditions than it is during La Niña conditions (C. f. NOAA 2021c).

11.1.3. Erosion

Coastal flooding usually coincides with storm events that have significant wave action. During coastal flooding, waves are able to reach higher up the beach face, resulting in greater rates of erosion. This can result in loss of beach volume and slumping and collapse of sections of coastal bluffs and cliffs.

Coastal erosion is a natural, ongoing sediment redistribution process that continually changes beaches, dunes, and bluffs. Waves, tides, currents, wind-driven water, ice, rainwater runoff, groundwater seepage, and rising sea levels all move sand, sediment, and water along the coastline (Giang 2011), resulting in the transfer of sediment from one location to another. Coastal erosion may also be exacerbated by human activities, such as boat wakes, shoreline hardening, and dredging (FEMA 1996).

The addition of sediment is referred to as accretion. Accretion can be beneficial if it strengthens a shoreline, leading to wider beaches and more material for dune building. However, it can also narrow channels and inlets, leading to an increase of coastal flooding or lack of safe water access for boats and ships (Galgano 2009).

Coastal erosion is one of the primary hazards leading to loss of lives or damage to property and infrastructure in coastal areas. It is typically discussed as a sporadic event associated with other types of natural hazards, such as winter weather, but also occurs constantly at a lower rate.

11.2. HAZARD LOCATION

11.2.1. Sea-Level Rise

No single sea-level rise inundation area dataset for the entire California coastline was available at the time this SHMP was prepared. A comprehensive data set is in the process of being developed under the "Our Coast, Our Future" program sponsored by the USGS, but it is not complete. Therefore, this assessment used two data sets that look at two timeframes for sea-level rise projections.

- The USGS "Our Coast, Our Future" data set that provides coverage from San Diego County to the Marin County/Mendocino County border.
- The NOAA Office for Coastal Management's Sea-Level Rise Viewer, a national data set that provided coverage from Mendocino County to Del Norte County.

Both data sets define inundation area for sea-level rise intervals that align with the State's sea-level rise projections for 2050 and 2100. However, the models use different approaches and therefore show different sea-level rise impacts. The differences in the models are summarized as follows:

- The Our Coast, Our Future data was modeled using the USGS Coastal Storm Modeling System. This system allows predictions of coastal flooding due to both future sea-level rise and storms integrated with long-term coastal evolution. The 100 cm (3.3 feet) of sea-level rise and 200 cm (6.6 feet) of sea-level rise intervals were chosen to align with the 2050 and 2100 projections, respectively.
- The NOAA data is often referred to as the "bathtub" model, showing a static rise over mean higher high water. The 3 feet of sea-level rise and 6 feet of sea-level rise intervals were chosen to align with the State's 2050 and 2100 projections, respectively.

Two aggregate data sets were developed to assess the risk from sea-level rise. Figure 11-2 and Figure 11-3 show the extent and location for the two projections.

Figure 11-2. Projected Sea-Level Rise Extents for 2050

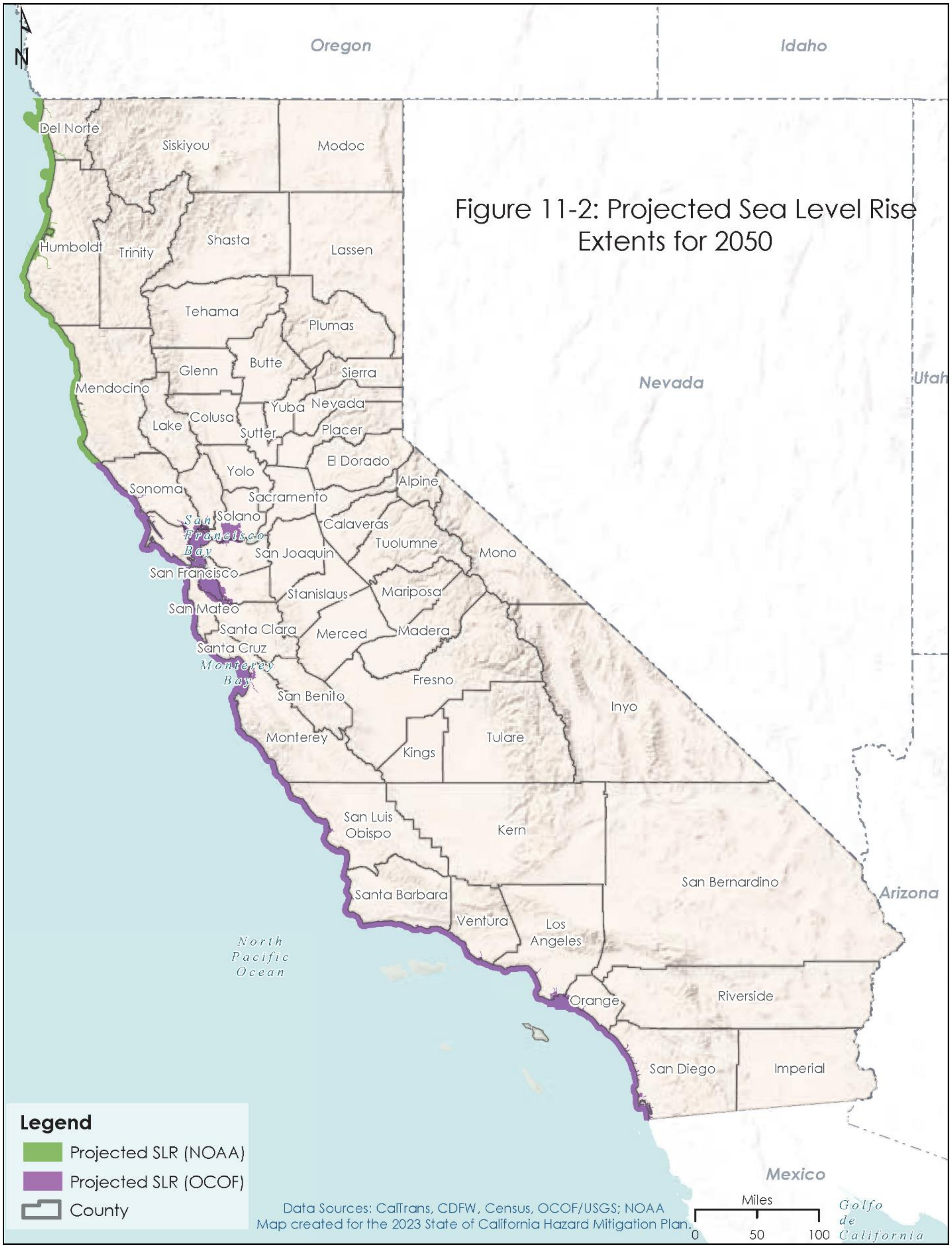


Figure 11-3. Projected Sea-Level Rise Extents for 2100

11.2.2. Coastal Flooding

Low-lying coastal areas in California are vulnerable to coastal flooding and can be impacted during high-water caused by storms, astronomical conditions, and significant wave action. Certain areas along the coast may have higher risk of experiencing structural damage caused by wave action or high-velocity water during the 1% annual-chance flood. These areas are identified on FIRMs as Coastal High-Hazard Areas (FEMA 2021b).

Storm surge modeling computes the maximum potential storm surges based on storm movement in different directions and strengths in combination with topography and tides (National Hurricane Center n.d.). Figure 11-4 shows the mapped coastal flood zones for the State of California.

11.2.3. Erosion

Coastal erosion, of varying degree, is possible at all locations along the California coastline. Erosional rates are dependent on numerous factors including sediment type, erosional forces, and sediment supply (A. Young 2021). There is no validated statewide dataset for mapping the extent and location of the coastal erosion hazard. Therefore, the assessment of coastal erosion risk in this plan is qualitative. If local mitigation planning efforts have good data on extent and location of the coastal erosion hazard, they are encouraged to use that data for more quantitative assessment of risk.

11.3. PREVIOUS HAZARD OCCURRENCES

11.3.1. Disaster and Emergency Declarations

The following disaster declarations or emergency proclamations related to flood-related events in coastal counties have been issued for California (see Appendix F for details):

- Federal DR or EM declaration, 1953 – 2022: 30 events, classified as flood, coastal storm, or hurricane (FEMA 2022d)
- California Emergency Proclamations, 1950 – 2022: 4, classified as flood/high tides
- USDA agricultural disaster declarations, 2012 – 2022: None

Figure 11-4. FEMA Mapped Coastal Flood Hazard Zones

11.3.2. Event History

Table 11-1 lists coastal flooding and severe episodic erosion events that have impacted California between 2018 and 2022. As shown in Figure 11-5, changes in sea level have been occurring for at least the last 100 years and are projected to continue. The rate of sea-level rise is increasing, and this trend is projected to continue.

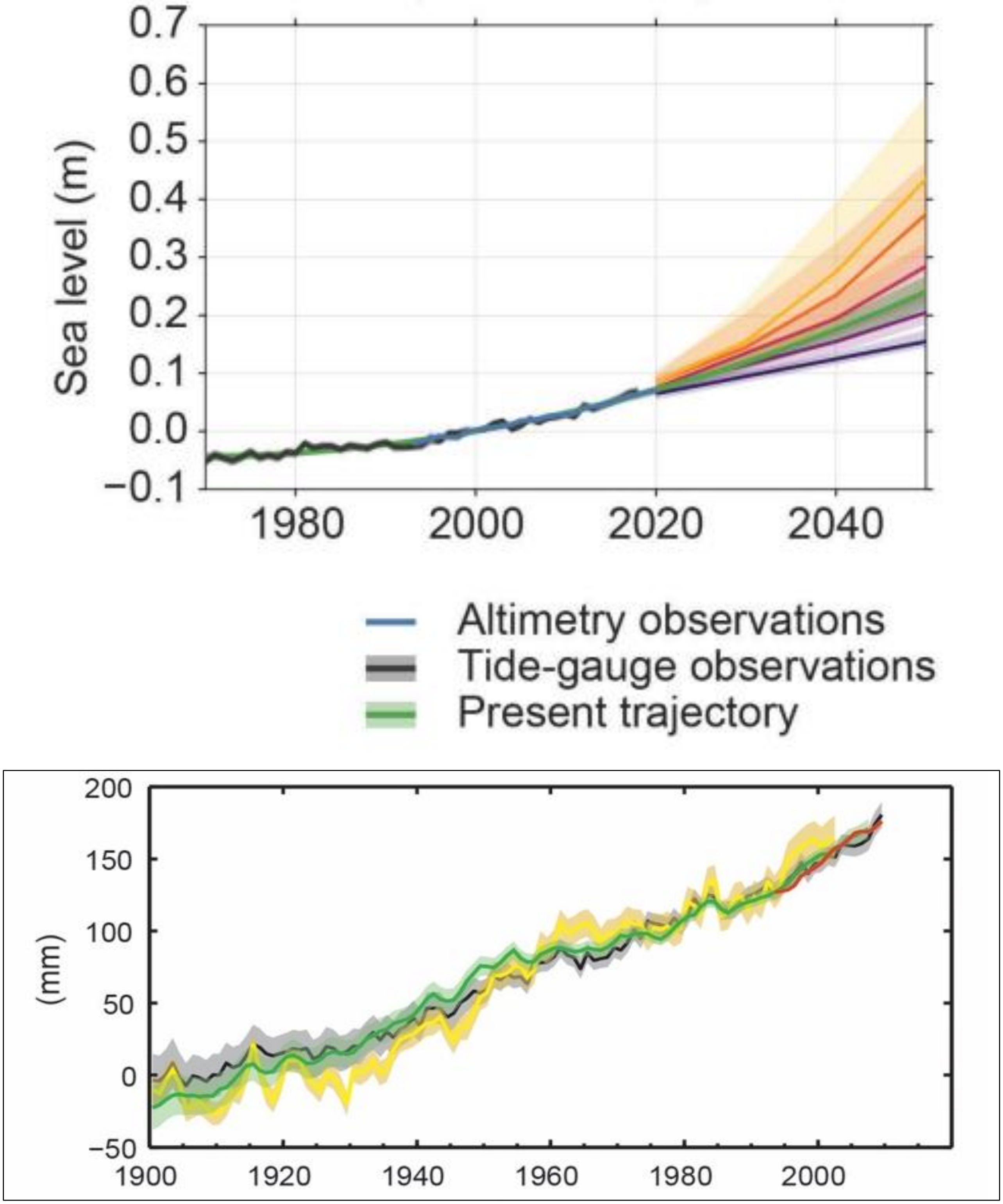
Table 11-1. Coastal Flooding and Erosion Events in California (2018 to 2022)

Date	Event Type	FEMA Declaration Number	USDA Declaration Number	Counties Impacted
January 16-20, 2018	Coastal Flood, High Surf	N/A	N/A	Orange, San Diego, San Francisco, Santa Cruz
Two rounds of large, long period northwest swells arrived at the beaches. High surf warnings were issued. Significant beach erosion was reported along with isolated coastal flooding.				
July 11, 2018	Coastal Flood	N/A	N/A	Orange
Minor coastal flooding occurred at high tide in Orange County. No damage to homes was reported.				
November 28-December 1, 2018	Erosion	N/A	N/A	Orange
A long period west-northwest swell brought high surf to Southern California beaches. Surf of 6-10 feet with sets to 12 feet were reported. Minor coastal flooding occurred. Beach erosion was reported during high surf, causing damage to the Boardwalk at Capistrano Beach in Dana Point. A walkway was severely damaged, palm trees were uprooted, and old buried cars were exposed.				
December 22-25, 2018	Coastal Flood	N/A	N/A	Marin, Humboldt
King tides impacted the coast. Low-lying areas and roadways were flooded. The Park and Ride lot in Manzanita Park in Mill Valley was closed. Portions of Shoreline Highway off 101 were closed by Caltrans.				
January 5, 2019	Coastal Flooding	N/A	N/A	San Francisco
Shallow thunderstorms developed over the coastal waters, some of which contained rotating cells. High tides and strong winds cause flooding on the Embarcadero in San Francisco causing officials to close it for a time.				

Date	Event Type	FEMA Declaration Number	USDA Declaration Number	Counties Impacted
January 16-20, 2019	Coastal Flooding	N/A	N/A	San Diego, Orange, San Francisco, Mendocino, Marin
High tides and surf brought large waves and coastal flooding to Southern California. Areas of the San Diego County coastline observed sets as high as 15 feet and significant coastal flooding. Orange County received significant coastal flooding. Many water rescues occurred due to the high surf and rip currents, and the Ocean Beach Pier in San Diego County saw extensive damage. High waves that coincided with high tides caused flooding on the Embarcadero where Pier 14 and one lane were shut down. High surf moved a large rock sea barrier in Mendocino County farther inland. Coastal flooding was reported in La Jolla Shores. King Tides flooded parking lots and roads in Sausalito and Mill Valley.				
November 15, 2020	Coastal Flooding	N/A	N/A	Humboldt, Marin
High tide at San Francisco reached 6.9 feet above sea level. Minor roadway flooding was observed in Sausalito. These high tides also brought rough seas to the coast. A person fell into the surf near Sutro Baths and drowned. Rough ocean conditions and the unusually high tide made for difficult search conditions. Minor roadway flooding occurred on Gate 5 Road in Sausalito. A parking lot on Shoreline Highway in Mill Valley experienced flooding				
December 13-15, 2020	Coastal Flooding	N/A	N/A	San Francisco, Marin, Monterey, San Diego
King Tides coincided with increased northwest swell. High tide at San Francisco exceeded 7 feet. The combination of these events led to minor flooding of low-lying coastal areas. Minor flooding occurred along the Embarcadero in San Francisco. The bike path between Sausalito and Mill Valley was flooded with seawater. Seawater flooded the walking patch at Salinas River State Beach near Moss Landing. The San Francisco Bay Trail north of the Oyster Point Marina was flooded. Moderate parking lot flooding was reported at Imperial Beach and Cardiff due to high King Tides.				
January 10-12, 2021	Coastal Flooding	N/A	N/A	Humboldt, San Francisco, Marin, Monterey
A large, long period swell produced large breaking surf along the coast and vulnerable coastal roads of northwest California. The large waves coincided with a high astronomical tide resulting in some minor coastal flooding. Flooding was reported in numerous locations, including Bucks Landing parking lot in Las Gallinas Creek, a parking lot at Lowrie Yacht Harbor, Manzanita Park and Ride near Sausalito, and Pier 14 in San Francisco.				

Source: (NOAA 2023a); (FEMA 2022u); (USDA 2022)

Figure 11-5. Global Sea-Level Rise Average



Source: (NOAA 2022)

11.4. PROBABILITY OF FUTURE HAZARD EVENTS

11.4.1. Overall Probability

The State is highly likely to experience some coastal flooding, erosion, and sea-level rise at least annually. California experienced 47 coastal flood events between 1996 and 2022—an average of nearly two events per year. Such events are likely to continue with at least that frequency in the future. Sea-level rise and erosion are ongoing long-term hazards and are expecting to continue their ongoing occurrence.

11.4.2. Climate Change Impacts

Coastal areas may be impacted by climate change in different ways. A warmer atmosphere means storms have the potential to be more intense and occur more often. Climate change also will result in sea-level rise. These changes will exacerbate coastal flooding and erosion and will have severe impacts along the California coast.

Coastal Flooding

The additive effects of high tides, storm surge, atmospheric patterns and large waves will be exacerbated by impacts from sea-level rise. This will likely increase the frequency of these events over time. The continued rise in sea level increases the risk of inundation in low coastal areas. Under sea-level rise scenarios, development adjacent to shoreline areas will be at increased risk of damage from everyday tidal conditions as well as storm events (Se-Hyeon Cheon 2016).

As sea-level rise continues, damaging floods that decades ago happened only during a storm will happen more regularly, such as during a full-moon tide or with a change in prevailing winds or currents (C. f. NOAA 2021c). In 2020, high tide flooding only occurred in the northern areas of the State. However, NOAA forecasts an increase in annual coastal flooding frequencies in the northern and southern ends of the State’s coastal areas. By 2030, the national high-tide flood frequency is likely to be about 2 to 3 times greater than today without additional flood-management efforts. By 2050, it is likely to be 5 to 15 times higher, and potentially in some locations reaching nearly 180 days per year, effectively becoming the new high tide.

Erosion

According to the California Climate Adaptation Strategy, rising water levels and increased storm activity will increase coastal erosion, impacting beaches and cliffs throughout the State. Near-shore wave heights and wave energy will increase, intensifying the potential for storm damage, beach erosion, and bluff retreat. For example, a projected 31 to 67 percent of Southern California beaches are projected to be lost by the end of the century if adaptation actions are not implemented.

Sea-Level Rise

Sea-level rise is driven by climate change. As the planet warms, land ice melts and flows into the ocean. Ocean temperatures rise and thermal expansion takes place. Figure 11-6 shows sea-level rise projections by decade from the California Sea-Level Rise Guidance 2018 Update, based on various GHG emissions scenarios.

Figure 11-6. Projected Decadal Sea-Level Rise (in Feet) for San Francisco

		Probabilistic Projections (in feet) (based on Kopp et al. 2014)						H++ scenario (Sweet et al. 2017) *Single scenario
		MEDIAN	LIKELY RANGE			1-IN-20 CHANCE	1-IN-200 CHANCE	
		50% probability sea-level rise meets or exceeds…	66% probability sea-level rise is between…			5% probability sea-level rise meets or exceeds…	0.5% probability sea-level rise meets or exceeds…	
					Low Risk Aversion		Medium - High Risk Aversion	Extreme Risk Aversion
High emissions	2030	0.4	0.3	-	0.5	0.6	0.8	1.0
	2040	0.6	0.5	-	0.8	1.0	1.3	1.8
	2050	0.9	0.6	-	1.1	1.4	1.9	2.7
Low emissions	2060	1.0	0.6	-	1.3	1.6	2.4	
High emissions	2060	1.1	0.8	-	1.5	1.8	2.6	3.9
Low emissions	2070	1.1	0.8	-	1.5	1.9	3.1	
High emissions	2070	1.4	1.0	-	1.9	2.4	3.5	5.2
Low emissions	2080	1.3	0.9	-	1.8	2.3	3.9	
High emissions	2080	1.7	1.2	-	2.4	3.0	4.5	6.6
Low emissions	2090	1.4	1.0	-	2.1	2.8	4.7	
High emissions	2090	2.1	1.4	-	2.9	3.6	5.6	8.3
Low emissions	2100	1.6	1.0	-	2.4	3.2	5.7	
High emissions	2100	2.5	1.6	-	3.4	4.4	6.9	10.2
Low emissions	2110*	1.7	1.2	-	2.5	3.4	6.3	
High emissions	2110*	2.6	1.9	-	3.5	4.5	7.3	11.9
Low emissions	2120	1.9	1.2	-	2.8	3.9	7.4	
High emissions	2120	3	2.2	-	4.1	5.2	8.6	14.2
Low emissions	2130	2.1	1.3	-	3.1	4.4	8.5	
High emissions	2130	3.3	2.4	-	4.6	6.0	10.0	16.6
Low emissions	2140	2.2	1.3	-	3.4	4.9	9.7	
High emissions	2140	3.7	2.6	-	5.2	6.8	11.4	19.1
Low emissions	2150	2.4	1.3	-	3.8	5.5	11.0	
High emissions	2150	4.1	2.8	-	5.8	5.7	13.0	21.9

Source: (CNRA, OPC 2018)

An extreme scenario, labeled as H++, is included, based on rapid ice melt on Antarctica. The H++ rapid loss scenario projects a 10.2-foot increase by 2100 and a 21.9-foot increase by 2150. The California Sea-Level Rise Guidance 2018 Update also shows the probability of sea level meeting or exceeding particular heights for each decade from 2030 to 2150. An example for San Francisco is shown in Figure 11-7.

Figure 11-7. Probability that San Francisco Sea-Level Rise Will Meet or Exceed a Particular Height

SAN FRANCISCO - High emissions (RCP 8.5)

	Probability that sea-level rise will meet or exceed... (excludes H++)									
	1 FT.	2 FT.	3 FT.	4 FT.	5 FT.	6 FT.	7 FT.	8 FT.	9 FT.	10 FT.
2030	0.1%									
2040	3.3%									
2050	31%	0.4%								
2060	65%	3%	0.2%	0.1%						
2070	84%	13%	1.2%	0.2%	0.1%					
2080	93%	34%	5%	0.9%	0.3%	0.1%	0.1%			
2090	96%	55%	14%	3%	0.9%	0.3%	0.2%	0.1%	0.1%	
2100	96%	70%	28%	8%	3%	1%	0.5%	0.3%	0.2%	0.1%
2150	100%	96%	79%	52%	28%	15%	8%	4%	3%	2%

SAN FRANCISCO - Low emissions (RCP 2.6)

	Probability that sea-level rise will meet or exceed... (excludes H++)									
	1 FT.	2 FT.	3 FT.	4 FT.	5 FT.	6 FT.	7 FT.	8 FT.	9 FT.	10 FT.
2060	43%	1.4%	0.2%							
2070	62%	4%	0.6%	0.2%	0%					
2080	74%	11%	2%	0.4%	0.2%	0.1%				
2090	80%	20%	3%	1.0%	0.4%	0.2%	0.1%	0.1%		
2100	84%	31%	7%	2%	0.8%	0.4%	0.2%	0.1%	0.1%	
2150	93%	62%	31%	14%	7%	4%	2%	2%	1%	1%

Source: (CNRA, OPC 2018)

11.5. IMPACT ANALYSIS

11.5.1. Severity

As indicated by the descriptions in Table 11-1 of nine coastal flooding events between 2018 and 2021, coastal flooding in California has significant potential for harm to people and damage to property. High surf has been reported with wave sets up to 15 feet. Roads and private properties have been damaged by the flooding. At least one person caught in high surf has drowned, and several have required rescue.

Coastal erosion can result in significant economic loss through the destruction of buildings, roads, infrastructure, natural resources, and wildlife habitats. Damage often results from an episodic event with the combination of severe storm waves and dune or bluff erosion. Collapses of coastal bluffs and cliffs present significant dangers to beachgoers that may be injured or killed by falling sediment and rock. Development at the top of the bluff or cliff may be lost or require abandonment as coastal bluff and cliff erosion takes place (State of California 2022a).

A September 2006 USGS coastal beach erosion study for California (*Historical Shoreline Change and Associated Coastal Land Loss Along Sandy Shorelines of the California Coast*) concludes that, based on the net shoreline changes in the short-term (25 to 40 years), 66 percent of California´s beaches are eroding. Central California, which covers the area from Point Reyes to just north of Santa Barbara, shows the highest percentage of erosion. Long-term coastal shoreline change (using data gathered over the last 120 years) shows a trend of expansion, which is likely attributable to large scale coastal engineering and beach fill projects in Southern California and to a high influx of sediments from coastal rivers in Northern California. This study identified the statewide average net shoreline change rates for the long and short term as 0.2 meters per year and -0.2 meters per year, respectively (USGS 2006).

The severity of the sea-level rise hazard can be assessed by projected future levels of rise, with the most extreme scenario indicting more than 10 feet of sea-level rise by 2100. During the 20th century, average sea level rose only about 7 inches along most of California’s coastline.

11.5.2. Warning Time

Coastal Flooding and Erosion

Coastal flooding and erosion events typically coincide with coastal storm events. These events are usually well forecast by NWS with up to several days of confident warning time.

Sea-Level Rise

Sea-level rise projections provide communities the ability to identify priorities for the most vulnerable locations and populations, keeping in mind that sea-level rise affects other coastal hazards such as erosion and flooding, as well as processes located a distance inland.

Sea-level rise forecasts extend out many decades but are dependent on the rate at which the planet warms, land ice masses collapse, and changes occur in land-water storage. Climate science evolves rapidly, and communities developing strategies to address sea-level rise should choose projections based on best available science at the time. The following are California's key sea-level rise guidance documents:

- California Sea-Level Rise Guidance 2018 Update (CNRA, OPC 2018) (a newer update is underway as of this SHMP update)
- 2017 Rising Seas in California: Update on Sea-Level Rise Science (OPC 2017)
- The California Coastal Commission's Sea-Level Rise Policy Guidance (California Coastal Commission 2018)

The California Sea-Level Rise Guidance recommends that decision makers use projections that assign a likelihood of occurrence to various sea-level rise heights and rates. Such projections are based on a range of scenarios for emissions of the GHGs that cause climate change and therefore sea-level rise. Because these projections may underestimate the likelihood of extreme sea-level rise (as would result, for example, from loss of the West Antarctic ice sheet), planning should include an extreme scenario for consideration for high stakes, long-term decisions.

11.5.3. Cascading Impacts

Cascading impacts are the impacts that result when one type of hazard event triggers one or more other hazard events, which may in turn trigger still others. The following are notable cascading impacts associated with sea-level rise, coastal flooding, and erosion:

- Loss of wetlands from erosion and wetland migration due to sea-level rise can reduce the natural filtration provided by wetland plants, increasing the likelihood of water quality issues.
- Healthy coastal ecosystems support fisheries, tourism, human health, and public safety. Many of these ecosystems are being transformed, degraded, or lost due in part to climate change, particularly sea-level rise and higher numbers of extreme weather events.
- As sea level continues to rise, repeated disruptions by coastal flooding will aggravate existing impacts on infrastructure, initiate cascading impacts on the larger economy, and burden people.
- Indirect economic costs (such as lost business) and adverse socio-psychological impacts have the potential to negatively affect people and their communities.
- Individuals exposed to weather- or climate-related disasters have been shown to experience negative mental health impacts. Among those most likely to suffer these impacts are some of society's most vulnerable populations, including older adults, people who are economically or transportation disadvantaged, or experiencing homelessness.
- Saltwater intrusion into drinking water sources can result in the need for water utilities to increase treatment, relocate water intakes, or develop alternate sources of fresh water. Saltwater intrusion, through surface water or groundwater sources, may diminish the availability or quality of source waters for drinking water utilities.
- Sea-level rise and associated coastal flooding could impact at least 400 hazardous facilities. These facilities, which include power plants, refineries, industrial facilities, and hazardous waste sites, have the potential to release hazardous pollutants into floodwater and nearby communities during a flood event. This could lead to adverse health impacts for residents exposed to hazardous pollutants. Coastal communities with more low-income residents and communities of color are disproportionately located near facilities at risk of spilling hazardous materials during a coastal flooding event (Rattini 2022).

11.5.4. Environmental Impacts

Most ecosystems that could be impacted by coastal flooding are able to quickly recover from a coastal flooding event with minor impacts. Examples of these ecosystems include wetlands and beaches.

Sea-level rise and long-term erosion can result in migration of ecosystems inland. If beaches, wetlands, and other coastal habitats are unable to migrate inland as sea levels rise—because of sediment availability, shoreline armoring, or other development that blocks natural migration—they can be lost to permanent inundation or degraded by saltwater intrusion. This can have resulting impacts related to land subsidence, loss of habitat for fish and wildlife, and loss of aesthetic, recreational, and commercial uses. Such loss would also mean the loss of important ecosystem services. For example, intact wetlands serve as a buffer to flooding events by increasing flood capacity, recharging groundwater, protecting water quality, and providing water supply reliability.

When wetlands are able to migrate inland, it can help to preserve wetland acreage, but it comes at the expense of the former inland habitats that the wetlands replace.

11.5.5. Local Hazard Impacts

LHMP Rankings

Twenty of the hazard mitigation plans prepared for California’s 58 counties list climate change as a hazard of concern, and 11 counties rank coastal hazards as a hazard of concern. The following counties rank these hazards as high impact hazards:

- Counties ranking climate change as a high impact hazard:
  - Alameda
  - Colusa
  - Los Angeles
  - Madera
  - Mariposa
  - Napa
  - Nevada
  - Santa Cruz
  - Tulare
  - Yolo

- Counties ranking coastal hazards as a high impact hazard:
  - San Mateo
  - Santa Barbara
  - Santa Cruz

LHMP Estimates of Potential Loss

Table 11-2 summarizes potential losses to vulnerable structures based on estimates from the local risk assessments (as called for in FEMA's Standard State Mitigation Planning Requirement S6.b). Due to variances in approaches to assessing risk at the local level as well as the hazards assessed and the age of each assessment reviewed, this data is considered approximate.

Table 11-2. Coastal Flood Risk Exposure Analysis for LHMP Reviews

Estimated Total Population Exposed	262,461
Estimated Number of Structures at Risk	54,607
Estimated Value of Structures at Risk	$13.67 billion

11.6. VULNERABILITY ANALYSIS

The vulnerability of State assets was based on the exposure of facilities and infrastructure to three spatial hazard data sets: coastal flooding; 2050 sea-level rise (SLR 2050); and 2100 sea-level rise (SLR 2100).

11.6.1. Exposure of State-Owned or -Leased Facilities

The statewide exposures of State-owned or -leased facilities and infrastructure to the coastal flooding, 2050 sea-level rise, and 2100 sea-level rise hazards are summarized in Table 11-3, and Table 11-4. Figure 11-8, Figure 11-9, and Figure 11-10 summarize the exposed assets as a percentage of total assets statewide. Appendix I provides detailed results by county.

Table 11-3. State-Owned or -Leased Facilities Exposed to Sea-Level Rise and Coastal Flooding

Type of Facility	Number of Structures	Total Area (sq. ft.)	Replacement Cost Value		
			Structure	Content	Total
State Facilities in the Mapped Coastal Flood Zone					
State-Leased Facilities	5	—	$5,680,089	$6,126,168	$11,806,257
State-Owned Facilities					
Facilities Housing Vulnerable Populations					
Correctional Facility	0	0	0	0	0
Development Center	0	0	0	0	0
Hospital	0	0	0	0	0
Migrant Center	0	0	0	0	0
Special School	0	0	0	0	0
All Other Facilities	76	60,175	$4,435,116	$3,307,192	$7,742,308
Total State-Owned	***76***	***60,175***	*$4,435,116*	*$3,307,192*	*$7,742,308*
Total Facilities	**81**	**N/A***	**$10,115,205**	**$9,433,360**	**$19,548,565**
State Facilities in the Mapped 2050 Sea-Level Rise Inundation Zone					
State-Leased Facilities	19	--	$63,392,405	$63,161,399	$126,553,804
State-Owned Facilities					
Facilities Housing Vulnerable Populations					
Correctional Facility	0	0	$0	$0	$0
Development Center	0	0	$0	$0	$0
Hospital	0	0	$0	$0	$0
Migrant Center	0	0	$0	$0	$0
Special School	0	0	$0	$0	$0
All Other Facilities	112	209,946	$23,580,238	$26,378,504	$49,958,742
Total State-Owned	*112*	*209,946*	*$23,580,238*	*$26,378,504*	*$49,958,742*
Total Facilities	**131**	**N/A***	**$86,972,643**	**$89,539,903**	**$176,512,546**

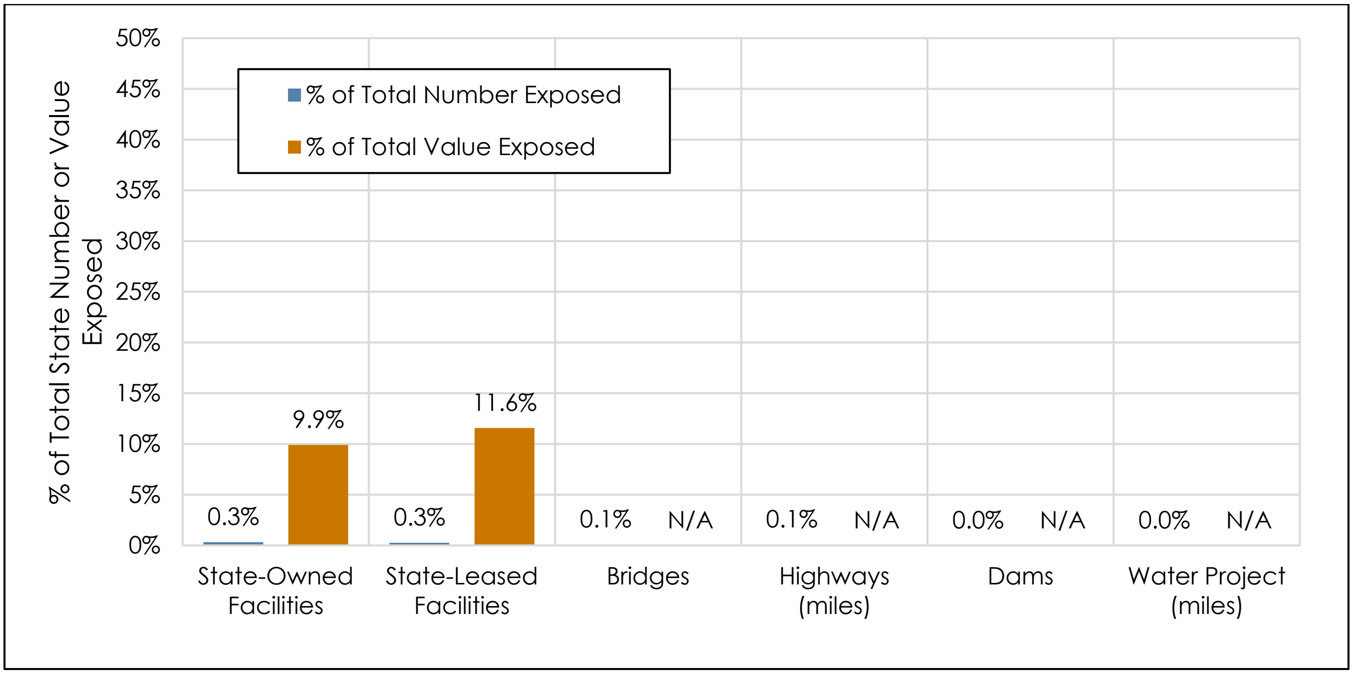
Type of Facility	Number of Structures	Total Area (sq. ft.)	Replacement Cost Value		
			Structure	Content	Total
State Facilities in the Mapped 2100 Sea-Level Rise Inundation Zone					
State-Leased Facilities	21	--	$38,705,790	$40,044,025	$78,749,815
State-Owned Facilities					
Facilities Housing Vulnerable Populations					
Correctional Facility	0	0	$0	$0	$0
Development Center	0	0	$0	$0	$0
Hospital	0	0	$0	$0	$0
Migrant Center	0	0	$0	$0	$0
Special School	0	0	$0	$0	$0
All Other Facilities	387	1,434,595	$464,965,753	$444,391,423	$909,357,177
Total State-Owned	*387*	*1,434,595*	*$464,965,753*	*$444,391,423*	*$909,357,177*
Total Facilities	**408**	**N/A***	**$503,671,543**	**$484,435,448**	**$988,106,991**

* The inventory of State assets does not include building area for State-leased facilities, so no total area for all State facilities is provided; the building area of vulnerable assets is shown for State-owned facilities only.

Table 11-4. State-Owned Infrastructure Exposed to Sea-Level Rise and Coastal Flooding

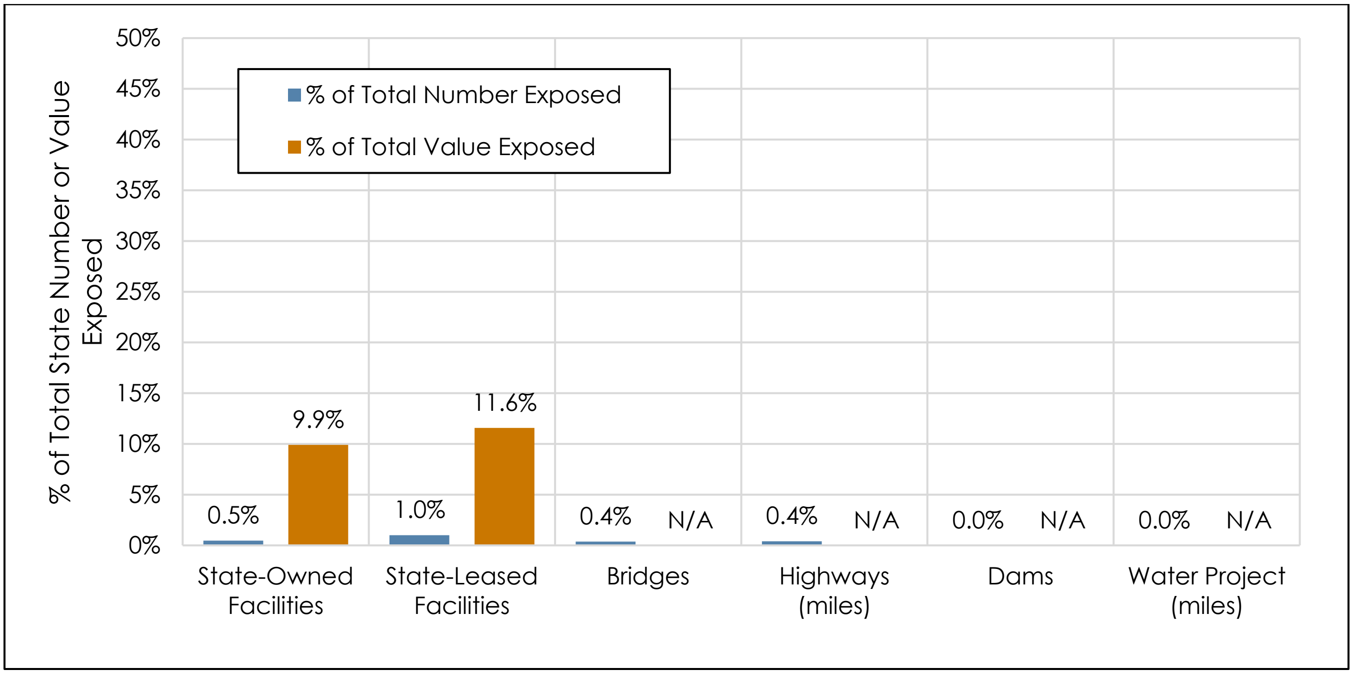
Type of Facility	State-Owned Infrastructure in the Mapped Hazard Area		
	Coastal Flood	2050 Sea-Level Rise	2100 Sea-Level Rise
Bridges	10	50	114
Highway (miles)	19.8	123	274.5
Dams	0	0	0
Water Project (miles)	0	0	0

Figure 11-8. State Assets Exposed to Coastal Flood, as % of Statewide Total



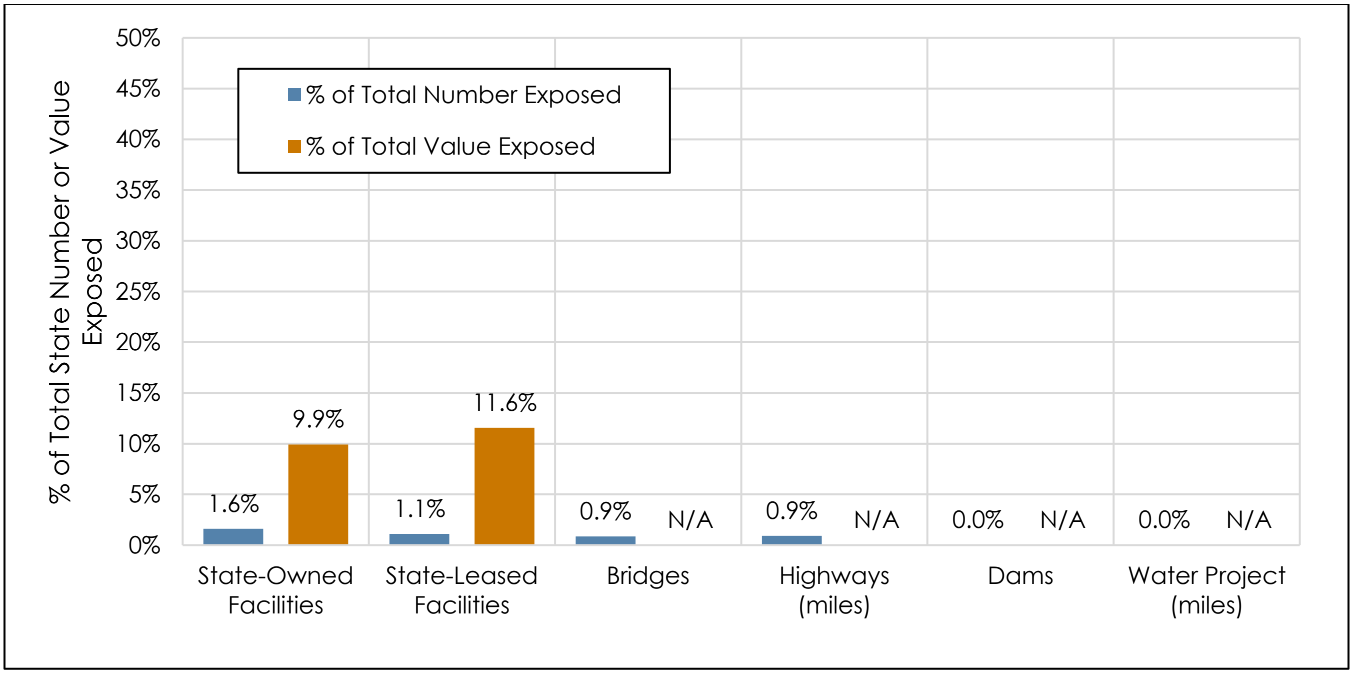
N/A: Values not defined for bridges, highways, dams, and water project

Figure 11-9. State Assets Exposed to Projected 2050 Sea-Level Rise, as % of Statewide Total



N/A: Values not defined for bridges, highways, dams, and water project

Figure 11-10. State Assets Exposed to Projected 2100 Sea-Level Rise, as % of Statewide Total



N/A: Values not defined for bridges, highways, dams, and water project

The following are significant results of the analysis of State-owned assets in mapped coastal flooding and sea-level rise inundation areas:

- For facilities that the State owns within the coastal flood zone, the average building area is 792 square feet, with an average replacement cost value of $101,872 (for both structure and contents).
- For facilities that the State owns within the SLR 2050 hazard zone, the average building area is 2,738 square feet, with an average replacement cost value of $505,600 (for both structure and contents).
- For facilities that the State owns within the SLR 2100 hazard zone, the average building area is 2,928 square feet, with an average replacement cost value of $1.3 million (for both structure and contents).
- The average replacement cost value for State-leased facilities within the coastal flood zone is $2.4 million (for both structure and contents).
- The average replacement cost value for State-leased facilities within the SLR 2050 hazard zone is $6.7 million (for both structure and contents).
- The average replacement cost value for State-leased facilities within the SLR 2100 Hazard zone is $5.3 million (for both structure and contents).
- The State agency with the most State-owned or -leased facilities within the coastal flood zone is State Parks (78).
- The State agencies with the most State-owned or -leased facilities within the SLR 2050 hazard zone are CDFW (66), State Parks (29) and Caltrans (13).
- The State agencies with the most State-owned or -leased facilities within the SLR 2100 hazard zone are the District Agricultural Associations (150). State Parks (134), C (74), Caltrans (23) and CHP (4).
- The State agency with the highest total replacement cost for State-owned or -leased facilities within the coastal flood zone is CDFW at $10.8 million.
- The State agency with the highest total replacement cost for State-owned or -leased facilities within the SLR 2050 zone is CDFW at $42.1 million.
- The State agency with the highest total replacement cost for State-owned or -leased facilities within the SLR 2100 zone is the District Agricultural Associations at $761 million.

11.6.2. Exposure of Critical Facilities and Community Lifelines

The Risk Assessment identified four critical facility and community lifelines within the coastal flood hazard zone, all of them under the "transportation" category. The facilities include one each in Humboldt, San Diego, San Francisco, and San Mateo counties.

The Risk Assessment identified 114 critical facility and community lifelines within the SLR 2050 hazard zone. The "transportation" lifeline category accounts for 67 percent of these, and "food, water, and shelter" accounts for 21 percent. The County with the largest percentage of these facilities is San Mateo (26.3 percent,) followed by Alameda (15.7 percent) and San Diego (15.7 percent).

The Risk Assessment identified 200 critical facility and community lifelines within the SLR 2100 hazard zone. The "transportation" lifeline category accounts for 65 percent of these, "food, water, and shelter" accounts for 16 percent, and "energy" accounts for 8 percent. The County with the largest percentage of these facilities is Alameda (24 percent,) followed by San Francisco (18 percent) and San Mateo (18 percent).

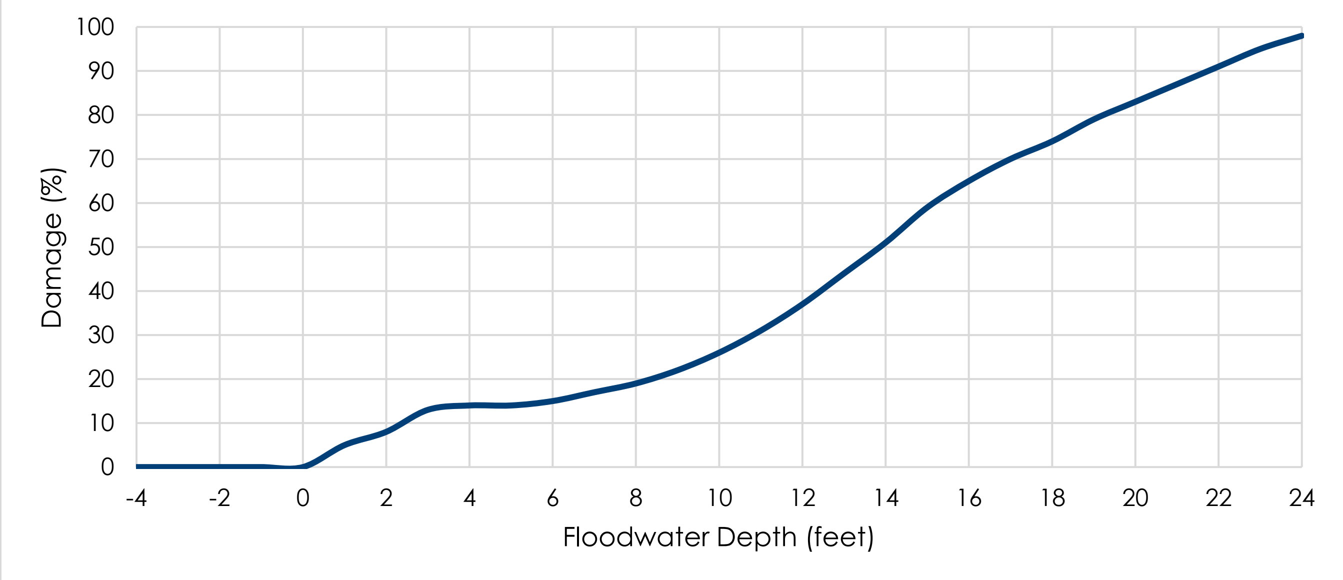
For a detailed breakdown of facility counts by County see Appendix I.

Critical facilities and community lifelines that are exposed to the sea-level rise, coastal flooding, and erosion hazards are likely to experience functional downtime following these events, which could increase the net impact of these events. Hazus estimates damage and functional downtime for flooding scenarios. Local governments are encouraged to use tools such as Hazus when creating or updating their LHMPs.

11.6.3. Estimates of Loss

Loss estimations for hazard events that cause flooding typically use an approach that correlates damage to the depth of flood water impacting a structure and the time of inundation. USACE has established depth/damage correlations based on analysis of the impacts historical flood events have had on the built environment. The assessment of potential loss associated with riverine flooding for this SHMP used the USACE depth-damage curve for facilities with "average government function" (see Figure 11-11).

Figure 11-11. Depth/Damage Curve for "Average Government Function" Occupancy



Source: Data exported from Hazus model

Table 11-5 shows the resulting estimates of potential damage to State-owned or -leased facilities in the SLR 2050 hazard zone per foot of flood depth, up to the flood depth that would trigger substantial damage (50 percent of replacement cost value).

Table 11-5. Estimates of Flood Loss for Facilities in the SLR 2050 Hazard Zone

Flood Depth (feet)	Estimates of Flood Loss*		
	State-Owned	State-Leased	Total
1	$23,248,288	$1,935,290	**$25,183,579**
2	$36,397,260	$3,096,463	**$39,493,725**
3	$60,445,548	$5,031,753	**$65,477,304**
4	$65,095,205	$5,418,811	**$70,514,020**
5	$65,095,205	$5,418,811	**$70,514,021**
6	$69,744,863	$5,805,869	**$75,550,738**
7	$79,044,178	$6,579,984	**$85,624,169**
8	$88,343,493	$7,354,100	**$95,697,601**
9	$102,292,466	$8,515,274	**$110,807,749**
10	$120,891,096	$10,063,505	**$130,954,611**
11	$144,139,383	$11,998,795	**$156,138,189**
12	$172,037,329	$14,321,142	**$186,358,483**
13	$204,584,931	$17,030,548	**$221,615,492**
14	$237,132,534	$19,229,953	**$256,362,501**

* Structure Losses only. Does not include contents or inventory losses.

Sea-level rise threatens many aspects of the coastal economy and California's broader economy, including coastal-related tourism, beach and ocean recreational activities, transfer of goods and services through ports and transportation networks, coastal agriculture, and commercial fishing and aquaculture. Sea-level rise will create difficulties for ports and harbors by affecting cargo transfer capability as ships ride higher along docks and by affecting transfer between roads or railways and docks.

11.6.4. Buildable Lands

Of the 11.7 million acres of land available for development in California, 0.05-percent (5,773 acres) is within the coastal flood hazard zone, 0.2-percent (24,014 acres) is in the SLR 2050 hazard area, and 0.29-percent (34,715 acres) is in the SLR 2100 hazard zone.

Any type of development in these areas will be susceptible to damage associated with coastal flood and sea-level rise. The combination of these two impacts will also impact the frequency and severity of areas along the California coast susceptible to coastal erosion. As a strong growth management state as well as strong participation in the NFIP, the State is well equipped with regulatory oversight of new development that may occur within these buildable lands.

11.6.5. Equity Priority Communities

The cost of interventions to protect properties from coastal flooding and erosion risk may financially stress lower- or middle-income residents. Relocating may be difficult because of the expenses and the availability of accessible housing or the time needed to make housing accessible. Tribal Nations and indigenous populations along the coast are at risk of losing access to culturally significant sites or plants and animals that hold cultural significance as a source of traditional medicine, ceremony, or subsistence (OPC 2022, OEHHA 2022c). Additionally, Tribal Nations may not have access to the resources or funds to relocate Tribal Nation members.

The population over the age of 65 is more vulnerable and, physically, may have more difficulty evacuating during severe coastal flooding and erosion events. They may require extra time or outside assistance during evacuations and are more likely to seek or need medical attention, which may not be available due to isolation during a flood event (U.S. EPA 2021).

The risk analysis for sea-level rise, coastal flooding and coastal erosion found the following vulnerability of equity priority communities (a breakdown of by county is included in Appendix I):

- 3 percent of people living in the coastal flood hazard zone live in equity priority communities (226 people)
- 8.5 percent of people living in the SLR 2050 hazard zone live in equity priority communities (16,465 people)
- 10.9 percent of people living in the SLR 2100 hazard zone live in equity priority communities (228,484 people)

11.6.6. NRI Scores

According to the NRI, 19 of the State's counties have coastal flooding risk, rated from very low to relatively moderate. Table 11-6 shows scores for the six counties with the highest rating. See Section 4.1.3 for a description of the components of the NRI.

Table 11-6. NRI Scoring of Counties for Coastal Flooding

County	Expected Annual Loss	Social Vulnerability Rating	Community Resilience Rating	Community Risk Factor	Risk Value	Score
Humboldt	$4,308,641	Very High	Relatively Moderate	1.36	$6,478,232	93.96
Marin	$3,801,318	Relatively Low	Very Haigh	1.02	$4,161,749	89.54
San Mateo	$1,626,573	Relatively Low	Very High	1.05	$1,858,026	79.88
Santa Clara	$1,001,237	Relatively Low	Relatively High	1.11	$1,119,806	74.04
Solano	$680,780	Relatively High	Very High	1.18	$1,002,823	72.64
Alameda	$875,558	Relatively Moderate	Very High	1.13	$977,693	72.23

11.7. MITIGATING THE HAZARD

11.7.1. Opportunities for Mitigating the Hazard

A range of potential opportunities for mitigating the sea-level rise, coastal flooding and erosion hazard is provided in Table 11-7. See Section 1.2.3 for a description of the different types of alternatives.

Table 11-7. Potential Opportunities to Mitigate the Sea-Level Rise, Coastal Flood, and Erosion Hazard

Community-Scale	Organizational Scale	Government-Scale
Manipulate the hazard: ▪ Barriers (sea wall), only when no nature-based alternative is feasible ▪ Pumps ▪ Protect, preserve, and restore beaches and dunes **Reduce exposure and vulnerability:** ▪ Voluntary retreat ▪ Elevate on fill above sea-level rise elevation ▪ Elevate utilities above base flood elevation ▪ Use low-impact development ▪ Elevate ▪ Floodproof **Build local capacity:** ▪ Buy flood insurance	**Manipulate the hazard:** ▪ Barriers (sea wall), only when no nature-based alternative is feasible ▪ Pump stations ▪ Protect, preserve, and restore wetlands ▪ Protect, preserve, and restore beaches and dunes **Reduce exposure and vulnerability:** ▪ Relocate out hazard zone ▪ Elevate on fill above sea-level rise elevation ▪ Locate critical facilities or functions outside hazard area ▪ Use low-impact development techniques ▪ Build redundancy for critical functions or retrofit critical buildings ▪ Maintain drainage facilities that service your property	**Manipulate the hazard:** ▪ Barriers (sea wall), only when no nature-based alternative is feasible ▪ Pump Stations ▪ Protect, preserve, and restore wetlands ▪ Protect, preserve, and restore beaches and dunes **Reduce exposure and vulnerability:** ▪ Buyout/Relocation Program ▪ Promote open space uses in identified high-hazard areas via techniques such as: planned unit developments, easements, setbacks, greenways, sensitive area tracks ▪ Adopt land development criteria such as planned unit developments, density transfers, clustering ▪ Institute low impact development techniques ▪ Acquire vacant land or promote open space uses in developing watersheds to control increases in runoff ▪ Harden infrastructure ▪ Provide redundancy for critical infrastructure nodes and systems ▪ Higher regulatory standards in sea-level rise zones ▪ Facilitate managed retreat from, or upgrade of, the most at-risk areas ▪ Implement tree management programs ▪ Elevate roads that are vital/critical to evacuation and local community operations ▪ Include nature-based elements in infrastructure adaptation projects (e.g., roads) such as living shorelines, ecotone levees, and habitat restoration to increase resilience ▪ Design or enhance existing drainage systems for higher design storms to provide increased capacity of the drainage system

Community-Scale	Organizational Scale	Government-Scale
▪ Develop household plan, such as retrofit savings, 72-hour self-sufficiency during and after an event	▪ Provide flood-proofing when new critical infrastructure must be located in floodplains **Build local capacity:** ▪ Be informed and understand future impacts of sea-level rise on your business ▪ Develop a Continuity of Operations Plan	▪ Maintain the drainage infrastructure to levels that equal or exceed their design specifications ▪ Require accounting of sea-level rise in all applications for new development in shoreline areas **Build local capacity:** ▪ Provide technical information and guidance ▪ Promote the purchase of flood insurance ▪ Enact tools to help manage development in hazard areas (stronger controls, tax incentives, information) ▪ Incorporate retrofitting or replacement of critical system elements in capital improvement plan ▪ Develop strategy to take advantage of post-disaster opportunities ▪ Provide incentives to guide development away from hazard areas or to retrofit in place ▪ Provide residents with sea-level rise inundation maps

Nature-based opportunities

- Restore wetlands, marshes, mudflats, oyster reefs, dunes, beaches, eelgrass, kelp forests, living shorelines and other coastal habitats to enhance resilience and reduce wave impacts during storms
- Preserve/restore tidal marshes to enhance resilience and provide multiple benefits, including absorbing floodwaters and reducing wave impacts during storms
- Conserve and protect coastal habitat and non-habitat areas suitable for habitat restoration
- Establish living shorelines (natural elements including plants, reefs, and oyster beds) to prevent erosion
- Incentivize voluntary retreat from coastal hazard areas

11.7.2. Selected Actions to Mitigate the Hazard

The mitigation strategy developed for this SHMP includes the following actions that address sea-level rise, coastal flooding, or coastal erosion:

- Action 2018-006: Enhance Collaboration on the Development and Sharing of Data Systems and GIS Modeling.
- Action 2018-008: Develop a database containing a description of the specific natural hazard event for which each project was designed to mitigate.
- Action 2018-050: Sea-Level Rise Guidance: Provide guidance on factors to consider in projecting sea- level rise, potential impacts, and adaptation strategies.
- Action 2018-051: State Agency Adaptation Planning: Assess vulnerability of State assets to sea-level rise and develop adaptation strategies to address potential impacts.

LANDSLIDE, DEBRIS FLOW AND OTHER MASS MOVEMENTS

Climate Impacts:
More intense rainfall events can increase landslide frequency

Equity Impacts:
2.7% of the exposed population (those living in mapped landslide hazard areas) identified as living in equity priority communities

State Facilities Exposed:
3,626 facilities in high landslide hazard areas; 85 facilities in very high landslide hazard areas; 30 facilities in landslide hazard zones

Community Lifelines Exposed:
Four lifelines in landslide hazard zones based on the data used for this assessment.

Impact Rating: High (30)

12. LANDSLIDE, DEBRIS FLOW, & OTHER MASS MOVEMENTS

The landslide, debris flow, and other mass movements hazard has been identified as a high-impact natural hazard of interest based on the hazard impact rating protocol applied for this SHMP. Events associated with this hazard happen frequently in the State and about 14 percent of State-owned or -leased facilities and community lifelines are exposed. Approximately 1.57 percent of the State's population is exposed, and more than 2.7 percent of that population has been identified as living in equity priority communities. Over 5 percent of identified buildable lands in the State intersect mapped landslide, debris flow and other mass movement hazard areas. These values represent minimum values because landslide, debris flow, and other mass movement hazards have not been mapped for the entire State. The frequency and severity of this hazard is anticipated to increase over the next 30 years due to the impacts from climate change.

12.1. HAZARD OVERVIEW

A landslide is the downslope movement of a mass of rock, debris, or earth down a slope under the direct influence of gravity (Cruden and Varnes 1996). Landslides can travel at speeds ranging from fractions of an inch per year to tens of miles per hour depending on the slope steepness and the rock and soil mass's water content. Landslides range from the size of an automobile to a mile or more in length and width. Due to their sheer weight and speed, they can cause serious damage and loss of life.

More than one-third of California is hilly and mountainous terrain that runs parallel to the coast, forming a barrier that captures moisture from offshore storms. Moderate to steep topography, weak rocks, heavy winter rains, wildfires, and earthquakes all lead to slope failures more frequently than would otherwise occur under gravity alone.

12.1.1. Deep-Seated Landslides

Deep-seated landslides (greater than 10 to 15 feet deep) tend to be triggered by deep infiltration of rainfall over a period of weeks to months, earthquake shaking, or the combination of both rainfall and earthquakes (Wieczorek 1996). Some deep-seated landslides move very slowly, though others can move quickly and with little notice. These landslides generally cause extensive property damage and major impacts on the State's infrastructure.

General Landslide Types

The California Department of Conservation (DOC) categorizes landslides into the following types:

- **Earth Flows**—Landslides made mostly of fine-grained, cohesive silt or clay that commonly occur on moderately steep slopes (10 to 30 percent grade), often triggered by prolonged rainfall. Earth flows move as slow as several centimeters or millimeters per day over a period of days to weeks.
- **Debris Flows**—Landslides made mostly of coarse-grained, non-cohesive fine sand to boulder-sized particles, triggered by intense rainfall after a dry period or by rapid snow melt. Debris flows are often small, and vegetation tends to grow back over their path rapidly.
- **Debris Slides**—Landslides made mostly of coarse-grained sandy or gravelly soil, usually occurring after heavy rainstorms on very steep slopes (60 to 70 percent grade) in areas where the base of a slope is undercut by erosion. Debris slides form steep scars that are likely to remain un-vegetated for years.
- **Rockslides**—Bedrock that largely stays intact for at least part of the landslide event. Rockslides occur in a variety of sizes on a variety of gradients (35 to 70 percent grade).
- **Rock Falls**—A landslide where a mass of rock detaches from a steep slope and descends mainly by falling, rolling, or bouncing through the air. Rock falls can be triggered by heavy rain, earthquakes, or freeze-thaw events, and tend occur on steep slopes. Scarring from a rock fall may not be visually distinct from the intact rock surrounding it, and the rubble it leaves at the bottom of a slope can dissipate by erosion.

Source: (DOC 2019)

12.1.2. Alluvial Fans and Debris Flows

Alluvial fans are geologic features built by runoff spreading out on a broad fan-like surface (see Figure 12-1) as successive debris-laden floods or debris flows are deposited (Harvey 2018). They range from small features on the order of an acre, to massive landforms that are visible from space. The processes that form these landforms become increasingly active with the occurrence of earthquakes, wildfires, and strong winter weather.

Figure 12-1. Debris Flows Spread Out on an Alluvial Fan in the Santa Rosa Mountains

Source: Jeremy Lancaster, California Geological Survey

As residential and business land uses have expanded onto mountain-front alluvial fan areas, more lives and property are at risk from debris-laden floods and debris flows in alluvial fan areas (see Figure 12-2).

Debris Flows Related to Shallow Landslides

The first type of debris flow occurs on hillslope due to soil failure in which soil liquefies and runs downhill. This type of debris flow generally results from a shallow landslide (less than 10 to 15 feet deep) and has a discrete initiation zone and depositional area.

Figure 12-2. A Santa Clara County Debris Flow Triggered by Storms Following the Loma Fire, 2017

Source: Brian Swanson, California Geological Survey

Shallow landslides tend to occur in winter but are most likely after prolonged periods of heavy rainfall when soil materials are saturated. Debris flows are typically more dangerous because they are fast moving, causing both property damage and loss of life.

According to the USGS, about 10 inches of seasonal rain is necessary for ground saturation in Southern California, and once the ground is saturated, as little as 0.2 inches of rain per hour can trigger a debris flow that deposits material on an alluvial fan (USGS 1975).

Post-Wildfire Debris Flows

The second type of debris flow is a result of post-fire conditions, where burned soil surfaces enhance rainfall runoff that concentrates and picks up debris as it moves. A post-fire debris flow has a less discrete initiation zone but is similar to a debris flow derived from hillslopes, in that it may result in a fast-moving flow, inundation, and a detrimental impact on lives and property within its zone of runout and deposition. It is also often the case that waves of muddy water follow the initial debris flow surges, causing additional flooding downstream.

Debris flows often start in areas that experienced wildfires during the previous fire season (California Water Science Center 2018). Research by the USGS in the western United States has refined the understanding of debris flows generated from recently burned watersheds (NOAA-USGS Debris Flow Task Force 2005). Post-fire debris flow hazards assessments prepared by the USGS can be found at the USGS debris flow website (USGS 2022j).

12.1.3. Earthquakes and Landslides

Although less frequent, the most devastating landslides worldwide have been triggered by earthquakes. Strong ground shaking can create the additional forces necessary to weaken slopes and cause those already distressed by gravity to fail. One of the most significant earthquake-related landslide disasters in history occurred in 1920 in central China, where an estimated magnitude 8.5 earthquake caused weak slopes to collapse into a densely populated valley, killing an estimated 180,000 people.

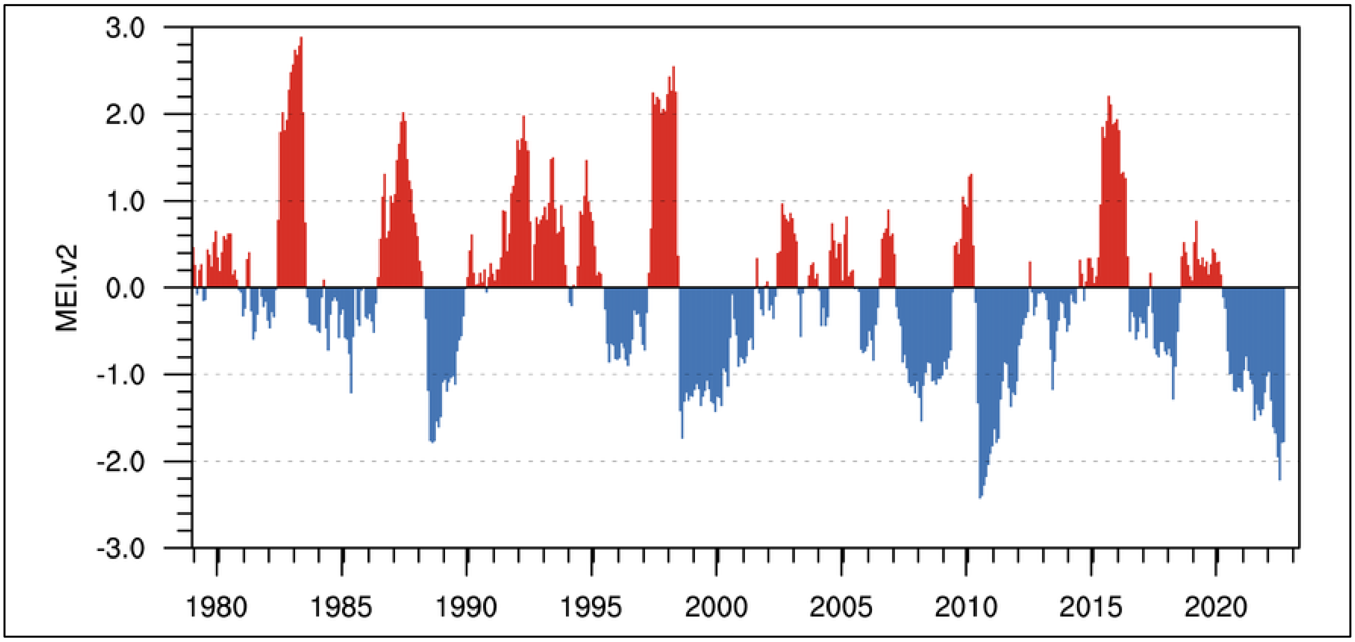
Earthquake shaking can also rapidly weaken loose water-saturated sediments via liquefaction, which can greatly increase ground deformation and sliding, even on gentle slopes. This happened during the 1971 San Fernando Earthquake, when the soil beneath two earth-fill dams partially liquefied and shifted, causing partial collapse of both facilities. Those events resulted in over a half-billion dollars in damage and the temporary evacuation of 80,000 people below the dam.

12.1.4. Rainfall and Landslides

A statewide pattern of landslide occurrences repeats itself during heavy winter seasons, which may coincide with numerous atmospheric rivers making landfall. This can occur during both El Niño Southern Oscillation and La Niña settings in the Pacific Ocean. (California Coastal Commission 2019). (L'Heureux 2014).

Figure 12-3 shows a history of El Niño occurrences using the Multivariate El Niño-Southern Oscillation index (v2). The red regions (above the 0.0 line) correspond to warmer sea surface temperatures, which bring unusually moist air into the north Pacific, producing wetter winters and more intense landslide and debris flow activity in California.

Figure 12-3. Multivariate El Niño Southern Oscillation Index



Source: (NOAA Physical Sciences Laboratory n.d.)

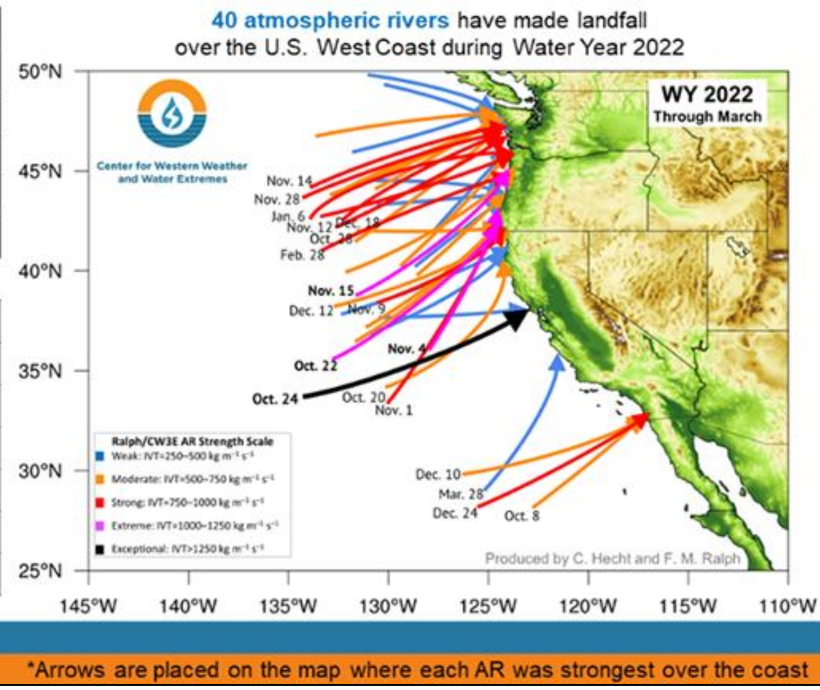
While El Niño is a condition that can result in high total rainfalls, there are other conditions that may result in record levels of rainfall, even in a non-El Niño year. The October 2021 severe storms were an example of an instance where record-breaking rainfall occurred during an exceptional atmospheric river event. As shown, these events are becoming less frequent. The blue regions (below the 0.0 line) correspond to the cooler sea surface temperatures of the drier La Niña events. Figure 12-4 summarizes incidents of atmospheric rivers that made landfall along the west coast of the U.S. from late 2021 through early 2022. Several landings in California brought an increased risk of landslide occurrence.

According to the USGS, variations in long-term precipitation may influence rainfall/debris-flow threshold values along the U.S. Pacific coast, where the mean annual precipitation and the number of rainfall days are influenced by topography, distance from the coastline, and geographic latitude. Studies have been performed using data from storms that triggered significant debris-flow activity in southern California, the San Francisco Bay region, and the Pacific Northwest (Mechanics, Prediction, and Assessment, 1997 1st International Conference on Debris-Flow Hazards Mitigation 1997)).

Figure 12-4. Landfalling Atmospheric Rivers, Water Year 2022 October Through March

AR Strength	AR Count
Weak	11
Moderate	15
Strong	10
Extreme	3
Exceptional	1

Regions Impacted by Each AR	
State/Region	AR Conditions
Washington	36
Oregon	36
Northern CA	26
Central CA	15
Southern CA	11



Source: (Center for Western Weather and Water Extremes 2022)

El Niño years and other high rainfall winter seasons that have strong atmospheric river storm events reveal similar patterns of landslide occurrences across the State. During heavy rainfall conditions, the added weight of rain-saturated slopes and weakened slopes from the pressure the groundwater exerts on porous hillside materials can trigger slope failure.

Figure 12-5 shows the statewide distribution of landslide damage reports that CGS investigated during the 2023 atmospheric river emergency response.

12.1.5. Post-Wildfire Landslides

Wildfires make the landscape more susceptible to landslides. When rainstorms pass through, the water liquefies unstable, dry soil and burned vegetation. Post-fire landslide hazards include fast-moving, highly destructive debris flows that can occur in response to high intensity rainfall events in the years immediately after wildfires, as well as flows generated over longer time periods accompanied by root decay and loss of soil strength. Post-fire debris flows are particularly hazardous because they can occur with little warning, exert great impulsive loads on objects in their paths, strip vegetation, block drainage ways, damage structures, and endanger human life.

Figure 12-5. 2023 Atmospheric River Response

Wildfires could result in the destabilization of pre-existing deep-seated landslides over long periods. Recent research shows California's wildfire season is getting longer, and the rainy season is getting shorter and more intense. This suggests Californians face a higher risk of wildfires and post-wildfire landslides that can damage property and endanger people's lives.

When Cal OES determines that post-fire watershed impacts pose a significant threat to life, safety, and property, the State will activate the Watershed/Debris Flow Task Force to coordinate with appropriate State, federal, Tribal Nation, and local stakeholders to mitigate against the identified hazards.

The task force works closely with State (Watershed Emergency Response Team [WERT]) and federal (Burned Area Emergency Response) post-fire assessment teams to identify "values at risk" that have potential to be impacted by post-fire flash floods or debris flows. Values at risk can include critical infrastructure, residences, or any physical asset at risk of impacts from debris flows. The task force communicates the WERT-identified risks to counties and provides technical assistance during values-at-risk mitigation efforts.

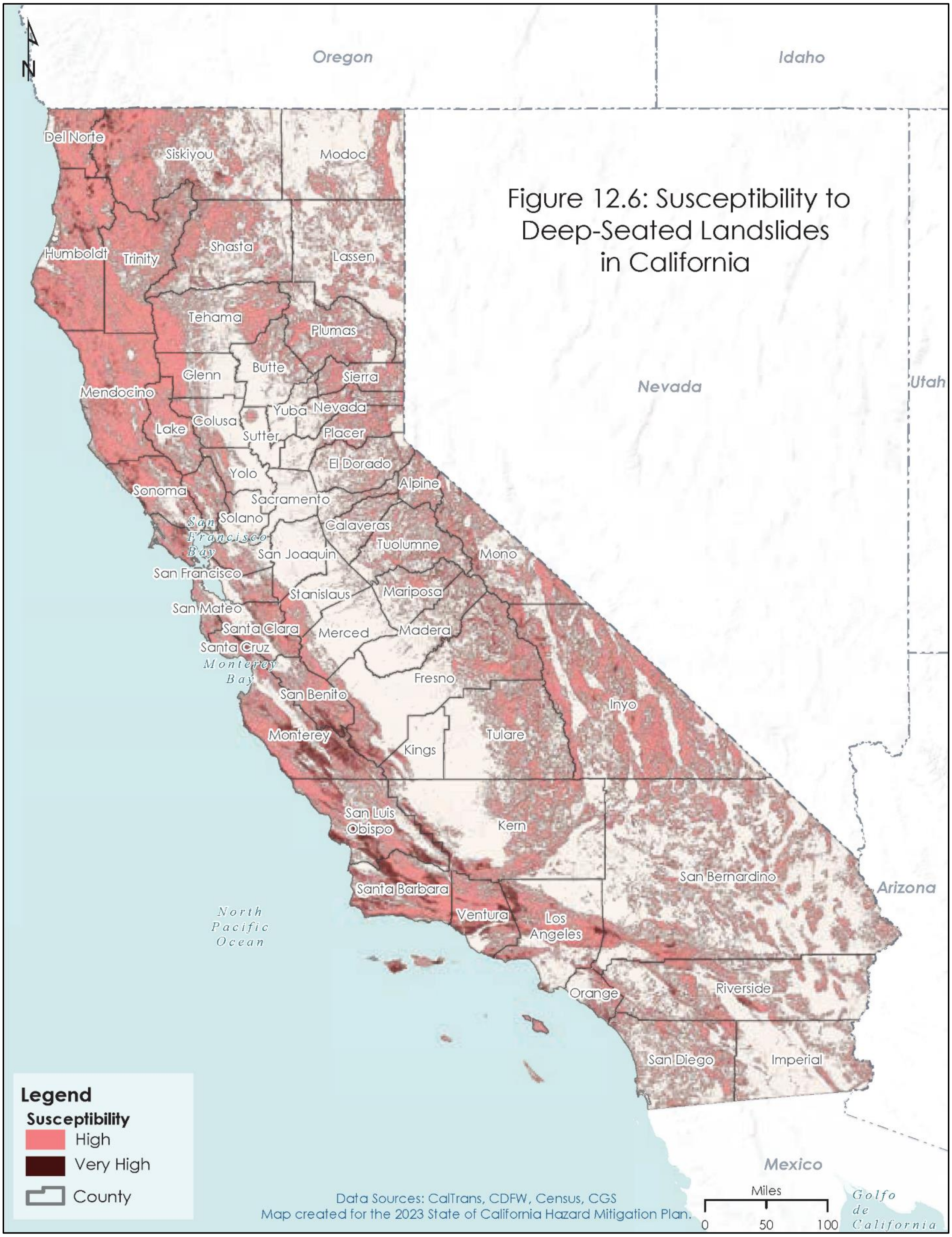
12.2. HAZARD LOCATION

Landslide hazards are present in many regions of California. Landslide probability of occurrence is notably high in the coastal regions of California, which are home to much of the State's population, industry, and infrastructure (DOC 2015).

General landslide susceptibility in California can be estimated from the distribution of weak rocks and steep slopes as shown in Figure 12-6. High and moderate landslide susceptibility, combined with high rainfall or high earthquake potential, leads to high landslide hazard in coastal California. The Franciscan Formation, which makes up much of the Northern California Coast Ranges, has weak rock that is both easily eroded and landslide prone.

Over the decades, development has spread into mountainous terrain where hazard exposure is high. Most reported landslide losses occur in these regions. An interactive map of deep-seated landslide susceptibility and landslide inventory mapping is publicly available on the CGS website (DOC 2022a).

Figure 12-6. Susceptibility to Deep-Seated Landslides in California



The concern for debris flows following wildfires is particularly acute wherever urban areas encroach upon alluvial fans. Figure 12-7 shows areas at moderate or high risk for post-fire debris flows. The areas of high or very high risk occur over burn scars, which can take several years to recover (Cotton 2021).

> Since the 1970s, CGS has produced numerous maps that show landslide features and delineate potential slope-stability problem areas. Preparation of these maps has been episodic, often driven by landslide disasters and subsequent legislative mandates. Many CGS landslide maps and related products have been produced for local or State agencies in response to their specific needs.
>
> (CGS 2022a)

12.3. PREVIOUS HAZARD OCCURRENCES

12.3.1. Disaster and Emergency Declarations

Figure 12-8 is a compilation of federal disasters declared due to landslides and flooding declarations where landslides occurred as a secondary factor to flooding. Also included are federal earthquake disasters that triggered significant damaging landslides, debris flows, rock falls and similar mass wasting movements. Many recently declared disasters include, as part of their description, "landslide" or "debris flow." Earlier disasters, such as the 1955 floods or the 1964 storms, do not include "landslides" as part of their description, but it is reasonable to expect that many damaging slides occurred. Similarly, earthquake disasters often have damaging landslides or rockfalls although not specifically mentioned in the disaster declaration. For this map, historical records and publications by Caltrans, USACE, California Department of Water Resources (DWR), the USGS, CGS and others were reviewed to determine whether damaging landslides occurred as part of the disaster. Consideration of the geology and general topographic relief of various counties assisted in the assessment. Data prior to 1953 was not reviewed, as this was the approximate year when federal disasters began being declared.

For counties in the Central Valley, if significant portions of the county are within an area of high relief and had a historical incident of damaging landslides, then that county was included with a particular disaster. For example, in Merced County, the hills around San Luis Reservoir and Highway 152 are relatively susceptible to landslides.

Figure 12-7. Post Fire Debris Flow Combined Hazard

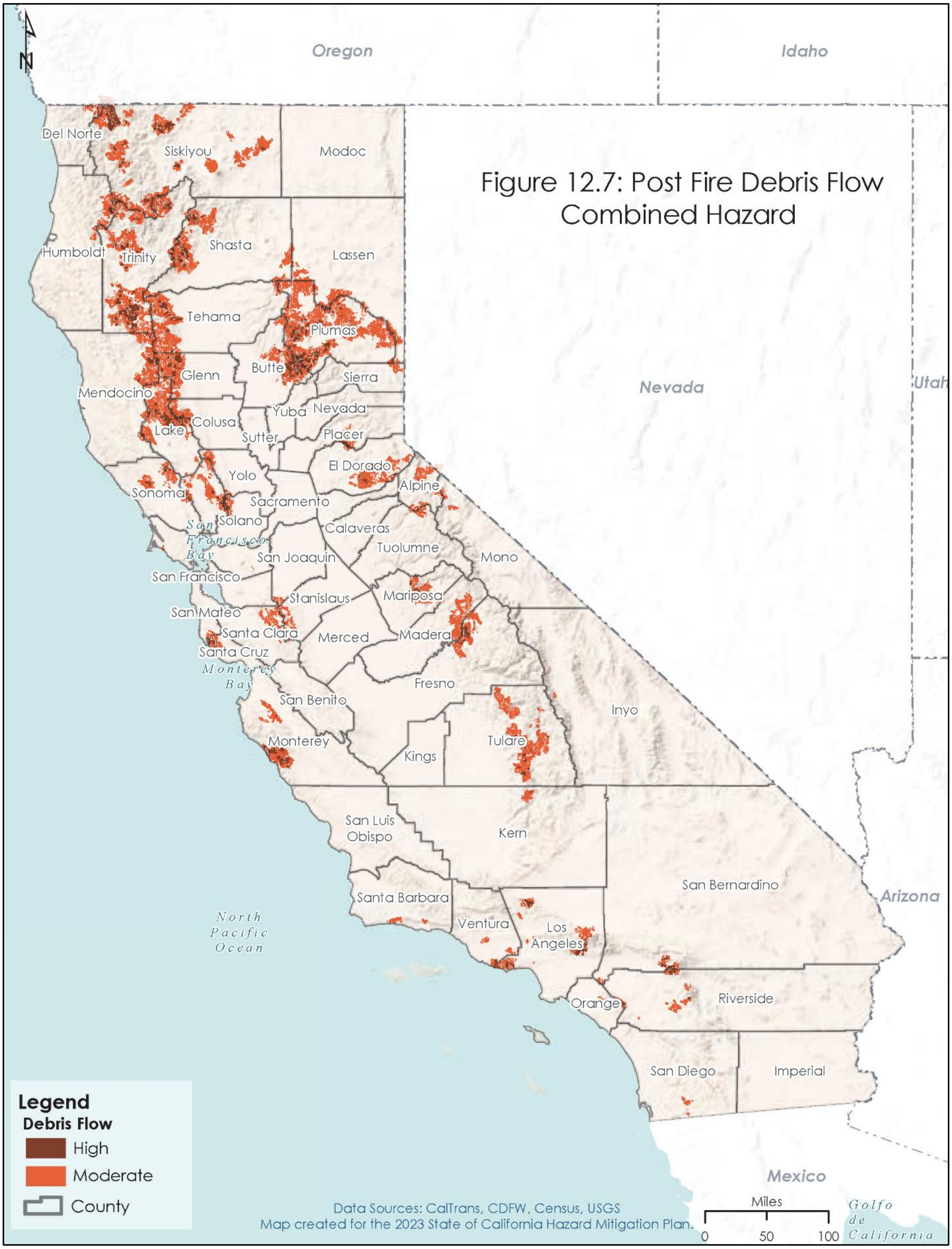
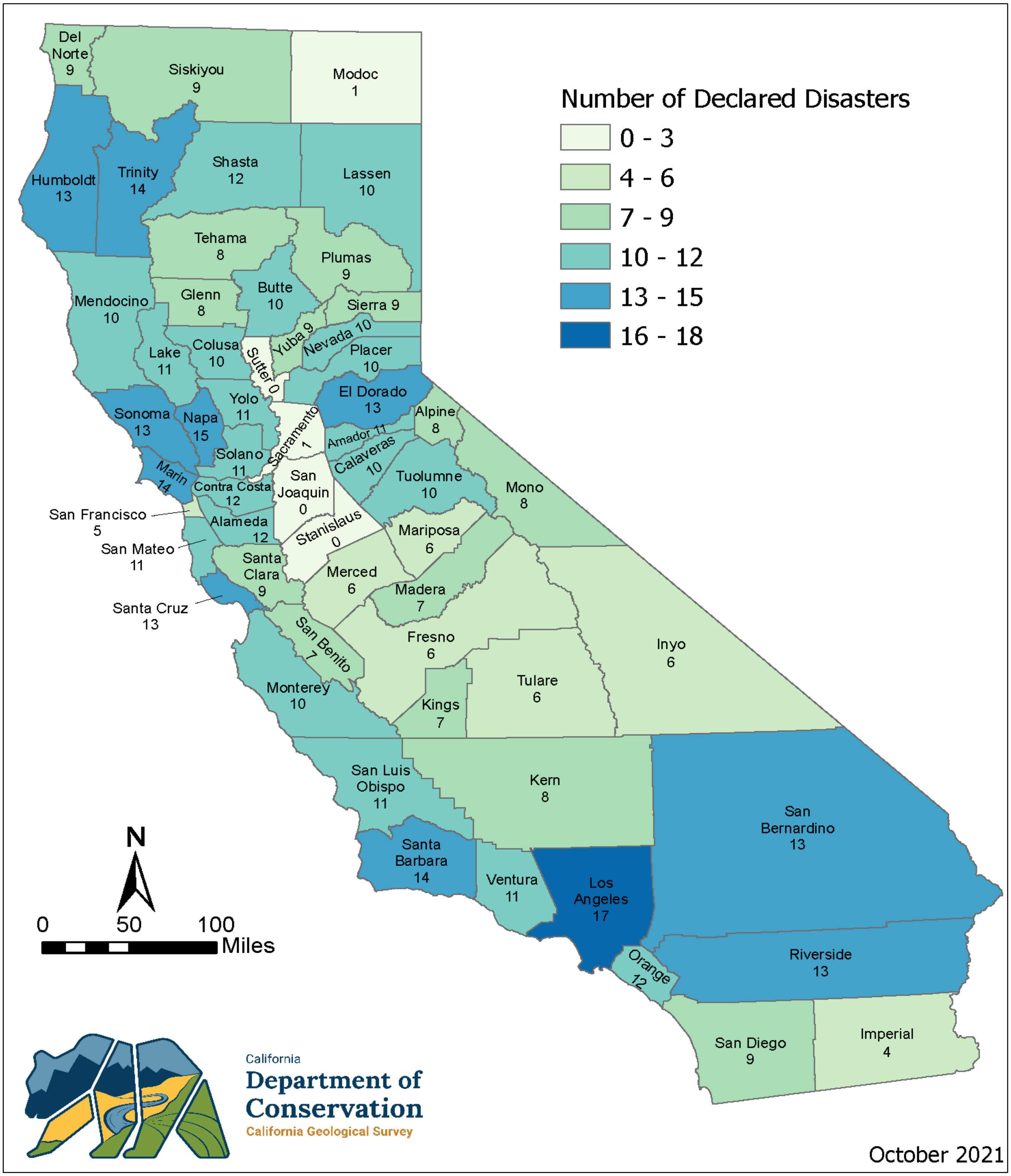


Figure 12-8. Federally Declared Landslide Disasters by County, 1953 – 2019



An investigation to identify any documented slides there for the 1955 flood disaster did not identify any; however, there are documented incidents of damaging landslides throughout the Coast Ranges (where the western portion of Merced County is) and it is reasonable to assume that damaging landslides occurred in Merced County even though verification is available.

12.3.2. Event History

Many large landslides are complex, being a combination of more than one landslide type. This is well illustrated by the La Conchita landslide that lies along the coastal bluffs in Ventura County. Historically active since the turn of the 19th century, it was reactivated as a slow-moving rotation slide during the 1995 winter rains that destroyed six homes in the subdivision below. The slow movement allowed homeowners to evacuate safely, resulting in no injuries during the event.

A portion of the same landslide moved again during the 2005 heavy winter rains as a fast-moving debris flow, which destroyed 30 more homes and caused 10 fatalities as the occupants had no time to escape (USGS 2006a).

More recently, a series of debris flows occurred in Southern California in early January 2018, particularly affecting areas northwest of Montecito in Santa Barbara County. The incident was responsible for 23 deaths, although the body of one of the victims has never been found. About 800 people were rescued, and about 160 people were hospitalized with injuries, including four in critical condition. The disaster occurred one month after a series of major wildfires. The fires scorched steep slopes, which caused loss of vegetation and destabilization of the soil and greatly facilitated subsequent mudflows. Over 500 structures were damaged or destroyed, with more than 40 swept of their foundations, all resulting in over $1 billion in direct and indirect economic losses.

Landslides triggered during the February 2017 severe storms caused damage across a large portion of the State, with a Major Disaster Declaration issued for 44 California counties and one Tribal Nation.

Many of the landslide events in the State have occurred during spring and winter when precipitation is high, causing slope instability and land movement. Table 12-1 lists landslide events that have occurred between 2018 and 2022.

Table 12-1. Landslide-Related Events in the State of California (2018 to 2022)

Date	Event Type	FEMA Declaration Number	USDA Declaration Number	Counties Impacted
March 10, 2021	Debris Flow	N/A	N/A	Orange
The debris flow brought areas of mud and debris over roads and into homes.				
January 27, 2021	Heavy Rain	N/A	N/A	Stanislaus
Rockslides caused by heavy rain.				
January 27, 2021	High Wind	N/A	N/A	Bakersfield
Mudslides and debris flows were reported in the West Side Hills near the Mineral Fire burn area.				
January 27, 2021	Debris Flow	N/A	N/A	San Benito
Mudslide on Panoche Rd.				
April 10, 2020	Debris Flow	N/A	N/A	San Diego
Interstate 8 landslide and debris on highway caused closure.				
April 9, 2020	Debris Flow	N/A	N/A	San Diego
Mudslide under a home spilled onto Black Mountain Road in Rancho Peñasquitos.				
December 26, 2019	Debris Flow	N/A	N/A	Kern
Caused by heavy rain.				
February 2019	Landslides, Mudslides	DR-4422	N/A	La Jolla Reservation
Heavy rains caused landslides on the 8,541-acre reservation. Facilities were damaged and destroyed.				
February and March 2019	Landslides, Mudslides	DR-4434	N/A	Amador, Butte, Colusa, Del Norte, El Dorado, Glenn, Humboldt, Lake, Marin, Mariposa, Mendocino, Monterey, Napa, Sonoma, Tehama, Trinity, Tuolumne, Yolo
An atmospheric river with extremely heavy rain caused flooding and mudslides throughout the State.				

Date	Event Type	FEMA Declaration Number	USDA Declaration Number	Counties Impacted
February 2019	Landslides, Mudslides	DR-4431	N/A	Calaveras, Colusa, Marin, Mariposa, Mendocino, Modoc, Napa, Riverside, Santa Barbara, Shasta, Trinity
An atmospheric river with extremely heavy rain caused flooding and mudslides throughout the State.				
November 29, 2018	Debris Flow	N/A	N/A	Butte
Caused by heavy rain/burn area.				
November 28, 2018	Debris Flow	N/A	N/A	Butte
Caused by heavy rain/burn area.				
July 11, 2018	Debris Flow	N/A	N/A	San Bernardino
Caused by heavy rain.				
March 22, 2018	Debris Flow	N/A	N/A	Mariposa
Caused by heavy rain/burn area.				
March 22, 2018	Debris Flow	N/A	N/A	Mariposa
Caused by heavy rain/burn area.				
March 22, 2018	Debris Flow	N/A	N/A	Mariposa
Caused by heavy rain/burn area.				
March 22, 2018	Debris Flow	N/A	N/A	Mariposa
Caused by heavy rain/burn area.				
March 22, 2018	Flash Flood	N/A	N/A	Tuolumne
Heavy rain led to significant erosion and at least one landslide.				
March 22, 2018	Flash Flood	N/A	N/A	Mariposa
Heavy rain caused rockslides and debris flows, closing several roads.				
March 21, 2018	Flood	N/A	N/A	El Dorado
Closed lanes on Highway 50 at Latrobe Rd/El Dorado Hills due to rockslide.				
January 2018	Mudslides	DR-4353	N/A	Santa Barbara
Post-Thomas Fire debris flows in Montecito. 129 homes destroyed, 307 homes damaged, 21 fatalities.				

Sources: (FEMA 2022u) (Climate Signals n.d.) (Nguyen 2019)
Note: Includes landslide events resulting in deaths, injuries, or damage of over $25,000.

12.4. PROBABILITY OF FUTURE HAZARD EVENTS

12.4.1. Overall Probability

Based on historical events in the State, California has a high probability of future landslide events. According to FEMA and NOAA reports, the State experienced 151 landslide events between 2018 and 2022 that caused enough damage to trigger federal disaster declarations. Based on this, California can expect at least 30 landslide events every year that may cause damage to property and infrastructure.

12.4.2. Climate Change Impacts

Landslides can result from intense rainfall and runoff events. Projected climate change-associated variance in rainfall events may result in more high-intensity events, which may increase landslide frequency (due to wetter wet periods and drier dry periods). While total average annual rainfall may decrease, rainfall is predicted to occur in fewer, more intense precipitation events (Ehlers 2022).

The combination of a generally drier climate in the future, which will increase the chance of drought and wildfires, and the occasional extreme downpour is likely to cause more mudslides and landslides. Climate change will also influence coastal areas, including both increased erosion and sea-level rise. Climate modeling will be a key component of understanding future landslide risks.

Increased wildfire occurrence associated with climate change escalates the risk of landslide and debris flows in the period following a fire, when slopes lack vegetation to stabilize soils and burned soil surfaces create more rainfall runoff. As climate change affects the length of the wildfire season, it is possible that a higher frequency of large fires may occur in late fall, when conditions remain dry, and then be followed immediately by intense rains early in the winter, as occurred with the Thomas Fire in December 2017 and subsequent Montecito and Carpinteria debris flows in January 2018.

12.5. IMPACT ANALYSIS

12.5.1. Severity

Landslides destroy property and infrastructure and can take the lives of people. According to the USGS, slope failures in the United States result in an average of 25 to 50 lives lost per year and an annual cost to society of about $1.5 billion. When landslides occur, they deform and tilt the ground surface. The result can be destruction of foundations, offset of roads, breaking of underground pipes, or overriding of downslope property and structures. The severity of a landslide will depend on the type and the size of the landslide.

12.5.2. Warning Time

Landslides can occur suddenly or slowly. The velocity may be a slow creep of inches per year for large, deep-seated landslides, while the runout from debris flows and post-fire debris flows may be many feet per second. Earthquake-induced landslides, including rock avalanche, may be almost instantaneous.

The warning time for landslides depends on awareness of the hazard as well as monitoring and alert systems. Assessments of pre-existing landsliding and areas that may be prone to landsliding helps to develop awareness of the hazard and planning for potential slope movement, depending on slope angle, material, and water content. Some methods used to monitor landslides can provide an idea of the type of movement and the amount of time prior to failure. It is also possible to determine what areas are at risk during general time periods. Assessing geology, vegetation, amount of predicted precipitation, and potential earthquake ground motions can help in these assessments.

For landslides or debris flows that may be triggered by rainfall, improved forecasting of El Niño events or other potentially high rainfall years can provide some advanced warning. Rainfall forecasting allows for better preparation and response to potential slope failures and flood events.

High-intensity, short-duration rainfall rates are the primary cause of debris flows. The USGS computes thresholds for post-burn areas based on statistical occurrences of debris flows and associated rainfall rates (burn areas less than two years old). For post-burn areas assessed by the WERT, USGS-generated thresholds are refined further using inputs from erosion modeling to field validated soil burn severity. In addition, those thresholds are adjusted on a continuous basis with input from local jurisdictions to reflect the revegetation of a post-burn area. Depending on conditions, some post-burn areas may take five years to recover. The WERT works with the USGS, the NWS, and Cal OES to develop thresholds as guidance for watches and warnings of possible flash flooding and debris flows.

Warning time for earthquake-induced landslide may be gained as the California Earthquake Early Warning System is developed. The California Earthquake Early Warning System may be able to provide the public with time for situational awareness of rapid earth movement.

Some large, deep-seated landslides can be instrumented with surficial and/or subsurface monitoring devices. This kind of monitoring is used when landslides may impact infrastructure or housing. The monitoring can provide alerts if movement begins or accelerates. This information can assist with evacuation alerts and provide data for protection and repair of infrastructure.

12.5.3. Cascading Impacts

Cascading impacts are the impacts that result when one type of hazard event triggers one or more other hazard events, which may in turn trigger still others. The following are notable cascading impacts associated with landslides:

- Landslides can collapse into water bodies, causing tsunamis or seiches. In 1958, a magnitude 8 earthquake collapsed a hillside into Lituya Bay, Alaska, causing a water splash wave that reached 1,720 feet up a mountain slope, stripping all vegetation. A massive landslide into the Vaiont Reservoir in Italy in 1963 caused a water splash wave that swept 800 feet over the top of a dam, causing a major flood that killed an estimated 2,600 people below.
- Landslides can relocate river channels, as occurred during the Oso mudslide in Washington State in March 2014.
- Landslides and debris flows can impact water quality and the storage capacity of surface water reservoirs used to store potable water.
- Landslides can act as dams, creating unplanned reservoirs, which in turn can create new hazards.
- Landslides can result in rapid water and debris blocking transportation routes or preventing key services for first responders.

12.5.4. Environmental Impacts

A landslide alters the landscape. In addition to changes in topography, vegetation and wildlife habitats may be damaged or destroyed. Soil and sediment runoff will accumulate downslope, potentially blocking waterways and roadways and impairing the quality of streams and other water bodies. Landslides that fall into streams may impact fish and wildlife habitat, as well as affecting water quality. Hillsides that provide wildlife habitat can be lost for prolonged periods due to landslides.

12.5.5. Local Hazard Impacts

LHMP Rankings

Forty-one of the hazard mitigation plans prepared for California's 58 counties list landslide as a hazard of concern, and 15 counties rank it as a high-impact hazard:

- Amador
- Butte
- Contra Costa
- Los Angeles
- Madera
- Marin
- Modoc
- Napa
- Nevada
- San Luis Obispo
- San Mateo
- Santa Barbara
- Santa Cruz
- Sonoma
- Ventura

An additional 18 counties identified landslide as a medium-impact hazard.

LHMP Estimates of Potential Loss

Table 12-2 summarizes potential losses to vulnerable structures based on estimates from the local risk assessments (as called for in FEMA's Standard State Mitigation Planning Requirement S6.b). Due to variances in approaches to assessing risk at the local level as well as the hazards assessed and the age of each assessment reviewed, this data is considered approximate.

Table 12-2. Landslide, Debris Flow and Other Mass Movements Risk Exposure Analysis for LHMP Reviews

Estimated Total Population Exposed	832,305
Estimated Number of Structures at Risk	385,036
Estimated Value of Structures at Risk	$325.9

12.6. VULNERABILITY ANALYSIS

A statewide assessment of landslide susceptibility was conducted using the following data provided by CGS:

Deep Seated landslide susceptibility mapping describes the relative likelihood of future landslides based solely on prior failure (from a landslide inventory), rock or soil strength, and steepness of slope. This analysis used the areas mapped having high or very high susceptibility to landslides (see Figure 12-6).

- **Landslide zone** mapping depicts areas with a higher probability of earthquake-induced landslides, within which specific actions are mandated by California law prior to any development. These maps do not show varying degrees of risk—a site is either in or out of the zone—and are designed for use as planning tools by non-scientists. Zone maps incorporate expected future earthquake shaking, existing landslide features, slope gradient, and strength of hillslope materials (see Figure 12-9). To date, CGS has evaluated and mapped only about 5 percent of the State for earthquake-induced landslide hazards.

12.6.1. Exposure of State-Owned or -Leased Facilities

Table 12-3, and Table 12-4 summarize the number and replacement cost value of State assets located in high landslide susceptibility areas, very high landslide susceptibility areas, landslide zones, and post-wildfire debris flow zones. Figure 12-10, Figure 12-11, Figure 12-12, and Figure 12-13 summarize the exposed assets as a percentage of total assets statewide. These quantities are based on a partial evaluation of landslide hazards in the State and therefore represent minimum values. Appendix I provides detailed results by county.

Figure 12-9. Earthquake-Induced Landslide Zones

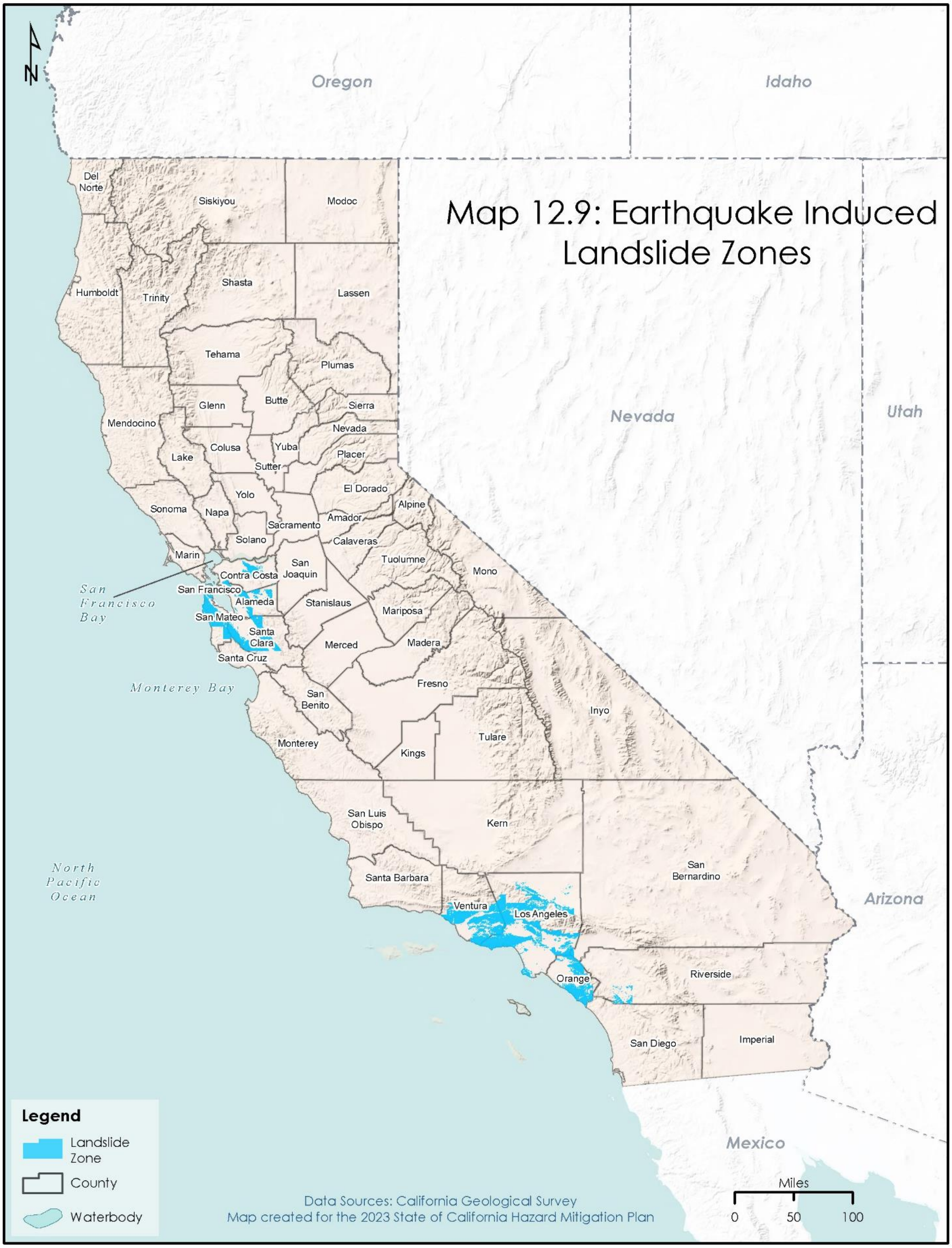


Table 12-3. State-Owned or -Leased Facilities Exposed to Landslide Hazards

Type of Facility	Number of Structures	Total Area (sq. ft.)	Replacement Cost Value		
			Structure	Content	Total
State Facilities in High Landslide Susceptibility Areas					
State-Leased Facilities	103	—	$856,634,521	$859,203,955	$1,715,838,476
State-Owned Facilities					
Facilities Housing Vulnerable Populations					
Correctional Facility	0	0	$0	$0	$0
Development Center	0	0	$0	$0	$0
Hospital	2	580	$31,043	$35,917	$66,960
Migrant Center	0	0	$0	$0	$0
Special School	0	0	$0	$0	$0
All Other Facilities	3,521	22,610,858	$1,594,469,379	$1,466,134,975	$3,060,604,354
Total State-Owned	***3,523***	***22,611,438***	***$1,594,500,422***	***$1,466,170,892***	***$3,060,671,314***
Total Facilities	**3,626**	**N/A***	**$2,451,134,943**	**$2,325,374,847**	**$4,776,509,790**
State Facilities in Very High Landslide Susceptibility Areas					
State-Leased Facilities	14	--	$13,419,205	$12,119,020	$25,538,225
State-Owned Facilities					
Facilities Housing Vulnerable Populations					
Correctional Facility	0	0	$0	$0	$0
Development Center	0	0	$0	$0	$0
Hospital	0	0	$0	$0	$0
Migrant Center	0	0	$0	$0	$0
Special School	0	0	$0	$0	$0
All Other Facilities	71	205,683	$3,578,775	$1,979,238	$5,558,013
Total State-Owned	***71***	***205,683***	***$3,578,775***	***$1,979,238***	***$5,558,013***
Total Facilities	**85**	**N/A***	**$16,997,980**	**$14,098,258**	**$31,096,238**

Type of Facility	Number of Structures	Total Area (sq. ft.)	Replacement Cost Value		
			Structure	Content	Total
State Facilities in Landslide Zones					
State-Leased Facilities	15	—	$59,425,049	$58,124,863	$117,549,912
State-Owned Facilities					
Facilities Housing Vulnerable Populations					
Correctional Facility	0	0	$0	$0	$0
Development Center	0	0	$0	$0	$0
Hospital	0	0	$0	$0	$0
Migrant Center	0	0	$0	$0	$0
Special School	0	0	$0	$0	$0
All Other Facilities	15	26,432	$487,087	$243,543	$730,630
Total State-Owned	***15***	***26,432***	***$487,087***	***$243,543***	***$730,630***
Total Facilities	**30**	**N/A***	**$59,912,136**	**$58,368,406**	**$118,280,542**
State Facilities in Post-Wildfire Debris Flow Zones					
State-Leased Facilities	7	—	$1,691,190	$2,410,051	$4,101,242
State-Owned Facilities					
Facilities Housing Vulnerable Populations					
Correctional Facility	0	0	$0	$0	$0
Development Center	0	0	$0	$0	$0
Hospital	0	0	$0	$0	$0
Migrant Center	0	0	$0	$0	$0
Special School	0	0	$0	$0	$0
All Other Facilities	180	306,495	$54,312,323	$42,042,407	$96,354,730
Total State-Owned	***180***	***306,495***	***$54,312,323***	***$42,042,407***	***$96,354,730***
Total Facilities	**187**	**N/A***	**$56,003,513**	**$44,452,459**	**$100,455,972**

* The inventory of State assets does not include building area for State-leased facilities, so no total area for all State facilities is provided; the building area of vulnerable assets is shown for State-owned facilities only.

Table 12-4. State-Owned or -Leased Infrastructure Exposed to Landslide Hazards

Type of Facility	State-Owned Infrastructure in the Mapped Hazard Area			
	High Landslide Susceptibility Areas	Very High Landslide Susceptibility Areas	Landslide Zones	Post-Wildfire Debris Flow Zones
Bridges	2,815	306	112	14
Highway (miles)	—	—	140.9	359.2
Dams	21	3	2	3
Water Project (miles)	—	—	9.6	0

Figure 12-10. State Assets in High Landslide Susceptibility Areas as % of Statewide Total

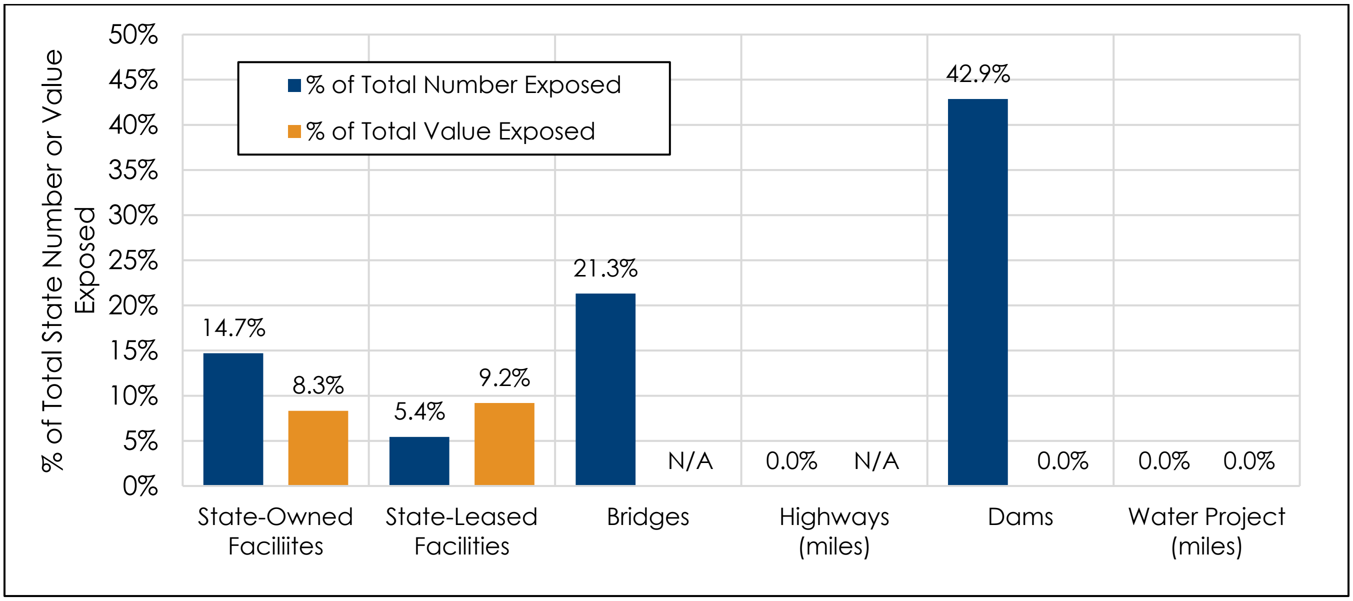


Figure 12-11. State Assets in Very High Landslide Susceptibility Areas as % of Statewide Total

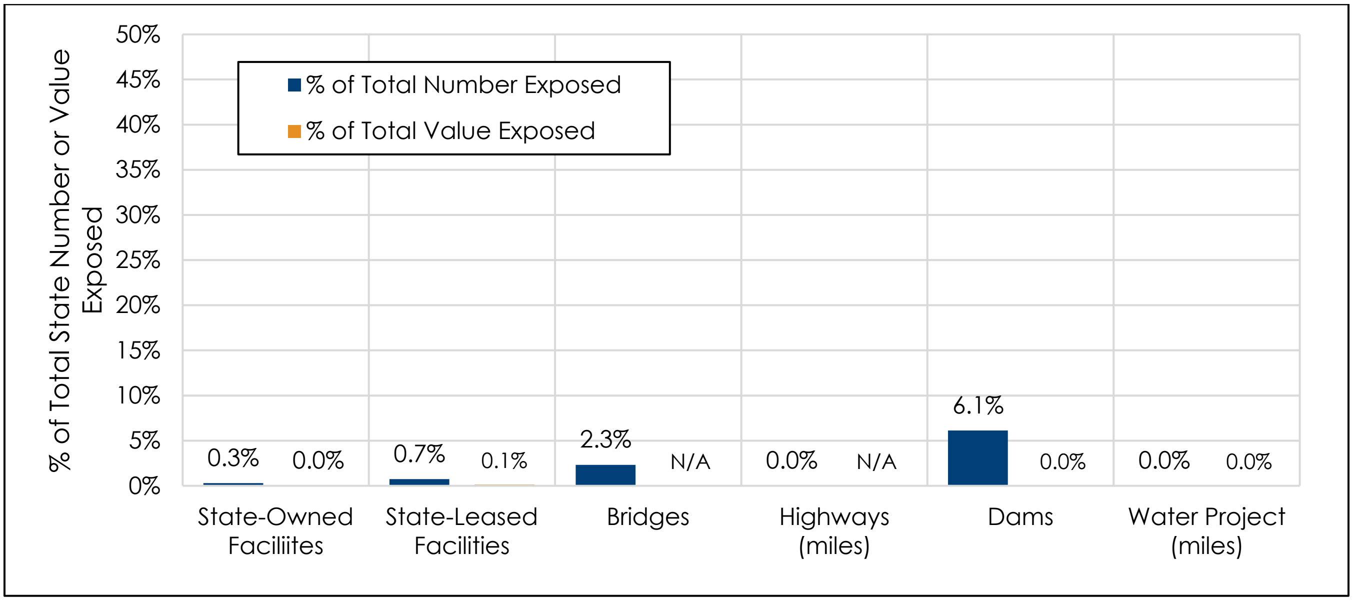


Figure 12-12. State Assets in Landslide Zones as % of Statewide Total

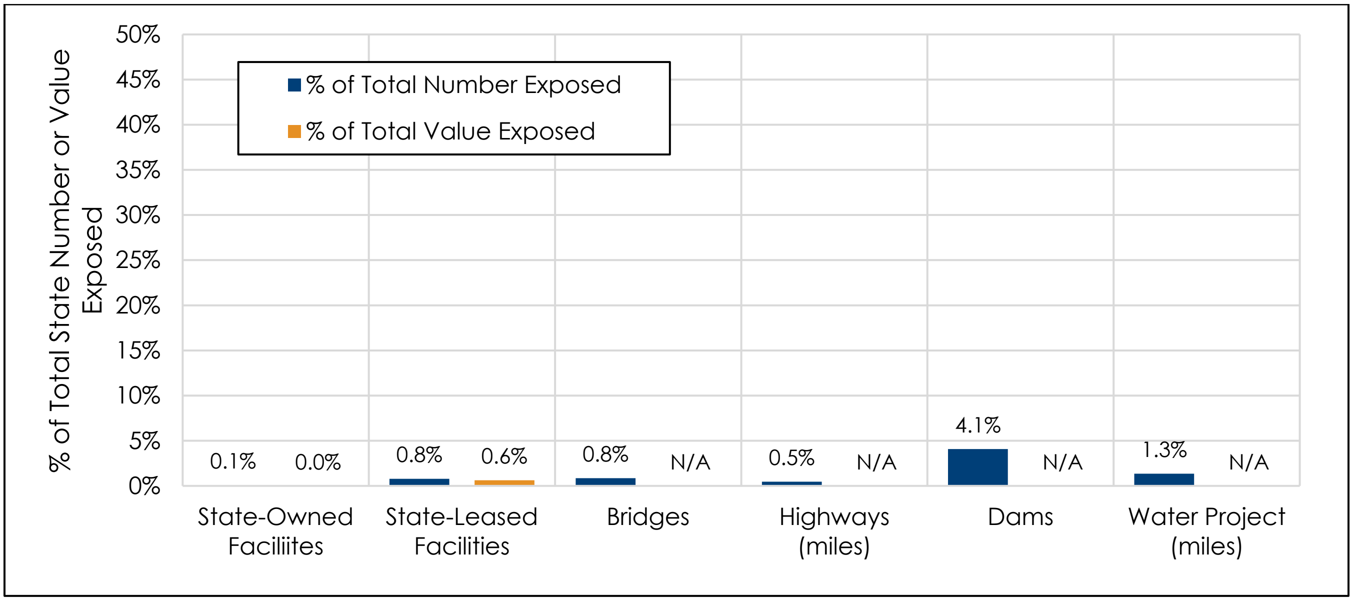
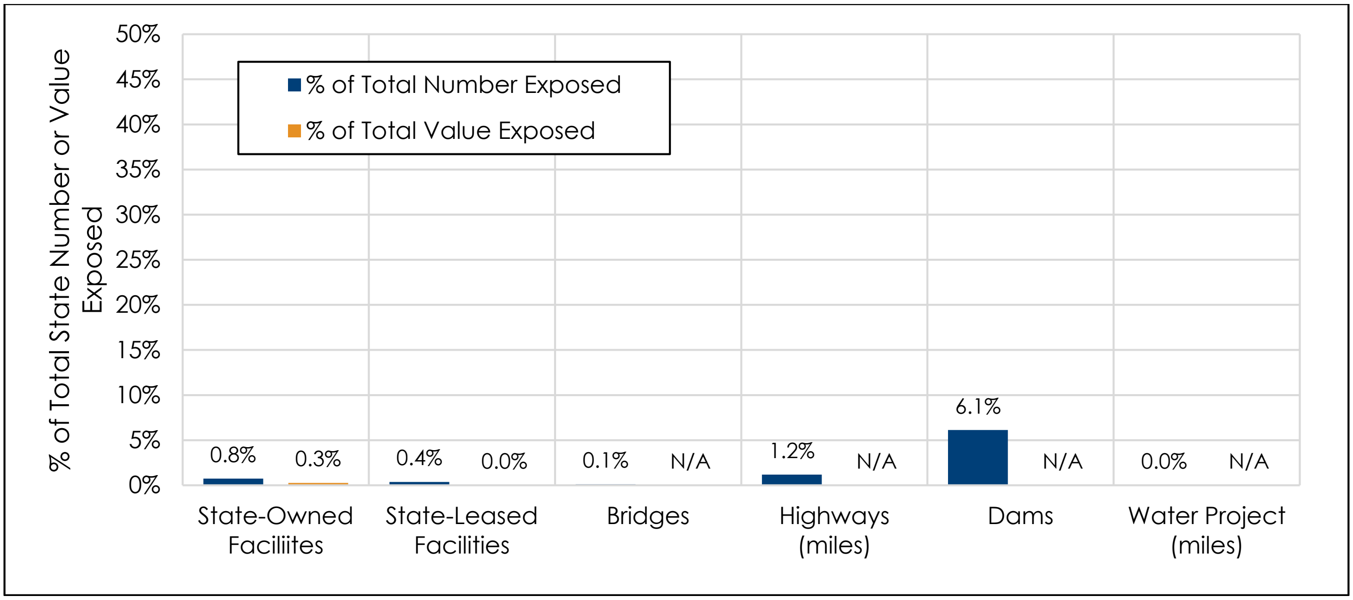


Figure 12-13. State Assets in Post-Wildfire Debris Flow Zones as % of Statewide Total



12.6.2. Exposure of Critical Facilities and Community Lifelines

Four critical facilities and lifelines are in landslide zones, and one is in a post-fire debris flow zone, as shown in Table 12-5. There are no critical facilities or community lifelines in the high or very high landslide susceptibility areas. These quantities are based on a partial evaluation of landslide hazards in the State and therefore represent minimum values.

Table 12-5. Critical Facilities and Community Lifelines in Landslide Zones

	Total Number of Facilities	Number of Facilities in Hazard Area				% of Total Facilities			
		High	Very High	Zone	Post-Fire Debris Flow	High	Very High	Zone	Post-Fire Debris Flow
Communications	42	—	—	0	0	—	—	0	0
Energy	176	—	—	0	1	—	—	0	0.6
Food, Water, Shelter	257	—	—	2	0	—	—	0.8	0
Hazardous Material	56	—	—	0	0	—	—	0	0
Health & Medical	47	—	—	0	0	—	—	0	0
Safety & Security	46	—	—	0	0	—	—	0	0
Transportation	131	—	—	2	0	—	—	1.5	0
Total	**755**	**—**	**—**	**4**	**1**	**—**	**—**	**0.5**	**0.1**

Critical facilities and community lifelines that are exposed to the landslide, debris flow and mass movement hazards are likely to experience functional downtime following these events, which could increase the net impact of these events.

12.6.3. Estimates of Loss

Although landslides can cause significant damage to State assets, there are no standard generic formulas for estimating associated losses. Instead, loss estimates were developed representing 10 percent, 30 percent, and 50 percent of the replacement cost value of all State-owned facilities exposed to landslide hazards (see Table 12-6).

Table 12-6. Loss Potential of State-Owned Assets for Landslide

Type of Facility	Total Replacement Cost Value (contents only)	Estimated Loss Potential Based on % Damage		
		10% Damage	30% Damage	50% Damage
Facilities Housing Vulnerable Populations				
Correctional Facility	$0	$0	$0	$0
Development Center	$0	$0	$0	$0
Hospital	$66,960	$6.696	$20,088	$33,480
Migrant Center	$0	$0	$0	$0
Special School	$0	$0	$0	$0
All Other Facilities	**$5,026,342,542**	**$502,634,254**	**$1,507,902,763**	**$2,513,171,271**
Total	**$5,026,409,502**	**$502,634,261**	**$1,507,922,851**	**$2,513,204,751**

Note: Quantities are based on a partial evaluation of landslide hazards in the State and therefore represent minimum values

This allows the State to select a range of potential economic impacts based on an estimate of the percentage of damage to these assets. Damage in excess of 50 percent is considered to be substantial by most building codes and typically requires total reconstruction of the structure.

12.6.4. Buildable Land

Of 11.7 million acres of land available for development statewide, 254,039 acres (2.2 percent) are located in a landslide zone (this quantity is based on a partial evaluation of landslide hazards in the State and therefore represents a minimum value). Appendix G provides a detailed assessment of exposed buildable lands by county.

12.6.5. Equity Priority Communities

The risk analysis for landslide found that 2.7 percent of people living in landslide zones live in equity priority communities (16,892 people). This quantity is based on partial evaluation of landslide hazards in the State and therefore represents a minimum value. Additionally, landslide hazards can affect lifelines and transportation networks, further impacting equity priority communities. A breakdown of exposed equity priority communities by county is included in Appendix I.

12.6.6. NRI Scores

According to the NRI, all of the State's counties have landslide risk, rated from relatively low to very high. Table 12-7 shows scores for the six counties with the highest rating. See Section 4.1.3 for a description of the components of the NRI.

Table 12-7. NRI Scoring of Counties for Landslide

County	Expected Annual Loss	Social Vulnerability Rating	Community Resilience Rating	Community Risk Factor	Risk Value	Score
Nevada	$732,244	Relatively Low	Relatively High	0.98	$812,736	98.55
Tuolumne	$634,232	Relatively Moderate	Relatively Moderate	1.16	$787,739	98.43
Marin	$770,102	Relatively Low	Very High	1.02	$736,098	98.33
Kern	$608,770	Very High	Very Low	1.41	$711, 545	98.23
San Bernardino	$509, 034	Very High	Relatively Moderate	1.34	$620,827	97.88
Sonoma	$502,986	Relatively Moderate	Relatively High	1.14	$535,891	97.53

12.7. MITIGATING THE HAZARD

12.7.1. Opportunities for Mitigating the Hazard

Exposure to landslide hazards can be reduced by effective land use planning and hillside development practice. Enhanced understanding of the risk through studies and plans that include risk assessment also creates the opportunities to identify mitigation actions. Like slope steepness and material strength, potential for water-saturated hillsides or earthquake shaking is a design parameter that should be considered when preparing a building site.

Reducing landslide hazard is accomplished by either reducing gravity forces acting on a slope by grading to decrease steepness or increasing slope resistance and restraint by using structural systems and effective dewatering and drainage. If either approach is not economically viable for a particular project, avoiding the hazard by relocating the project to a safer site is the alternative.

Landslides that affect existing structures can often be stabilized using engineering resistance and retention systems and effective dewatering that strengthen the slope and hold the rock and/or soil mass in place (Cal OES 2018).

Table 12-8 provides a range of potential alternatives for mitigating the landslide hazard (see Section 1.2.3 for a description of the different types of alternatives).

Additionally, the State has many current landslide hazard mitigation efforts, some of which are explained further in Appendix T.

12.7.2. Selected Actions to Mitigate the Hazard

The mitigation strategy developed for this SHMP includes the following actions that address the landslide hazard:

- Action 2023-011: Pre-Wildfire Geologic Hazard Mitigation Planning & Post-Wildfire Hazard Identification Program: Build capacity by increasing current staffing and resources to fully implement each task of the Program.
- Action 2018-008: Develop a database containing a description of the specific natural hazard event for which each project was designed to mitigate.
- Action 2018-037: Landslide Inventory Maps: Continue to map earthquake induced landslides through the Seismic Hazards Mapping Program.
- Action 2018-038: Post-Fire Runoff & Debris Flows: Develop regional modeling to assess potential effects of post-fire runoff. Develop an early warning system for post-fire flash floods and debris flows.

Table 12-8. Potential Opportunities to Mitigate the Landslide/Mass Movement Hazard

Community-Scale	Organizational Scale	Government-Scale
Manipulate the hazard: ▪ Stabilize slope (dewater, armor toe) ▪ Reduce weight on top of slope ▪ Minimize vegetation removal and the addition of impervious surfaces ▪ Apply engineering solutions that minimize/eliminate the hazard **Reduce exposure and vulnerability:** ▪ Locate structures outside of hazard area (off unstable land and away from slide-run out area) ▪ Retrofit home **Build local capacity:** ▪ Institute warning system, and develop evacuation plan ▪ Keep cash reserves for reconstruction	**Manipulate the hazard:** ▪ Stabilize slope (dewater, armor toe) ▪ Reduce weight on top of slope ▪ Apply engineering solutions that minimize/eliminate the hazard **Reduce exposure and vulnerability:** ▪ Locate structures outside of hazard area (off unstable land and away from slide-run out area) ▪ Retrofit at-risk facilities **Build local capacity:** ▪ Institute warning system, and develop evacuation plan ▪ Keep cash reserves for reconstruction ▪ Develop a continuity of operations plan ▪ Educate employees on the potential exposure to landslide hazards and emergency response protocol	**Manipulate the hazard:** ▪ Stabilize slope (dewater, armor toe) ▪ Reduce weight on top of slope ▪ Apply engineering solutions that minimize/eliminate the hazard **Reduce exposure and vulnerability:** ▪ Acquire properties in high-risk landslide areas ▪ Adopt land use policies that prohibit the placement of habitable structures in high-risk landslide areas ▪ Adopt higher regulatory standards for new development within unstable slope areas ▪ Armor/retrofit critical infrastructure against the impact of landslides **Build local capacity:** ▪ Produce better hazard maps Implement WERT-recommended mitigation measures. ▪ Provide technical information and guidance ▪ Enact tools to help manage development in hazard areas: better land controls, tax incentives, information ▪ Develop strategy to take advantage of post-disaster opportunities ▪ Warehouse critical infrastructure components ▪ Develop and adopt a continuity of operations plan ▪ Educate the public on the landslide hazard and appropriate risk reduction alternatives. ▪ Consider the probable impacts of climate change on the risk associated with the landslide hazard ▪ Create risk communication products

<table>
<tr><th>Community-Scale</th><th>Organizational Scale</th><th>Government-Scale</th></tr>
<tr><td>Become educated on risk reduction techniques for landslide hazards</td><td></td><td></td></tr>
<tr><td colspan="3">Nature-based opportunities:
Replace or restore native vegetation known to stabilize steep slope areas.
Soil bioengineering can be used to mitigate risk in larger areas that have a potential for shallow, slow-moving landslides or areas abandoned after past landslides that show signs of reactivation and have a high landslide hazard potential.
Hybrid solutions refer to conventional engineering solutions that are combined with nature-based solutions using appropriate vegetation.</td></tr>
</table>

DROUGHT

Climate Impacts:
Hazard expected to increase in frequency, duration, and intensity
Equity Impacts:
The entire population of the State is considered to be exposed; 30.4% of exposed population has been identified as living in equity priority communities
State Facilities Exposed:
All facilities exposed, but no impacts
Community Lifelines Exposed:
All lifelines exposed

Impact Rating: Medium (27)

13. DROUGHT

Drought has been identified as a medium-impact natural hazard of interest based on the hazard impact rating protocol applied for this SHMP. Droughts happen frequently but have little to no potential impact on State-owned or -leased facilities and community lifelines. The entire population of the State is exposed to this hazard, and greater than 30 percent of that population has been identified as living in equity priority communities. The greatest impacts from drought tend to be on the economy, the environment, public health, and safety. Economic impacts could be increased by future development with increasing demand for water supply. The frequency and severity of droughts is anticipated to increase over the next 30 years due to impacts from climate change.

13.1. HAZARD OVERVIEW

Drought is defined as a deficiency in precipitation over an extended period, resulting in a water shortage (National Integrated Drought Information System 2022b). Normally, one dry year does not constitute a drought in California. The State's extensive system of water supply infrastructure (reservoirs, groundwater basins, and interregional conveyance facilities) generally mitigates the effects of short-term dry periods for most water users (DWR n.d.-a), yet there are water shortage emergencies caused by drought. Drought is a gradual phenomenon, occurring slowly over a period of time.

13.1.1. The Impacts of Drought

Drought results in a decline of stream flows, lake levels, and reservoir levels and a decrease in water depth in wells (USGS n.d.-e). It can lead to serious problems, including crop losses, fish and wildlife losses, subsidence, saltwater intrusion, reduced water quality, and water supply shortages. As a drought continues, its impacts increase (DWR 2022k).

Drought Types

There are five ways drought is commonly defined:

- Meteorological drought is said to occur when rainfall has been deficient for an extended period.
- Hydrological drought is said to occur when rainfall deficits impact the water supply available from streams, reservoirs, lakes, and groundwater.
- Agricultural drought is said to occur when factors such as rainfall deficits, soil water deficits, reduced groundwater, or low reservoir levels for irrigation result in impacts on agriculture.
- Socioeconomic drought is said to occur when diminished water supply reduces the supply of economic goods such as fruits, vegetables, grains, or meat.
- Ecological drought is said to occur when a prolonged and widespread deficit in naturally available water supplies—including changes in natural and managed hydrology—creates multiple stresses across ecosystems.

Sources: (National Drought Mitigation Center 2022); (NWS 2022c)

Drought increases wildfire risk, and wildfires in turn increase demand for water. Prolonged periods of drought can result in detrimental changes in the vegetative structure and health of forests, making them more vulnerable not only to pest outbreaks but also to fire (EPA 2011). The loss of forests due to distressed health, pests, or fire can produce increased risk of other hazards due to reduced ability to retain runoff during heavy rainfall events (Hoegh-Guldberg 2018).

During droughts, groundwater use intensifies, stressing groundwater-dependent ecosystems and potentially resulting in increased overdraft, subsidence, and saltwater intrusion (in some areas), which can result in permanent loss of storage and damage to overlying infrastructure. Groundwater is the only source of water for much of California’s most productive farmland, and agricultural water needs are likely to be heightened during prolonged hot and dry periods. Groundwater is also often the only source of water for small, rural water systems and households (CNRA 2018). Additionally, droughts exasperate headwater streams’ ability to naturally recharge groundwater.

The impacts of drought can lead to harmful health impacts on California residents (NWS 2022f). Drought can have financial, physical, and emotional impacts on farmers and farm workers and others in Tribal Nation, rural, and farming communities (Walters 2021). In 2021, water allocations and deliveries to farms were significantly reduced across the State. Total surface water deliveries for Central Valley and North Coast farms dropped 41 percent below the 2002-2016 average (Escriva-Bou, et al. 2022). Impacts include hardships for farmers, farm workers, packers, and shippers of agricultural products. In some cases, drought can cause significant increases in food prices to the consumer due to agriculture production shortages and can result in lack of water and feed for grazing livestock, potentially leading to risk of livestock death (L. Anderson 2022).

Drought is harmful to water quality and public health. Reduced stream and river flows can increase the concentration of pollutants and bacteria in water, making contamination or water-related illness more likely (CDC 2020). Other infectious disease threats arise when drought leads to the contamination of surface waters and other types of water that are used for recreational purposes (CDC 2020). When temperatures rise and rainfall declines, algal blooms can grow and release dangerous toxins. At the same time, people are more likely to participate in water-related recreation, and those exposed to contaminated recreational waters are more likely to become infected with pathogens (CDC 2020). Drought and its consequences can also lead to increased mental health impacts, including acute or post-traumatic stress, substance abuse, domestic violence, and suicide (National Integrated Drought Information System 2022).

Droughts can exasperate conditions in the Sacramento San Joaquin Delta and other water sources where harmful algal blooms can develop. A lack of water flow and volume conflate with warmer temperatures, which allow conditions for out-of-control production of harmful algal blooms. These can be toxic or harmful and affect people, fish, shellfish, marine mammals, and birds.

During California droughts, impacts have been felt first by those most dependent on or affected by annual rainfall and snowpack. These include but are not limited to agencies fighting forest fires, ranchers engaged in dryland grazing, farmers growing crops in arid zones, rural residents relying on wells in low-yield rock formations, or small water systems lacking a reliable water source.

13.1.2. Declaring a Drought

California has not established an official definition of when a drought begins or ends or process for defining or declaring drought. A proclamation of emergency conditions pursuant to the California Emergency Services Act may be used to respond to drought impacts, but such a proclamation is not a drought definition (DWR 2021a).

Hydrologic conditions causing impacts for water users in one location may not represent drought for water users in a different part of California, or for users with a different water supply. Individual water agencies may use criteria such as rainfall/runoff, amount of water in storage, or expected supply from a water wholesaler to define their water supply conditions (DWR 2022e).

13.2. HAZARD LOCATION

The entire State of California is vulnerable to drought, although the conditions of drought are not experienced uniformly across the State (California Water Watch 2022). The effects of drought depend on the climate zone, the type of water supply available, and water users' ability to manage drought impacts (California Water Watch 2022).

Droughts are dynamic, and locations of the State susceptible to drought can change monthly. The U.S. Drought Monitor is a map that is updated weekly to show the location and intensity of drought across the country. The drought monitor uses the five-category system shown in Table 13-1.

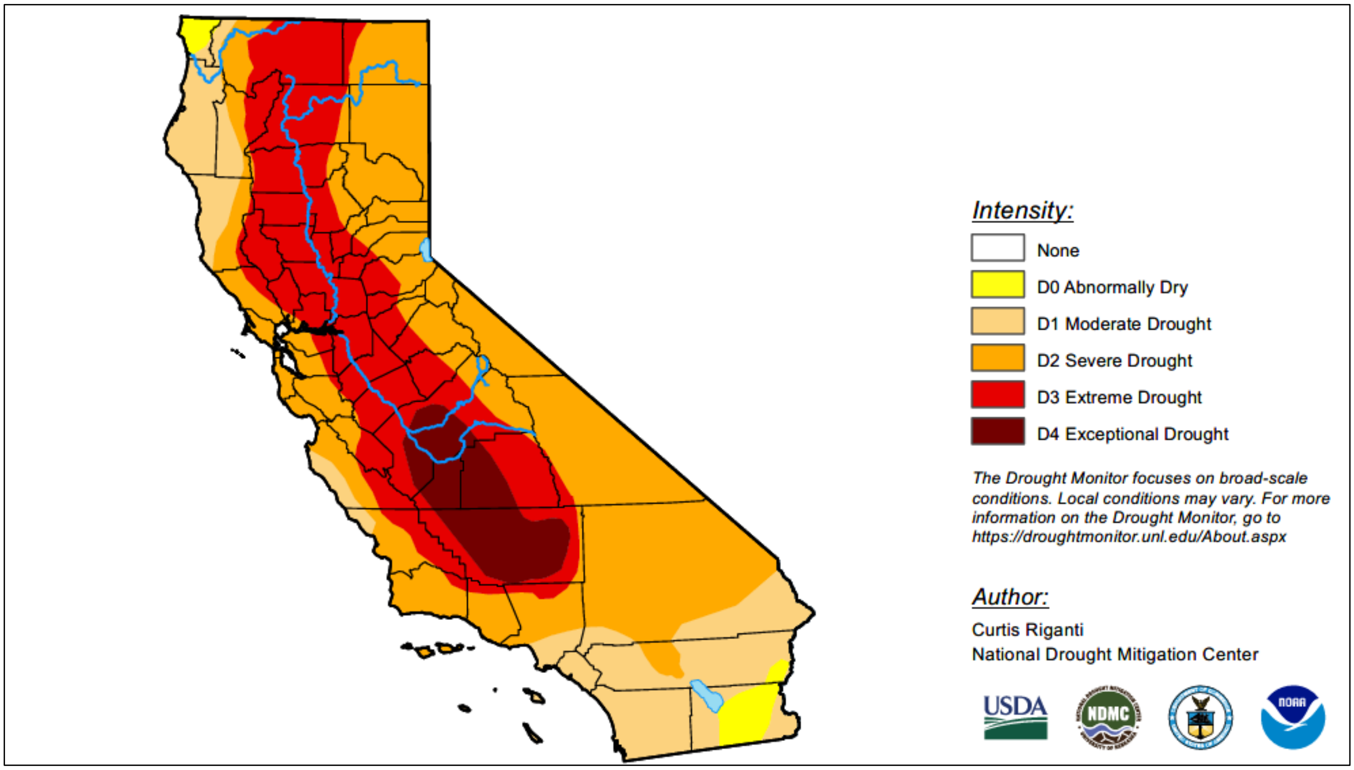
Table 13-1. U.S. Drought Monitor Categories

Category	Description	Possible Impacts
D0	Abnormally Dry	▪ Short-term dryness slowing planting, growth of crops ▪ Some lingering water deficits ▪ Pastures or crops not fully recovered
D1	Moderate Drought	▪ Some damage to crops, pastures ▪ Some water shortages developing ▪ Voluntary water-use restrictions requested
D2	Severe Drought	▪ Crop or pasture loss likely ▪ Water shortages common ▪ Water restrictions imposed
D3	Extreme Drought	▪ Major crop/pasture losses ▪ Widespread water shortages or restrictions
D4	Exceptional Drought	▪ Exceptional and widespread crop/pasture losses ▪ Shortages of water creating water emergencies

Source: (U.S. Drought Monitor 2023)

Figure 13-1 shows an example drought monitor map, for December 13, 2022, giving an example of the level of detail for this type of mapping. These maps can be accessed at: [California | U.S. Drought Monitor (unl.edu).](#)

Figure 13-1. U.S. Drought Monitor Map of California, December 13, 2022



Source: (U.S. Drought Monitor 2022)

13.3. PREVIOUS HAZARD OCCURRENCES

13.3.1. Disaster and Emergency Declarations

The following disaster declarations or emergency proclamations related to drought have been issued for California (see Appendix F for details):

- Federal DR or EM declaration, 1953 – 2022: one event, classified as drought
- California Emergency Proclamations, 1950 – 2022: 11 events, classified as drought
- USDA agricultural disaster declarations, 2012 – 2022: 112 events

13.3.2. Event History

Drought played a role in shaping California's early history. The so-called Great Drought in 1863–1864 contributed to the demise of the cattle rancho system, especially in Southern California. A period of extended dry conditions was experienced during most of the 1920s and well into the 1930s, which was when the Dustbowl drought gripped much of the United States. Three 20th-century droughts were of particular importance from a water supply standpoint:

- The 1929–1934 drought was notable for its duration and for its occurrence within a longer period of very dry hydrology. This drought's hydrology was subsequently widely used in evaluating and designing storage capacity and yield of large Northern California reservoirs.
- The 1976–1977 drought served as a wake-up call for California water agencies that were unprepared for major cutbacks in their supplies. Forty-seven of the State's 58 counties declared local drought-related emergencies at that time.
- The 1987–1992 drought stands out because of its six-year duration. Twenty-three counties declared local drought emergencies. Santa Barbara experienced the greatest water supply reductions among the larger urban areas.

Twenty-first century statewide droughts include the three-year 2007–2009 event and the five-year 2012–2016 event. These events were the first statewide emergency proclamations used to respond to drought impacts. They illustrated the effect of a warming climate on drought impacts (DWR 2021a). The experiences of California during recent years have motivated actions to examine more closely the State's water storage, distribution, management, conservation, and use policies.

Drought has affected virtually every county in California at one time or another, causing billions of dollars in damage. Droughts exceeding three years are relatively rare in Northern California, which is the regional source of much of the State's water supply. The 2018 SHMP discussed drought events that occurred in the State from 1972 through February 2017. Drought events in the State since then are listed in Table 13-2. There has never been a FEMA-designated disaster declaration for drought in California.

Table 13-2. Drought Events in the State of California (2017 to 2022)

Date	Event Type	FEMA Declaration Number	USDA Declaration Number	Counties/Areas Impacted
January 2017	Drought	N/A	S4144, S4151, S4157, S4158	Alameda, Alpine, Amador, Calaveras, Contra Costa, Fresno, Imperial, Inyo, Kern, Kings, Los Angeles, Madera, Mariposa, Merced, Mono, Monterey, Orange, Riverside, Sacramento, San Benito, San Bernardino, San Diego, San Joaquin, San Luis Obispo, San Diego, San Mateo, Santa Barbara, Santa Clara, Santa Cruz, Stanislaus, Tulare, Tuolumne, Ventura
Impacts from the 2016 drought continued through January 2017 in many counties.				
January – August 2018	Drought	N/A	S4279, S4298, S4303, S4332, S4359, S4390, S4399, S4427, S4460, S4477, S4467	Del Norte, Humboldt, Imperial, Inyo, Kern, Kings, Lassen, Los Angeles, Mendocino, Modoc, Monterey, Nevada, Orange, Placer, Riverside, San Bernardino, San Diego, San Luis Obispo, Santa Barbara, Shasta, Sierra, Siskiyou, Tehama, Trinity, Tulare, Ventura
July was the warmest month in the history of the State. A 120 °F temperature was recorded at the Chino Airport in San Bernardino County on July 6, 2018. Record-breaking temperatures across the State amplified already dangerous fire conditions where vegetation fuels were exceptionally dry and prone to ignition.				
September – November 2019	Drought	N/A	S4647, S4575, S4593	Imperial, Inyo, Kern, Los Angeles, Orange, Riverside, San Bernardino
October started dry, tying for the 10th driest October statewide, with records dating back to 1895. The dryness continued into November.				

Date	Event Type	FEMA Declaration Number	USDA Declaration Number	Counties/Areas Impacted
April – September 2020	Drought	N/A	S4675, S4676, S4691, S4697, S4717, S4715, S4741, S4758, S4765, S4769, S4780, S4797, S4819, S4824, S4859	Alameda, Amador, Butte, Calaveras, Colusa, Contra Costa, Del Norte, El Dorado, Glenn, Humboldt, Imperial, Inyo, Kern, Lake, Lassen, Los Angeles, Marin, Mendocino, Merced, Modoc, Mono, Napa, Nevada, Orange, Placer, Plumas, Riverside, Sacramento, San Benito, San Bernardino, San Francisco, San Joaquin, San Mateo, Santa Clara, Santa Cruz, Shasta, Sierra, Siskiyou, Solano, Sonoma, Stanislaus, Sutter, Tehama, Trinity, Yolo, Yuba
Precipitation was below average, and temperatures were above average. For maximum temperature, August 2020 came in second to 1967. For September, the maximum temperature ranked sixth warmest. On August 16, Death Valley recorded a temperature of 130 °F. Five of the State's largest six fires in history were ignited in August and September.				
October 2020 – May 2021	Drought	N/A	S4915, S4916, S4921, S4923, S4927, S4936, S4941, S4945, S4958, S4963, S4969, S4979, S4995, S5131	Alameda, Alpine, Alpine, Amador, Butte, Calaveras, Colusa, Contra Costa, Del Norte, Del Norte, El Dorado, Fresno, Glenn, Humboldt, Imperial, Inyo, Kern, Kern, Kings, Lake, Lassen, Los Angeles, Madera, Marin, Mariposa, Mendocino, Merced, Modoc, Mono, Monterey, Napa, Nevada, Orange, Pauma and Yuima, Placer, Plumas, Riverside, Sacramento, San Benito, San Bernardino, San Diego, San Francisco, San Joaquin, San Luis Obispo, San Mateo, Santa Barbara, Santa Clara, Santa Cruz, Shasta, Sierra, Siskiyou, Solano, Sonoma, Stanislaus, Sutter, Tehama, Trinity, Tulare, Tuolumne, Ventura, Yolo, Yuba

Date	Event Type	FEMA Declaration Number	USDA Declaration Number	Counties/Areas Impacted
October 2021 – April 2022	Drought	N/A	S5145, S5146, S5155, S5157, S5165, S5169, S5208	Alameda, Alpine, Alpine, Amador, Butte, Calaveras, Colusa, Contra Costa, Del Norte, El Dorado, Fresno, Glenn, Humboldt, Imperial, Inyo, Kern, Kings, Lake, Lassen, Los Angeles, Madera, Marin, Mariposa, Mendocino, Merced, Modoc, Mono, Monterey, Napa, Nevada, Orange, Placer, Plumas, Riverside, Sacramento, San Benito, San Bernardino, San Diego, San Francisco, San Joaquin, San Luis Obispo, San Mateo, Santa Barbara, Santa Clara, Santa Cruz, Shasta, Sierra, Siskiyou, Solano, Sonoma, Stanislaus, Sutter, Tehama, Trinity, Tulare, Tuolumne, Ventura, Yolo, Yuba
The 2021 water year was the second driest on record, with extreme heat and lack of precipitation. By the end of 2021, all 58 counties in California were placed under a drought emergency proclamation (State of California 2022d). The drought has continued through 2022; as of April 2022, the snowpack of the Sierra Nevada was at 38% of its statewide average (Becker 2022). The State experienced $1.2 billion in crop damage as a result of this drought period.				

13.4. PROBABILITY OF FUTURE HAZARD EVENTS

13.4.1. Overall Probability

The cyclical occurrence of drought and documentation of past and current losses point to the strong probability that California will continue to be vulnerable to short- and longer-term drought impacts. Based on the historical and more recent drought events in California, the State has a high probability of future drought events. According to FEMA, USDA, and NOAA, California experienced 117 drought events between 1950 and 2022. California can anticipate at least one period of drought somewhere in the State every year.

13.4.2. Climate Change Impacts

Climate change is expected to affect California's water supply conditions over the long term, with a significant impact being reduction in mountain snowpack. Climate change models show pronounced impacts—such as loss of half or more of the Sierra Nevada snowpack—by the end of the century, with noticeable impacts occurring by mid-century. Even though some climate models predict that Northern California may be slightly wetter by century's end, the loss of winter storage capacity in mountain snowpack and warmer temperatures will exacerbate drought conditions.

The record warm temperatures California experienced in the winters of Water Years 2014 and 2015 illustrate how future droughts may unfold, with greatly reduced spring runoff into major reservoirs and water temperatures too warm to support anadromous fish populations in many areas. Climate change is intensifying drought impacts, as observed in the 2012-16 drought and in the 2020-2022 drought years. Figure 13-2 illustrates the projected climate shift, showing a warmer average temperature.

Rising temperatures also will affect snowpack. By the end of the 21st century, California's Sierra Nevada snowpack is projected to experience a 48 to 65 percent loss from the historical April 1 average. California's snowpack has historically been an integral part of California's water supply systems (Water Education Foundation 2014).

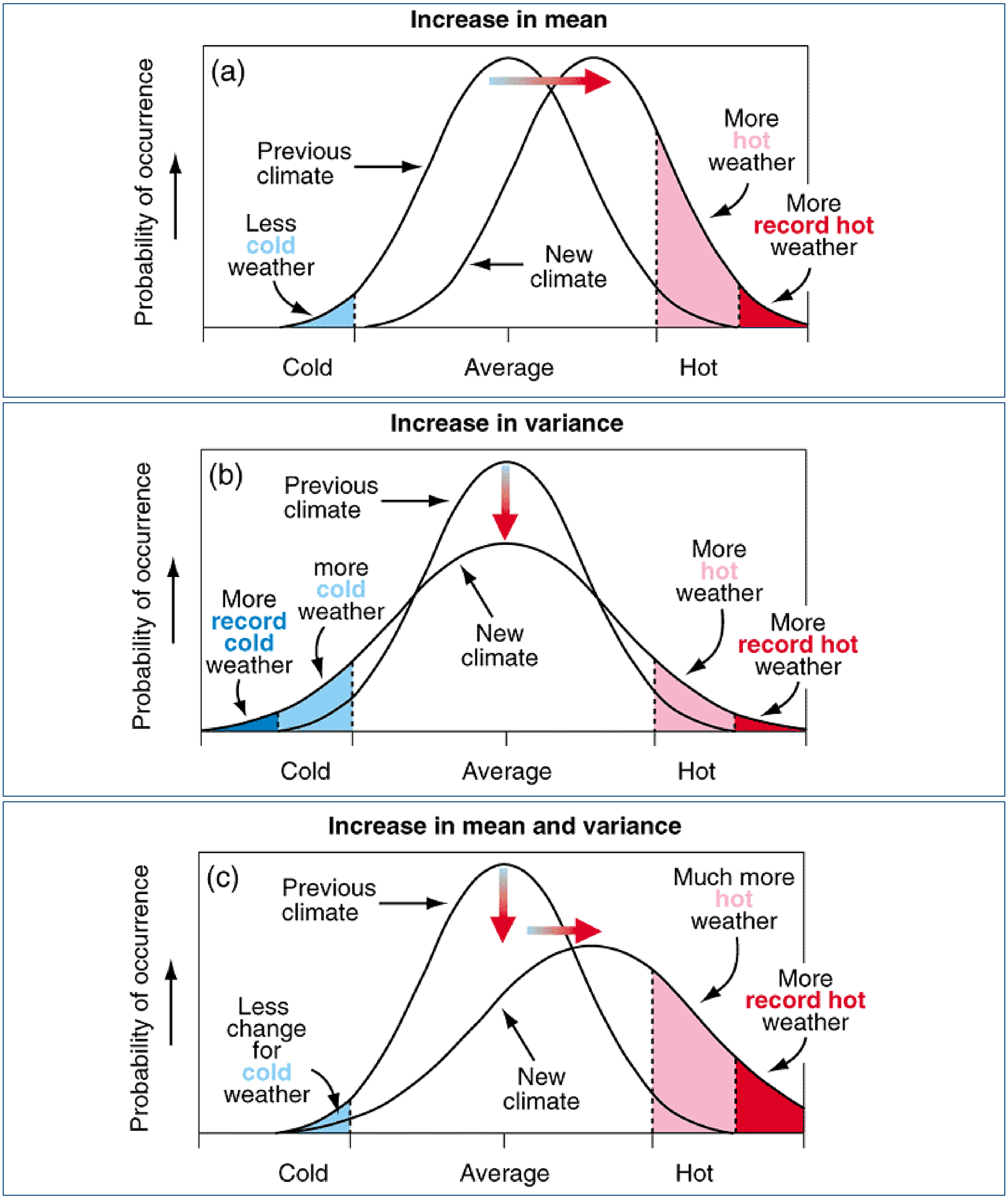
13.5. IMPACT ANALYSIS

13.5.1. Severity

The State of California uses three indicators to define the severity of a drought: weather, runoff, and water supply. Figure 13-3 shows recent (2009 through 2021) drought severity in the State based on indicators commonly used to evaluate water conditions in California.

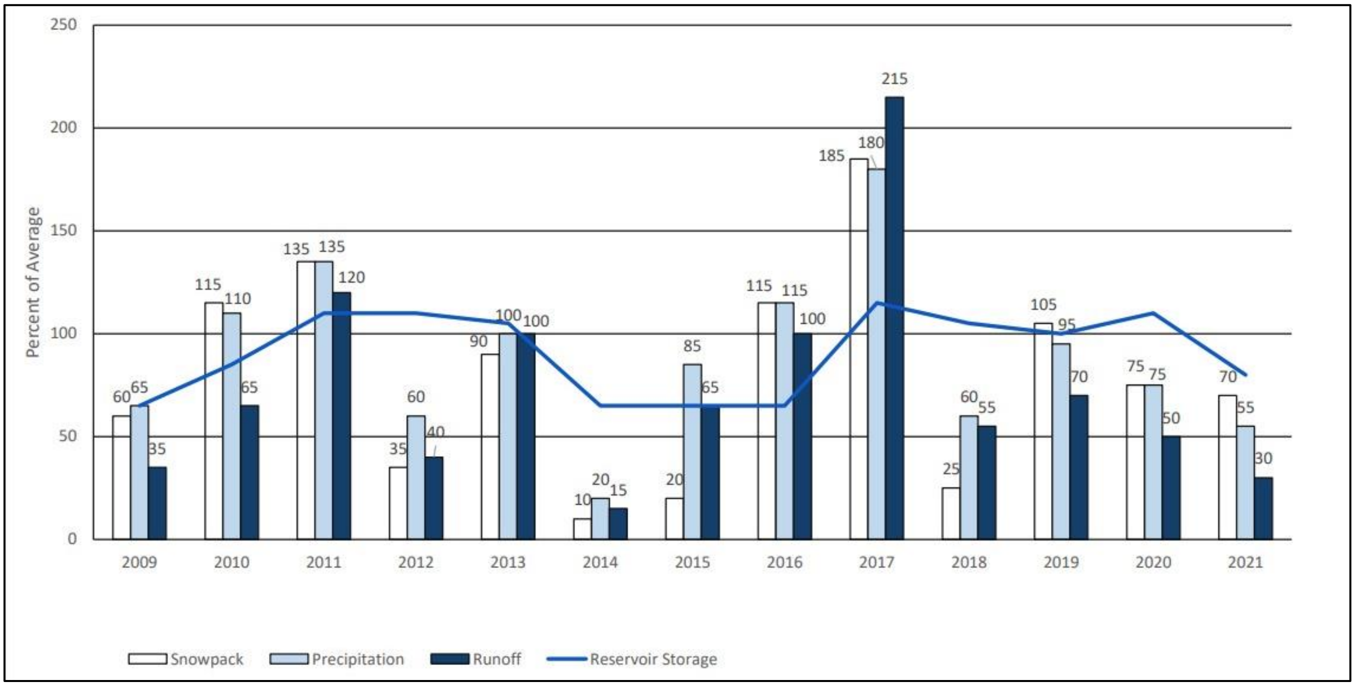
The percentage of average values in the figure is determined by measurements made in each of the State's 10 major hydrological regions. The chart illustrates the cyclical nature of weather patterns in California.

Figure 13-2. Future Climate Shift



Source: (IPCC 2001)

Figure 13-3. Water Supply Conditions, 2009 to 2021



Source: (DWR 2021)

Snowpack and precipitation increased from 2009 to 2011, decreased sharply in 2012, recovered somewhat in 2013, and again dramatically declined in 2014. Snowpack levels in 2015 remained low before reaching average levels again in 2016 (DWR 2021). In 2017, precipitation, snowpack, and runoff were significantly above average (resulting in other hazard events such as flooding), but 2018 followed with rainfall and snowpack well below average. Rainfall and snowpack returned to about average levels in 2019, before falling again in 2020 and 2021 (DWR 2021).

13.5.2. Warning Time

Most of California's moisture originates from the Pacific Ocean. During the wet season, the atmospheric high-pressure belt that sits off western North America shifts southward, allowing Pacific storms to bring moisture to California. On average, 75 percent of the State's average annual precipitation occurs between November and March, with half of it occurring between December and February. A persistent high-pressure zone over California during the peak winter water production months predisposes the water year to be dry.

The ability to reliably predict precipitation conditions at seasonal or annual timescales is very limited. The El Niño-Southern Oscillation—a periodic shifting of ocean-atmosphere conditions in the tropical Pacific that ranges from El Niño (warm phase) to neutral to La Niña (cold phase)—offers only limited predictive capability for precipitation in California. La Niña conditions tend to favor a drier outlook for Southern California, but do not typically show significant correlation with water year type for Northern and Central California. Seasonal precipitation forecasting is an important drought response tool and a research area requiring focused investment to develop the predictive ability needed to support water management. Dry conditions become a drought when the impacts of prolonged dry conditions create problems.

13.5.3. Cascading Impacts

Cascading impacts are the impacts that result when one type of hazard event triggers one or more other hazard events, which may in turn trigger still others. The following sections describe notable cascading impacts associated with drought:

Public Health

Drought can lead to various physical and mental health impacts: diminished water quality, groundwater contamination, reduced air quality from arid lands and dust, and increased stagnant water creating breeding grounds for disease-carrying pests, such as mosquitoes. These impacts, in turn, increase the risk of water-borne or food-borne diseases, worsen chronic respiratory conditions or risk of acute respiratory illness, and increase risk of Valley fever as well as vector-borne diseases. Drought and its consequences can also lead to increased mental health impacts, including acute or post-traumatic stress, substance abuse, domestic violence, and suicide.

A 2015 assessment of the potential vulnerability of populations exposed to drought conditions in Tulare and Mariposa counties evaluated household water access, acute stressors, exacerbations of chronic diseases, behavioral health issues, and financial impacts (Barreau, et al. 2017).

The household impact ranged from 3 to 12 percent of households reporting not having running water, 25 to 39 percent reporting impacts on finances, 39 to 54 percent reporting impacts on property, 10 to 20 percent reporting impacts on health, and 33 to 61 percent reporting impacts on peace of mind. Additionally, 16 to 46 percent of households reported worsening conditions for chronic disease, 8 to 26 percent reported worsening conditions for acute stress, and 14 to 34 percent considered moving. Impacts on finances and property were associated with impacts on health, peace of mind, and acute stress levels. Issues related to personal hygiene that could lead to personal health issues included a decrease in frequency or duration of handwashing, which ranged from 58 to 68 percent (CDPH, MCHD 2016); (CDPH, TCHHSA 2016).

Wildfire

Drought can create hazardous conditions in forests and other vegetation-covered spaces, providing fuel for wildfires (LAO 2022). Droughts can also create more prolonged fires fueled by excessively dry vegetation, along with reduced water supply for firefighting (NIDIS n.d.). Bouts of severe drought, heat, and low humidity are becoming more extreme as the climate warms. As climate change makes hot and dry conditions more common and severe, vegetation dries out and landscapes become more flammable, pushing up the odds of dangerous wildfires.

Tree Mortality

Droughts put stress on trees and make them more susceptible to pest infestations. This, in turn, can lead to more diseased, dying, and dead trees, (LAO 2022). Increased tree mortality has resulted in millions of dead trees around the State, causing hazards to people, property, and infrastructure and creating a greater risk of wildfires (Borunda 2020). An estimated 170 million trees in forest lands died between 2010 and 2021. Extreme drought puts additional pressure on already stressed trees, leading to new and expanding mortality. According to the Fourth National Climate Assessment Report, the combination of worsening droughts and expanding bark beetle populations due to warming winters killed 7 percent of the western U.S. Forest area over the past four decades (NCA 2018).

Subsidence

Drought can contribute to land subsidence caused by groundwater pumping from wells. Land subsidence is the phenomenon in which the earth’s surface gradually settles or sinks due to sub-surface activities, primarily groundwater pumping, which compacts aquifer systems (Water Science School 2018). Pumping of groundwater is greatly increased during dry years. Land subsidence due to groundwater pumping can permanently damage or collapse underground aquifers, increase flood risk in low-lying areas, and pose hazards to buildings, infrastructure, and water storage facilities (Water Science School 2018). Long-term subsidence can alter water system flow patterns and exacerbate water managers’ capabilities to move and distribute water supplies to and within subsided affected areas.

Water Quality

Over-pumping of groundwater can diminish the water quality of groundwater supplies through contamination from agricultural runoff or infiltration of saltwater in coastal basins. This can cause water to become unsafe to drink and require costly treatment to remove contaminants. This can be an insurmountable challenge for rural residents who rely on private wells for drinking water, as well as small, rural water systems that are dependent on local basins or aquifers (Hanak, Chappelle and Harter 2017). These impacts can lead to localized conflicts, anxiety, and stress, as well as increased risk of infectious diseases, such as water- or food-borne diseases (CDC 2020). Over-pumping of groundwater can diminish the water quality of groundwater supplies through contamination from agricultural runoff, movement of nearby contaminated aquifers into non-contaminated aquifers, or infiltration of saltwater in coastal basins.

Energy

All sources of energy require water in their production processes, and energy is required to extract, convey, and deliver water. Because energy and water are so interdependent, the availability and predictability of water resources can directly affect energy systems.

Dust Storms

Reduced moisture in air and soil and longer periods between precipitation periods can result in increased coating of dust and other contaminants, mainly impacting electrical transmission lines.

13.5.4. Environmental Impacts

Drought affects animal and plant species. A 2016 CDFW report on wildlife affected by the 2012-2016 drought indicated that amphibian, reptile, bird, and mammal populations that depend on freshwater marsh, streamside habitat, and wet meadows struggled the most to endure the drought. Tribal Nations from Owens Valley in the Eastern Sierra region saw near loss of an entire habitat that holds cultural significance, as drought accompanied by over-pumping groundwater and exporting water from Owens Valley to Los Angeles resulted in loss of alkali meadows (State of California 2018). The lack of surface water affects migratory birds and alters their patterns, which in turn can impact agriculture that relies on migratory bird habitat within the ecosystem.

The lack of surface water also threatens salmon and other fish species in California rivers. And it forces farmers to pump more water from groundwater aquifers, which leads to land subsidence that also stresses infrastructure.

13.5.5. Local Hazard Impacts

LHMP Rankings

Of the 58 counties in California, 54 assessed drought as a hazard of concern in their hazard mitigation plans. Of these, 30 ranked drought as high risk, 17 ranked it as medium risk, and seven ranked it as low risk. The following counties listed drought as a high-risk hazard:

- Alameda
- Alpine
- Butte
- Calaveras
- Colusa
- El Dorado
- Glenn
- Inyo
- Kern
- Kings
- Lake
- Lassen
- Los Angeles
- Madera
- Mendocino
- Merced
- Modoc
- Monterey
- Napa
- Nevada
- Placer
- San Diego
- San Luis Obispo
- Santa Barbara
- Santa Cruz
- Solano
- Stanislaus
- Trinity
- Yolo
- Yuba

LHMP Estimates of Potential Loss

A review of the LHMPs in the counties (as called for in FEMA's Standard State Mitigation Planning Requirement S6.b) found no quantitative risk analysis that identifies population or structures exposed to this hazard. This can be attributed to the lack of extent and location hazard mapping to use for such an analysis. Therefore, no summary of risk for local plan reviews is provided for this hazard.

13.6. VULNERABILITY ANALYSIS

13.6.1. Exposure of State-Owned or -Leased Facilities, Critical Facilities, and Community Lifelines

For drought, the entire State of California is exposed and vulnerable. Drought events generally do not impact buildings. No structures are anticipated to be directly affected by a drought, and all are expected to be operational during a drought event. However, facilities that provide potable water may be affected by short supplies of water.

13.6.2. Estimates of Loss

Drought can impact the economy, including loss of business function and damage and loss of inventory. Economic impacts may include the following:

- Losses from crop, livestock, timber, and aquaculture production and associated businesses
- Losses from recreation providers and associated businesses
- Increased costs resulting from increased energy demand and from shortages caused by reduced hydroelectric generation capacity
- Revenue losses for federal, State, and local governments from a reduced tax base and for financial institutions from defaults and postponed payments
- Long-term loss of economic growth and development

Even though the majority of businesses will still be operational, they may be impacted aesthetically. These aesthetic impacts are most significant to the recreation and tourism industry which is an important part of the State's economy. In 2021, the tourism industry brought in over $100 billion, contributing to $9.8 billion in State and local tax revenue and supported 927,100 jobs (CalChamber 2022).

Industries that rely on water for business may be impacted the hardest (e.g., agriculture/aquaculture). A prolonged drought event could have significant impacts in counties that have large amounts of agricultural lands. According to the current Census of Agriculture 2017 State Profile, there are 70,521 farms across California covering more than 24 million acres. The market value of products sold is estimated at $45.1 billion (USDA 2017).

13.6.3. Buildable Lands

An estimated 11.7 million acres of land is available for development in California. Because the entire State is vulnerable to drought, any type of development of any of this land will be susceptible to damage and impacts from this hazard. With ongoing development, the demand for water will increase, exacerbating drought instances. As water is drawn down from increased rates of use, drought can occur more readily than from lack of precipitation alone.

13.6.4. Equity Priority Communities

The 2012-2017 drought adversely affected at least one public water system in 39 of the State's 58 counties, and the most impacts were seen in the San Joaquin Valley, North Coast, and Central Coast regions. A study of that drought found that, among 92 drought-affected water systems, two-thirds served a disadvantaged community (characterized by a medium household income less than 80 percent of the State median) and almost one-third served a cumulatively burdened community (a community that ranks in the top quarter of census tracts in the State for environmental burdens and socioeconomic vulnerability) (Feinstein, et al. 2017). These communities include rural communities, and those with high rates of low-income households, as well as federally and non-federally recognized Tribal Nations. The lack of available water during a drought impacts culturally significant habitat and species. Tribal Nations usually do not have recourse to provide additional water supplies to protect such culturally significant habitat and species.

Overall, the entire population of the State of California is exposed and vulnerable to drought. Therefore, the exposed population to drought in equity priority communities is equal to the statewide percentage: 30.4 percent of the total population (12 million people). The sections below describe potential drought impacts on specific equity priority communities.

Tribal Nations

The State's history has left many Tribal Nations with limited or no access to their traditional or culturally significant water sources, (Secaira 2021); (State of California 2018). Furthermore, Tribal Nations that do have autonomous water systems do not have the funding to properly maintain this infrastructure, due to their low population size and resources. This places Tribal Nation residents at greater risk of exposure to contaminated water or loss of water as a result of drought (National Integrated Drought Information System 2022a).

Farmworkers

When surface water runs dry in a drought, farms become increasingly reliant on groundwater. Not all farms have access to sufficient groundwater, and some owners opt to leave their farmland uncultivated during a prolonged drought. During the height of the drought in 2015, California experienced a 45 percent increase in idle land area and lost over 10,000 seasonal farming jobs (Mahadevan 2021).

Low-Income Communities of Color

Low-income communities of color in California, especially in the Central Valley, are highly vulnerable to drought (Mahadevan 2021). Hispanic/Latina/e/o residents make up about 40 percent of the population in the Central Valley. About 25 percent of households in the region experience poverty. These residents were highly vulnerable during the 2012-2017 drought as they were both a majority of rural farmworkers vulnerable to job losses and disproportionately living in areas that lost access to safe drinking water (Mahadevan 2021).

During the 2012-2017 drought, 50 percent of State emergency food assistance was distributed to Tulare County residents (Feinstein, et al. 2017). Reduced food production as a result of drought can cause food prices to increase, and those who experience food insecurity or are low-income may be further burdened with limited access to affordable, healthy food (EPA 2022a).

Households Using Wells for Water Supply

Dry household wells are a major problem for vulnerable communities. In Tulare County during the 2012-2017 drought, for example, two-thirds of 1,600 reported dry wells were in a disadvantaged community, and nearly 90 percent were in a cumulatively burdened community.

13.6.5. NRI Scores

According to the NRI, 55 of the State's counties have drought risk, rated from very low to very high. Table 13-3 shows scores for the six counties with the highest rating. See Section 4.1.3 for a description of the components of the NRI.

Table 13-3. NRI Scoring of Counties for Drought

County	Expected Annual Loss	Social Vulnerability Rating	Community Resilience Rating	Community Risk Factor	Risk Value	Score
Santa Barbara	$214,679,980	Very High	Relatively Moderate	1.21	$255,580,287	100
Yolo	$101,615,001	Relatively High	Relatively High	1.26	$127,479,110	99.97
Sutter	$72,530,063	Relatively High	Relatively Moderate	1.36	$96,884,296	99.94
Napa	$85,116,691	Relatively High	Relatively High	1.17	$96,048,060	99.90
Colusa	$61,575,357	Relatively High	Relatively Low	1.48	$90,715,786	99.87
Butte	$57,215,924	Very High	Relatively High	1.25	$67,313,611	99.81

13.7. MITIGATING THE HAZARD

13.7.1. Existing Measures for Mitigating the Hazard

Hazard mitigation planning can help the State reduce the impact of droughts in California and plan for future events. Since 2016, California has made key improvements to its drought response:

- Requiring local agencies to bring over-drafted groundwater basins into sustainable conditions by 2042 (under the Sustainable Groundwater Management Act)
- Establishing new standards for indoor, outdoor, and industrial use of water
- Funding solutions for disadvantaged communities lacking access to safe drinking water
- Increasing the frequency of water use reporting
- Ordering failing public water systems to consolidate with better-run systems
- Tightening landscape efficiency standards for new developments
- Analyzing the drought risk of thousands of water suppliers
- Gathering stakeholder recommendations on drought contingency plans
- Assessing failing or at-risk water systems across the State and compiling the first-ever comprehensive needs assessment

- 2018 legislation required larger urban water suppliers to plan for 5 years of drought, up from 3 years, in the water shortage contingency plan element of their Urban Watershed Master Plans
- SB 552 for the first time required drought planning for smaller suppliers and by counties on behalf of the smallest suppliers and self-supplied residential properties

13.7.2. Opportunities for Mitigating the Hazard

A range of potential opportunities for mitigating the hazard is provided in Table 13-4. See Section 1.2.3 for a description of the different types of alternatives.

13.7.3. Selected Actions to Mitigate the Hazard

The mitigation strategy developed for this SHMP includes the following actions that address the drought hazard:

- Action 2023-005: Coordinate planning efforts for aquifer storage and recharge actions within areas of known liquefaction risk so that the liquefaction risk is not increased by the storage basin mitigation action.
- Action 2018-048: California Water Plans: Ensure reliable water supplies and foundational actions for sustainable water use in California.
- Action 2018-075: State Water Efficiency and Enhancement Program: Reduce agricultural water usage through installation of more efficient irrigation practices.
- Action 2018-079: California Drought Contingency Plan: Minimize drought impacts by improving agency coordination and enhancing monitoring and early warning capabilities.

Table 13-4. Potential Opportunities to Mitigate the Drought Hazard

Community-Scale	Organizational Scale	Government-Scale
Manipulate the hazard: ▪ Recycle gray water **Reduce exposure and vulnerability:** ▪ Drought-resistant landscapes ▪ Reduce water system losses ▪ Modify plumbing systems through water saving kits ▪ For homes with on-site water systems, increase storage, utilize rainwater catchment ▪ Increased access to water testing **Build local capacity:**	**Manipulate the hazard:** ▪ Recycle gray water **Reduce exposure and vulnerability:** ▪ Drought-resistant landscapes ▪ Reduce water system losses ▪ Support alternative irrigation techniques to reduce water use and use climate-sensitive water supplies ▪ For businesses with on-site water systems, increase storage, utilize rainwater catchment ▪ For corporate-owned farms, reduce over-pumping/over-reliance on groundwater and identify methods to reduce overall water use **Build local capacity:**	**Manipulate the hazard:** ▪ Groundwater recharge through stormwater management ▪ Develop a water recycling program ▪ Increase "above-the-dam" regional natural water storage systems ▪ Maintain and improve Delta levees **Reduce exposure and vulnerability:** ▪ Identify and create groundwater backup sources ▪ Water use conflict regulations ▪ Reduce water system losses ▪ Distribute water saving kits ▪ Increase conventional storage that is filled during high-flow periods ▪ Create water storage space to capitalize on big storms when they occur and store water for dry periods ▪ Capture stormwater and desalinate ocean water and salty water in groundwater basins ▪ Expand average annual groundwater recharge ▪ Rehabilitate dams to regain storage capacity ▪ Mutual aid/financial support for farmworkers or disadvantaged-population-owned farms that must fallow their land ▪ Regularly maintain and improve Delta levees **Build local capacity:** ▪ Public education and intentional community engagement on drought mitigation plans ▪ Identify alternative water supplies for times of drought, mutual aid agreements with alternative suppliers ▪ Work with Tribal Nations to regain water access/rights and increase water sources managed by Tribal Nations (to redress historical and

Community-Scale	Organizational Scale	Government-Scale
▪ Practice active water conservation	▪ Practice active water conservation ▪ Participate in the Integrated Regional Water Management program	current harms, and reduce over-pumping and syphoning/channeling of water) ▪ Develop drought contingency plans ▪ Develop criteria triggers for drought-related actions ▪ Improve accuracy of water supply forecasts ▪ Modify rate structure to influence active water conservation techniques ▪ Consider the probable impacts of climate change on the risk associated with the drought hazard ▪ Support, participate in and advocate for funding for the Integrated Regional Water Management program ▪ Support, encourage, and implement multi-benefit nature-based recharge projects such as off-channel wetlands that provide habitat and groundwater filtration and infiltration ▪ Improve data collection and modernize forecasts for a changed climate ▪ Continue to support the Delta Levees Program to mitigate impacts on water supply ▪ Improve sub-seasonal to seasonal precipitation forecasting to support actions such as Forecast-Informed Reservoir Operations and Flood-MAR
Nature-based opportunities ▪ Promote and use reclaimed water supplies ▪ Increase capacity for stored surface water to create habitats and ecosystems for aquatic species ▪ Promote and use active groundwater recharge		

TSUNAMI AND SEICHE

Climate Impacts:
Tsunamis are geologically driven events and are therefore not likely to be directly impacted by climate change; increases in severe storm events may result in an increased probability of seiches

Equity Impacts:
10.2% of exposed population (those living in mapped tsunami inundation areas) identified as living in equity priority communities

State Facilities Exposed:
994 facilities in the mapped tsunami inundation area

Community Lifelines Exposed:
43 lifelines in the mapped tsunami inundation area

Impact Rating: Medium (24)

14. TSUNAMI AND SEICHE

The tsunami and seiche hazard have been identified as a medium-impact natural hazard of interest based on the hazard impact rating protocol applied for this SHMP. These events happen frequently and impact only the coastal exposures of the State. Less than 5 percent of State-owned or -leased facilities and community lifelines are exposed to this hazard. Less than 1 percent of the population resides in tsunami inundation area; over 10 percent of that population has been identified as living in equity priority communities. Less than 1 percent of buildable land in the State intersects mapped tsunami inundation areas. While the frequency of tsunamis is not anticipated to significantly increase over the next 100 years due to impacts from climate change, there could be an associated increase in severity in these events when they do occur due to the impacts from sea-level rise.

14.1. HAZARD OVERVIEW

14.1.1. Tsunami

A tsunami is a wave triggered by any form of land displacement along the edge or bottom of an ocean or lake. Submarine landslides or submarine seismic events can move the overlying water at the surface and cause a tsunami (W. F. Chen and C. Scawthorn 2003). The size of the tsunami is proportional to the mass of material that moved to generate it. A tsunami also can be generated from air pressure disturbances associated with fast-moving weather systems, but these events are often minor and are uncommon on the West Coast.

Tsunamis travel radially outward from the area of initiation. They can travel at speeds of over 600 miles per hour in the open ocean and can grow to over 50 feet in height when they approach a shallow shoreline.

Tsunamis can originate near the affected shoreline (local source tsunamis) or far from it (distant source tsunamis). Local tsunamis present higher risk because they leave exposed populations only a few minutes to find safety. As a tsunami approaches the shore and the water depth decreases, the energy in the wave pushes the wave crest above the water surface resulting in a larger wave height. Wave run-up is the elevation above mean sea level on dry land that a tsunami reaches. Run-up inundates coastal areas that are below the run-up height (W. F. Chen and C. Scawthorn 2003).

At some locations, the advancing turbulent wave front is the most destructive part of a tsunami. In other situations, the greatest damage is caused by the outflow of water back to the sea between crests, sweeping away items on the surface and undermining roads, buildings, bulkheads, and other structures. This outflow action can carry enormous amounts of highly damaging debris, resulting in further destruction. Ships and boats, unless moved away from shore, may be forced against breakwaters, wharves, and other craft, or be washed ashore and left grounded after the seawater withdraws.

Tsunami hazards include coastal flooding, strong damaging currents, extreme water-level fluctuations, eddies, erosion, and sedimentation. Once coastal areas become flooded, any subsequent, tsunami-induced hazards can include free-floating debris and environmental contamination from spills (W. F. Chen and C. Scawthorn 2003).

14.1.2. Seiche

A seiche is a large wave in a body of water that has been disturbed by wind, atmospheric pressure variations, or seismic activity. The wave travels the length of the water basin and reflects off the other end or sides. These reflected waves can then interfere with each other and create amplified standing waves. Seiches can occur in large bays or lakes as well as large, odd-shaped harbors.

14.2. HAZARD LOCATION

The Cascadia Subduction Zone is the most significant local tsunami source for the California coast north of Cape Mendocino. This subduction zone stretches from the coast of British Columbia to offshore of California north of Cape Mendocino. It could generate large tsunami surges onshore within minutes after an earthquake. The most significant tsunami source region for the entire State from a distant-source event is the subduction zone off the coast of the eastern Aleutian Islands.

In addition, local tsunamis can be caused by offshore faults or coastal and submarine landslides and have the potential to cause locally greater wave heights that pose a threat to the State. The largest historical local-source tsunami on the west coast was caused by the 1927 Point Arguello, California, earthquake that produced waves of about 7 feet in the nearby coastal area.

CGS and Cal OES have prepared California tsunami hazard area maps and data to assist cities and counties in identifying the tsunami hazard for their tsunami response planning. These maps and data are compiled with the best currently available scientific information and represent areas that could be exposed to tsunami hazards during a tsunami event. They are based on the State of California 2009 Tsunami Inundation Maps for Emergency Planning (recently updated in 2021-2022) and enhanced high-resolution, 975-year return period probabilistic tsunami inundation model results.

The boundaries of tsunami hazard areas are defined by CGS. These limits have been extended to reflect potential local tsunami sources not considered in probabilistic analysis and are modified to reflect the practical need to define limits that coincide with geographic features or city streets. Local stakeholders, including emergency managers, first responders, and subject matter experts, are consulted on the placement of the final hazard area in places that would help the public and government safely evacuate during a tsunami event. Figure 14-1 shows the approximate extent of the maps for the entire State. These maps can be viewed in higher detail and resolution at: https://www.conservation.ca.gov/cgs/tsunami/maps.

Seiches can occur in natural basins such as Lake Tahoe or human-made basins such as the Ports of Los Angeles and Long Beach.

Figure 14-1. Tsunami Hazard Areas

14.3. PREVIOUS HAZARD OCCURRENCES

14.3.1. Disaster and Emergency Declarations

The following disaster declarations or emergency proclamations related to tsunami or seiche have been issued for California (see Appendix F for details):

- Federal DR or EM declaration, 1953 – 2022: Two events, classified as "tsunami waves" and "seismic sea waves"
- California Emergency Proclamations, 1950 – 2022: Two events, classified as tsunami
- USDA agricultural disaster declarations, 2012 – 2022: None

14.3.2. Event History

Geological evidence indicates that large Cascadia earthquakes and associated tsunamis have occurred at least 19 times over the past 10,000 years. Event recurrence varies from 200 years to more than a thousand years over that 10,000-year period. A 2005 report by SSC indicates that over 80 tsunamis have been observed or recorded along the coast of California in the past 150 years (SSC 2005).

NOAA's Global Historical Tsunami Database identifies 831 wave runup events impacting the California coastline since 1806 (NCEI 2023).

The following sections describe the most recent event to affect California and the largest known event.

Most Recent Tsunami Affecting California

An underwater volcano erupted near the island of Tonga on January 15, 2022, generating a tsunami. Strong currents, rising tides, tsunami waves, and minor damage were reported in four California coastal counties (NOAA 2023a); (FEMA 2022u); (USDA 2022):

- In Santa Cruz County, wave energy caused $6.5 million in damage to Santa Cruz Harbor. Damage was inflicted on utility infrastructure, pilings, and bathroom facilities, as more than 3 feet of water poured in. Waves knocked out power around the harbor docks, where many people live on their boats.

- In Monterey County, the tsunami caused at least $3 million in damage to the Moss Landing Harbor District. There was also potential damage to the shoreline and a possible need for dredging.
- In Orange County, damage was reported across the coast, including a buoy reported to be broken off from Huntington Bay.
- In San Diego County, water rise of 0.6 feet was reported at La Jolla and 1.7 feet at San Diego Bay. Strong currents were observed at San Diego Bay. Minor damage was reported across the coast, including damaged ballast pipes and damage to floating docks. The county issued wireless emergency alerts through the morning.
- In Ventura County, damage occurred in Ventura Harbor. A 100-foot section of a dock was broken off with a 75-foot yacht attached. A Harbor Patrol boat capsized. This event occurred about seven years after the last event recorded in California, which was the September 2015 event triggered by an 8.3 magnitude earthquake that struck off the coast of Chile.

Largest Known Tsunami Affecting California

In 1700, an earthquake estimated at magnitude 9.0 ruptured along the Cascadia Subduction Zone. Scientists originally recognized the event from geological evidence and oral histories from the Native American people in the area as no local, written accounts of the event exist. This information was eventually cross-referenced with Japanese documents that described an “orphan” tsunami that was not accompanied by a large earthquake in Japan. The exact date and time of this earthquake are known because of a combination of tsunami deposit evidence, carbon-14 and tree-ring dating, tsunami modeling, and historical Japanese records (The Seattle Times 2021).

14.4. PROBABILITY OF FUTURE HAZARD EVENTS

14.4.1. Overall Probability

Based on the previous tsunami and seiche events, California can expect a tsunami event about every five years.

14.4.2. Climate Change Impacts

The earthquakes and landslides that create tsunamis could be impacted by climate change. Some scientists say that melting glaciers could induce tectonic activity. Heavy rainfall could cause soil instability that may increase the likelihood of landslides into water bodies, which can generate tsunamis. Increases in severe storms may result in an increased probability of seiches. Rising seas could result in an increase in wave runup when tsunamis occur. Even modest rises in sea level will dramatically increase the frequency and intensity of flooding when a tsunami occurs, as the tsunami can travel further inland. Future smaller tsunamis could have the same impact as larger tsunamis today. A warming climate can increase the risk of underwater and above ground landslides, thereby increasing the risk of local tsunamis.

14.5. IMPACT ANALYSIS

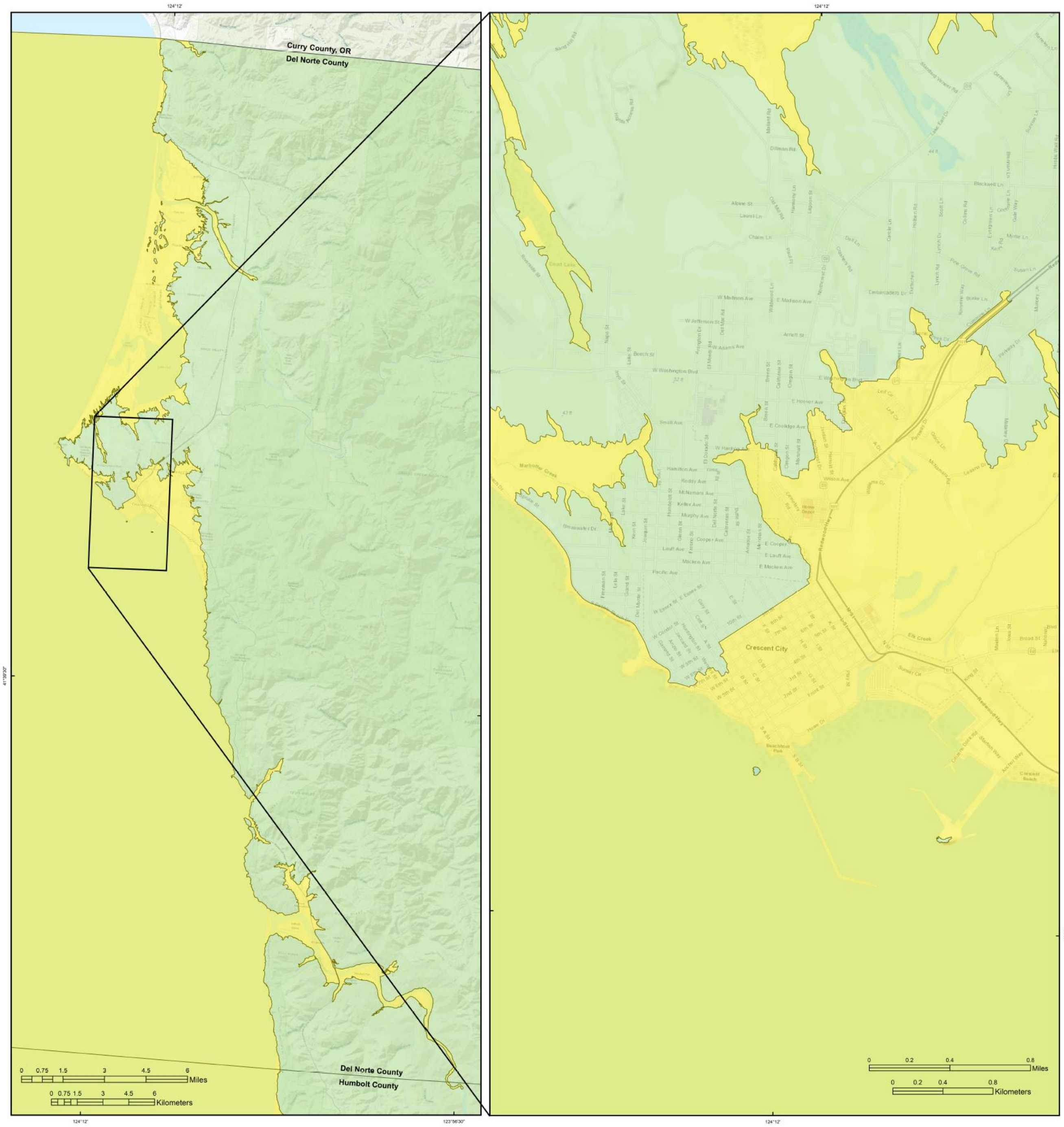
14.5.1. Severity

In tsunami-inundation mapping developed by the California Tsunami Program and the University of Southern California Tsunami Research Center, projected maximum tsunami flood elevations varied from 25 to 50 feet along the coast north of Cape Mendocino, from 15 to 30 feet along the coast from Cape Mendocino to Point Conception, from 3 to 12 feet within the San Francisco Bay, and from 5 to 15 feet south of Point Conception. Figure 14-2 shows an example local area tsunami inundation map for Crescent City prepared by CGS.

14.5.2. Warning Time

The cause of a tsunami (earthquake, landslide, etc.) and its distance from the coast determine the warning time. Warning times can range from a little less than a day for an event triggered in the South Pacific Ocean to no warning at all for events triggered locally (NCEI n.d.). NOAA developed Deep-Ocean Assessment and Reporting of Tsunami (DART) systems to detect, measure, and report tsunamis in the open ocean in real-time. The NWS National Data Buoy Center operates and maintains the U.S. network of DART systems, which is part of a larger international network. The Tsunami Warning Center, a branch of the National Weather Service, releases tsunamis warnings. The National Tsunami Warning Center in Palmer, Alaska, serves the continental United States, Alaska, and Canada. (NWS n.d.-b).

Figure 14-2. Tsunami Inundation Map—Crescent City



Source: (CGS 2022)

The Tsunami Warning Center depends on an observation system that includes seismic and water-level networks from around the world to help determine when and where to issue tsunami messages. These networks are critical to the warning centers' ability to provide timely and accurate messages (NWS n.d.-b):

- Seismic Networks—When an earthquake occurs, seismic networks provide information about the location, depth, magnitude, and other characteristics. The warning centers analyze this information to determine if the earthquake could have generated a tsunami and if a tsunami message is necessary.
- Water-Level Networks—If an earthquake meets certain criteria, the warning centers turn to water-level information, looking for changes in water-level height that could indicate the existence and size of a tsunami. The primary sources of information about water-level change are a network of DART systems and an extensive array of coastal water-level stations. Tsunami warnings are typically issued following coastal earthquakes of magnitude 6.5 or greater for U.S. and Canadian Atlantic and Gulf coasts, and magnitude 7.1 or greater for all coasts along the Pacific Ocean and Caribbean Sea.

In most cases, the first sign of a potential tsunami is an earthquake. Seismic waves travel about 100 times faster than tsunamis, so information about an earthquake is available before information about any tsunami it may have generated. The Tsunami Warning Center uses preliminary seismic information on an earthquake's location, depth, and magnitude to decide if it should issue a tsunami message and at what alert level. The warning center then conducts additional seismic analysis and runs tsunami forecast models using information from the seismic and water-level networks as it becomes available. The resulting forecasts, combined with historical tsunami information and additional seismic analysis, help the warning center decide if it should issue an updated or cancellation message (NWS n.d.-b).

It is more difficult to forecast non-seismic tsunamis (caused by landslide, volcanic activity, or atmospheric factors), which can arrive with little to no warning. Even if a DART system or coastal water-level station detects a non-seismic tsunami, there may not be time to develop a detailed forecast (NWS n.d.-b).

For local tsunami sources, where there are only minutes before a tsunami can arrive after an earthquake, people must rely on the "natural" warnings of a tsunami. These natural warning signs include feeling strong shaking from the earthquake, observing the water receding away from the beach, and hearing a loud rumbling wave coming toward the shore. The only way to prepare the public is to educate them about tsunamis and the natural warning signs. The California Tsunami Program and local emergency managers hold workshops and meetings to continuously educate the public about tsunamis, so they know what to do and where to evacuate.

14.5.3. Cascading Impacts

Cascading impacts are the impacts that result when one type of hazard event triggers one or more other hazard events, which may in turn trigger still others. The following are notable cascading impacts associated with tsunami or seiche:

- Tsunami inundation can result in flooding, erosion and scouring, debris movement and impact, water contamination, and spread of disease due to standing water.
- Loss of wetlands from erosion and wetland migration due to tsunami inundation can reduce the natural filtration provided by wetland plants, increasing the likelihood of water quality issues.
- Healthy coastal ecosystems support fisheries, tourism, human health, and public safety. Many of these ecosystems are being transformed, degraded, or lost due in part to climate change, particularly sea-level rise and higher numbers of extreme weather events.
- Indirect economic costs (such as lost business) and adverse socio-psychological impacts have the potential to negatively affect people and their communities.
- Individuals exposed to weather- or climate-related disasters have been shown to experience negative mental health impacts. Among those most likely to suffer these impacts are some of society’s most priority populations.
- Fires can be fueled by spreading water-borne liquid fuels released from petrochemical facilities damaged by the tsunami. These are referred to as “tsunamigenic fires.”

14.5.4. Environmental Impacts

Ecosystems within the inundation areas for tsunamis and seiches that can withstand periodic inundation, such as wetlands, may be relatively unharmed by minor events. However, severe events that result in larger inundation areas may result in negative environmental impacts due to sediment, erosion, debris, saltwater and pollutant contamination of soil and water bodies, and other impacts (Geoffrey S. Plumlee 2013).

14.5.5. Local Hazard Impacts

LHMP Rankings

Of the 58 counties in California, 15 assessed tsunami or seiche as a hazard of concern in their hazard mitigation plans. Of these, two ranked this hazard as high risk (Del Norte and Santa Cruz), five ranked it as medium risk, and eight ranked it as low risk.

LHMP Estimates of Potential Loss

Table 14-1 summarizes potential losses to vulnerable structures based on estimates from the local risk assessments (as called for in FEMA's Standard State Mitigation Planning Requirement S6.b). Due to variances in approaches to assessing risk at the local level as well as the hazards assessed and the age of each assessment reviewed, this data is considered approximate.

Table 14-1. Tsunami Risk Exposure Analysis for LHMP Reviews

Estimated Total Population Exposed	262,461
Estimated Number of Structures at Risk	54,607
Estimated Value of Structures at Risk	$13.67 billion

14.6. VULNERABILITY ANALYSIS

To assess the vulnerability of State assets to the tsunami hazard, GIS software was used to overlay State assets with mapped tsunami inundation areas (see Figure 14-1).

14.6.1. Exposure of State-Owned or -Leased Facilities

Table 14-2 and Table 14-3 summarize the numbers and replacement cost value of State-owned or -leased assets within the mapped tsunami inundation areas. Figure 14-3 summarizes the exposed assets as a percentage of total assets statewide. Appendix I provides detailed results by county.

Table 14-2. State-Owned or -Leased Facilities Exposed to the Tsunami Hazard

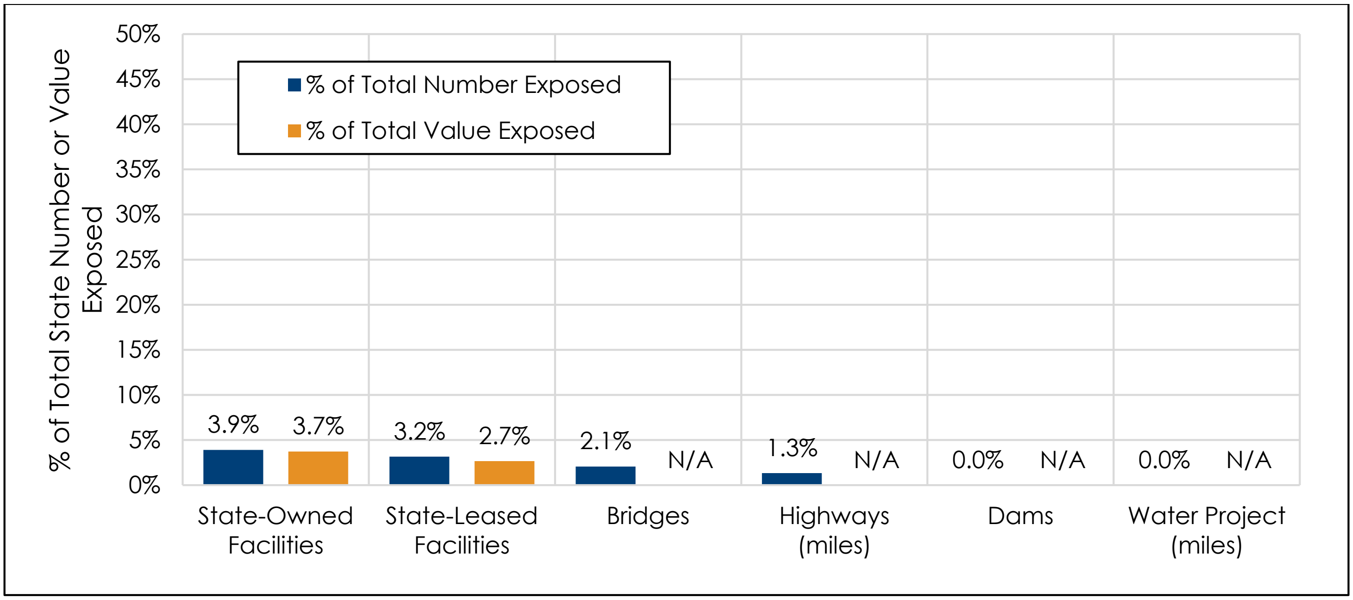
Type of Facility	Number of Structures	Total Area (sq. ft.)	Replacement Cost Value		
			Structure	Content	Total
State-Leased Facilities	60	—	$251,248,391	$244,989,719	$496,238,110
State-Owned Facilities					
Facilities Housing Vulnerable Populations					
Correctional Facility	3	174,077	$6,184,245	$3,160,553	$9,344,798
Development Center	0	0	$0	$0	0
Hospital	0	0	$0	$0	0
Migrant Center	0	0	$0	$0	0
Special School	0	0	$0	$0	0
All Other Facilities	931	2,275,168	$691,272,289	$671,568,162	$1,362,840,452
Total State-Owned	***934***	***2,449,245***	***$697,456,535***	***$674,728,715***	***$1,372,185,250***
Total Facilities	**994**	**N/A***	**$948,704,926**	**$919,718,434**	**$1,868,423,359**

* The inventory of State assets does not include building area for State-leased facilities, so no total area for all State facilities is provided; the building area of vulnerable assets is shown for State-owned facilities only.

Table 14-3. State-Owned or -Leased Infrastructure Exposed to the Tsunami Hazard

Type of Facility	State-Owned Infrastructure in the Mapped Hazard Area
Bridges	273
Highway (miles)	401.3
Dams	0
Water Project (miles)	0

Figure 14-3. State Assets Exposed to Tsunami Inundation as % of Statewide Total



The following are significant results of the analysis of State-owned assets in mapped tsunami inundation areas:

- For facilities that the State owns within the tsunami inundation area, the average building area is 2,622 square feet, with an average replacement cost value of $1.5 million.
- The average replacement cost value for State-leased facilities within the tsunami inundation area is $496 million.
- The five State agencies with the most State-owned or -leased facilities within the tsunami inundation area are State Parks (690), District Agriculture Associates (166), CDFW (75), CSU (14) and Caltrans (12).

- The State agency with the highest total replacement cost for State-owned or -leased facilities within the tsunami inundation area is the District Agriculture Associations at $857 million.

14.6.2. Exposure of Critical Facilities and Community Lifelines

Table 14-4 summarizes the total number of critical facilities, by community lifeline, located in the tsunami inundation areas statewide. The County with the largest percentage of exposed community lifelines is Alameda (23.2 percent) followed by Los Angeles (18.6 percent) and San Francisco (14 percent). Appendix I provides detailed results by county.

Table 14-4. Critical Facilities and Community Lifelines Exposure to Tsunami

Lifeline Category	Total Number of Facilities	Number of Facilities in Hazard Area	% of Total Facilities
Communications	42	1	2.4%
Energy	176	5	2.8%
Food, Water, Shelter	257	5	1.9%
Hazardous Material	56	0	0.0%
Health & Medical	47	1	2.1%
Safety & Security	46	0	0.0%
Transportation	131	31	23.7%
Total	**755**	**43**	**5.7%**

Critical facilities and community lifelines that are exposed to the tsunami and seiche hazard are likely to experience functional downtime following these events, which could increase the net impact of the event. Hazus estimates damage and functional downtime for tsunami scenarios. Local governments are encouraged to use tools such as Hazus when creating or updating their LHMPs.

14.6.3. Estimates of Loss

While models exist that can estimate damages for tsunami events, it was not feasible to model the 994 facilities identified as exposed to the tsunami hazard. To estimate losses to these exposed facilities, this Plan applies the methodologies that FEMA's Hazus risk assessment platform uses for tsunami hazards. The Hazus methodology applies loss ratios of 15, 50, and 85 percent that consider factors associated with building strength. Each of the three loss ratios considers two lateral strength conditions:

- Building strength corresponding to modern construction in a high seismic region (high-code)
- Building strength corresponding to older construction (pre-code)

Table 14-5 shows the loss estimations applying this methodology.

Table 14-5. Tsunami Loss Estimation Summary

State Asset	15% Loss Ratio	50% Loss Ratio	85% Loss Ratio
State-Owned	$205,827,787	$686,092,625	$1,166,357,462
State-Leased	$74,435,716	$248,119,055	$421,802,393
Total	**$280,263,503**	**$934,211,680**	**$1,588,159,855**

14.6.4. Buildable Lands

The State has over 11.7 million acres of land available for development and 0.35 percent (40,808 acres) is within the tsunami inundation area. Any type of development in these exposed areas will be susceptible to damage associated with a tsunami event.

With its growth management policies and active participation in the NFIP, the State is well equipped with regulatory oversight of new development that may occur within these buildable lands. State regulations have provisions that significantly overlap the inundation areas and the mapped floodplain. The State will need to continually improve its understanding of tsunami risk within these buildable land areas so that its regulatory capacity can be effective.

14.6.5. Equity Priority Communities

The cost of interventions to protect properties from tsunami and seiche risk may financially stress lower- or middle-income residents. Relocating may be difficult because of the expenses and the availability of accessible housing or the time needed to make housing accessible.

The population over the age of 65 is also more vulnerable and, physically, may have more difficulty evacuating during tsunami and seiche events. They may require extra time or outside assistance during evacuations and are more likely to seek or need medical attention, which may not be available due to isolation during a tsunami or seiche event.

The risk analysis for tsunami found that 10.2 percent of people living in the mapped tsunami inundation area live in equity priority communities (35,891people). A breakdown of by county is included in Appendix I.

14.6.6. NRI Scores

According to the NRI, 19 of the State's counties have tsunami risk, rated from very low to relatively high. Table 14-6 shows scores for the six counties with the highest rating. See Section 4.1.3 for a description of the components of the NRI.

Table 14-6. NRI Scoring of Counties for Tsunami

County	Expected Annual Loss	Social Vulnerability Rating	Community Resilience Rating	Community Risk Factor	Risk Value	Score
Del Norte	$172,758	Very High	Relatively Low	1.42	$298,500	94.59
Humboldt	$114,717	Very High	Relatively Moderate	1.36	$144,615	89.19
Santa Cruz	$114,064	Relatively High	Relatively High	1.18	$143,153	87.84
Monterey	$59,112	Very High	Relatively Low	1.37	$67,482	75.68
Alameda	$46,364	Relatively Moderate	Very High	1.13	$56,120	71.62
San Mateo	$44,573	Relatively Low	Relatively High	1.05	$42,986	68.92

14.7. MITIGATING THE HAZARD

Tsunamis and seiches are rare, but they can quickly put the lives of millions in jeopardy. The impacts on people and property in the wake of the 2004 Indian Ocean tsunami (230,000 fatalities in 14 countries) and 2011 Japan tsunami (18,000 fatalities in Japan alone; costliest modern natural disaster at $235 billion) emphasize the need to improve tsunami and seiche preparedness, mitigation, and recovery planning efforts wherever these hazards present themselves.

(DOF 2017)

14.7.1. Existing Measures to Mitigate the Hazard

A recent study indicated that a large tsunami event originating from the Aleutian Islands could cause coastal flooding that would result in extensive damage and lead to years of recovery, costing the State billions of dollars. However, this study also found that 80 to 90 percent of the damage could be prevented with detailed response, mitigation, land use, and recovery planning. The California Tsunami Program, led by Cal OES and CGS, is coordinating among all levels of government to engage in this type of hazard mitigation and planning work.

Harbor Studies

Cal OES, CGS, and the University of Southern California have prepared 33 Maritime Tsunami Response Playbooks covering over 70 ports, harbors, and marinas to provide harbor officials with information about where damage could occur during a distant-source tsunami. Figure 14-4 shows an example for the Port of Long Beach.

Tsunami Inundation Mapping

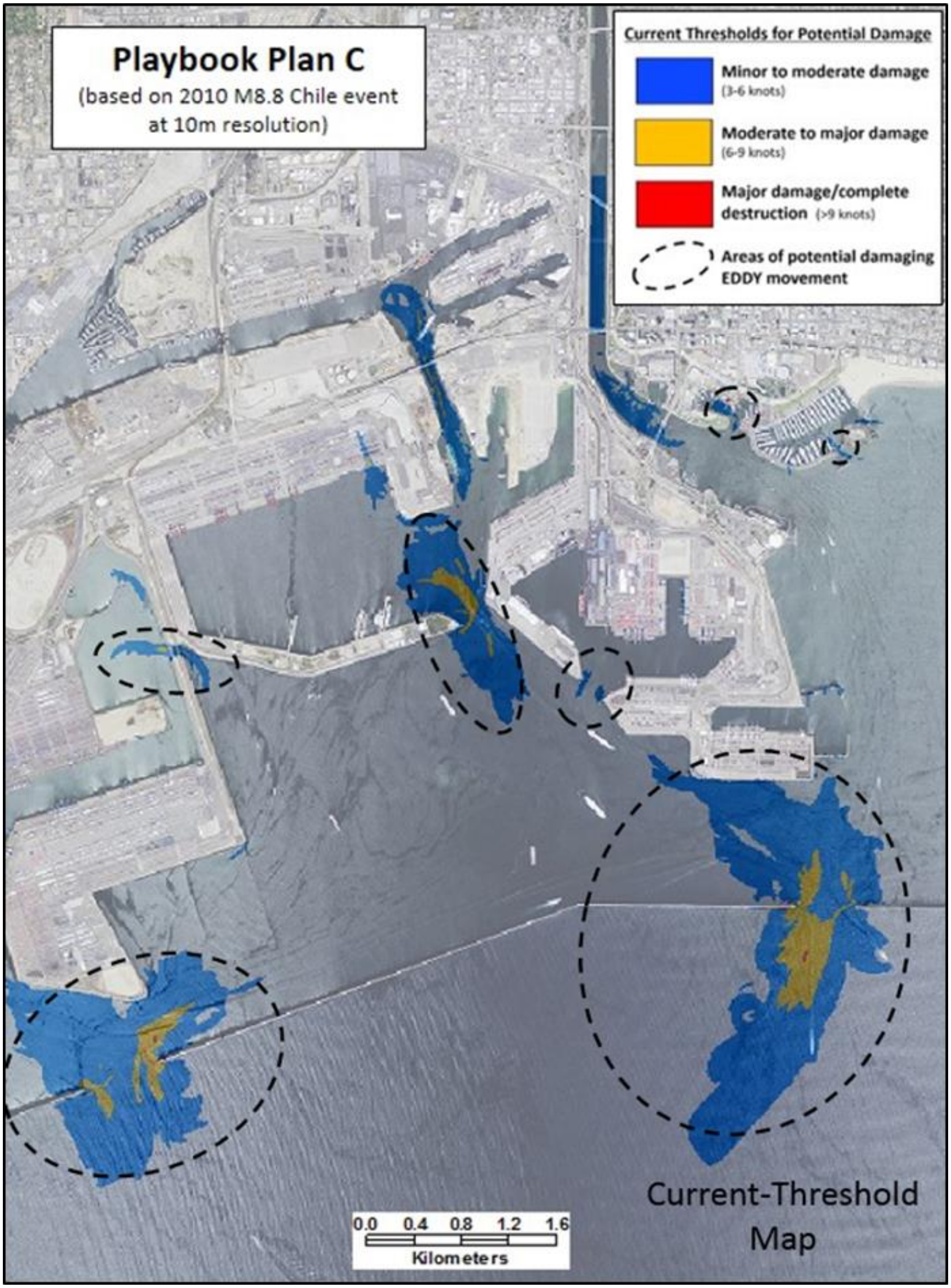
In 2009, the California Tsunami Program and the University of Southern California Tsunami Research Center completed statewide tsunami inundation maps appropriate for evacuation planning. These maps, most recently updated in 2021 and 2022, are a composite of numerical tsunami inundation model runs from a suite of large, realistic tsunami sources both local and distant. They are developed for all populated areas at risk from tsunamis in California and represent a combination of the maximum considered tsunamis for each area. The most recently updated maps identify areas of expected flooding for various average return periods: 100-, 200-, 475-, 975-, 2,475-, and 3,000-year.

Investigations of Previous Events

A statewide assessment for geological evidence of tsunamis included a reconnaissance of 20 coastal marshlands through site visits and coring of shallow surface sediments to look for evidence for past tsunamis existed. Geologic evidence consistent with tsunami inundation was found at two locations: three marshes in the Crescent City area for the 1700 and 1964 tsunamis, and Pillar Point Marsh near Half Moon Bay from the 1946 Aleutian Islands event. Potential tsunami deposits were also evaluated at the Carpinteria Salt Marsh Reserve in Santa Barbara County. The absence of tsunami evidence does not necessarily imply that no large tsunamis have occurred. This most likely means that the geologic conditions were not suitable for capturing these past events at most locations.

The State also worked with Cal Poly Humboldt State University to complete a tsunami deposit database cataloging data from the statewide study and other studies, especially past studies which have found tsunami deposits in Northern California from pre-historic Cascadia events.

Figure 14-4. Example Maritime Tsunami Playbook Current-Threshold Map for the Port of Long Beach



Source: (CGS 2016)

14.7.2. Opportunities for Mitigating the Hazard

A range of potential opportunities for mitigating the tsunami and seiche hazards is provided in Table 14-7 (see Section 1.2.3 for a description of the different types of alternatives).

14.7.3. Selected Actions to Mitigate the Hazard

The mitigation strategy developed for this SHMP includes the following actions that address the tsunami and seiche hazard:

- Action 2018-054: Reducing Tsunami Hazards and Risks—Support and provide matching funds for development of improved technologies and methodologies to assess, mitigate, and recover from the tsunami risk.
- Action 2018-055: Understanding and Utilizing Tsunami Probability—Improve the understanding of tsunami hazards in California through coordinated research and apply these products to land-use and construction mitigation practices.
- Action 2018-056: Tsunami Mitigation and Preparedness Planning—Continue tsunami preparedness activities and develop loss estimation models to compute potential impacts from tsunamis.

Table 14-7. Potential Opportunities to Mitigate the Tsunami and Seiche Hazard

Community-Scale	Organizational Scale	Government-Scale
Manipulate the hazard: ▪ Implement tsunami construction measures at a project level, including elevated living spaces and debris deflection structures **Reduce exposure and vulnerability:** ▪ Locate outside of hazard area ▪ Apply personal property mitigation techniques to your home such as anchoring your foundation and foundation openings to allow flow though **Build local capacity:** ▪ Develop and practice a household evacuation plan	**Manipulate the hazard:** ▪ Implement tsunami construction measures at a project level, including elevated living spaces and debris deflection structures **Reduce exposure and vulnerability:** ▪ Locate structure or mission critical functions outside of hazard area whenever possible ▪ Mitigate property for the impacts of tsunami ▪ Construct vertical evacuation shelters **Build local capacity:** ▪ Develop and practice a corporate response and evacuation plan	**Manipulate the hazard:** ▪ Build wave abatement structures (e.g., sea walls and the "jacks- looking structures designed by the Japanese) **Reduce exposure and vulnerability:** ▪ Locate structure or functions outside of hazard area whenever possible ▪ Harden infrastructure for tsunami impacts ▪ Relocate identified critical facilities located in tsunami high-hazard areas ▪ Adopt higher regulatory standards that will provide higher levels of protection to structures built in a tsunami inundation area ▪ Use tsunami mapping and land use planning to guide development away from high-risk areas ▪ Construct vertical evacuation shelters **Build local capacity:** ▪ Use probabilistic tsunami mapping and land use guidance from the State ▪ Provide incentives to guide development away from hazard areas ▪ Improve the tsunami warning and response system ▪ Provide residents with updated tsunami hazard and inundation maps for the coast and vulnerable in-land lakes ▪ Join NOAA's Tsunami Ready program ▪ Develop and communicate evacuation time products and routes ▪ Enhance the public information program to include risk reduction options for the tsunami hazard ▪ Develop products useful for tsunami mitigation and recovery

Community-Scale	Organizational Scale	Government-Scale
▪ Become educated about the risk exposure from the tsunami hazard and ways to minimize that risk ▪ Understand tsunami warning signs and signals	▪ Educate employees on the risk exposure from the tsunami hazard and ways to minimize that risk	▪ Utilize multi-hazard mitigation strategies that address tsunami hazards and sea-level rise from global climate change ▪ Provide tsunami products useful for the maritime industry

Nature-based opportunities

- Restore wetlands, mangroves, marshes, and oyster reefs, and install living shorelines to help reduce wave impacts
- Preserve/restore tidal marshes
- Establish living shorelines (plants and natural elements designed to stabilize and protect coastlines) to prevent erosion
- Incentivize voluntary retreat from coastal hazard areas

Dam Failure

Climate Impacts:

Increase in severe weather events will increase dam failure potential

Equity Impacts:

34.9% of exposed population (those living in mapped dam failure inundation areas) identified as living in equity priority communities

State Facilities Exposed:

2,308 facilities in dam failure inundation areas

Community Lifelines Exposed:

300 lifelines in dam failure inundation areas

Impact Rating: Medium (24)

15. DAM FAILURE

Dam failure has been identified as a medium-impact natural hazard of interest based on the hazard impact rating protocol applied for this SHMP. These events do not happen frequently and impact only areas downstream of dams. Less than 10 percent of State-owned or -leased facilities and community lifelines are exposed to this hazard. Less than 13 percent of the population resides in dam failure inundation area; over 34 percent of that population has been identified as living in equity priority communities. Less than 4 percent of the buildable land in the State intersects mapped dam failure inundation areas. The frequency and severity of dam failure events is anticipated to increase over the next 50 years due to impacts from climate change.

The DWR Division of Safety of Dams (DSOD) was a major contributor to this chapter, providing Section 15.2.1 (Dam Locations), Figure 15-1 (Dam Inundations), content up to page 15-5, and final review and approval of the entire chapter.

HHPD2. Did Element S6 (risk assessment) address all dam risk for high hazard potential dams in the risk assessment?
Chapter 15 include a comprehensive assessment of State-owned and -regulated dams within California, and a limited assessment of federal dams. The federal dam assessment was limited due to the accessibility of data on federal dams.

15.1. HAZARD OVERVIEW

A dam is an artificial barrier that can store water, wastewater, or any liquid-borne material for reasons including flood control, water supply, irrigation, livestock water supply, energy generation, recreation, and pollution control (ASDSO 2022).

Dam failure is the structural collapse of a dam, resulting in release of the water or other liquid stored behind it (Monterey County Office of Emergency Services 2022a). Dam failures usually occur when spillway capacity is inadequate and excess flow overtops the dam, or when internal erosion through the dam or its foundation occurs. Complete failure is the complete structural breach of the dam, releasing a high-velocity wall of debris-filled water that rushes downstream damaging anything in its path.

Hundreds of dam failures in the United States have caused property and environmental damage, injuries, and fatalities. The Association of State Dam Safety Officials identifies the most likely causes of dam failures as follows (ASDSO 2021a):

- Overtopping caused by water spilling over the top of a dam
- Foundation defects, including settlement and slope instability
- Cracking caused by movement
- Inadequate maintenance and upkeep
- Seepage through a dam that is not properly filtered, so that soil particles form sinkholes in the dam

Common Types of Dams

Dams can be classified according to their construction, slope, purpose, or method of resisting water pressure or controlling seepage. The following are common dam types:

- **Embankment Dams** are the most common type of dam used today. Natural soil, rock, or waste materials are used to construct these dams. An embankment dam is an earth fill or rockfill dam, depending on whether it is made of compacted earth or mostly compacted or dumped rock. The ability of an embankment dam to resist the reservoir water pressure is primarily a result of the mass weight, type, and strength of the materials from which the dam is made.
- **Concrete Dams** are categorized according to the designs used to resist the stress of reservoir water pressure:
  - **Gravity Dams** are the most common type of concrete dams. The weight of concrete and friction resist the reservoir water pressure.
  - **Buttress Dam** is a specific type of gravity dam where a large mass of concrete is reduced, and the forces are diverted to the dam foundation through vertical or sloping buttresses.
  - **Arch Dams** are thin in cross section and where the reservoir water forces acting on the dam are carried laterally into the abutments. These dams are made of thin, vertical blocks keyed together.

Source: (ASDSO 2021)

15.2. HAZARD LOCATION

15.2.1. Jurisdictional Dams

The California Water Code defines a "jurisdictional" dam (one that falls under the jurisdiction of State dam regulations) as a dam with a height greater than 6 feet that impounds 50 acre-feet or more, or a height greater than 25 feet with storage capacity of 15 acre-feet or more (DWR 2022c). About 1,250 jurisdictional-sized dams are under the jurisdiction of the DSOD, which is part of DWR (DWR 2018). Of these jurisdictional dams, 265 have been identified as "extremely high" hazard and 461 have been identified as "high" hazard, based on possible downstream impacts to life and property (see Table 15-1). The number of dams that fall into the categories shown in the table changes annually; these numbers are a representation of these statistics as of this SHMP update.

Table 15-1. Downstream Hazard Potential Classifications

Downstream Hazard Potential Classifications	Potential Downstream Impacts to Life and Safety	Number of Dams in California
Low	No probable loss of human life and low economic and environmental losses. Losses are expected to be principally limited to the owner's property.	370
Significant	No probable loss of human life but can cause economic loss, environmental damage, impacts to critical facilities, or other significant impacts.	141
High	Expected to cause loss of at least one human life.	461
Extremely High	Expected to cause considerable loss of human life or would result in an inundation area with a population of 1,000 or more.	265

Source: (DSOD 2022a)

Due to the number of such dams in California, information specific to each dam is not provided in this SHMP. The information can be accessed on the DSOD website (https://fmds.water.ca.gov/maps/damim/). This website is maintained regularly and reflects the most updated information each time it is accessed. Appendix S provides a list of high hazard dams that have been rated as being in unsatisfactory, poor, or fair condition. These are potential targets for funding under the High Hazard Potential Dam (HHPD) grant program. This list of dams can change annually.

Dam Locations

Los Angeles County leads the State with 90 jurisdictional dams, followed by Sonoma County with 64 dams. Del Norte County is the only county in the State that has no dams of jurisdictional size (DSOD 2021).

Dam Failure Inundation Mapping

Inundation maps show where flooding is expected in the event of a dam failure at a specific dam. The California Legislature passed a law in 2017 (California Water Code section 6161) requiring all State jurisdictional dams—except low hazard dams—to develop inundation maps and emergency action plans (EAPs). The maps must be submitted for approval to the DSOD, and the plans must be submitted for approval to Cal OES.

Inundation maps for extremely high, high, and significant hazard dams and their critical appurtenant structures are prepared by licensed engineers and submitted by dam owners for DSOD review and approval. The maps are based on a hypothetical failure of a dam or critical appurtenant structure and the information depicted on the maps is approximate. Areas to be evacuated in the event of an actual failure of a dam or critical appurtenant structure are determined by local emergency managers.

DSOD has made inundation mapping available online for extremely high, high, and significant hazard dams in the State (https://fmds.water.ca.gov/maps/damim/) (DWR 2022h). These maps are the basis for this impact analysis. A statewide overview of the mapped inundation areas for high hazard dams and extremely high hazard dams is provided in Figure 15-1. For access to information on all State jurisdictional dams regulated by DSOD, visit: https://gis.water.ca.gov/app/boundaries/

The National Inventory of Dams
The National Inventory of Dams documents all known dams in the U.S. and its territories that meet certain criteria. It provides users the ability to search for specific data about dams in the U.S. and serves as a resource to support awareness of dams and actions to prepare for a dam-related emergency. The National Inventory of Dams can be accessed at: https://nid.usace.army.mil/#/.

Figure 15-1. Inundation Boundaries for Extremely-High-Hazard or High-Hazard Jurisdictional Dams

15.2.2. Federal Dams

Dams and reservoirs owned by the federal government are not subject to State jurisdiction except as otherwise provided by federal law. According to USACE, there are 220 dams in California owned by federal government agencies, such as the National Park Service, U.S. Forest Service, U.S. Bureau of Reclamation, and USACE (USACE 2021).

In California, Whittier Narrows Dam is the only dam owned by the federal government with a mapped inundation area that was made available to support this SHMP update (see Figure 15-2). Whittier Narrows Dam is a 56-foot-tall earthen dam built, owned, and operated by the USACE Los Angeles District. Table 15-2 presents the National Inventory of Dams information for the Whittier Narrows Dam. The dam is within the City of Pico Rivera.

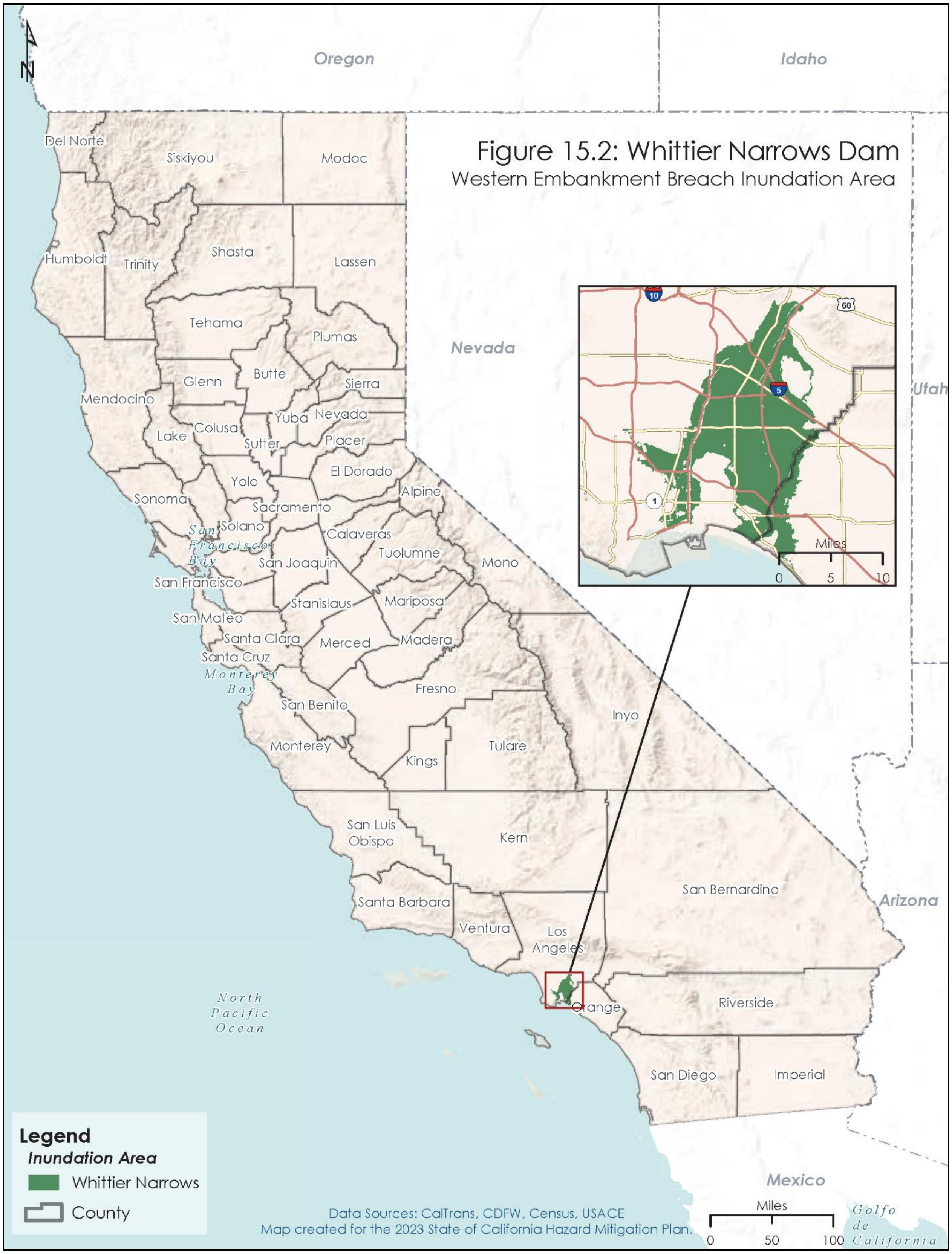
Table 15-2. National Inventory of Dams Detail Report on Whittier Narrows Dam

Dam Name	Whittier Narrows Dam	**River**	San Gabriel River
Other Name	Whittier Narrows Reservoir	**City**	Pico Rivera
ID	CA10027	**County**	Los Angeles
Owner Type	Federal	**Inspection Date**	June 6, 2017
Owner Name	Corps of Engineers Los Angeles District	**State Permitting Authority?**	No
Height	56 feet	**State Inspection Authority?**	No
Storage	66,702 acre-feet	**State Enforcement Authority?**	No
Primary Purpose	Flood Control	**EAP Last Date**	August 1, 2014
Dam Type	Earth	**Data Current as of**	September 30, 2018

Source: (USACE 2021)

Inundation mapping is not required by law for federally owned dams. To address this data deficiency, a mitigation action has been added to this SHMP to map inundation areas of all federal high-hazard dams in the State.

Figure 15-2. Whittier Narrows Dam Western Embankment Breach Inundation Area



15.2.3. Obstacles and Challenges

Since the development and implementation of the 2018 SHMP, California has made great strides in addressing challenges identified for overall State dam safety. Driven by SB 92 (2017), DSOD has made inundation mapping available on jurisdictional dams in the State and has made that information publicly accessible through an interactive website. The availability and accessibility of this type of information has had a significant impact on increasing the understanding of dam failure risk in California.

However, some challenges identified in the 2018 SHMP remain. Some dam owners lack resources to respond to new State requirements. The financial burden on dam owners to produce inundation maps is significant. Inundation maps are required to be produced by a qualified, licensed engineer for the dams and any critical appurtenant structures. With a limited pool of qualified engineers, there may not be enough resources to produce the maps, and the expense to dam owners may be increased if they need to contract out for mapping services. As of this SHMP update, all of the extremely-high-hazard dams and several of the high-hazard dams have presented updated EAPs to meet the requirements of SB 92. DSOD is committed to providing the necessary technical assistance to dam owners with outstanding EAPs to close this gap.

15.3. PREVIOUS HAZARD OCCURRENCES

15.3.1. Disaster and Emergency Declarations

The following disaster declarations or emergency proclamations related to dam failure have been issued for California (see Appendix F for details):

- Federal DR or EM declaration, 1953 – 2022: three events, classified as dam failure
- California Emergency Proclamations, 1950 – 2022: nine events, classified as flood/dam/levee failure
- USDA agricultural disaster declarations, 2012 – 2022: None

15.3.2. Event History

In the past 50 years, there have been few dam failures in California. The 2018 SHMP update discussed dam failure events that occurred from 1928 through 2017. Dam failure events that have impacted the State between 2018 and 2022 are identified in Table 15-3. Refer to Appendix K for the complete history of past events.

Table 15-3. Dam Safety Incidents in the State of California (2018 to 2022)

Date	Event Type	FEMA Declaration Number	USDA Declaration Number	Counties/Areas Impacted
February 2017	Gated Spillway Failure—Oroville Dam	N/A	N/A	Butte, Yuba, Sutter
The gated spillway at Oroville Dam, the tallest dam in the United States, suffered a failure within its concrete chute. A 60-foot-deep hole developed in the lower third of the chute as a result of normal spillway operations undertaken to lower the reservoir in advance of a moderately large storm. The subsequent occurrence of the storm in the days after the initial incident and the inability to fully use the primary spillway led to the filling of the reservoir and the use of its unlined emergency spillway for the first time ever. After two days of usage and erosion of the unlined hillside and head cutting, concerns regarding the stability of the emergency spillway weir developed, and nearly 200,000 people downstream were evacuated.				
March 22, 2018	Insufficient Spillway Capacity—Moccasin Lower	N/A	N/A	Tuolumne
Blockage of Moccasin Creek Bypass Tunnel caused sudden rise of the reservoir above core wall to nearly the dam crest because of insufficient spillway capacity. Twenty people had to be evacuated from their homes as a result of this event. One property was flooded, and water and sewer lines were impacted. This event caused approximately $25 million to $50 million in damages.				
April 2, 2018	Insufficient Spillway Capacity—Auberry Lumber Mill	N/A	N/A	Fresno
The dam overtopped due to spillway pipes being clogged with overgrown vegetation. Overtopping eroded the downstream slope, which could have potentially led to failure. No evacuations or damages reported for this event.				
June 26, 2018	Seepage/Internal Erosion—Lower Blue Lake	N/A	N/A	Alpine
Damp spots on the downstream face along the length of the left embankment, localized small active seep from damp area, and seepage boil located approximately 10 feet downstream of the toe on left side of the dam. No evacuations or damages reported for this event.				
April 30, 2019	Deterioration Or Poor Condition—Lake Van Norden	N/A	N/A	Nevada and Placer
Large hole at the downstream right end of the spillway invert during high spring spill flows. No evacuations or damages reported for this event.				

Date	Event Type	FEMA Declaration Number	USDA Declaration Number	Counties/Areas Impacted
June 3, 2019	Sediment Build-up – Misselbeck	N/A	N/A	Shasta
Sediment build-up in the reservoir has likely caused the entrance of the outlet works to become plugged. A combined release of approximately 1 cubic foot per second from both pipes while all four valves were fully open was observed during inspections. No evacuations or damages reported for this event.				

Source: (ASDSO 2020)

15.4. PROBABILITY OF FUTURE HAZARD EVENTS

15.4.1. Overall Probability

Dam failure events are infrequent and usually coincide with events that cause them, such as earthquakes, landslides, excessive rain, and snowmelt. The three federal disaster declarations for dam failure-related events between 1953 and 2022 represent an average of one event about every 23 years. Dam safety incidents, which are less severe than actual dam failures, occurred multiple times per year in 2018 and 2019.

15.4.2. Climate Change Impacts

Modeling described in California's Fourth Climate Change Assessment projects less frequent but more extreme daily precipitation. Year-to-year precipitation will become more volatile, and the number of dry years will increase by mid-century. As the climate continues to warm, atmospheric rivers will carry more moisture, and extreme precipitation may increase. Climate model projections show a tendency for the northern part of the State to become wetter, and the very southern portion of California, extending and intensifying in Mexico, to become drier (CNRA; CEC; OPR 2022). Several Fourth Assessment technical reports (State of California 2018) provide improved projections and analysis of precipitation impacts to facilitate adaptive decision-making for water management. Strategically employing precipitation and runoff forecasts has some potential to improve the operation of reservoirs, flood control, infiltration strategies, and hydropower.

Climate change played a significant role in one recent example of dam failure in California. Severe weather events caused by climate change were a causal factor in the potential overflow of the spillway at Oroville Dam in 2017. More specifically, an atmospheric river moved into Northern California from the Pacific, causing additional snow to fall on what was already an unusually large snowpack, and then causing warmer precipitation to fall upon the expanded snowpack a few days later, melting much of the snow and causing a greater—and more difficult to accommodate—inflow of water into Oroville Dam's reservoir (Michalis, et al. 2022). Some experts see the Oroville Dam episode as a demonstration of how severe weather events brought on by climate change, combined with the aging and degrading condition of dam infrastructure, could result in more dam failure incidents (Mount, Swain and Ullrich 2019).

15.5. IMPACT ANALYSIS

15.5.1. Severity

DSOD assigns hazard ratings to large dams in the State based on a classification system developed by FEMA (FEMA 2013). FEMA categorizes the downstream hazard potential into three categories in increasing severity: Low, Significant, and High. DSOD adds a fourth category of "Extremely High" (DSOD 2021a). The definitions of the hazard categories and the numbers of California jurisdictional dams assigned to each category are shown in Table 15-1.

15.5.2. Warning Time

Warning time for dam failure depends on the cause of the failure, and the size and location of the dam. In the event of a structural failure due to earthquake, there may be no warning time. In events of extreme precipitation or massive snowmelt, the weather can be predicted, and evacuations can be planned with sufficient time. When dam operators need to release water to relieve pressure from a dam, with potential for flooding downstream, advance warning can be provided (Monterey County Office of Emergency Services 2022).

A dam's structural type affects the warning time of how quickly a failure occurs. A dam failure can sometimes occur within hours of the first signs of breaching. Other failures and breaches can take much longer—from days to weeks—as a result of debris jams, the accumulation of melting snow, buildup of water pressure on a dam with deficiencies after days of heavy rain, etc. (FEMA 2013); (FEMA 2016).

15.5.3. Cascading Impacts

Cascading impacts are the impacts that result when one type of hazard event triggers one or more other hazard events, which may in turn trigger still others. The notable cascading impacts associated with dam failure are flooding, landslides, bank erosion, and destruction of habitat. Dam failure can be a cascading impact itself; hazards that can lead to a dam failure include earthquakes, landslides, and floods. Other notable cascading impacts from dam failures include:

- Potential to impact multiple downstream jurisdictions
- Loss of power associated with facilities that provide hydropower
- Loss of water supply
- Damage to agricultural lands
- Impacts on multiple jurisdictions

15.5.4. Environmental Impacts

Dam failures can cause downstream flooding and can transport large volumes of sediment and debris. Other examples of environmental impacts include pollution from septic system failures, pollution of potable water supplies, changes in configurations of streams, loss of wildlife habitats, and degradation of wetlands (FEMA 2012).

15.5.5. Local Hazard Impacts

LHMP Rankings

Of the 58 counties in California, 54 assessed dam failure as a hazard of concern in their hazard mitigation plans. Of these, 28 ranked dam failure as high risk, 17 ranked it as medium risk, and nine ranked it as low risk. The following counties listed dam failure as a high-risk hazard:

- Alameda
- Amador
- Butte
- Colusa
- El Dorado
- Fresno
- Imperial
- Kings
- Los Angeles
- Madera
- Marin
- Mendocino
- Merced
- Modoc
- Nevada
- Orange
- Placer
- Plumas
- Sacramento
- San Diego
- San Joaquin
- San Luis Obispo
- Stanislaus
- Sutter
- Trinity
- Ventura
- Yolo
- Yuba

LHMP Estimates of Potential Loss

Table 15-4 summarizes potential losses to vulnerable structures based on estimates from the local risk assessments (as called for in FEMA's Standard State Mitigation Planning Requirement S6.b). These losses also represent the potential multi-jurisdictional impacts from dam failures (as called for in FEMA's HHPD requirement HHPD2-b). Due to variances in approaches to assessing risk at the local level as well as the hazards assessed and the age of each assessment reviewed, this data is considered approximate. Not all LHMPs have assessed dam failure risk, even though there may be high hazard potential dams within a defined planning area.

Table 15-4. Dam Failure Risk Exposure Analysis for LHMP Reviews

Estimated Total Population Exposed	5,027,019
Estimated Number of Structures at Risk	1,237,432
Estimated Value of Structures at Risk	$56.6 billion

15.6. VULNERABILITY ANALYSIS

To assess the vulnerability of State assets to the dam failure hazard, GIS software was used to overlay dam failure inundation areas with State assets. The analysis included State dams that are rated as extremely high or high hazard. A separate analysis was conducted with the available mapping of the federal Whittier Narrows Dam.

15.6.1. Exposure of State-Owned or -Leased Facilities

Table 15-5 and Table 15-6 summarize the number and replacement cost value of State assets located in the State jurisdiction dam failure inundation areas for high-hazard or extremely-high-hazard dams and those in the federally owned Whittier Narrows Dam failure inundation area.

Figure 15-3 summarizes the exposed assets from State jurisdiction dams as a percentage of total assets statewide. Figure 15-4 summarizes the exposed assets from the Whittier Narrows Dam as a percentage of total assets statewide. Appendix I provides detailed results by county.

Table 15-5. State-Owned or -Leased Facilities Exposed to the Dam Failure Hazard

Type of Facility	Number of Structures	Total Area (sq. ft.)	Replacement Cost Value		
			Structure	Content	Total
State Facilities in the Extremely-High-Hazard or High-Hazard Dam Inundation Area					
State-Leased Facilities	275	—	$1,075,039,281	$1,083,589,590	$2,158,628,872
State-Owned Facilities					
Facilities Housing Vulnerable Populations					
Correctional Facility	188	2,103,228	$79,249,251	$72,977,386	$152,226,636
Development Center	0	0	$0	$0	$0
Hospital	0	0	$0	$0	$0
Migrant Center	6	426,750	$51,675,434	$32,181,714	$83,857,148
Special School	64	510,744	$10,729,356	$9,928,709	$20,658,065
All Other Facilities	1,775	16,259,876	$1,711,584,724	$1,670,821,422	$3,382,406,146
Total State-Owned	***2,033***	***19,300,598***	***$1,853,238,764***	***$1,785,909,230***	***$3,639,147,994***
Total Facilities	**2,308**	**N/A***	**$2,928,278,046**	**$2,869,498,820**	**$5,797,776,866**
State Facilities in the Whittier Narrows Dam Western Embankment Breach Inundation Area					
State-Leased Facilities	31	—	$183,499,555	$186,215,032	$369,714,587
State-Owned Facilities					
Facilities Housing Vulnerable Populations					
Correctional Facility	26	166,767	$3,664,024	$3,141,158	$6,805,182
Development Center	0	0	$0	$0	$0
Hospital	0	0	$0	$0	$0
Migrant Center	0	0	$0	$0	$0
Special School	0	0	$0	$0	$0
All Other Facilities	124	3,398,562	$74,669,522	$64,013,981	$138,683,503
Total State-Owned	***150***	***3,565,329***	***$78,333,546***	***$67,155,139***	***$145,488,685***
Total Facilities	***181***	**N/A***	***$258,169,077***	***$250,229,013***	***$508,398,090***

* The inventory of State assets does not include building area for State-leased facilities, so no total area for all State facilities is provided; the building area of vulnerable assets is shown for State-owned facilities only.

Table 15-6. State-Owned or -Leased Infrastructure Exposed to the Dam Failure Hazard

Type of Facility	State-Owned Infrastructure in the Mapped Hazard Area: Extremely-High-Hazard or High-Hazard Dam Inundation Area	State-Owned Infrastructure in the Mapped Hazard Area: Whittier Narrows Dam Western Embankment Breach Inundation Area
Bridges	3,180	185
Highway (miles)	4,810.7	93.8
Dams	18*	0
Water Project (miles)	46.8	0

* This number includes dams that are within dam inundation areas. Some of these dams would not be at risk if they have capacity to pass on the flow from a failed dam upstream.

Figure 15-3. State Assets Exposed to Jurisdictional Dam Failure as % of Statewide Total

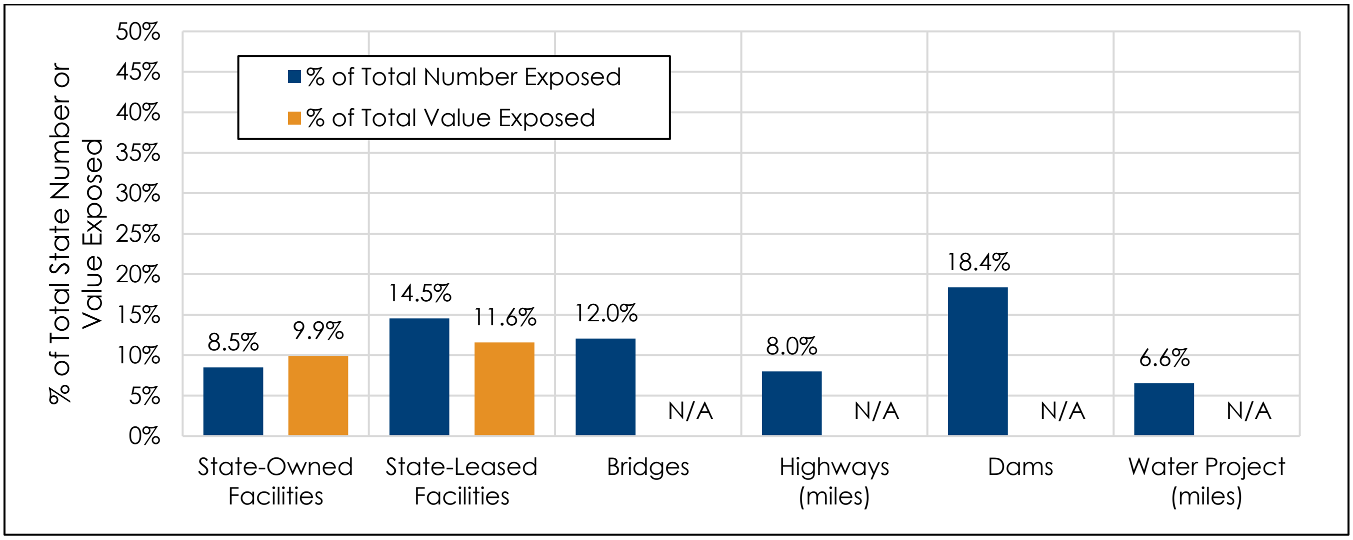
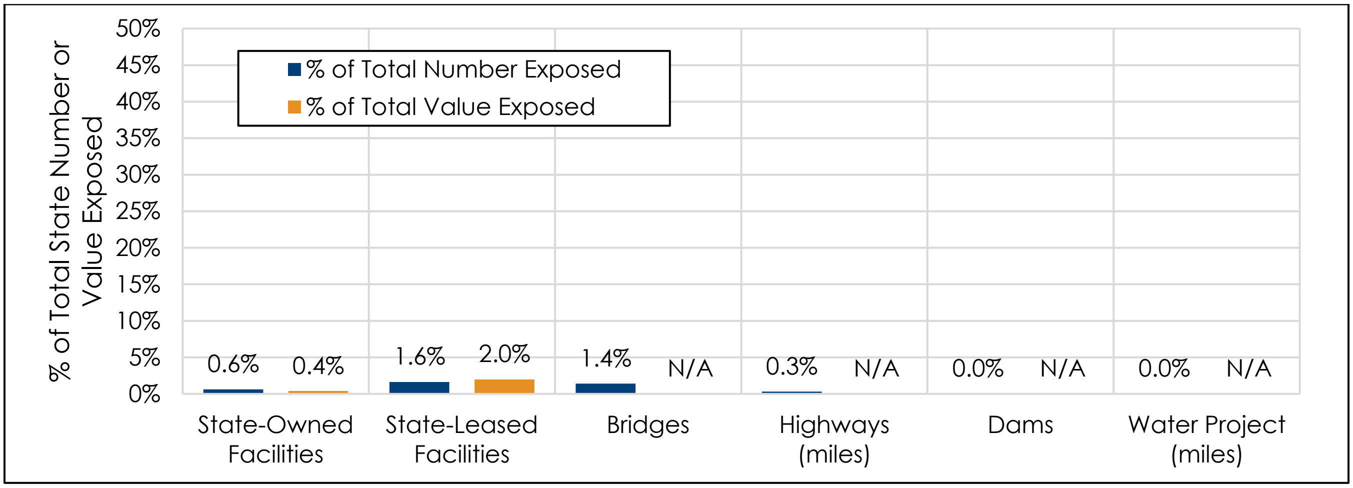


Figure 15-4. State Assets Exposed to Whittier Narrows Dam Inundation Area as % of Statewide Total



The following are noteworthy statistics on State-owned or -leased facilities in the dam failure Inundation areas:

- For facilities that the State owns in the dam failure inundation area, the average building area is 9,494 square feet, and the average replacement cost value is $17.9 million (structure and contents).
- The average replacement cost value for State-leased facilities in the dam failure inundation area is $ 7.8 million (Structure and Contents).
- The five State agencies with the most State-owned or -leased facilities in the dam failure inundation area are State Parks (422), Caltrans (396), District Agricultural Associations (318), CDFW (295) and CSU (237).
- The State agency with the highest total replacement cost for State-owned or -leased facilities in the dam failure inundation area is CSU at $1.0 billion.

15.6.2. Exposure of Critical Facilities and Community Lifelines

Transportation routes, including bridges and highways, are vulnerable to dam inundation and have the potential to be wiped out, creating isolation and supply chain issues. Those that are most vulnerable are those that are already in poor condition and would not be able to withstand a large water surge. The State’s utility infrastructure is also vulnerable; interruption of services may impact priority populations as well as facilities that need to be in operation during a disaster.

Table 15-7 summarizes the total number of critical facilities, by community lifeline, located in the dam failure inundation areas statewide. Appendix I provides detailed results by county.

Table 15-7. Critical Facilities and Community Lifelines Exposure to Dam Failure Inundation Areas

Lifeline Category	Total Number of Facilities	Number of Facilities in Hazard Area	% of Total Facilities
Communications	42	12	28.6%
Energy	176	37	21.0%
Food, Water, Shelter	257	135	52.5%
Hazardous Material	56	16	28.6%
Health & Medical	47	11	23.4%
Safety & Security	46	9	19.6%
Transportation	131	80	61.1%
Total	**755**	**300**	**39.7%**

Functional downtime is the most significant dam failure impact on critical facilities and community lifelines. The severity of this impact is based on the amount of time it takes to restore damaged facilities to an operational status. Hazus estimates damage and functional downtime for dam failure scenarios. Local governments are encouraged to use Hazus or similar tools when developing LHMPs.

15.6.3. Estimates of Loss

Loss estimations for hazard events that cause flooding typically use an approach that correlates damage to the depth of flood water impacting a structure and the time of inundation. USACE has established depth/damage correlations based on analysis of the impacts historical flood events have had on the built environment. The assessment of potential loss associated with dam failure for this SHMP used the USACE depth-damage curve for facilities with "average government function" (see Figure 15-5).

Table 15-8 shows the resulting estimates of potential damage to State-owned or -leased facilities in the dam failure inundation zone per foot of flood depth, up to the flood depth that would trigger substantial damage (50 percent of replacement cost value).

Figure 15-5. Depth/Damage Curve for "Average Government Function" Occupancy

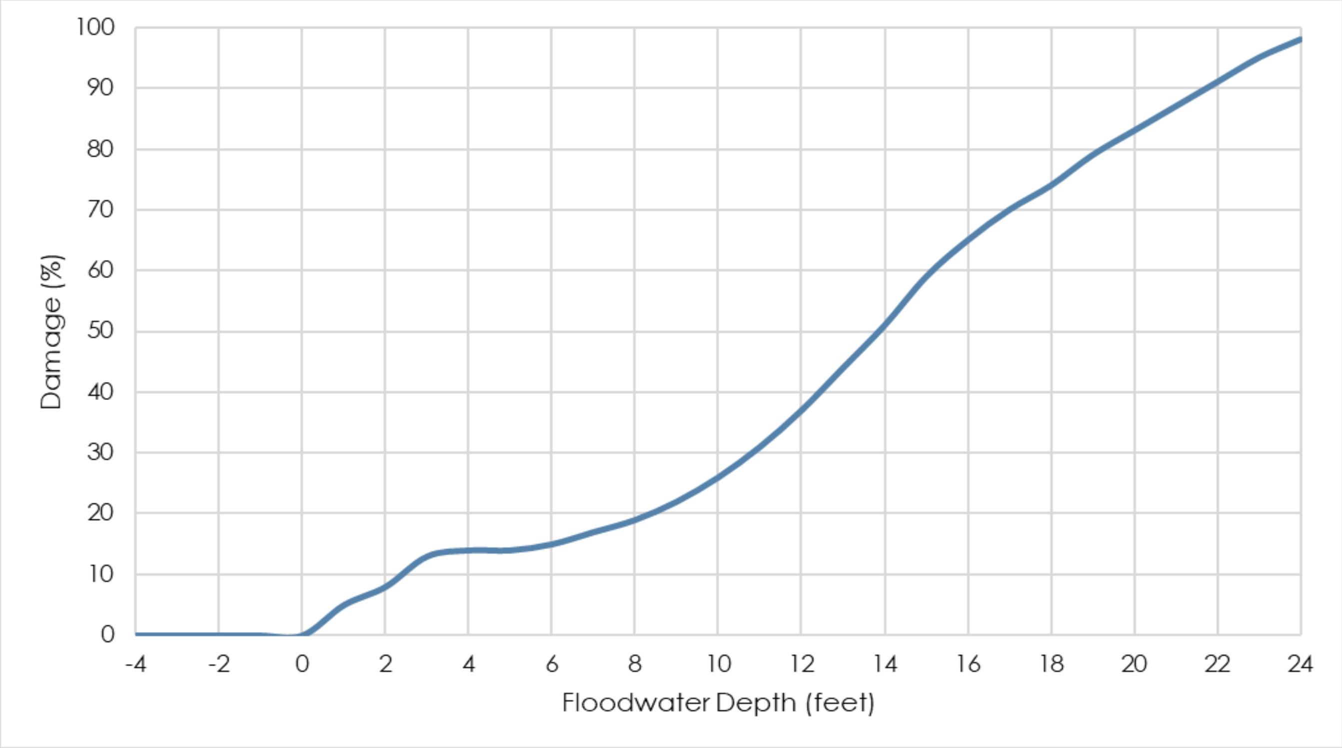


Table 15-8. Estimates of Flood Loss for Facilities in the Dam Failure Inundation Zone

Flood Depth (feet)	Estimates of Flood Loss*		
	State-Owned	State-Leased	Total
1	$92,661,938	$53,751,964	$146,413,902
2	$148,259,101	$86,003,143	$234,262,244
3	$240,921,039	$139,755,107	$380,676,146
4	$259,453,427	$150,505,499	$409,958,926
5	$259,453,427	$150,505,499	$409,958,926
6	$277,985,815	$161,255,892	$439,241,707
7	$296,518,202	$172,006,285	$468,524,487
8	$352,115,365	$204,257,463	$556,372,829
9	$407,712,528	$236,508,642	$644,221,170
10	$481,842,079	$279,510,213	$761,352,292
11	$574,504,017	$333,262,177	$907,766,194
12	$685,698,343	$397,764,534	$1,083,462,877
13	$815,425,056	$473,017,284	$1,288,442,340
14	$945,151,770	$548,270,033	$1,493,421,803

* Structure losses only. Does not include contents losses.

15.6.4. Buildable Land

Of the 11.7 million acres of land available for development in California, 3.2 percent (375,861 acres) is within dam failure inundation areas. This does not include all dam failure risk in the State because only a subset of dam inundation areas was analyzed. There are likely other dams whose failures would impact buildable land areas as well.

Any development in these areas will be susceptible to damage associated with a dam failure. While existing floodplain development regulations at the county level may offer some protection for new development in these areas, such protections would likely not be sufficient for a catastrophic dam failure. Such a failure could have an inundation area much larger than the regulated floodplain and greater water depths and higher flow velocities than the 1% annual chance flood event.

15.6.5. Equity Priority Communities

The risk analysis for dam failure found that 34.9 percent of people exposed to the dam failure hazard live in equity priority communities (1,756,718 people). A breakdown of exposed equity priority communities by county is included in Appendix I.

15.6.6. NRI Scores

The National Risk Index does not provide rankings for the dam failure hazard.

15.7. MITIGATING THE HAZARD

15.7.1. Opportunities for Mitigating the Hazard

A range of potential opportunities for mitigating the dam failure hazard is provided in Table 15-9. See Section 1.2.3 for a description of the different types of alternatives.

Table 15-9. Potential Opportunities to Mitigate the Dam Failure Hazard

Community-Scale	Organizational Scale	Government-Scale
Manipulate the hazard: ▪ None **Reduce exposure and vulnerability:** ▪ Relocate out of dam failure inundation areas ▪ Elevate home to appropriate levels **Build local capacity:** ▪ Learn about risk reduction for the dam failure hazard ▪ Learn the evacuation routes for a dam failure event ▪ Become educated about early warning systems and the dissemination of warnings	**Manipulate the hazard:** ▪ Remove dams ▪ Harden dams **Reduce exposure and vulnerability:** ▪ Replace or rehabilitate dams with deficiencies ▪ Flood-proof facilities within dam failure inundation areas **Build local capacity:** ▪ Educate employees on the probable impacts of a dam failure ▪ Develop a continuity of operations plan	**Manipulate the hazard:** ▪ Remove dams ▪ Harden dams **Reduce exposure and vulnerability:** ▪ Replace earthen dams with hardened structures ▪ Relocate critical facilities out of dam failure inundation areas ▪ Consider open space land use in designated dam failure inundation areas ▪ Adopt higher floodplain standards in mapped dam failure inundation areas ▪ Retrofit critical facilities within dam failure inundation areas **Build local capacity:** ▪ Map dam failure inundation areas ▪ Enhance emergency operations plan to include a dam failure component ▪ Institute monthly communications checks with dam operators ▪ Inform the public on risk reduction techniques ▪ Adopt real-estate disclosure requirements for the re-sale of property located within dam failure inundation areas ▪ Consider the probable impacts of climate change in assessing the risk associated with the dam failure hazard ▪ Establish early warning capability downstream of listed high-hazard dams ▪ Consider the residual risk associated with protection provided by dams in future land use decisions
Nature-based opportunities ▪ Restore and reconnect floodplains that intersect dam failure inundation areas that have been degraded by development and structural flood control		

Community-Scale	Organizational Scale	Government-Scale
▪ Use soft approaches for stream bank restoration and hardening. Soft approaches can include but are not limited to the introduction of large woody debris into a system ▪ Set back levees on systems that rely on levee protection to allow the river channel to meander, which reduces erosion and scour potential ▪ Acquire property within dam failure inundation areas, remove or relocate structures, and preserve these areas as open space in perpetuity ▪ Preserve floodplain storage capacity by limiting or prohibiting the use of fill within the floodplain		

15.7.2. Selected Actions to Mitigate the Hazard

The mitigation strategy developed for this SHMP includes the following actions that address the dam failure hazard:

- Action 2023-013: Federal HHPD Inundation Mapping: Develop inundation models for federal high hazard potential damsin the State.
- Action 2018-008: Develop a database containing a description of the specific natural hazard event for which each project was designed to mitigate.
- Action 2018-062: Ensure dam safety.
- Action 2018-063: Review and approve EAPs for State jurisdictional dams with a hazard classification from DSOD of significant, high, or extremely high.

Levee Failure

Climate Impacts:
As sea levels rise, flood stages in the Sacramento-San Joaquin Delta may also rise, increasing pressure on Delta levees

Equity Impacts:
34.0% of exposed population (those living in the levee flood protection zone) identified as living in equity priority communities

State Facilities Exposed:
577 facilities in levee flood protection zone; $4.2 billion total replacement cost values for facilities in levee flood protection zone

Community Lifelines Exposed:
16 lifelines in levee flood protection zone

Impact Rating: Medium (21)

16. Levee Failure

Levee failure has been identified as a medium-impact natural hazard of interest based on the hazard impact rating protocol applied for this SHMP. These events happen frequently and impact only areas protected by levee systems. Less than 3 percent of State-owned or -leased facilities and community lifelines are exposed to this hazard. Less than 1 percent of the population resides in levee failure inundation area; over 34 percent of that population has been identified as living in equity priority communities. Less than 1 percent of buildable land in the State intersects mapped levee failure inundation areas. The frequency and severity of levee failure events is anticipated to increase over the next 50 years due to impacts from climate change.

16.1. HAZARD OVERVIEW

A levee is a physical barrier constructed to protect areas from floodwaters. A levee breach occurs when part of a levee gives way, creating an opening through which floodwaters may pass. A breach can occur gradually or suddenly. The most dangerous breaches happen quickly during periods of high water. A catastrophic and sudden failure under extreme flood events has the potential to result in loss of life and destruction of property (National Geographic 2022a).

16.1.1. History of Levees in California

Soils in California's Central Valley and on islands in the Sacramento-San Joaquin Delta place these regions among the most agriculturally productive regions in the world, providing a significant economic benefit for California. The soil is rich for growing crops as a result of river-deposited silts or river-nourished backwater peats in these locations.

During the 1850s, hydraulic mining in the mountains at the headwaters of the rivers that feed the Delta flushed huge amounts of sediment downstream, raising riverbeds and causing increased flooding. To prevent buildup of this sediment and to protect or reclaim floodplain for agricultural purposes in the Central Valley and Delta, construction began on new or enlarged levees. In many cases, soil was scraped from adjacent land or dredged from adjacent channels and placed onto existing natural levees. However, the soils that make this region ideal for agriculture generally make poor foundation material for levees.

After several devastating floods, USACE started modifying and constructing levees as early as the early 1900s using soils from adjacent rivers and channels. Levees were also constructed by others in the early 1900s in areas subject to coastal influences, such as in San Francisco and San Pablo Bays.

Until about the 1940s to 1950s, most levees were not engineered to appropriate standards and frequently failed. The levees have been augmented since their early construction to produce the current system, but many remain as they were first built or have deteriorated. Some of the areas protected by the Central Valley levees have evolved from their original agricultural uses to urban development. The levees protecting urban areas today have mostly been investigated and improved to meet current levee design standards developed by USACE and supported by FEMA.

What Causes a Levee to Fail

Earthen levees can be damaged in several ways:

- Strong river currents and waves can erode the surface.
- Trees growing on a levee can blow over, leaving a hole where the root wad and soil used to be.
- Burrowing animals can create holes that enable water to pass through a levee.
- In seismically active areas, earthquakes and ground shaking can cause a loss of soil strength, weakening a levee and possibly resulting in failure. Seismic activity also can cause levees to slide or slump, which also can lead to failure.

Any of these situations can lead to a zone of weakness that causes a levee breach.

Source: (ASCE 2010)

16.1.2. Increasing Risk and Consequences

Low-Elevation Land Adjacent to Levees

Levees typically remove valuable floodplain storage and block the ability of a river channel to move water. With reclaimed floodplains not being replenished with new sediment and the drying out of some of the boggy areas, the land protected by the levees began to drop in elevation via subsidence and wind erosion of topsoil.

The Bay Area has numerous substandard levees protecting both low-lying and below-sea-level urban areas and infrastructure, including the Oakland International Airport. With potential sea-level rise due to climate change exacerbating the situation, land behind the levees will continue to drop. As can be seen in Figure 16-1, vast areas in the Delta are already below sea level.

Risks to Water Systems

Water systems face risks from potential Delta levee failures. The Bay-Delta is a complex system where three rivers bring in fresh water and tidal fluctuations cycle in saltwater or brackish water. Water projects carry fresh water to millions of citizens in Central and Southern California. Approximately 60 percent of the water supply of the San Francisco Bay Area is extracted from or passes through the Delta.

Levee Designs Insufficient for Large Storm Events

Many of the levees in California are intended to protect against a storm that as a 1 percent chance of occurring in any year. Some areas have an even lower level of protection. For perspective, the levee system protecting the city of New Orleans was intended to protect against a storm that has a 0.4 percent chance of occurring in any year but failed in 2005 due to Hurricane Katrina.

16.2. HAZARD LOCATION

California's levees protect farmland, ranchland, rural residential areas, urban residential areas, and infrastructure such as roads, highways, and waterways or canals. According to the USACE National Levee Database, there are 1,756 levee systems in California, comprising 5,403 miles of levee (USACE n.d.). The average age of these levees is 59 years. Figure 16-2 shows the statewide levee system relative to mapped 1% annual chance flood zones. Based on the levee locations, mapping was developed to show regions of the State that are protected by levees, as shown in Figure 16-3.

Figure 16-1. Delta Elevation Relative to Mean Sea Level

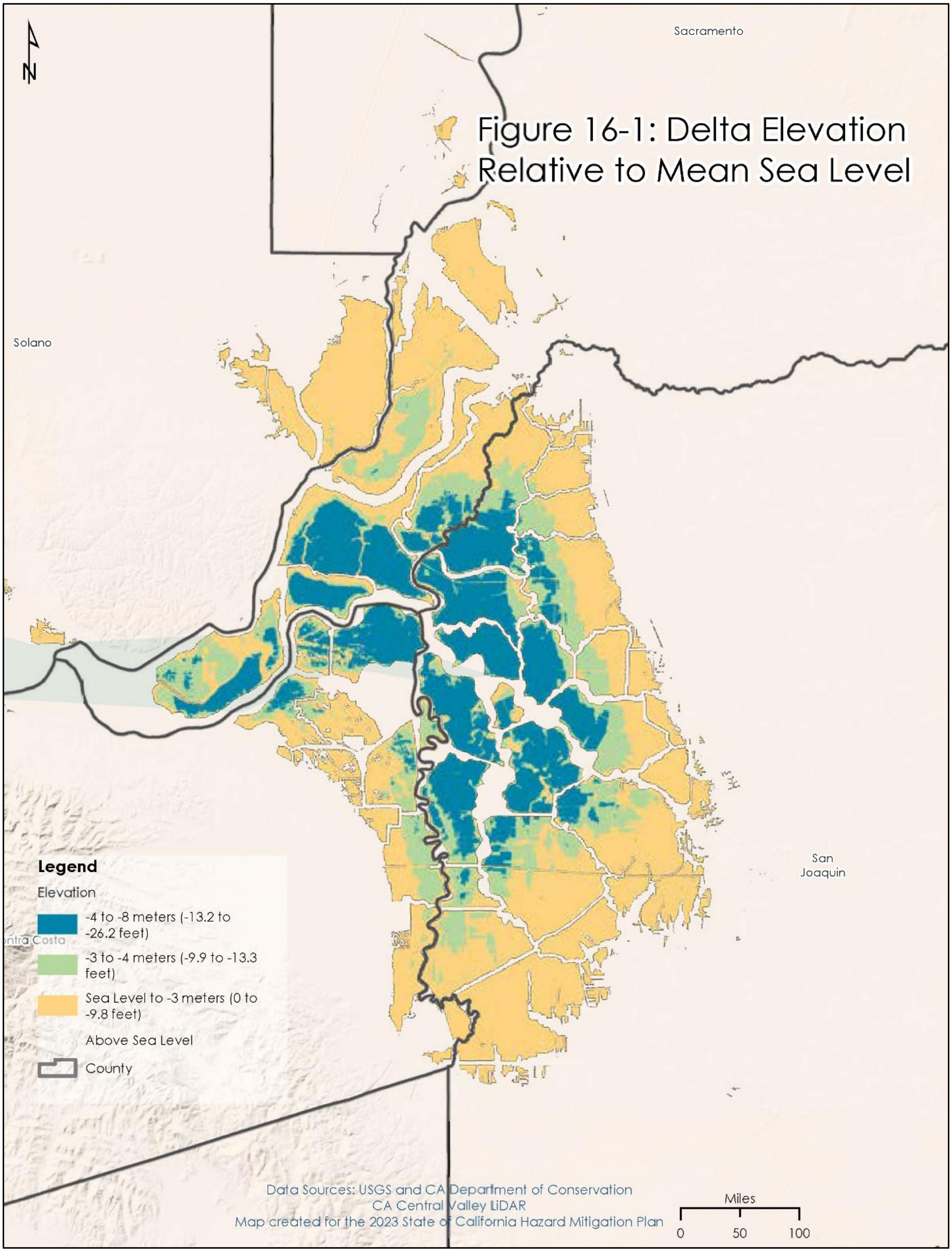


Figure 16-2. California Levee System with 1% Annual Chance Flood Zones

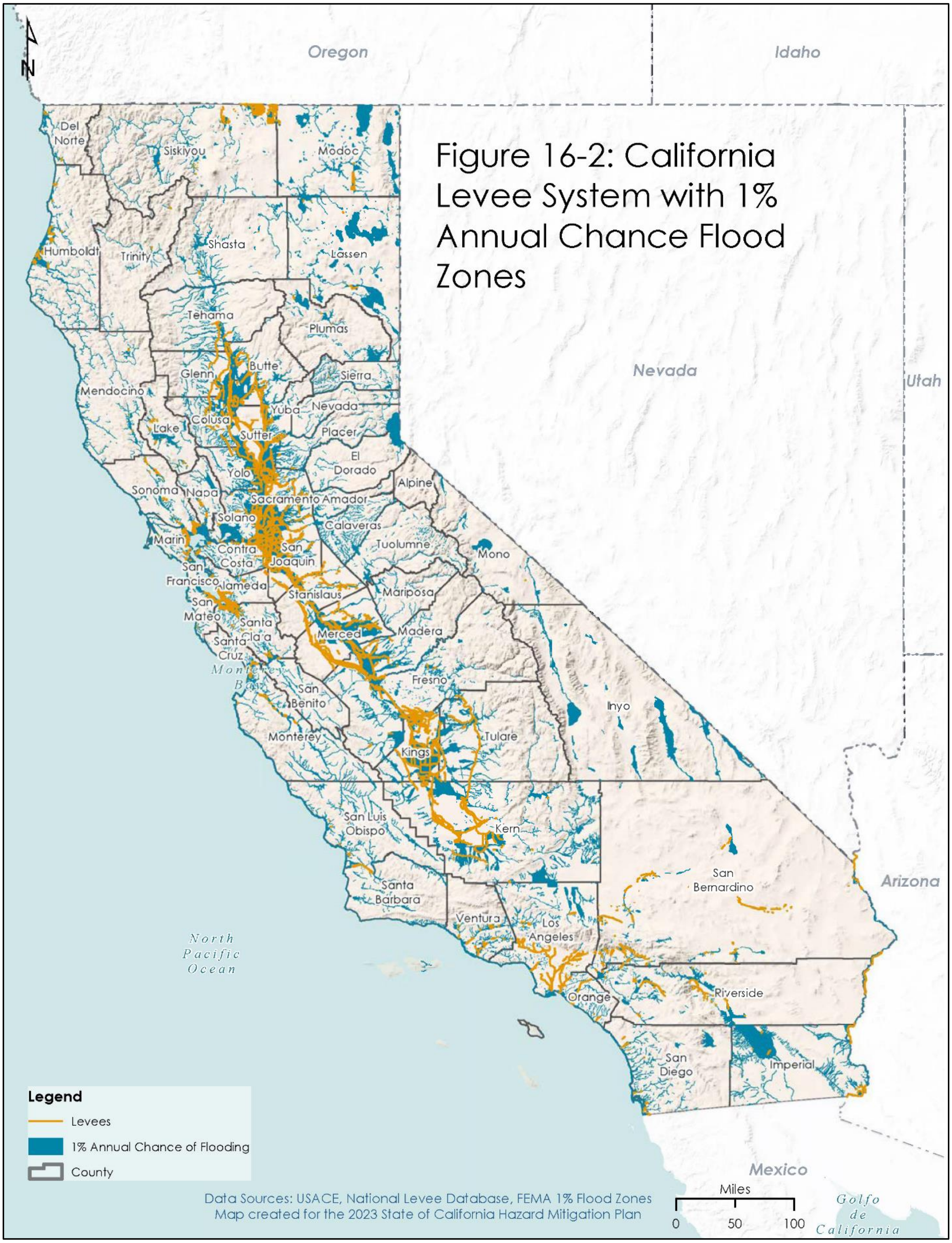
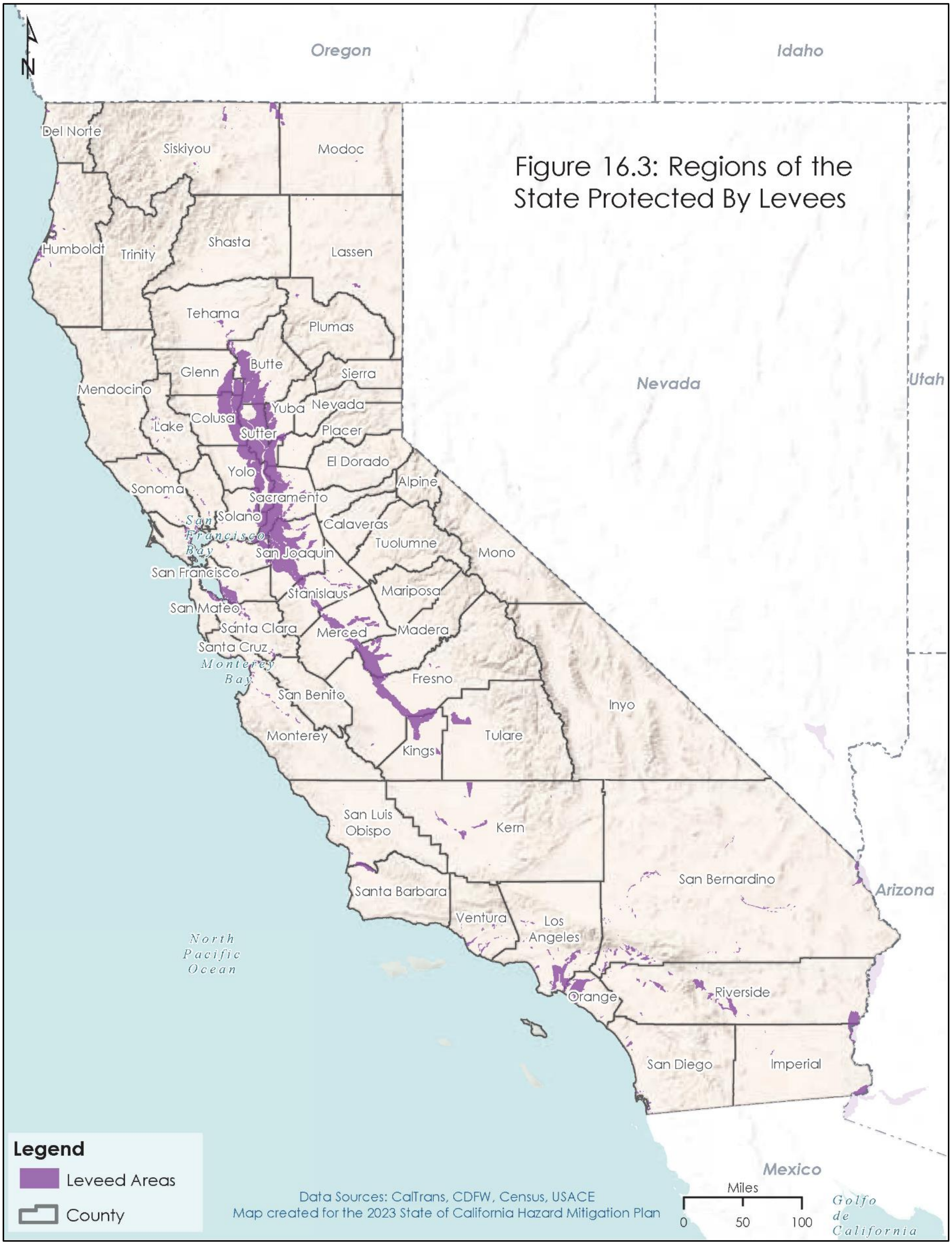


Figure 16-3. Regions of the State Protected by Levees



In 2007, the California legislature designated USACE Project levees in most of the Sacramento-San Joaquin Valley under the State Plan of Flood Control (SPFC) to be assessed every five years as part of the CVFPP. The costs of these assessments and resulting improvements are so high that the legislature limited this legal requirement to areas for which courts have held the State financially responsible. The Previous Occurrences and Vulnerability Assessment reflect this legislatively and judicially imposed limitation.

The Risk Assessment for State-owned or -leased facilities used levee flood protection zone (LFPZ) mapping prepared for the Central Valley by DWR. The LFPZ maps were developed by DWR as required by Water Code Section 9130 to increase awareness of flood risks associated with State and federal levees. DWR prepared LFPZ maps by estimating the maximum area that could be flooded if a levee under federal or State regulation were to fail while conveying flows at the maximum reasonable capacity. Lands in the LFPZ may be subject to flooding due to other factors, but the mapping indicates only inundation attributable to levee breach.

Figure 16-4 shows the LFPZ mapping used for this SHMP. The LFPZ is only available for the Central Valley of California and represents the best available uniform data set to assess the risk from this hazard to State-owned or -leased facilities and community lifelines. This is not a complete data set for all levees in the State, so the Risk Assessment is not representative of the total risk from this hazard. The Risk Assessment is inclusive of the best available data and science for this hazard of concern at the time of this SHMP update.

16.3. PREVIOUS HAZARD OCCURRENCES

Table 16-1 lists significant levee failures in the Bay-Delta from 1900 to the present. This list documents the spatial and temporal variability of levee failure but does not attribute the failures to a particular loading function or failure mechanism.

Figure 16-4. California Central Valley Levee Flood Protection Zones

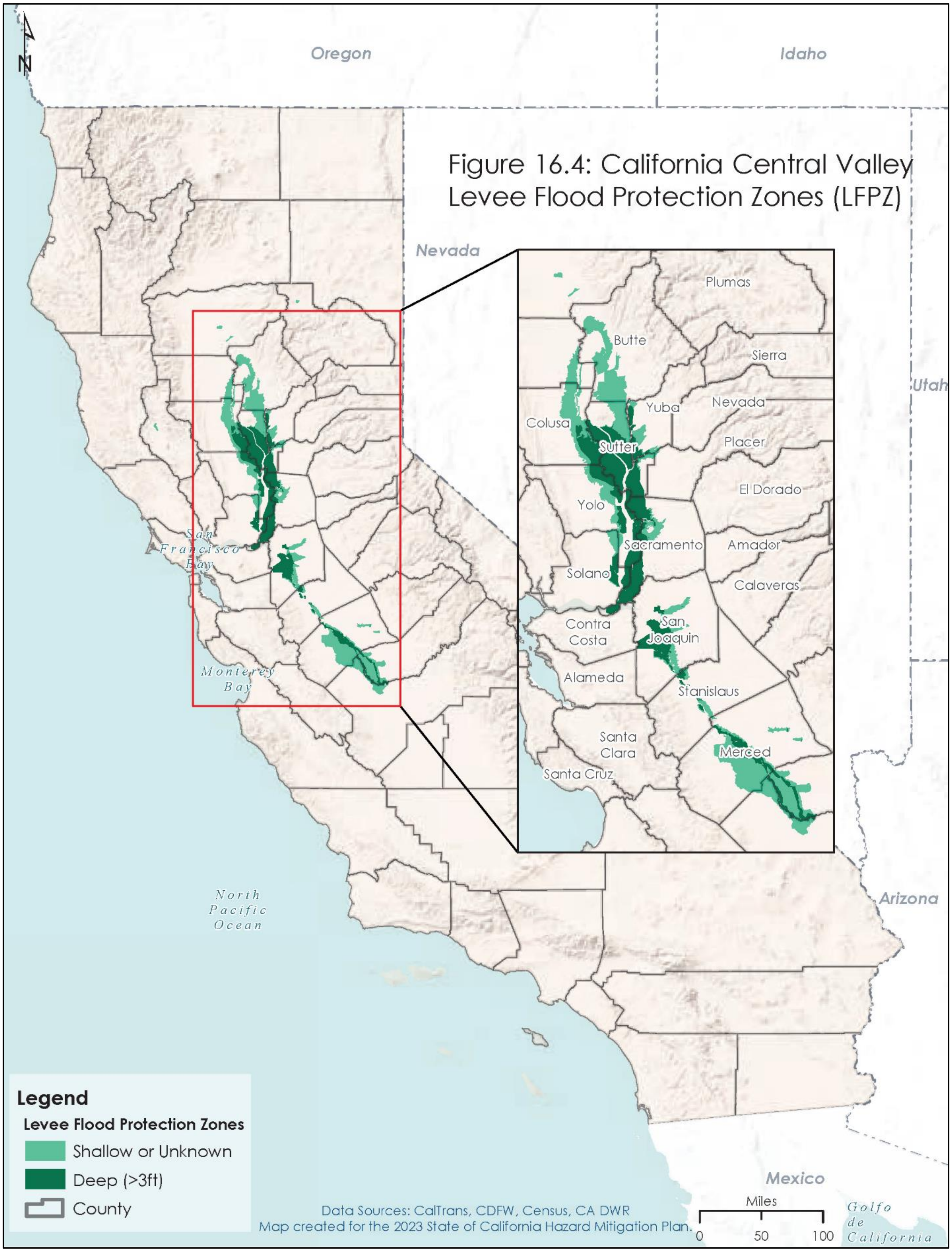


Table 16-1. San Francisco Bay-San Joaquin-Sacramento Delta Levee Failures, 1900-2022

Delta Island Tract	Total Acres Flooded	Year Flooded
Andrus Island	7,200	1902, 1907, 1909, 1972
Bacon Island	5,546	1938
Bethel Island	3,400	1907, 1908, 1909, 1911, 1971, 1981, 1983
Big Break	2,200	1927
Bishop Tract	2,100	1904
Bouldin Tract	5,600	1904, 1907, 1908, 1972
Brack Tract	2,500	1904
Bradford Island	2,000	1950, 1983
Brannan Island	7,500	1902, 1904, 1909, 1972
Byron Tract	6,100	1907
Canal Ranch Tract	500	1958, 1986
Clifton Court Tract	3,100	1901, 1907
Coney Island	900	1907
Dead Horse Island	200	1950, 1955, 1958, 1980, 1986, 1997
Donlon Island	3,000	1937
Edgerly Island	150	1983
Empire Tract	3,500	1950, 1955
Fabian Tract	6,200	1901, 1906
Fay Island	100	1983
Franks Tract	3,300	1907, 1936, 1938
Glanville Tract	--	1986, 1997
Grand Island	--	1955
Grizzly Island	8,000	1983
Holland Tract	4,100	1980
Ida Island	100	1950, 1955
Jersey Island	3,400	1900, 1904, 1907, 1909, 1981, 1983
Little Franks Tract	350	1981, 1982, 1983
Little Mandeville Island	22	1980
Lower Jones Tract	5,700	1907, 1980
Lower Roberts Island	10,300	1906
Lower Sherman Island	3,200	1907, 1925
Mandeville Island	5,000	1938
McCormack Williamson Tract	1,500	1938, 1950, 1955, 1958, 1986, 1997, 2017
McDonald Island	5,800	1982
Medford Island	1,100	1936, 1983
Middle Roberts Island	500	1938
Mildred Island	900	1965, 1969, 1983
New Hope Tract	2,000	1900, 1904, 1907, 1928, 1950, 1986

Delta Island Tract	Total Acres Flooded	Year Flooded
Palm Tract	2,300	1907
Pescadero	3,000	1938, 1950
Prospect Island	1,100	1980, 1981, 1982, 1983, 1986
Quimby Island	700	1936, 1938, 1950, 1955, 1986
RD 1007	3,000	1925
RD 17	4,500	1901, 1911, 1950
Rhode Island	100	1938
Ryer Island	11,600	1904, 1907
Sargent Barnhart Tract	1,100	1904, 1907
Sherman Island	10,000	1904, 1906, 1909, 1937, 1969
Shima	2,394	1983
Shin Kee Tract	700	1938, 1958, 1965, 1986
Staten Island	8,700	1904, 1907
Stewart Tract	3,900	1938, 1950, 1997
Terminous Tract	5,000	1907, 1958
Twitchell Island	3,400	1906, 1907, 1909
Tyler Island	8,700	1904, 1907, 1986
Union Island	2,400	1906
Upper Jones Tract	5,700	1906, 1980, 2004
Upper Roberts Island	500	1938
Van Sickle	--	1983, 2017
Venice Island	3,000	1904, 1906, 1907, 1909, 1932, 1938, 1950, 1982
Victoria Island	7,000	1901, 1907
Webb Tract	5,200	1950, 1980

Source: (Cal OES 2018a)

16.4. PROBABILITY OF FUTURE HAZARD EVENTS

16.4.1. Overall Probability

Complete levee failures are infrequent and typically coincide with the events that cause them, such as heavy rainfall, storm surge, or earthquakes. Over the past 120 years, 124 levee failure events have occurred in California, which equates to an annual recurrence interval. As levees continue to age, the State will continue to see annual recurrence of levee failure events.

16.4.2. Climate Change Impacts

Increased flood frequency and magnitude are predicted consequences of climate change, which in turn will increase the probability of levee failures. The following climate-related changes are expected to result in flooding increases:

- As annual temperatures increase, more of the precipitation that would have fallen into the Sierra Nevada Mountain range as snow may fall instead as rain, increasing winter flows in rivers downstream into the Delta system.
- As the sea levels rise, flood stages in the Sacramento-San Joaquin Delta may also rise, putting increasing pressure on Delta levees. Water levels upstream in the Sacramento and San Joaquin Rivers will also increase, putting pressure on levees there. Extreme high-water levels in the Bay and Delta will increase markedly if the sea level rises above its historical rate. During storm events, these extremes are likely to lead to more severe damage from waves and floods.

16.5. IMPACT ANALYSIS

16.5.1. Severity

Levees provide strong flood protection, but they are not infallible. Levees are designed to protect against a specific flood level and could be overtopped during severe weather events. Levees reduce but do not eliminate the risk to people and structures behind them. A levee system failure or overtopping can create severe flooding and high-water velocities. Proper operation and maintenance are necessary to reduce the probability of failure.

Overtopping is common during high water events in winter, and levee failures during large floods generally do not pose an immediate threat to water supplies outside the Delta.

16.5.2. Warning Time

Warning time depends on the cause of the failure:

- If heavy rains are impacting a levee system, communities in the immediate danger zone can be evacuated before a failure occurs.

- If a levee failure is caused by overtopping, the community may or may not be able to recognize the impending failure and evacuate.
- If a levee failure occurs suddenly, evacuation may not be possible. A levee breach caused by structural failure can occur with little to no warning.
- A structural failure during a period of low inflow, such as summer, can draw ocean salinity into the Delta. The saline water could cause a multi-year disruption to statewide water use. Large-scale disruptions could cost hundreds of billions of dollars annually.

16.5.3. Cascading Impacts

Cascading impacts are the impacts that result when one type of hazard event triggers one or more other hazard events, which may in turn trigger still others.

The following are notable cascading impacts associated with levee failure:

- Levee failure can cause bank erosion, which can have effects worse than those of flooding itself. On the upper courses of rivers where there are steep gradients, floodwaters pass quickly and scour the banks, edging properties closer to the water way or causing them to fall in.
- Flooding associated with levee failure can lead to landslides if high flows over-saturate soils on steep slopes, causing them to fail. Hazardous materials spills can occur if waters that overtop levees rupture storage tanks and cause them to spill into streams, rivers, or drainage sewers.
- Critical infrastructure failures such as loss of power, potable and wastewater treatment, and road and bridge failure can be caused by levee failure events, depending on the magnitude of the resulting flood.

16.5.4. Environmental Impacts

Wildlife and fish can be impacted if flood waters from a levee failure destroy or fundamentally alter plant communities and thus reduce habitat. Floodwaters can also erode riverbanks and convey sediment to locations where it can clog riverbeds and streams, smother aquatic organisms, and destroy habitats. Erosion and sedimentation have a more negative impact on ecosystems that are already degraded. Receding flood waters can leave behind stagnant pools that provide breeding grounds for mosquitoes, which can transmit diseases.

16.5.5. Local Hazard Impacts

LHMP Rankings

According to the USACE National Levee Database, Alpine, Amador, Calaveras, El Dorado, Inyo, and Tuolumne Counties do not have any State or federally regulated levees. Of the remaining 52 counties in California, 23 assessed levee failure as a hazard of concern in their hazard mitigation plans. Of these, 11 ranked levee failure as high risk, nine ranked it as medium risk, and three ranked it as low risk. The following counties listed levee failure as a high-risk hazard:

- Butte
- Calusa
- Fresno
- Glenn
- Lassen
- Merced
- Orange
- Sacramento
- San Joaquin
- Sutter
- Yolo

LHMP Estimates of Potential Loss

A review of the LHMPs in the counties (as called for in FEMA's Standard State Mitigation Planning Requirement S6.b) found no quantitative risk analysis that identifies population or structures exposed to this hazard. This can be attributed to the lack of extent and location hazard mapping to use for such an analysis. Therefore, no summary of risk for local plan reviews is provided for this hazard.

16.6. VULNERABILITY ANALYSIS

16.6.1. Exposure of State-Owned or -Leased Facilities

Table 16-2 and Table 16-3 summarize the number and replacement cost value of State assets located in the LFPZ. Figure 16-5 summarizes the exposed assets as a percentage of total assets statewide. Appendix I provides detailed results by county.

Table 16-2. State-Owned or -Leased Facilities Exposed to Levee Flood Protection Zones

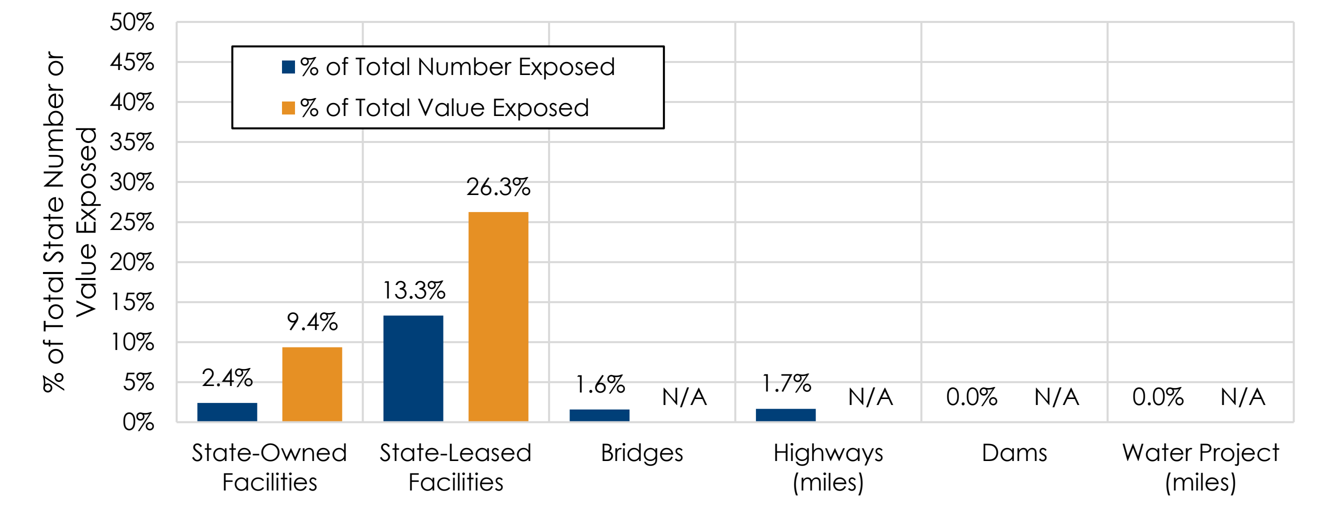
Type of Facility	Number of Structures	Total Area (sq. ft.)	Replacement Cost Value		
			Structure	Content	Total
State-Leased Facilities	252	—	$2,404,840,757	$2,492,284,065	$4,897,124,822
State-Owned Facilities					
Facilities Housing Vulnerable Populations					
Correctional Facility	82	884,450	$47,371,469	$47,371,469	$94,742,939
Development Center	0	0	$0	$0	$0
Hospital	0	0	$0	$0	$0
Migrant Center	1	81,500	$8,146,732	$4,544,727	$12,691,459
Special School	0	0	$0	$0	$0
All Other Facilities	242	13,771,328	$1,652,186,723	$1,681,578,914	$3,333,765,637
Total State-Owned	***325***	***14,737,278***	***$1,707,704,925***	***$1,733,495,110***	***$3,441,200,035***
Total Facilities	**577**	**N/A***	**$4,112,545,682**	**$4,225,779,175**	**$8,338,324,857**

* The inventory of State assets does not include building area for State-leased facilities, so no total area for all State facilities is provided; the building area of vulnerable assets is shown for State-owned facilities only.

Table 16-3. State-Owned or -Leased Infrastructure Exposed to Levee Flood Protection Zones

Type of Facility	State-Owned Infrastructure in the Mapped Hazard Area
Bridges	210
Highway (miles)	498.7
Dams	0
Water Project (miles)	0

Figure 16-5. State Assets Exposed to Levee Failure as % of Statewide Total



The following are key findings of the levee failure Risk Assessment for State-owned or -leased assets:

- The average building area of State-owned or -leased facilities in the LFPZ is 43,345 square feet, and the average replacement cost value is $10.6 million.
- The average replacement cost value for State-owned or -leased facilities in the LFPZ is $19.4 million.
- The following are the five State agencies with the most State-owned or -leased facilities in the LFPZ:
  - DGS (126)
  - CDCR (85)
  - California Exposition and State Fair (47)
  - Caltrans (40)
  - CDFW (35)

- The State agency with the highest total replacement cost value for State-owned or -leased facilities in the LFPZ is DGS, at $2.2 billion.

16.6.2. Exposure of Critical Facilities and Community Lifelines

The analysis identified 16 facilities and community lifelines in the LFPZ for which it is critical for the State to maintain continuity of operations during and after hazard events. Of those, 25 percent are in the "hazardous material" lifeline category and another 25 percent are in the "transportation" lifeline category. The County with the largest percentage of these facilities is Sacramento (37.5 percent) followed by San Joaquin (31.3 percent) and Ventura (12.5 percent). For a detailed breakdown of facility counts by county, see Appendix I.

Critical facilities and community lifelines exposed to the levee failure hazard are likely to experience functional downtime following failure events, which could increase the net impact in the affected area. Hazus estimates damage and functional downtime for flood-related events such as levee failures. Local governments are encouraged to use tools such as Hazus when creating or updating their LHMPs.

16.6.3. Estimates of Loss

Loss estimations for hazard events that cause flooding typically use an approach that correlates damage to the depth of flood water impacting a structure and the time of inundation. USACE has established depth/damage correlations based on analysis of the impacts historical flood events have had on the built environment. The assessment of potential loss associated with levee failure for this SHMP used the USACE depth-damage curve for facilities with "average government function" (see Figure 16-6).

Table 16-4 shows the resulting estimates of potential damage to State-owned or -leased facilities in the LFPZ per foot of flood depth, up to the flood depth that would trigger substantial damage (50 percent of replacement cost value).

Figure 16-6. Depth/Damage Curve for "Average Government Function" Occupancy

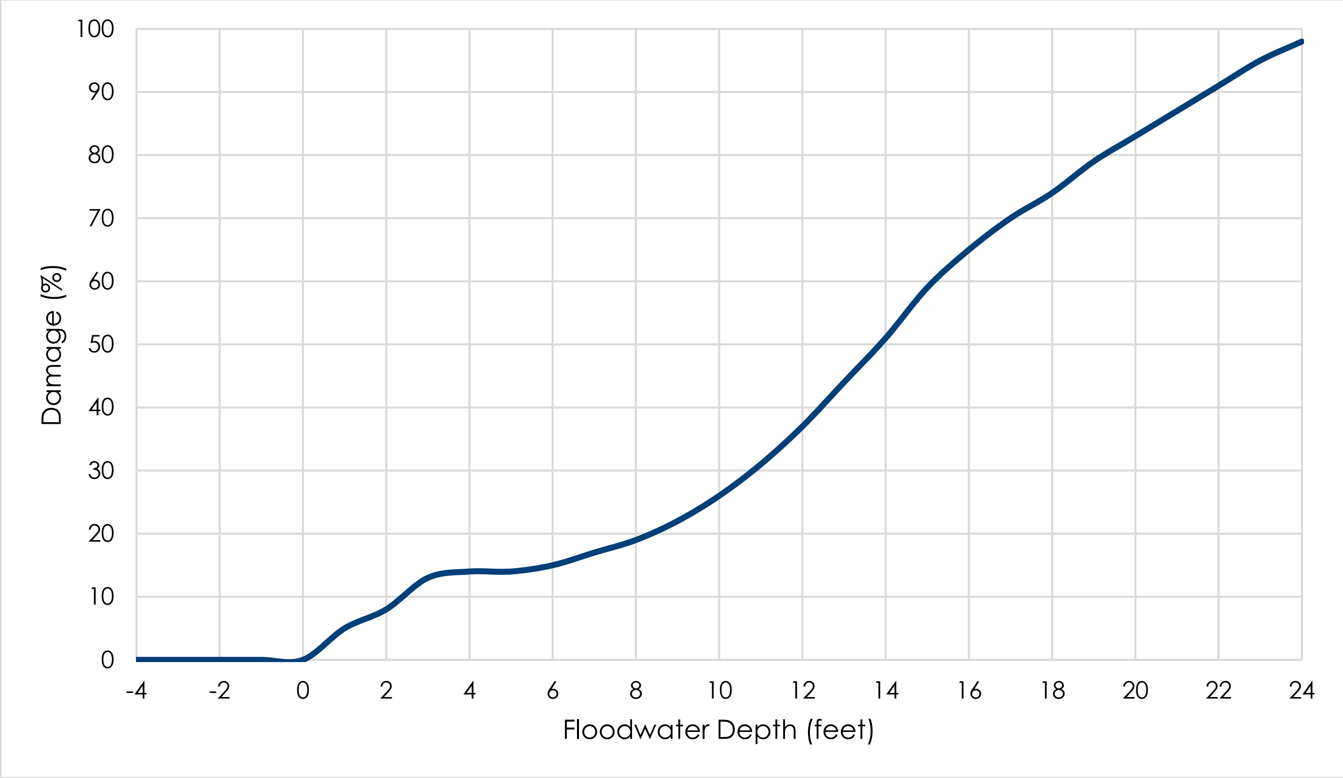


Table 16-4. Estimates of Flood Loss for Facilities in the LFPZ

Flood Depth (feet)	Estimates of Flood Loss*		
	State-Owned	State-Leased	Total
1	$172,060,002	$244,856,241	$416,916,243
2	$275,296,003	$391,769,986	$667,065,989
3	$447,356,005	$636,626,227	$1,083,982,231
4	$481,768,005	$685,597,475	$1,167,365,480
5	$481,768,005	$685,597,475	$1,167,365,480
6	$516,180,005	$734,568,723	$1,250,748,729
7	$585,004,006	$832,511,220	$1,417,515,226
8	$653,828,007	$930,453,716	$1,584,281,723
9	$757,064,008	$1,077,367,461	$1,834,431,469
10	$894,712,009	$1,273,252,454	$2,167,964,463
11	$1,066,772,011	$1,518,108,695	$2,584,880,706
12	$1,273,244,013	$1,811,936,184	$3,085,180,197
13	$1,514,128,016	$2,154,734,922	$3,668,862,937
14	$1,755,012,018	$2,497,533,659	$4,252,545,677

* Structure losses only. Does not include contents losses.

16.6.4. Buildable Land

Of 11.7 million acres of land available for development statewide, 55,363 acres (0.5 percent) are located in the LFPZ. Appendix G provides a detailed assessment of exposed buildable lands by county.

16.6.5. Equity Priority Communities

The risk analysis for levee failure found that 34.0 percent of people exposed to the levee failure hazard live in equity priority communities (186,000 people). A breakdown of exposed equity priority communities by county is included in Appendix I.

16.6.6. NRI Scores

The National Risk Index does not provide rankings for the levee failure hazard.

16.7. MITIGATING THE HAZARD

16.7.1. Opportunities for Mitigating the Hazard

A range of potential opportunities for mitigating the levee failure hazard is provided in Table 16-5. See Section 1.2.3 for a description of the different types of alternatives.

16.7.2. Selected Actions to Mitigate the Hazard

The mitigation strategy developed for this SHMP includes the following actions that address the levee failure hazard:

- Action 2023-009: Implement the 2022 CVFPP.
- Action 2018-006: Enhance Collaboration on the Development and Sharing of Data Systems and GIS Modeling.
- Action 2018-008: Develop a database containing a description of the specific natural hazard event for which each project was designed to mitigate.
- Action 2018-059: Delta Levees Program: Provide funding to local agencies in the Sacramento- San Joaquin for levee maintenance and improvement and for habitat mitigation and enhancement.

Table 16-5. Potential Opportunities to Mitigate the Levee Failure Hazard

Community-Scale	Organizational Scale	Government-Scale
Manipulate the hazard: ▪ None **Reduce exposure and vulnerability:** ▪ Relocate out of levee failure inundation areas ▪ Elevate home to appropriate levels ▪ Have designated shelters or temporary or permanent housing locations for displaced persons **Build local capacity:** ▪ Learn about risk reduction for the levee failure hazard ▪ Learn the evacuation routes for a levee failure event ▪ Become educated about early warning systems and the dissemination of warnings	**Manipulate the hazard:** ▪ Remove levees ▪ Harden levees ▪ Set back levees **Reduce exposure and vulnerability:** ▪ Replace earthen levees with hardened structures such as floodwalls ▪ Floodproof facilities in levee failure inundation areas **Build local capacity:** ▪ Educate employees on the probable impacts of a levee failure ▪ Develop a continuity of operations plan	**Manipulate the hazard:** ▪ Remove levees ▪ Harden levees ▪ Set back levees **Reduce exposure and vulnerability:** ▪ Replace earthen levees with hardened structures such as floodwalls ▪ Relocate critical facilities out of levee failure inundation areas ▪ Consider open space land use in designated levee failure inundation areas ▪ Adopt higher floodplain standards in mapped levee failure inundation areas ▪ Retrofit critical facilities in levee failure inundation areas **Build local capacity:** ▪ Map levee failure inundation areas ▪ Enhance emergency operations plans to include a levee failure component ▪ Inform the public on risk reduction techniques ▪ Adopt real-estate disclosure requirements for the re-sale of property located within levee failure inundation areas ▪ Consider the probable impacts of climate change in assessing the risk associated with the levee failure hazard ▪ Establish early warning capability for those protected by levees ▪ Consider the residual risk associated with protection provided by levees in future land use decisions ▪ Increase ability to respond quickly to events
Nature-based opportunities ▪ Restore and reconnect floodplains that have been degraded by development and structural flood control		

Community-Scale	Organizational Scale	Government-Scale
▪ Use soft approaches for stream bank restoration and hardening. Soft approaches can include but are not limited to the introduction of large woody debris into a system ▪ Set back levees on systems that rely on levee protection to allow the river channel to meander, which reduces erosion and scour potential ▪ Acquire property within the floodplain, remove or relocate structures, and preserve these areas as open space in perpetuity ▪ Preserve floodplain storage capacity by limiting or prohibiting the use of fill within the floodplain ▪ Incorporate green infrastructure into stormwater management facilities ▪ Protect and/or restore riparian buffers		

SNOW AVALANCHE

Climate Impacts:
Greater variability in weather patterns driven by climate change will cause layers of rain to fall after light layers of snow, and these forms of precipitation can destabilize snowpack and increase the frequency, and severity, of avalanches

Equity Impacts:
Approximately 20% of the exposed population is identified as living in equity priority communities; however, those living in counties susceptible to avalanches are at greater risk

State Facilities Exposed:
All facilities in counties identified with avalanche susceptibility are exposed; however, those located in areas prone to avalanches are more at risk

Community Lifelines Exposed:
All lifelines in counties identified with avalanche susceptibility are exposed; however, those located in areas prone to avalanches are more at risk

Impact Rating: Medium (21)

17. Snow Avalanche

Snow avalanche has been identified as a medium-impact natural hazard of interest based on the hazard impact rating protocol applied for this SHMP. These events happen frequently in areas susceptible to accumulated snowfall. Less than 14 percent of State-owned or -leased facilities and community lifelines are exposed to this hazard. Less than 14 percent of the State population resides in counties with snow avalanche susceptibility; about 20 percent of that population has been identified as living in equity priority communities. The chance of the risk of this hazard increasing due to new development is low, since the majority of areas that are susceptible are State or national forests or are currently zoned for recreational use. The frequency and severity of snow avalanche is anticipated to increase over the next 30 years due to impacts from climate change.

17.1. HAZARD OVERVIEW

An avalanche is a mass of snow, ice, soil, or rocks that fall down a mountainside. Avalanches of rock and soil are landslides, as assessed in Chapter 12. This chapter assesses avalanches of snow (National Geographic n.d.). Snow avalanches occur in the steep mountainous areas of California that receive significant amounts of snow. They are weather-related threats to communities, residents, and visitors in the high mountain areas of the State.

17.2. HAZARD LOCATION

Avalanches tend to occur in three distinct areas in California: the Eastern Sierras, the Central Sierra Nevada, and the southern part of the Cascade Range near Mount Shasta (Avalanche.org 2022).

17.3. PREVIOUS HAZARD OCCURRENCES

Avalanches are a yearly occurrence in California. The main source of documentation for avalanches in the United States is NOAA's National Center for Environmental Information, which provides details on avalanches in California.

17.3.1. Disaster and Emergency Declarations

No FEMA, USDA, or State disaster declarations or proclamations related to snow avalanche have been issued relevant to California or any of its counties.

17.3.2. Event History

Avalanches have caused property damage and loss of life in California. The 2018 SHMP discussed avalanches that occurred in the State from 1996 to 2016. Table 17-1 lists avalanches that occurred in the State since January 2018. Refer to Appendix K for the history of avalanches since 1996.

Table 17-1. Avalanche Events in the State of California (2018 to 2022)

Date	Event Type	FEMA Declaration Number	USDA Declaration Number	Counties/Areas Impacted
January 27, 2018	Avalanche	N/A	N/A	Greater Lake Tahoe Area
A dry slab avalanche was triggered by a snowboarder on North Castle Peak. No injuries or deaths reported.				
March 2, 2018	Avalanche	N/A	N/A	Greater Lake Tahoe Area
Avalanche occurred at Squaw Valley Ski Resort. The avalanche caught five people, all of whom survived.				
March 3, 2018	Avalanche	N/A	N/A	Mono
Avalanche occurred at Mammoth Mountain Ski Area. Six people were partially caught but freed themselves with only minor injuries.				
March 17, 2018	Avalanche	N/A	N/A	Tamarack Peak
This slide was triggered by the seventh person to ski the slope. The person was carried by the avalanche and lost skis and poles. When the slide stopped moving the person ended up only partially buried and was able to self-rescue.				
March 22, 2018	Avalanche	N/A	N/A	Mono
Avalanche occurred on McGee Mountain. No injuries or deaths reported.				

Date	Event Type	FEMA Declaration Number	USDA Declaration Number	Counties/Areas Impacted
December 2, 2018	Avalanche	N/A	N/A	Red Lake Peak, Above Crater Lake
As a skier went down the mountain, it released a 60-foot-wide slab avalanche; however, no injuries were reported.				
December 9, 2018	Avalanche	N/A	N/A	Mt. Tallac
A skier set off a small slab avalanche and knocked him off his feet. The skier fell 200 feet and was seriously injured.				
December 16, 2018	Avalanche	N/A	N/A	Frog Lake into Red Lake
Avalanche triggered by a snowboard, setting off a wind slab that dropped into Red Lake.				
March 23, 2019	Avalanche	N/A	N/A	Mono
A full course slab avalanche was accidentally triggered by two skiers, both of whom survived.				
April 1, 2019	Avalanche	N/A	N/A	West Slope Northern Sierra Nevada
An avalanche closed Hwy 50 at Echo Summit.				
January 17, 2020	Avalanche	N/A	N/A	Greater Lake Tahoe Area
A large avalanche occurred at Alpine Meadows Resort, causing one death.				
January 17, 2020	Avalanche	N/A	N/A	Greater Lake Tahoe Area
A full burial slab avalanche occurred along the north side of Independence Lake. One skier was buried but survived with minor injuries.				
January 27, 2021	Blizzard	N/A	N/A	Mono/Greater Lake Tahoe Area
Avalanche occurred on U.S. 395 within Walker River Canyon.				
January 28, 2021	Avalanche	N/A	N/A	Mono
Multiple avalanches occurred in Walker River Canyon with up to 15 feet of debris covering U.S. 395.				
February 3, 2021	Avalanche	N/A	N/A	Western Siskiyou County
An avalanche near Etna Summit buried two skiers, killing one of them.				
December 11, 2021	Avalanche	N/A	N/A	Base of Elephants Back
A skier triggered a wind slab; two people were caught in the incident.				
December 18, 2021	Avalanche	N/A	N/A	Stevens Peak
A skier triggered a slow-moving avalanche that pulled another skier down approximately 30 feet, burying one leg.				
January 3, 2022	Avalanche	N/A	N/A	Stanford Rock
Small avalanche caught one skier.				

Date	Event Type	FEMA Declaration Number	USDA Declaration Number	Counties/Areas Impacted
April 15, 2022	Avalanche	N/A	N/A	Andesite Peak
Heavy snow and moderate avalanche conditions; two skiers were caught in the avalanche.				
May 7, 2022	Avalanche	N/A	N/A	Alpine/Keyhole Area
A skier was caught in about 20 feet of snow and was able to dig out.				

Sources: (Mount Shasta Avalanche and Climbing Information 2022); (Sierra Avalanche Center 2022a); (Bridgeport Avalanche Center 2022)

17.4. PROBABILITY OF FUTURE HAZARD EVENTS

17.4.1. Overall Probability

California's record of more than 100 avalanche events between 2009 and 2022 represent an average of more than seven events per year. The State is expected to continue to experience a similar number of avalanches each year.

17.4.2. Climate Change Impacts

Scientists have only recently begun examining the effects climate change might have on avalanches. According to some experts, greater variability in weather patterns will cause layers of rain to fall after light layers of snow, and this sequence can destabilize snowpack and increase the frequency and severity of avalanches (USFS 2019a). Some experts believe that an overall reduction in snowpack could lead to fewer avalanches in winter but changing precipitation patterns could make avalanches more frequent in the springtime instead (Peitzsch, et al. 2021).

17.5. IMPACT ANALYSIS

17.5.1. Severity

The fact that avalanches take place in remote settings far from large population centers means they do not pose the same degree of danger to life and property as other hazards do. The people most vulnerable to avalanches tend to be skiers, snowboarders, and others engaged in recreational activities in snow-covered, mountainous areas. Transportation infrastructure and structures that serve those areas also are vulnerable.

17.5.2. Warning Time

The North American Avalanche Danger Scale is a tool used by avalanche forecasters to communicate the potential for avalanche occurrence and the general size and distribution of avalanches if they occur (Avalanche.org 2022b). The scale is a five-category estimation of the avalanche danger: low, moderate, considerable, high, and extreme. The scale is presented in Figure 17-1.

Figure 17-1. North American Avalanche Danger Scale

Danger Level		Travel Advice	Likelihood of Avalanches	Avalanche Size and Distribution
5 Extreme	4 5	Avoid all avalanche terrain.	Natural and human-triggered avalanches certain.	Large to very large avalanches in many areas.
4 High	4 5	Very dangerous avalanche conditions. Travel in avalanche terrain **not** recommended.	Natural avalanches likely; human-triggered avalanches **very** likely.	Large avalanches in many areas; or very large avalanches in specific areas.
3 Considerable	3	Dangerous avalanche conditions. Careful snowpack evaluation, cautious route-finding and conservative decision-making essential.	Natural avalanches possible; human-triggered avalanches likely.	Small avalanches in many areas; or large avalanches in specific areas; or very large avalanches in isolated areas.
2 Moderate	2	Heightened avalanche conditions on specific terrain features. Evaluate snow and terrain carefully; identify features of concern.	Natural avalanches unlikely; human-triggered avalanches possible.	Small avalanches in specific areas; or large avalanches in isolated areas.
1 Low	1	Generally safe avalanche conditions. Watch for unstable snow on isolated terrain features.	Natural and human-triggered avalanches unlikely.	Small avalanches in isolated areas or extreme terrain.
Safe backcountry travel requires training and experience. You control your own risk by choosing where, when and how you travel.				
No Rating		Watch for signs of unstable snow such as recent avalanches, cracking in the snow, and audible collapsing. Avoid traveling on or under similar slopes.		

Source: (Avalanche.org 2022b)

The National Weather Service provides current weather conditions and forecast information to regional avalanche forecast centers that in turn issue avalanche forecasts. Avalanche warnings and special advisories are included on NWS websites and broadcast over NOAA Weather Radio (NWS 2021). In California, several avalanche centers provide forecasts, advisories, and warnings. Each center employs avalanche forecasters to provide daily avalanche advisories and field observations (Sierra Avalanche Center 2022); (Avalanche.org 2022a).

17.5.3. Cascading Impacts

Cascading impacts are the impacts that result when one type of hazard event triggers one or more other hazard events, which may in turn trigger still others. The following are notable cascading impacts associated with snow avalanche:

- The most significant cascading impacts from snow avalanches are the closure of transportation corridors, which can isolate populations and interrupt commodity flows.
- Avalanches tend to occur independently of other types of hazards, although it is possible for avalanches to be triggered by severe weather and earthquakes. There may be occasions where avalanches contribute to the presence of other hazards (Colorado Department of Local Affairs n.d.), such as flash floods resulting from mountainside erosion.
- Avalanches might cause erosion on sloped terrain, thereby increasing the likelihood of future landslides. In addition, debris deposited in a river or stream because of avalanches might alter its flow and contribute to flooding later.

17.5.4. Environmental Impacts

The effects avalanches have on wildlife and natural ecosystems are considered to be beneficial (Muller and Straub 2016). For example, the chutes and debris created by avalanches help provide favorable habitat for a variety of flora and fauna. Avalanches can also form firebreaks that help limit wildfires in wooded areas. Moreover, a self-regulating feedback loop occurs between avalanches and the trees in a forest. Trees that experience avalanches become stronger and more resilient, and these more robust trees in turn reduce the frequency of avalanches by reinforcing the snowpack and reducing the effects of strong winds.

17.5.5. Local Hazard Impacts

LHMP Rankings

Five of the hazard mitigation plans prepared for California's 58 counties list landslide as a hazard of concern; all of them rank it as a medium-impact hazard:

- Fresno
- Inyo
- Lassen
- Mono
- Placer

LHMP Estimates of Potential Loss

A review of the LHMPs in the counties (as called for in FEMA's Standard State Mitigation Planning Requirement S6.b) found no quantitative risk analysis that identifies population or structures exposed to this hazard. This can be attributed to the lack of extent and location hazard mapping to use for such an analysis. Therefore, no summary of risk for local plan reviews is provided for this hazard.

17.6. VULNERABILITY ANALYSIS

17.6.1. Exposure of State-Owned or -Leased Facilities, Critical Facilities, and Community Lifelines

With no mapping of avalanche hazard zones available, there is no valid way to quantify the exposure of State assets to this hazard. Given the remoteness of avalanche areas, it is unlikely that State-owned or -leased facilities are directly exposed. Critical infrastructure such as roads are more likely to be exposed. Impacts on these lifelines could isolate populations and interrupt commodity flows.

17.6.2. Estimates of Loss

Snow avalanche events are not likely to result in any losses associated with damage or impairment to State assets. All losses from this hazard would be associated with impacts on the economy, based on limitations on activities in avalanche risk areas.

17.6.3. Buildable Land

Areas of snow avalanche susceptibility are typically not well suited for development due to the steepness of slope in these areas. However, the run-out areas down-slope can be targets for developments. Most the lands identified as susceptible to snow avalanches are either State or national forest or have existing uses associated with winter sport recreation. Therefore, the buildable land exposure for this hazard is considered to be low.

17.6.4. Equity Priority Communities

In determining whether equity priority populations are exposed to the threat of avalanches, the best method available at the time of this Plan update is to consider how the counties in which avalanches take place score on existing social vulnerability indexes. Table 17-2 summarizes relevant scores.

Table 17-2. SVI in Counties with Avalanches

County	FEMA National Risk Index Social Vulnerability Score	County	FEMA National Risk Index Social Vulnerability Score
Alpine	40.68 out of 100—relatively moderate	**Mono**	33.70 out of 100—relatively low
Amador	35.63 out of 100—relatively moderate	**Nevada**	36.89 out of 100—relatively moderate
Butte	42.14 out of 100—relatively moderate	**Placer**	25.90 out of 100—relatively low
Calaveras	37.92 out of 100—relatively moderate	**Plumas**	46.63 out of 100—relatively high
El Dorado	26.69 out of 100—relatively low	**San Diego**	32.20 out of 100—relatively low
Fresno	49.70 out of 100—relatively high	**San Bernardino**	40.28 out of 100—relatively moderate
Inyo	48.48 out of 100—relatively high	**Shasta**	43.20 out of 100—relatively moderate
Lassen	9.78 out of 100—very low	**Sierra**	46.67 out of 100—relatively high
Los Angeles	44.90 out of 100—relatively high	**Siskiyou**	48.48 out of 100—relatively high
Madera	48.99 out of 100—relatively high	**Tulare**	51.28 out of 100—relatively high
Mariposa	46.24 out of 100—relatively high	**Tuolumne**	42.14 out of 100—relatively moderate
Modoc	49.07 out of 100—relatively high	**Yuba**	39.81 out of 100—relatively moderate

Many counties in California are large and encompass a variety of demographically diverse and geographically dispersed communities. This means that the county-level data may not reflect equity priority in separate communities within a specific county. Nevertheless, this is the most appropriate data available at the time of this Plan update.

17.6.5. NRI Scores

According to the NRI, 19 of the State's counties have avalanche risk, rated from relatively low to relatively moderate. Table 17-3 shows scores for the six counties with the highest rating. See Section 4.1.3 for a description of the components of the NRI.

Table 17-3. NRI Scoring of Counties for Avalanche

County	Expected Annual Loss	Social Vulnerability Rating	Community Resilience Rating	Community Risk Factor	Risk Value	Score
Placer	$682,573	Very Low	Very High	0.91	$607,950	83.17
Alpine	$386,644	Relatively Moderate	Relatively Moderate	1.35	$521,920	81.25
Inyo	$368,508	Relatively Moderate	Relatively Low	1.31	$432,020	77.4
Mono	$373,333	Relatively moderate	Relatively High	1.17	$431,803	76.92
Nevada	$386,664	Relatively Low	Relatively High	0.98	$424,655	76.44
El Dorado	$424,586	Relatively Low	Relatively High	1.02	$397,395	75.00

17.7. MITIGATING THE HAZARD

17.7.1. Existing Measures to Mitigate the Hazard

Each of the three main avalanche areas of California has an avalanche center, a non-profit institution that operates as a partner of the U.S. Forest Service for monitoring avalanches and educating the public about them:

- The Eastern Sierra Avalanche Center (Eastern Sierra Avalanche Center 2022)
- The Sierra Avalanche Center (Sierra Avalanche Center n.d.)
- The Mount Shasta Avalanche Center (Mount Shasta Avalanche Center n.d.)

The establishment of avalanche centers in these areas means that avalanches are consistently detected and documented therein.

17.7.2. Opportunities for Mitigating the Hazard

In areas affected by avalanches, the threat can be reduced through ongoing control programs, installing protection structures, and public outreach. A range of potential alternatives for mitigating the snow avalanche hazard is provided in Table 17-4.

17.7.3. Selected Actions to Mitigate the Hazard

The mitigation strategy developed for this SHMP includes the following actions that address snow avalanche:

- Action 2018-001: Support Legislative Efforts that Formalize California's Comprehensive Mitigation Program.
- Action 2018-006: Enhance Collaboration on the Development and Sharing of Data Systems and GIS Modeling.
- Action 2018-008: Develop a database containing a description of the specific natural hazard event for which each project was designed to mitigate.

Table 17-4. Potential Opportunities to Mitigate the Snow Avalanche Hazard

Community-Scale	Organizational Scale	Government-Scale
Manipulate the hazard: ▪ None **Reduce exposure and vulnerability:** ▪ Monitor avalanche reports before any winter-related outdoor activities ▪ Avoid avalanche areas ▪ Monitor avalanche reports before any winter-related outdoor activities **Build local capacity:** ▪ None	**Manipulate the hazard:** ▪ None **Reduce exposure and vulnerability:** ▪ None **Build local capacity:** ▪ None	**Manipulate the hazard:** ▪ None **Reduce exposure and vulnerability:** ▪ Controlled avalanches as necessary (i.e., triggering an avalanche through detonation ▪ Install static defense structures in avalanche areas ▪ Identify and map avalanche paths and avalanche areas in the State ▪ Construct snow sheds over highways and railroads that cross potential avalanche paths ▪ Have proper equipment to support rescue, mitigate head injuries, and create air pockets (avalanche beacon, portable shovel, avalanche probe in backpack, helmet, and avalanche airbags) **Build local capacity:** ▪ Identify and map avalanche paths and avalanche areas in the State
Nature-based opportunities ▪ Restrict or prohibit new development downslope of areas susceptible to avalanche and preserve these areas for open space/recreational uses ▪ Preserve forest ecosystems in avalanche-prone areas to provide a resistance buffer area to absorb impacts from avalanches		

SUBSIDENCE

Climate Impacts:
Subsidence impacts can be directly tied to prolonged periods of drought and extreme heat; changes in precipitation, reduced snowpack, and more frequent droughts are likely to increase the demand on groundwater sources, risking overdraft, ground subsidence, and decreased water quality

Equity Impacts:
32.9% of exposed population (those living in subsidence susceptible counties) identified as living in equity priority communities

State Facilities Exposed:
10,713 State facilities located in subsidence susceptible counties

Community Lifelines Exposed:
462 community lifelines located in subsidence susceptible counties

Impact Rating: Medium (18)

18. SUBSIDENCE

Subsidence has been identified as a medium-impact natural hazard of interest based on the hazard impact rating protocol applied for this SHMP. These events are likely to occur in some regions of the State within the next 100 years. An estimated 41.4 percent of State-owned or -leased facilities and community lifelines are exposed to this hazard. Less than 25 percent of the population resides in areas considered to be susceptible to subsidence; over 32.9 percent of that population has been identified as living in equity priority communities. Less than 6 percent of buildable land in the State is in regions that are susceptible to subsidence. The frequency and severity of subsidence is anticipated to increase over the next 30 years due to the impacts from climate change.

18.1. HAZARD OVERVIEW

DWR defines land subsidence as "the sinking of the land surface due to excessive groundwater pumping" (DWR 2022j). The sinking may be gradual or sudden. Subsidence happens either due to natural processes or as a result of human activities.

Effects of land subsidence in California include increased flood risk in low-lying areas, damage to buildings and infrastructure, loss of groundwater aquifers, and damage to aquatic ecosystems. Figure 18-1 shows typical physical signs of subsidence activity.

18.2. HAZARD LOCATION

Figure 18-2 shows known areas of subsidence risk in California today. Figure 18-3 shows the critically over-drafted groundwater basins in California. The areas shown are potentially more susceptible to subsidence. Table 18-1 describes areas of historically significant subsidence across the State. The sections below describe the conditions that typically lead to subsidence in specific regions of California.

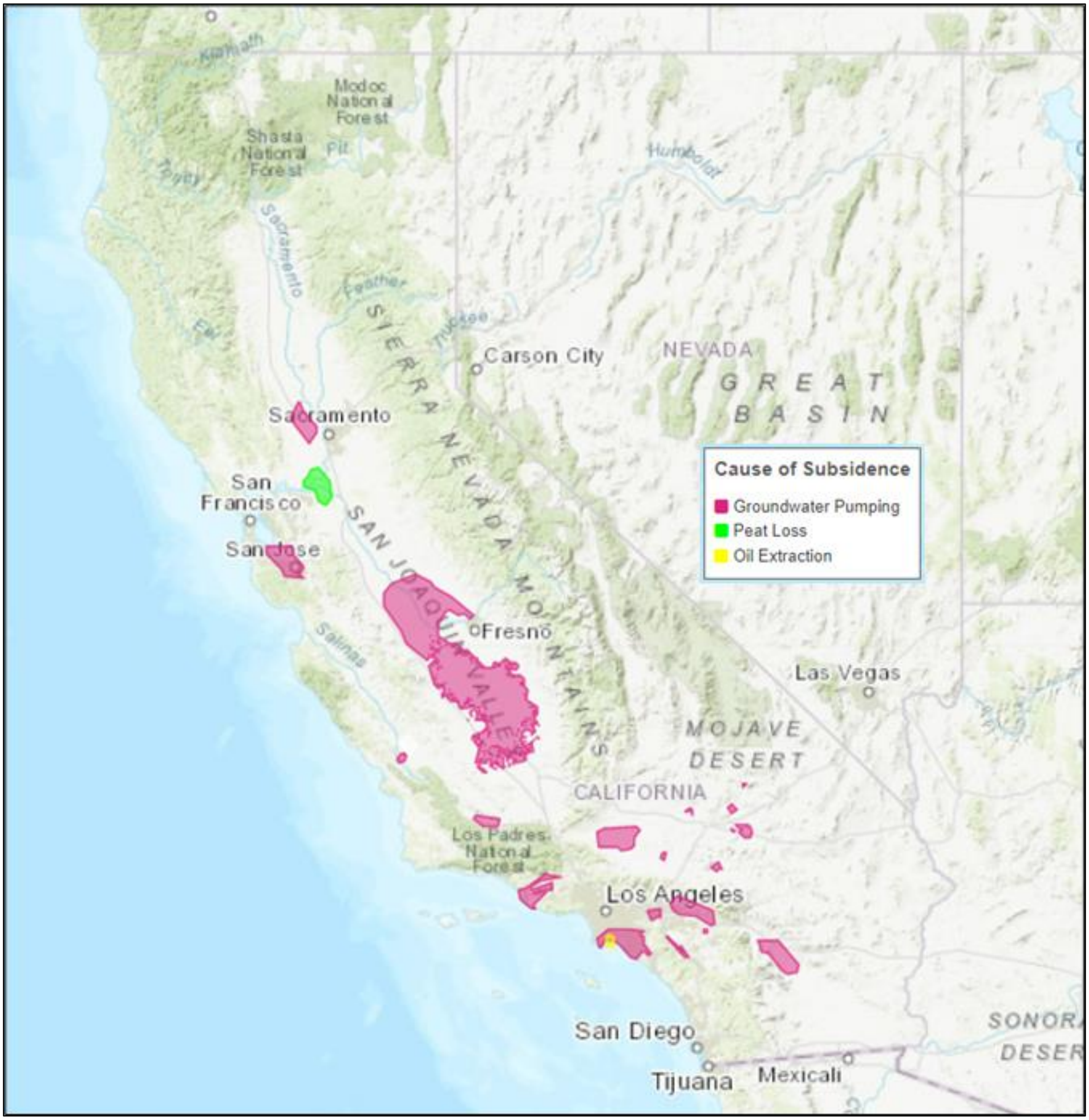
Figure 18-1. Physical Signs of Subsidence

Source: (USGS 2018e)

Source: (USGS 2018c)

Source: (USGS 2017)

Figure 18-2. Areas of Land Subsidence in California



Source: (USGS 2023)

Figure 18-3. Critically Over-Drafted Groundwater Basins in California

Source: (DWR 2020a)

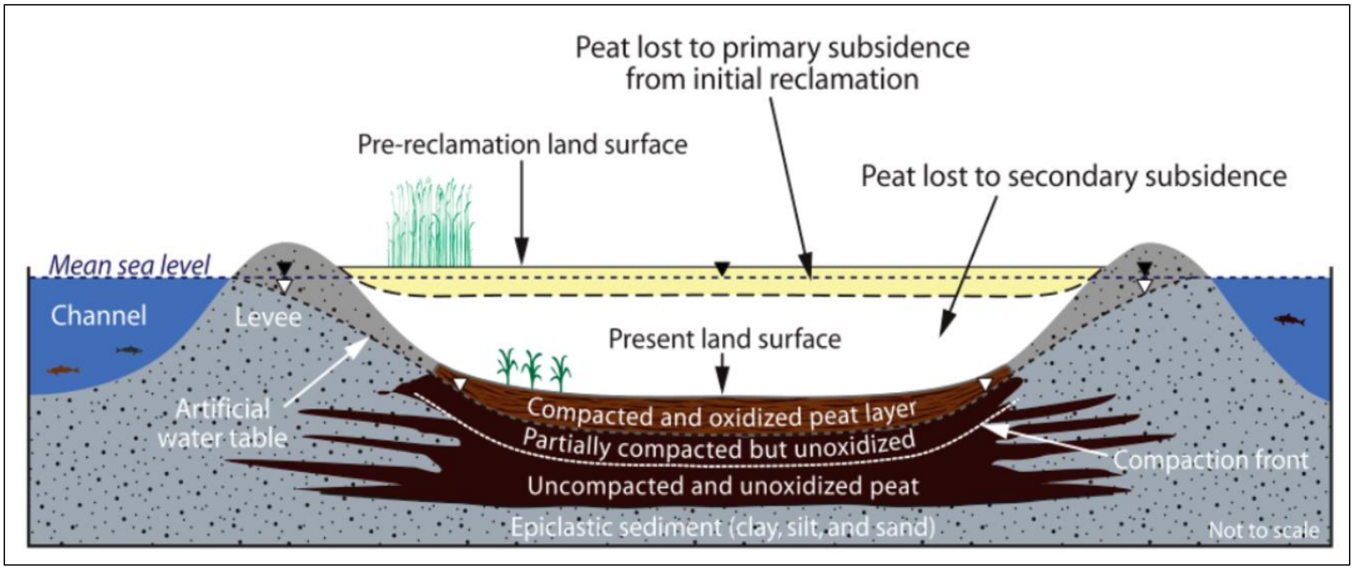
Table 18-1. Significant Locations and Causes of Subsidence in California

Causes	Measured Subsidence	Comments
Sacramento Valley (DWR 2014); (DWR 2019a)		
Although the Sacramento Valley has a large supply of surface water, drought periods have led communities to rely more heavily on groundwater	0.73 to 3.9 feet since 1949 2.14 feet from 2008 through 2017 in the Arbuckle area	Caused damage to irrigation wells and increased the extent of flooding in certain areas
Antelope Valley (Siade, et al. 2014)		
Groundwater pumping; groundwater level declines of more than 270 feet in some parts of the groundwater basin	More than 6 feet in some areas	Growth and limits on imported water may increase future reliance on groundwater.
Oxnard Plain (Borchers and Carpenter 2014)		
Groundwater withdrawal and oil and gas production are probably major causes; tectonic activity is likely a minor cause	—	First measured in 1939. Subsidence occurred primarily in the upper-aquifer system prior to 1959; some subsidence occurred in the lower-aquifer system during 1959-1993, owing to an increase in groundwater extraction
Greater Los Angeles Metropolitan Area (Borchers and Carpenter 2014)		
Tectonic deformation, oil field operations, and groundwater extraction and injection occur in overlapping proximity; separate cases of subsidence have been attributed to groundwater pumping, oil extraction, and tectonic movement	—	Given the expansive infrastructure and population density in this region, the effects of land subsidence are potentially catastrophic; however, the rate of subsidence is presently not high enough to cause major concern
Mojave and Morongo Groundwater Basins (California Water Science Center 2018a)		
		Land subsidence has been ongoing in the dry lakebeds here since the 1960s
Yucaipa and Coachella Valleys (USGS 2018d)		
Primarily due to excessive groundwater pumping, as neither region has adequate surface water to support its domestic and non-domestic uses	As much as 50 feet between the early 1920s and the late 1940s before the importation of Colorado River water in 1949	
San Joaquin Valley (USGS 2018f)		
Over-pumping caused groundwater level declines and associated aquifer system compaction and land subsidence that resulted in permanent aquifer-system storage loss	By 1970, significant land subsidence (more than 1 foot) had occurred in about half of the San Joaquin Valley, or about 5,200 square miles, and locally some areas had subsided by as much as 28 feet	As the largest and most productive agricultural region in California, the San Joaquin Valley does not have sufficient surface water to support farming or domestic uses. Beginning around the 1920s, farmers relied upon groundwater for water supply.

18.2.1. Organic Soil Decomposition in the Sacramento-San Joaquin Delta

The Sacramento-San Joaquin Delta was once a great tidal freshwater marsh. It is blanketed by peat and peaty alluvium deposited where streams originating in the Sierra Nevada, Coast Ranges, and South Cascade Range enter San Francisco Bay. The dominant cause of land subsidence in the Delta is decomposition of organic carbon in the peat soils (see Figure 18-4). Under natural waterlogged conditions, the soil was anaerobic (oxygen-poor), and organic carbon accumulated faster than it could decompose. Drainage of peat soils for agriculture led to aerobic (oxygen-rich) conditions. Under aerobic conditions, microbial activity rapidly oxidizes the carbon in the peat soil. Most of the carbon loss from the soil occurs as a flux of carbon-dioxide gas to the atmosphere.

Figure 18-4. Land Subsidence Due to Decomposition of Organic Soils



Source: (USGS 2014)

18.2.2. Aquifer Compaction Due to Groundwater Pumping

Fine-grained sediments (clays and silts) in an aquifer system are the main causes of land subsidence due to groundwater pumping. Such sediments tend to be deposited in random orientations with a lot of room between them to store water. However, when groundwater levels fall, the sediments are rearranged into stacks that occupy less space and have less space between them to store water (USGS 2018).

Such compaction affects manmade infrastructure as well as natural systems. The greatest effects occur to infrastructure that crosses a subsiding area, such as water conveyance structures in the San Joaquin Valley. Many water conveyance structures, including long stretches of the California Aqueduct, are gravity driven with only very small gradients; even minor changes in these gradients can cause reductions in designed flow capacity.

Canal managers—such as DWR, the San Luis Delta-Mendota Authority, the Bureau of Reclamation, and the Central California Irrigation District—have to repeatedly retrofit the canals to keep the water flowing. Damage to roads, railways, bridges, pipelines, buildings, and wells also can occur.

18.3. PREVIOUS HAZARD OCCURRENCES

18.3.1. Disaster and Emergency Declarations

The following disaster declarations or emergency proclamations related to subsidence have been issued for California (see Appendix F for details):

- Federal DR or EM declaration, 1953 – 2022: none
- California Emergency Proclamations, 1950 – 2022: one event, classified as "sinkhole"
- USDA agricultural disaster declarations, 2012 – 2022: None

18.3.2. Event History

In California, large areas of land subsidence were first documented by USGS scientists in the first half of the 20th century. In 1976 the USGS identified peat loss as a leading cause of subsidence in the San Joaquin Delta. In 1988 the USGS identified oil extraction as a leading cause of subsidence in and around the Long Beach area of Los Angeles. However, most of this subsidence was a result of excessive groundwater pumping. The following are key findings regarding past land subsidence in California (additional historical information is provided in Table 18-1):

- More than 2,000 square miles in the Tulare Lake Hydrologic Region experienced subsidence of 0.25 foot (3 inches) to 3 feet, with a maximum rate of 1.5 feet per year.

- Nearly 900 square miles in the San Joaquin River Hydrologic Region experienced subsidence ranging from 0.25 foot (3 inches) to 2.25 feet, with a maximum rate of almost 1 foot per year.
- More than 20 square miles of the Sacramento River Hydrologic Region experienced subsidence ranging from 3 inches to 9 inches.

Operational- and drought-related reductions in surface water deliveries and an increase in crop acreage in areas with only groundwater supplies have resulted in increased groundwater pumping and associated groundwater level declines and land subsidence. For more information on drought impacts in the State, see Chapter 13. The completion of State and federal water projects helped some groundwater aquifers recover and decreased subsidence in some areas. However, subsidence continues today across the State (USGS 2022); (Thomas and Phoenix 1976).

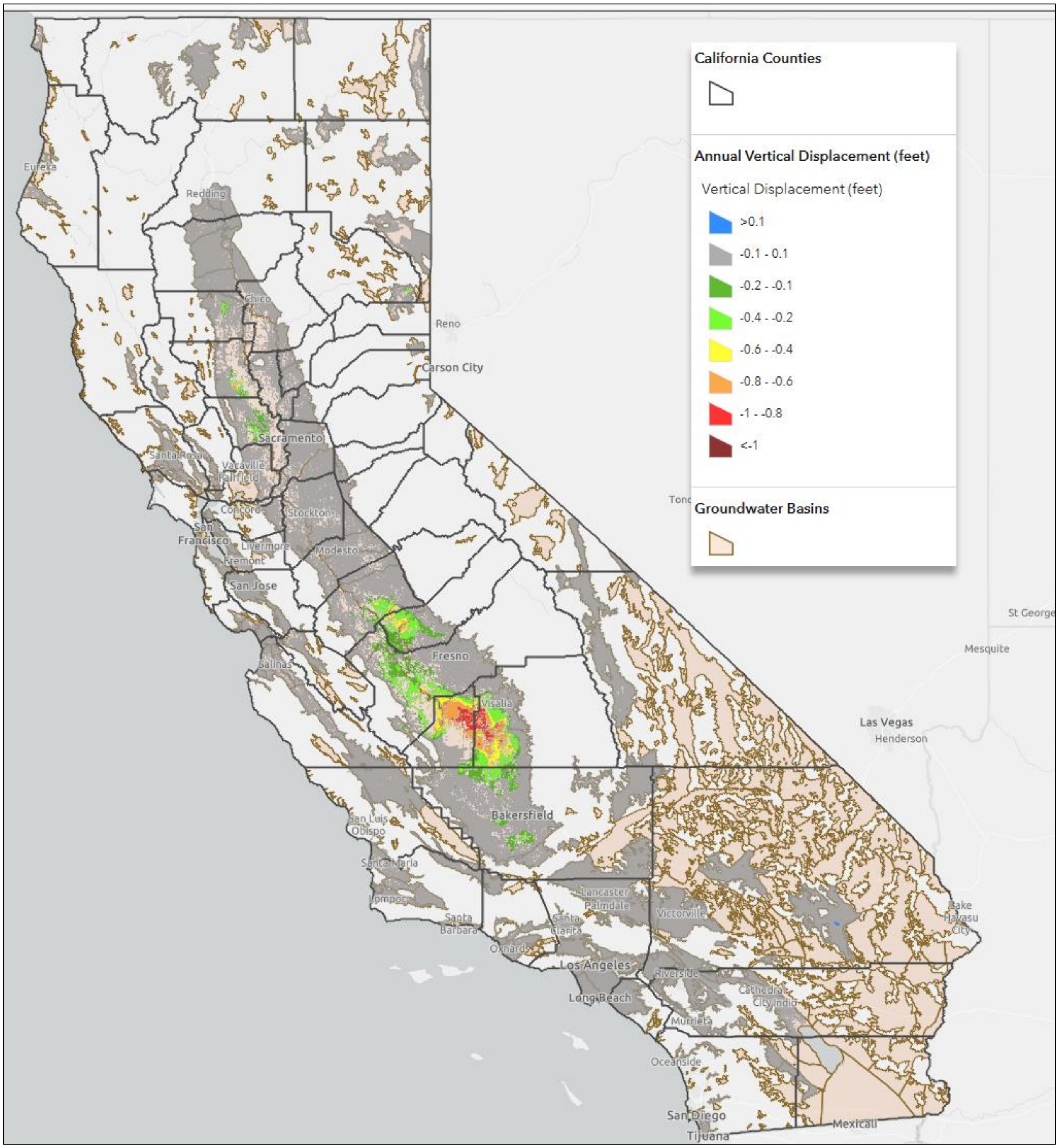
Portions of the Central Valley have been experiencing land subsidence at differing rates since the 1920s. Some areas are estimated to have subsided as much as 28 feet. From 2015 through 2018, which included the last two years of the most recent severe statewide drought (2012-2016), significant amounts of land subsidence occurred, primarily in the San Joaquin Valley. The statewide land subsidence from June 2015 through June 2018 is presented in Figure 18-5.

18.4. PROBABILITY OF FUTURE HAZARD EVENTS

18.4.1. Overall Probability

California’s land subsidence is tied to prolonged droughts and simultaneous record-breaking heat. When the State endures prolonged periods of drought, surface water stores are depleted, and the reliance on groundwater for water supply is increased. Given the frequency and duration of these types of events, it is reasonable to assume an increase in probability of subsidence events as well. Subsidence is a continuing hazard in California; therefore, the probability of occurrence is high. As more areas are developed, the strain on the aquifers can increase. This can lead to a higher probability of subsidence occurring in those areas.

Figure 18-5. Statewide Land Subsidence From October 2020 Through September 2021



Source: (DWR 2022d)

18.4.2. Climate Change Impacts

Changes in precipitation, reduced snowpack, and more frequent droughts are likely to increase the demand on groundwater sources, risking overdraft, ground subsidence, and decreased water quality.

A recent study found that a large part of the California coast is sinking due to ground subsidence, linked to extreme heat and prolonged droughts. Combined with rising sea levels, the fate of California's coastal regions is at risk. In addition to rising sea levels, California is experiencing vertical land motion—that is, the rising (uplift) and sinking (subsidence) of land. California's land subsidence is intrinsically tied to prolonged droughts and simultaneous record-breaking heat. To compensate for the lack of rainwater during the droughts, the region has been depleting local aquifers at alarming rates to sustain its $50 billion agricultural industries. So much water has been pumped out that the Central Valley region is sinking at rates of up to 25 centimeters per year. This combination of land subsidence and rising sea levels increases the relative sea-level rise, heightening the risk of coastal flooding, saltwater intrusion, infrastructure damage, and loss of wetland and biodiversity.

18.5. IMPACT ANALYSIS

18.5.1. Severity

The U.S. Geological Survey recognizes that in spite of projects moving water from wet parts of California to drier areas, the State still is not immune to "nearly historically high [subsidence] rates of more than 1 foot/year" (USGS 2022). As noted in Table 18-1, subsidence of up to 50 feet over a period of decades has been recorded in the Yucaipa and Coachella Valleys.

Subsidence has caused impacts on critical water infrastructure, including reduced conveyance capacity in local, State, and federal conveyance facilities, reduced levee heights, and damaged well casings (Borchers and Carpenter 2014). Throughout California, subsidence has damaged buildings, aqueducts, well casings, bridges, and highways.

Subsidence and the California Aqueduct

Subsidence along the California Aqueduct, the cornerstone of the State Water Project, has caused the canal to slump, putting reliable water delivery at risk. The damage has resulted in higher operational and power costs and increased water delivery outages and major repairs. The State Water Project has lost more than 20 percent of its capacity due to subsidence. The impacts of this subsidence are felt far beyond the Central Valley. The reduced capacity for conveyance can hinder climate change adaptation efforts that deliver and store water when conditions are wet.

(California Municipal Utilities Association 2021a)

18.5.2. Warning Time

Subsidence can occur slowly and continuously over time, or it can happen abruptly without warning.

18.5.3. Cascading Impacts

Cascading impacts are the impacts that result when one type of hazard event triggers one or more other hazard events, which may in turn trigger still others. The following are notable cascading impacts associated with subsidence:

- As the land sinks, it can experience increased flooding and adverse impacts on sewer lines and stormwater drainage (Water Education Foundation 2022a).
- As subsidence progresses, areas protected by levees are impacted. The levees in the Sacramento-San Joaquin Delta must be regularly maintained and periodically raised and strengthened to support the increasing stresses on them that result when the Delta islands subside.
- Compaction of the aquifer system may permanently decrease its capacity to store water.
- Subsidence can lead to damage to critical infrastructure and facilities.

18.5.4. Environmental Impacts

Subsidence can cause permanent inundation of land, increase flooding, change the topography of land, and reduce the capacity of aqueducts to store water (Holzer and Galloway 2005).

18.5.5. Local Hazard Impacts

LHMP Rankings

Four of the hazard mitigation plans prepared for California's 58 counties—San Luis Obispo, Santa Cruz, Tuolumne, and Yolo—list subsidence as a hazard of concern. Yolo County ranks it as a high-impact hazard; the others rank it low impact. In addition, some plans address subsidence under the title of "mass movements," which also includes landslide and debris flows.

LHMP Estimates of Potential Loss

Table 18-2 summarizes potential losses to vulnerable structures based on estimates from the local risk assessments (as called for in FEMA's Standard State Mitigation Planning Requirement S6.b). Due to variances in approaches to assessing risk at the local level as well as the hazards assessed and the age of each assessment reviewed, this data is considered approximate.

Table 18-2. Subsidence Risk Exposure Analysis for LHMP Reviews

Estimated Total Population Exposed	8,867,827
Estimated Number of Structures at Risk	20,000+
Estimated Value of Structures at Risk	< $4 billion

18.6. VULNERABILITY ANALYSIS

Based on the mapping shown in Figure 18-5, 17 of the State's 58 counties are susceptible to subsidence risk:

- Contra Costa
- Fresno
- Kern
- Kings
- Los Angeles
- Madera
- Merced
- Orange
- Riverside
- Sacramento
- San Joaquin
- San Luis Obispo
- San Mateo
- Santa Barbara
- Santa Clara
- Tulare
- Ventura

The vulnerability assessment focuses on these counties.

18.6.1. Exposure of State-Owned or -Leased Facilities

Table 18-3 and Table 18-4 summarize the State-owned assets located in the subsidence-susceptible counties. Appendix I provides detailed results by county.

Table 18-3. State-Owned or -Leased Facilities Exposed to Subsidence

Type of Facility	Number of Structures	Total Area (sq. ft.)	Replacement Cost Value		
			Structure	Content	Total
State-Owned Facilities	9,571	142,280,818	$11,151,339,008	$10,799,474,260	$21,950,813,268
State-Leased Facilities	1,142	N/A*	$7,033,990,440	$7,163,442,648	$14,197,433,088
Total Facilities	**10,713**	**N/A***	**$18,185,329,448**	**$17,962,916,908**	**$36,148,246,356**

* The inventory of State assets does not include building area for State-leased facilities, so no total area for all State facilities is provided; the building area of vulnerable assets is shown for State-owned facilities only.

Table 18-4. State-Owned or -Leased Infrastructure Exposed to the Subsidence Hazard

Type of Facility	State-Owned Infrastructure in the Mapped Hazard Area
Bridges	7,254
Highway (miles)	11,988
Dams	13
Water Project (miles)	0

The following are significant results of the analysis of State-owned assets in the subsidence susceptible counties:

- For facilities that the State owns within the subsidence-susceptible counties, the average building area is 14,866 square feet, with an average replacement cost value of $2.3 million (structure and contents).
- The average replacement cost value for State-leased facilities within the subsidence-susceptible counties is $12.4 million (structure and contents).

Transportation routes, including bridges and highways, are vulnerable to subsidence and have the potential to be wiped out, creating isolation issues. Those that are most vulnerable are those that are already in poor condition.

18.6.2. Exposure of Critical Facilities and Community Lifelines

Table 18-5 summaries the number of critical facilities, by community lifeline, located in the subsidence-susceptible counties. Appendix I provides detailed results by county. Critical facilities and community lifelines are likely to experience functional downtime associated with impacts from subsidence. This loss of function could be permanent based on it not being feasible to rebuild a damaged facility at a location due to the change in ground elevation. This would require relocation of these facilities, which could have cascading impacts on a region.

Table 18-5. Critical Facilities and Community Lifelines Exposure to Subsidence

Lifeline Category	Total Number of Facilities	Number of Facilities in Hazard Area	% of Total Facilities
Communications	42	36	85.7%
Energy	176	117	66.5%
Food, Water, Shelter	257	151	58.8%
Hazardous Material	56	37	66.1%
Health & Medical	47	28	59.6%
Safety & Security	46	28	60.9%
Transportation	131	65	49.6%
Total	**755**	**462**	**61.2%**

18.6.3. Estimates of Loss

Although subsidence can cause significant damage to State assets, there are no standard generic formulas for estimating associated losses. Instead, loss estimates were developed representing 10 percent, 30 percent, and 50 percent of the replacement cost value of all State-owned facilities in the subsidence-susceptible counties (see Table 18-6). This allows the State to select a range of potential economic impacts based on an estimate of the percentage of damage to these assets. Damage in excess of 50 percent is considered to be substantial by most building codes and typically requires total reconstruction of the structure.

Table 18-6. Estimates of Loss From Subsidence

Asset	10% Damage	30% Damage	50% Damage
State-Owned Assets	$2,195,081,327	6,585,243,981	$10,975,406,634
State-Leased Assets	$1,243,208	$3,729,623	$6,216,039
Total	**$2,196,324,535.00**	**$6,588,973,604.00**	**$10,981,622,673.00**

18.6.4. Buildable Land

An estimated 11.7 million acres of land is available for development in California. Any development of subsidence-susceptible areas will be susceptible to damage and impacts from such events.

18.6.5. Equity Priority Communities

The risk analysis for subsidence found that 32.9 percent of people in the subsidence-susceptible counties live in equity priority communities (8,867,827 people). A breakdown of exposed equity priority communities by county is included in Appendix I. Additionally, subsidence may impact the availability of safe drinking water in low-income communities and communities of color.

18.6.6. NRI Scores

The National Risk Index does not provide rankings for the subsidence hazard.

18.7. MITIGATING THE HAZARD

18.7.1. Existing Measures to Mitigate the Hazard

There have been significant improvements in the State's subsidence monitoring network, most notably in the processing and reporting of satellite-based Interferometric Synthetic Aperture Radar, or InSAR, data, which now provides monthly subsidence data for more than 160 groundwater basins.

18.7.2. Opportunities for Mitigating the Hazard

A range of potential opportunities for mitigating the subsidence hazard is provided in Table 18-7. See Section 1.2.3 for a description of the different types of alternatives.

Table 18-7. Potential Opportunities to Mitigate the Subsidence Hazard

Community-Scale	Organizational Scale	Government-Scale
Manipulate the hazard: Reduce reliance on groundwater ▪ Practice groundwater recharge techniques **Reduce exposure and vulnerability** ▪ Relocate vulnerable property ▪ Harden vulnerable assets **Build local capacity** ▪ Learn and understand the Risk ▪ Practice water conservation ▪ Carry out regular inspections of your property, paying particular attention to pipework, gutters, and drainage systems in case of leaks or blocks. ▪ Maintain trees close to your home as they can contribute to causes for subsidence	**Manipulate the hazard:** ▪ Reduce reliance on groundwater ▪ Practice groundwater recharge techniques ▪ Deploy onsite detention of stormwater runoff **Reduce exposure and vulnerability** ▪ Relocate vulnerable property ▪ Harden vulnerable assets **Build local capacity** ▪ Learn and understand the risk ▪ Enhance monitoring capability ▪ Understand your soil type ▪ Practice water conservation	**Manipulate the hazard:** ▪ Reduce reliance on groundwater ▪ Groundwater injection ▪ Increase surface water storage capacity **Reduce exposure and vulnerability** ▪ Acquire vulnerable property ▪ Harden vulnerable assets **Build local capacity** ▪ Communicate the risk ▪ Enhance Monitoring Capability ▪ Identify vulnerable soil types in areas of high groundwater extraction ▪ Promote water conservation
Nature-based opportunities ▪ Take steps to facilitate the recharge of groundwater, which can mitigate impacts from subsidence ▪ Use green infrastructure measures in regions known to be susceptible to subsidence		

18.7.3. Selected Actions to Mitigate the Hazard

The mitigation strategy developed for this SHMP includes the following actions that address subsidence:

- Action 2018-001: Support Legislative Efforts that Formalize California's Comprehensive Mitigation Program.
- Action 2018-006: Enhance Collaboration on the Development and Sharing of Data Systems and GIS Modeling.
- Action 2018-008: Develop a database containing a description of the specific natural hazard event for which each project was designed to mitigate.

VOLCANO

Climate Impacts:
Volcanic events may impact climate change, climate change is not known to increase the probability of volcanic events

Equity Impacts:
11.5% of exposed population (those living in volcanic hazard areas) identified as living in equity priority communities

State Facilities Exposed:
1,079 State facilities in the volcanic hazard area; $499.7 million in total replacement cost value for facilities in the volcanic hazard area

Community Lifelines Exposed:
37 community lifelines in the volcanic hazard area

Impact Rating: Low (10)

19. VOLCANO

Volcano has been identified as a low-impact natural hazard of interest based on the hazard impact rating protocol applied for this SHMP. These events happen infrequently and predominantly in the northern part of the State where the Cascade Mountain range terminates. Less than 5 percent of State-owned or -leased facilities and community lifelines are exposed to this hazard. Less than 1 percent of the population resides in counties considered to be susceptible to volcanoes; and 11.5 percent of that population has been identified as living in equity priority communities. Less than 1 percent of buildable land in the State is in counties considered to be susceptible to this hazard. The frequency and severity of volcano events is not anticipated to be impacted by climate change.

19.1. HAZARD OVERVIEW

Many of California's volcanoes pose a threat to people and property. A new effort to identify, prepare for, and mitigate volcanic hazards within California is underway. Cal OES, the USGS California Volcano Observatory, and CGS are working to produce the first statewide assessment of California's exposure and vulnerability to future volcanic hazards (Ewert, Kiefenbach and Ramsey 2018).

19.1.1. Types of Volcanoes

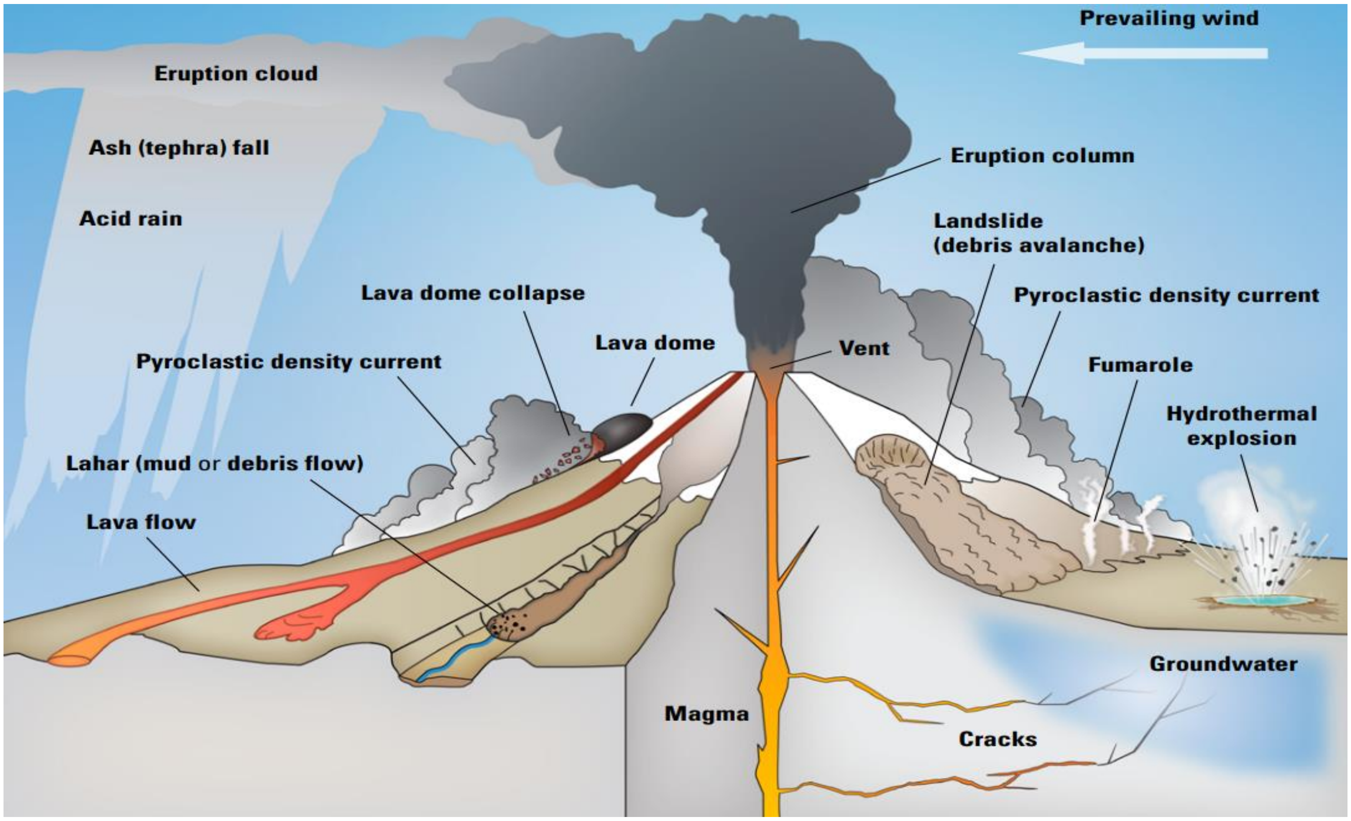
Caldera Systems

Caldera systems are large volcanic centers usually characterized by a massive central crater, like at Long Valley. Calderas are formed when a volcano erupts, and its walls collapse inward. A volcanic caldera can be more than 60 miles in diameter (National Geographic 2023).

Stratovolcanoes

Stratovolcanoes (Figure 19-1) are tall, cone-shaped, volcanoes that tend to erupt explosively. Magma (underground molten rock) rises from deep below the volcano, and explosive eruptions blast volcanic debris into the sky, forming an eruption column and cloud.

Figure 19-1. Stratovolcano Hazard Components



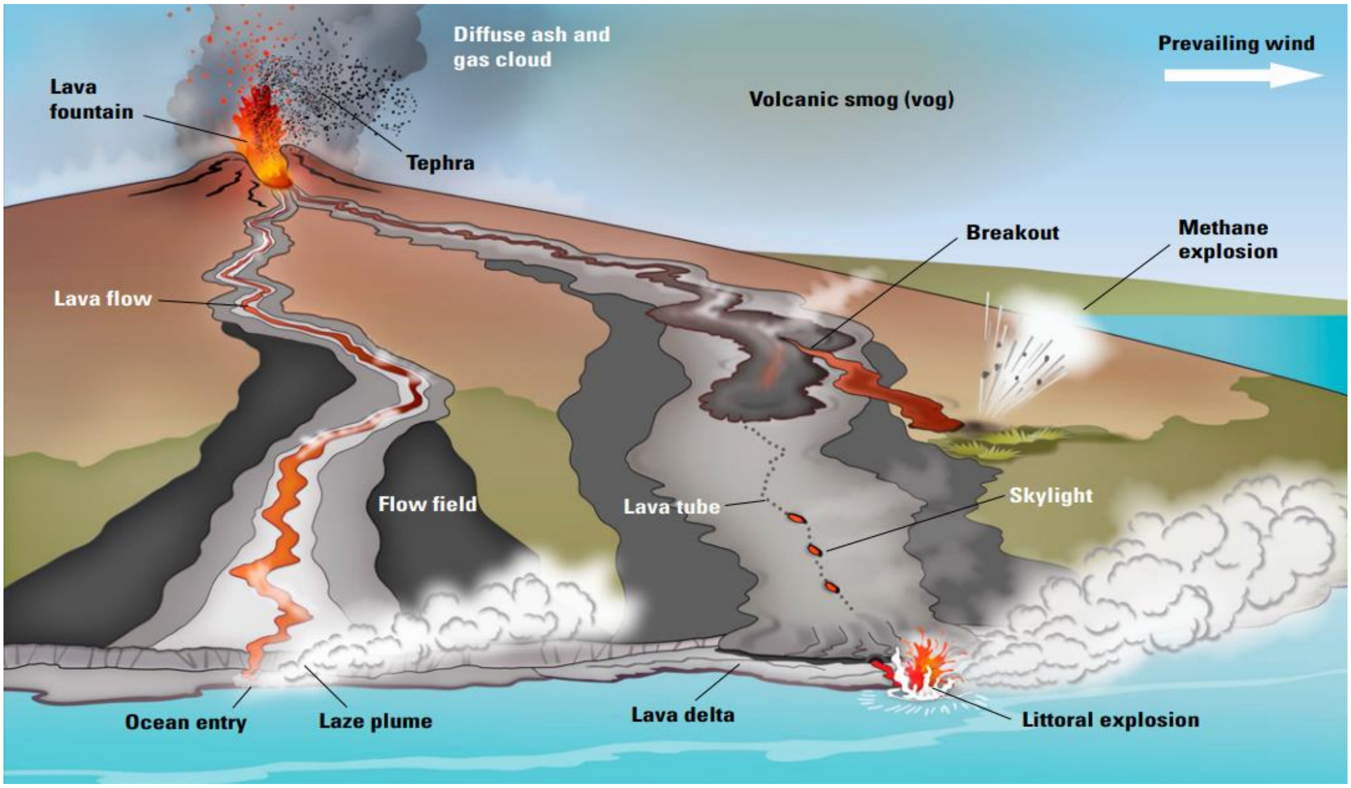
Source: (USGS 2019c)

Ash in the eruption cloud, carried by the prevailing winds, may remain suspended for thousands of miles before settling to the ground (USGS 2019c). Lava flows move downslope or form lava domes at the erupting vent. Eruption columns, lava flows, or lava domes collapse, creating hot currents that can melt snow and ice or enter rivers.

Shield Volcanoes

Shield volcanoes (Figure 19-2) have a broad, shield shape and tend to erupt lava that can travel many miles; violent explosive eruptions are also possible. Most eruptions begin as a vertical sheet of rising magma that discharges from groups of vents that can extend for miles. Low lava fountains jet skyward, and fragments cool as they fall.

Figure 19-2. Shield Volcano and Lava Field Components



Source: (EarthHow 2023)

Lava can pour from a vent for months or years to form a lava flow field that can feed breakouts of new lava flows. Lava entering a body of water creates new, unstable land called a lava delta that can explosively collapse into the water. Lava entering cold water typically causes explosions of hot water and acidic clouds of gas, steam, and volcanic glass (USGS 2019c).

During and after an eruption, loose volcanic debris on the flanks of the volcano can be mobilized by heavy rainfall or melting snow and ice, forming floods of mud and rock resembling rivers of wet concrete. These can rush down valleys and stream channels, destroying roads and bridges and carrying away entire buildings. Flooding can also occur due to melting of ice and snow or by diversion of streams blocked by debris.

"California is the most geologically diverse state in the nation. We are known for our earthquakes, landslides, and flood hazards. But a nearly forgotten hazard is our volcanoes."

John Parrish, State Geologist of California, February 9, 2012 (SSC 2022)

19.1.2. Common Impacts of Volcanoes

Table 19-1 describes the common characteristics and impacts of volcanoes in California.

Table 19-1. Characteristics and Potential Impacts of California Volcano Hazards

Characteristics	Impact
Pyroclastic Flow	
Sudden eruption of hot gas-pressurized flows of ash and lava fragments that rush outward from the volcano with great force at ground speeds greater than 50 mph. Typically follow valleys but can overtop ridges and travel 30 miles or more from the volcano.	Pyroclastic flows travel much too fast for people to outrun and are thus a main cause of eruption-related fatalities. Flows knock down, shatter, bury, or carry away nearly all objects and structures. Extreme temperatures burn forests, crops, buildings, furnishings, and vehicles.
Lava Flow	
Gradual inundation by lava from sustained low-level eruptions moving at speeds of less than 30 mph. Lava may pile up near the vent in a lava dome or move across the landscape for many miles as rivers of molten rock.	Everything in the path of slow speed lava flows will be knocked down, buried, or burned. The flows generally travel slowly enough that people, possessions, and transportable infrastructure can be moved out of the way. The flows often ignite wildfires, and areas inundated by flows can be buried by 10 feet or more of hardened rock, making it impossible to rebuild or repair structures.
Debris Flows	
Slurry-like floods of volcanic ash, rock, and water that look like wet concrete. Large flows may carry boulders 30 feet across and travel through valleys and stream channels at speeds of 20 to 40 mph. Flows can be hot, with temperatures close to boiling.	Most debris flows travel much too fast for people to outrun and are thus a main cause of eruption-related fatalities. Debris flows can destroy buildings and bridges and bury vast areas with deposits of mud and rock up to 160 feet thick as far as 65 miles from the volcano.
Lahar Flows	
Eruptions may trigger lahars by melting snow and ice or by ejecting water from a crater lake. Pyroclastic flows can generate lahars when extremely hot, flowing rock debris erodes, mixes with, and melts snow and ice as it travels rapidly down steep slopes.	Large lahars can crush, abrade, bury, or carry away almost anything in their paths. Buildings and valuable land may be partially or completely buried. By destroying bridges and roads, lahars can also trap people in areas vulnerable to other hazardous volcanic activity, especially if the lahars leave fresh deposits that are too deep, too soft, or too hot to cross.
Ballistics	
Ballistic ejection of coarse, hot fragments of lava from the volcanic vent, usually softball size or smaller.	The impact of coarse air fall is limited to the immediate area of the volcanic vent. Structures may be damaged by accumulation of falling lava

Characteristics	Impact
	fragments or burnt by their high heat. Wildfires may be ignited.
Ash Fall	
Fine fragments of lava—sand size and smaller—deposited from drifting ash clouds. Impact zone may be hundreds of miles from the volcano.	Fine ash fall is the most widespread and disruptive volcanic hazard. People exposed to fine ash experience eye, nose, and throat symptoms. Ash covers surfaces and infiltrates openings in machinery, buildings, and electronics. It can reduce visibility to zero. When wet, it can make paved surfaces slippery. Fine ash is abrasive, damaging surfaces and mechanical parts. Ash may result in short-term physical and chemical changes in water quality. Close to the volcano, heavy ash fall may cause roofs to collapse, wastewater systems to clog, and power systems to shut down. Fine ash can damage crops and sicken livestock.
Floods	
Sudden melting of snow or ice by volcanic heat, or diversion of water by blocked drainages or breached embankments.	Impacts are similar those of non-volcanic floods, but the onset is usually sudden.
Volcanic Gas	
Large eruptions can release enormous amounts of gas in a short time.	Significant amounts of carbon dioxide, sulfur dioxide, hydrogen sulfide and hydrogen halides can also be emitted from volcanoes. Depending on their concentrations, these gases are all potentially hazardous to people, animals, agriculture, and property.

Source: (Cal OES 2018a)

19.2. HAZARD LOCATION

Table 19-2 lists potentially hazardous volcanoes in California as identified by the USGS.

Table 19-2. Potentially Hazardous Volcanoes in California

County	Volcano
Imperial	Salton Buttes
Inyo	Coso Volcanic Field Ubehebe Crater
Lake	Clear Lake Volcanic Field
Madera	Mammoth Mountain

County	Volcano
Mono	Long Valley Caldera Mono-Inyo Craters Mono Lake Volcanic Field Mammoth Mountain
Shasta	Lassen Volcanic Center
Siskiyou	Mount Shasta Medicine Lake
Tulare	One other young volcano in California, with lower threat ranking, is identified in the 2018 USGS report: Golden Trout Creek Volcanic Field.

Source: (Ewert, Kiefenbach and Ramsey 2018)

Figure 19-3 and Figure 19-4 show the volcanoes by threat ranking and eruption hazard. The threat rankings are derived from a combination of factors:

- Age of the volcano
- Potential hazards (the destructive natural phenomena produced by a volcano)
- Exposure (people and property at risk from the hazards)
- Current level of monitoring (real-time sensors in place to detect volcanic unrest)

Threat rankings are periodically re-evaluated and revised, if necessary, as ongoing research provides new information on potential hazards or exposure is altered by changes in population and regional aviation (Ewert, Kiefenbach and Ramsey 2018).

19.3. PREVIOUS HAZARD OCCURRENCES

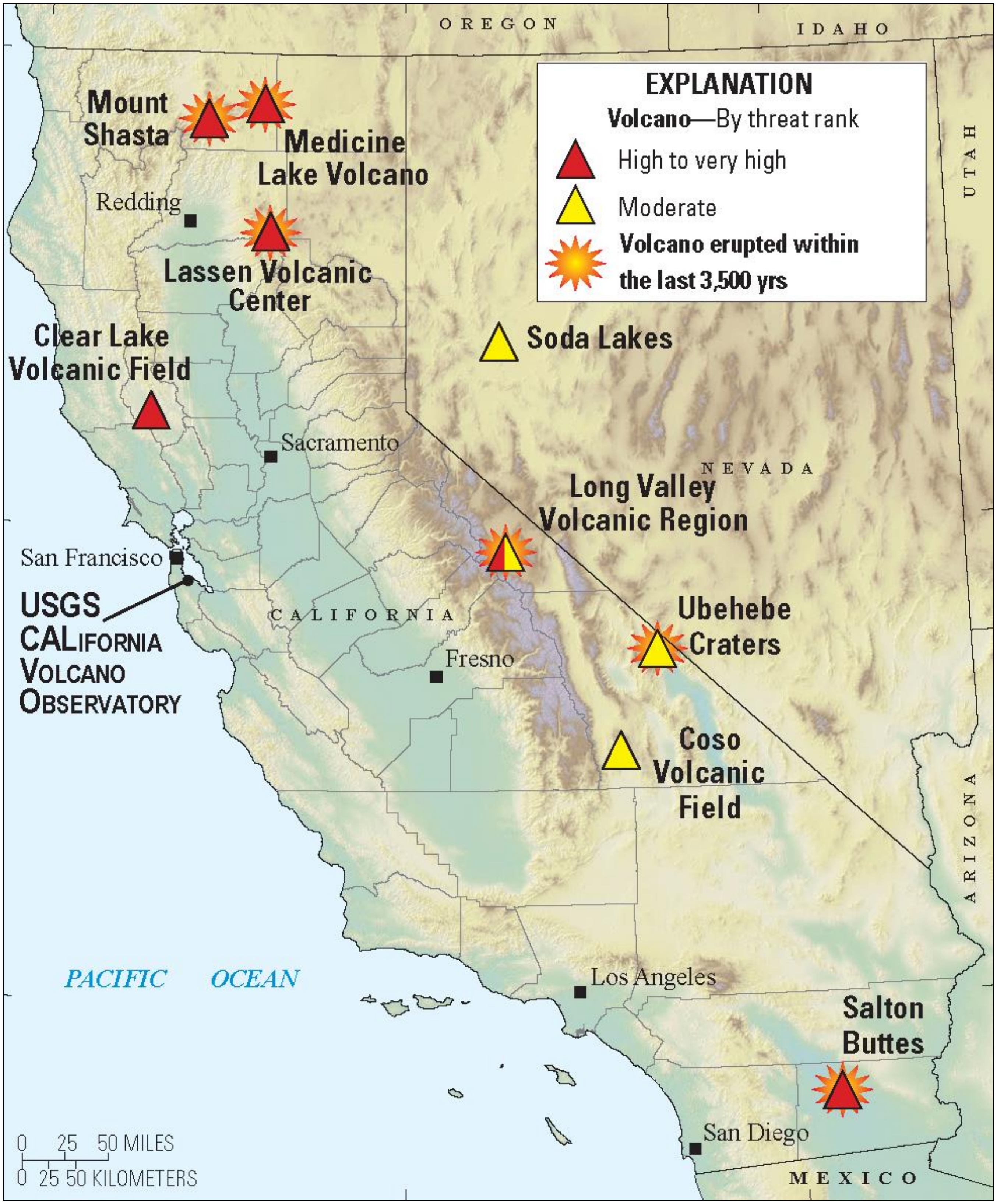
19.3.1. Disaster and Emergency Declarations

No FEMA, USDA, or State disaster declarations or proclamations related to volcano have been issued relevant to California or any of its counties.

19.3.2. Event History

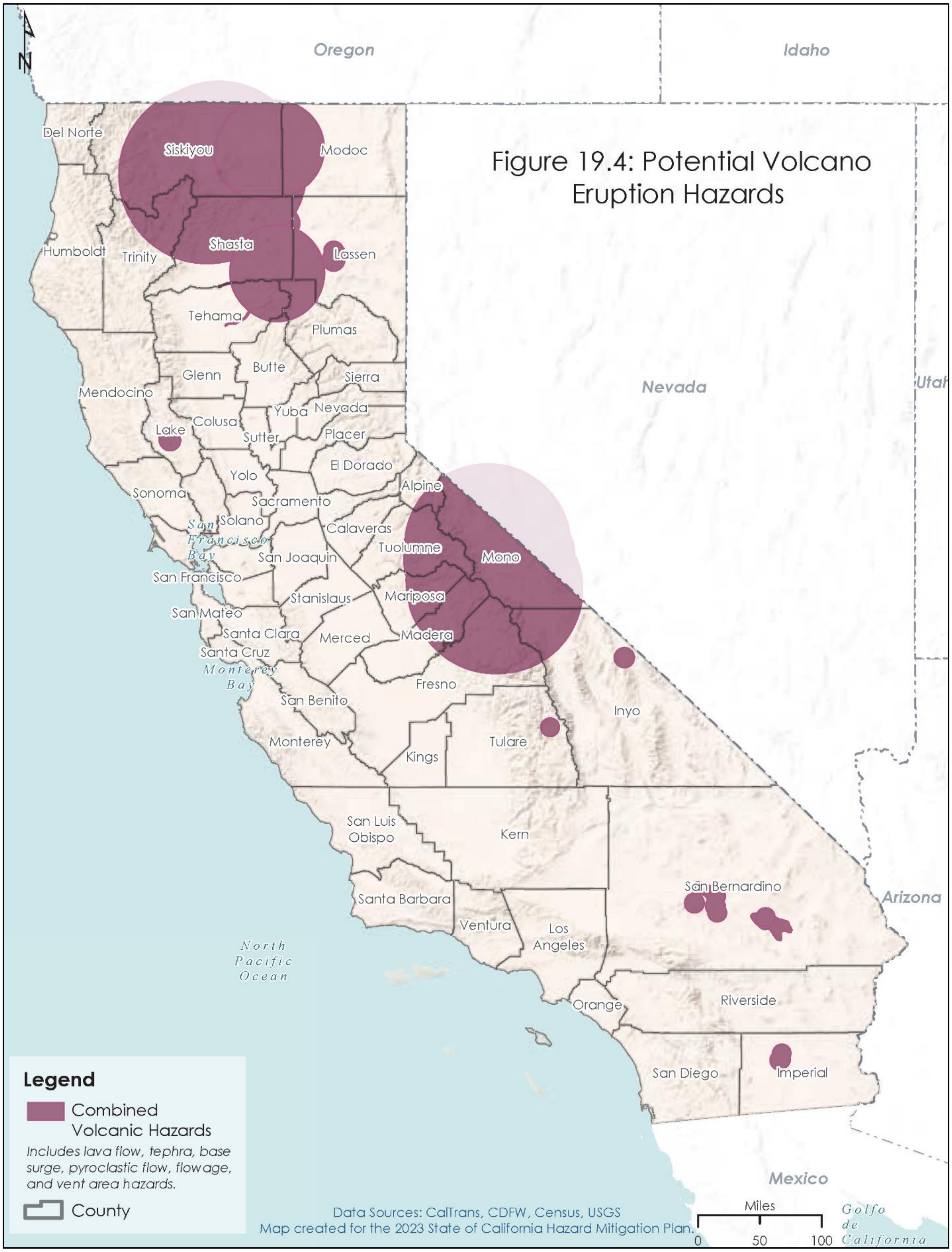
California is susceptible to volcanic-related events, though they are infrequent. At least 76 volcanic vents have erupted, some repeatedly, during the last 10,000 years (SSC 2022).

Figure 19-3. Potentially Hazardous Volcanoes in California



Source: (USGS 2022a)

Figure 19-4. Potential Volcano Eruption Hazards



Only one volcanic eruption is on record—the eruption of Mount Lassen from 1914 through 1917. The first steam explosion occurred in May 1914 and more than 180 subsequent steam explosions enlarged the crater over the next 11 months. By May 2015, a lava dome filled the crater and exploded. The hot lava blocks caused a giant mudflow of volcanic materials. Residents suffered minor injuries, and many fish in the waterways were killed by the muddy water. A powerful explosion on May 22, 1915, resulted in a pyroclastic flow that devastated 3 square miles. A layer of pumice and volcanic ash spread for 25 miles to the northeast. Vigorous steam explosions occurred in May 1917 (USGS n.d.-c).

19.4. PROBABILITY OF FUTURE HAZARD EVENTS

19.4.1. Overall Probability

At least seven California volcanoes—Medicine Lake Volcano, Mount Shasta, Lassen Volcanic Center, Clear Lake Volcanic Field, Long Valley Volcanic Region, Coso Volcanic Field, and Salton Buttes—have partially molten rock (magma) deep within their roots, and research on past eruptions indicates they will erupt again in the future (Mangan, et al. 2019).

Based on the record of volcanic activity over the last five millennia, the probability of another small- to moderate sized eruption in California in the next 30 years is estimated to be about 16 percent (USGS 2019). This is similar to the forecast for a magnitude 6.7 or greater earthquake specific to the San Andreas Fault in the San Francisco Bay region, which is estimated to be about a 22 percent probability in 30 years, starting from 2014.

Volcanic eruptions occur in the State about as frequently as the largest San Andreas Fault Zone earthquakes; at least 10 eruptions have occurred in California in the last 1,000 years and only one has occurred since 1917 (Mangan, et al. 2019). The probability in any given year of renewed volcanism in the State is on the order of one in a few hundred to one in a few thousand.

19.4.2. Climate Change Impacts

Climate change is not expected to increase the probability of volcanic events. However, when volcanic eruption does occur, climate change could impact the consequences of volcanic events. As the atmosphere warms due to climate change, the plumes of ash and gas emitted by large volcanic eruptions will rise higher. Climate change will also accelerate the transport of volcanic material—in the form of small, shiny droplets called volcanic sulfate aerosols—from the tropics to higher latitudes. For large eruptions, the combined effect of these phenomena will cause the haze created by volcanic aerosols to block more sunlight from reaching Earth's surface, ultimately amplifying the temporary cooling caused by volcanic eruptions (University of Cambridge 2021).

19.5. IMPACT ANALYSIS

19.5.1. Severity

Low-energy eruptions are destructive, but generally not life threatening. High-energy explosive eruptions are both destructive and life threatening. Volcanic areas can be hazardous even when the volcano is not erupting, with unstable ground, noxious gas emissions, intense heat, and steaming ground (USGS 2019c).

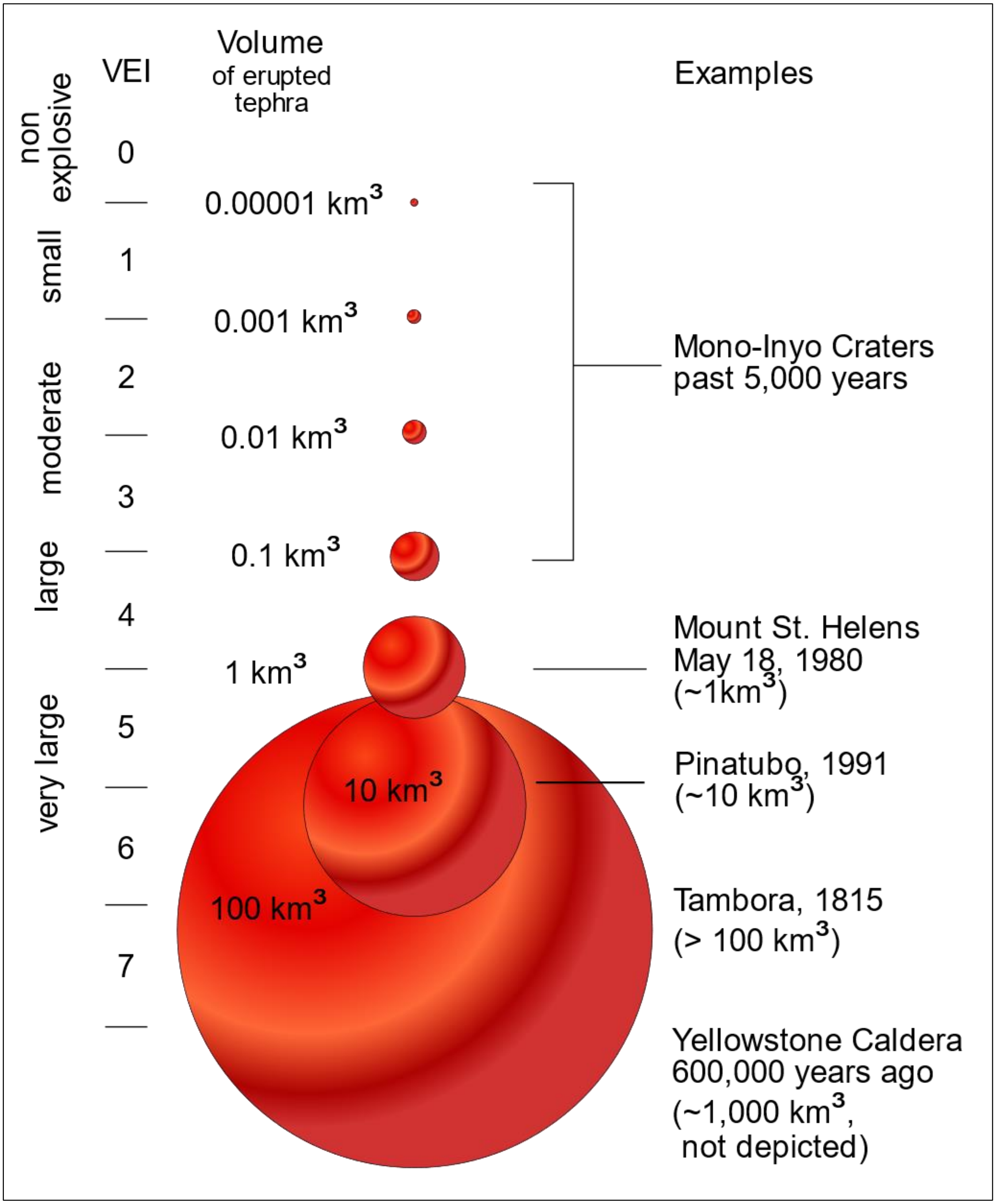
Timely warnings reduce the risk of fatalities, but depending on hazard type, destruction and disruptions to the community can extend many miles from the volcano. In addition, some post eruption hazards—rain remobilized debris flows, re-suspended ash, and seeping volcanic gas—may disrupt human activities or cause annoyances for years, even decades after an eruption has stopped (USGS 2019c).

The volcanic explosivity index is a measure of the explosiveness of volcanic eruptions, based on volume of product, eruption cloud height, and qualitative observations (using terms ranging from "gentle" to "mega-colossal"). A value of zero is given for non-explosive eruptions, defined as less than 350,000 cubic feet of tephra ejected; and a value of 8 represents a mega-colossal eruption that can eject 240 cubic miles of tephra and have a cloud column height of over 66,000 feet. The scale is logarithmic, with each interval representing a tenfold increase in observed criteria. Figure 19-5 shows the volcanic explosivity index and product volume correlation.

19.5.2. Warning Time

Eruption hazards are most severe within a few miles of the vent, with life-threatening or highly destructive phenomena evolving rapidly, often within seconds to minutes, leaving little time to mount evasive actions. The time available to issue warnings increases as distance from the vent increases.

Figure 19-5. Volcanic Explosivity Index and Product Volume Correlation



Source: (USGS 2022e)

Seismic activity beneath the volcanic area is an important warning sign of an impending volcanic eruption. Seismologists can interpret differences between earthquakes related to the rise of magma and those caused by tectonic faulting. Other warning signs of magma rising into the shallow subsurface might include increased release of volcanic gases from openings and changes in the gas composition. Deformation of the ground surface in the vicinity of a volcano may also indicate that magma is approaching the surface. Typically, these warning signs appear a few weeks to months before an eruption, but they can last for decades or even centuries without leading to an eruption (USGS 2005).

19.5.3. Cascading Impacts

Cascading impacts are the impacts that result when one type of hazard event triggers one or more other hazard events, which may in turn trigger still others. The following are notable cascading impacts associated with volcanoes:

- Mudflows, floods, landslides, and possibly seismic activity can occur in the region of the eruption.
- Tephra can damage vegetation by direct burial, heat, or breakage.
- Tephra modifies hydrology and lowers air quality, affecting human health both directly—through inhalation or the abrasion of skin and eyes—and indirectly—through impacts on terrestrial and aquatic environments.
- Post-eruptive processes extend the area of influence of a volcanic eruption some distance from the initial deposition area and can last for years.
- Volcanic eruptions can substantially disrupt hydrologic systems, most notably by altering stream flow and choking waterways with ash and volcanic debris.
- Volcanic events can severely impact ground transportation on roads and railways, disrupting daily activities, commerce, and response capabilities.
- Exposure of crops, pastures, and livestock to volcanic ash fall can be serious, even for a light dusting. Ash falls on forage most commonly results in digestive tract problems in livestock, including gastrointestinal tract obstruction, and it is common for dairy production to drop significantly owing to cows off feed.
- Volcanic eruptions can result in heightened health concerns, including infectious disease, respiratory illness, burns, injuries from falls, and motor vehicle crashes related to poor visibility.

19.5.4. Environmental Impacts

The environment is highly exposed to the effects of a volcanic eruption, including deterioration of water quality, fewer periods of rain, crop damages, and the destruction of vegetation (Zuskin, et al. 2007).

19.5.5. Local Hazard Impacts

LHMP Rankings

Eighteen of the hazard mitigation plans prepared for California's 58 counties list volcano as a hazard of concern, and five counties rank it as a high-impact hazard:

- Colusa
- Lake
- Yolo
- Imperial
- Modoc

An additional five counties identified volcano as a medium-impact hazard.

LHMP Estimates of Potential Loss

A review of the LHMPs in the counties (as called for in FEMA's Standard State Mitigation Planning Requirement S6.b) found no quantitative risk analysis that identifies population or structures exposed to this hazard. This can be attributed to the lack of extent and location hazard mapping to use for such an analysis. Therefore, no summary of risk for local plan reviews is provided for this hazard.

19.6. VULNERABILITY ANALYSIS

19.6.1. Exposure of State-Owned or -Leased Facilities

Table 19-3 and Table 19-4 summarize State-owned or -leased assets within the volcanic hazard zone shown in Figure 19-4. Figure 19-6 summarizes the exposed assets as a percentage of total assets statewide. Appendix I provides detailed results by county.

Table 19-3. State-Owned or -Leased Facilities Exposed to the Volcanic Hazard

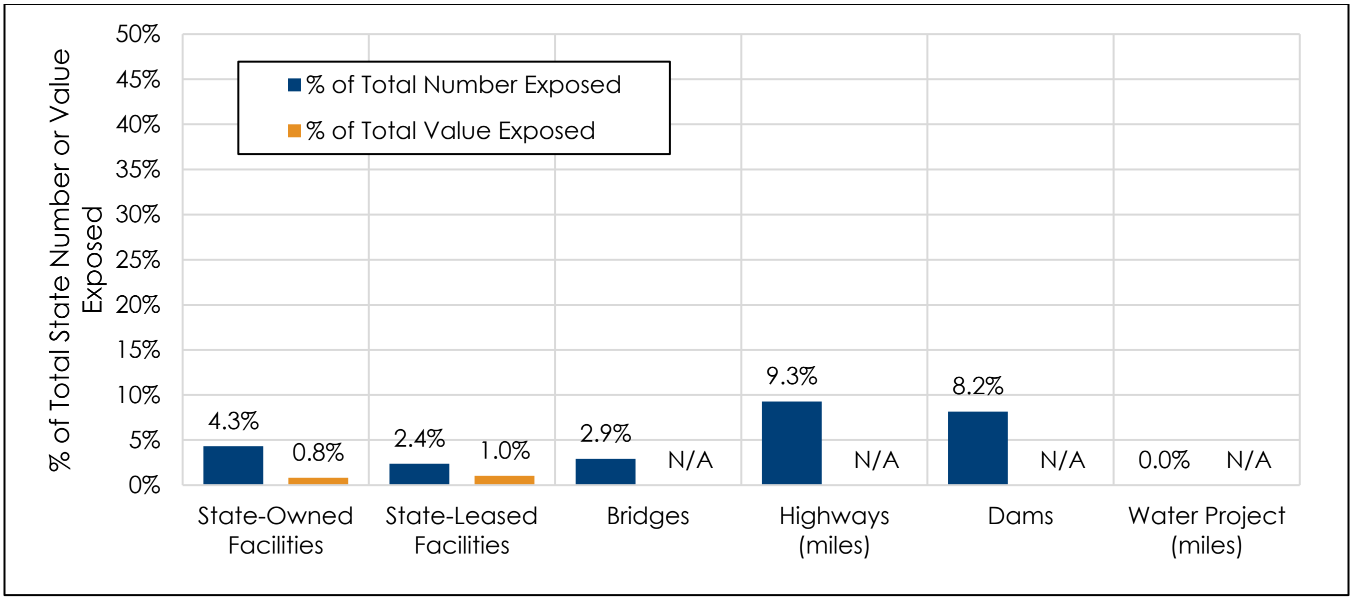
Type of Facility	Number of Structures	Total Area (sq. ft.)	Replacement Cost Value		
			Structure	Content	Total
State-Leased Facilities	45	—	$85,656,022	$109,681,124	$195,337,146
State-Owned Facilities					
Facilities Housing Vulnerable Populations					
Correctional Facility	0	0	$0	$0	$0
Development Center	0	0	$0	$0	$0
Hospital	0	0	$0	$0	$0
Migrant Center	2	77,750	$9,914,238	$4,957,119	$14,871,357
Special School	0	0	$0	$0	$0
All Other Facilities	1,032	1,951,261	$148,144,003	$141,361,842	$289,505,844
Total State-Owned	***1,034***	***2,029,011***	***$158,058,241***	***$146,318,961***	***$304,377,202***
Total Facilities	***1,079***	**N/A***	***$243,714,263***	***$256,000,085***	***$499,714,348***

* The inventory of State assets does not include building area for State-leased facilities, so no total area for all State facilities is provided; the building area of vulnerable assets is shown for State-owned facilities only.

Table 19-4. State-Owned or -Leased Infrastructure Exposed to the Volcanic Hazard

Type of Facility	State-Owned Infrastructure in the Mapped Hazard Area
Bridges	384
Highway (miles)	2,794.9
Dams	4
Water Project (miles)	0

Figure 19-6. State Assets Exposed to Volcanic Hazards as % of Statewide Total



The following are noteworthy statistics on State-owned or -leased facilities in the volcanic hazard areas:

- For facilities that the State owns within the volcanic hazard area, the average building area is 1,962 square feet, with an average replacement cost value of $294,369.
- The five State agencies with the most State-owned facilities within the volcanic hazard area are State Parks (274), Caltrans (227), CDFW (207), CAL FIRE (198), and the District Agriculture Associations (108).
- The State agency with the highest total replacement cost for State-owned or -leased facilities within the volcanic hazard area is Caltrans at $88.3 million.

19.6.2. Exposure of Critical Facilities and Community Lifelines

Table 19-5 summarizes the total number of critical facilities, by community lifeline, located in the volcano hazard areas statewide. The county with the largest percentage of these facilities is Mono (29.7 percent) followed by Shasta and Siskiyou (18.9 percent each). Appendix I provides detailed results by county.

Table 19-5. Critical Facilities and Community Lifelines Exposure to Volcano Hazard Areas

Lifeline Category	Total Number of Facilities	Number of Facilities in Hazard Area	% of Total Facilities
Communications	42	0	0.0%
Energy	176	21	11.9%
Food, Water, Shelter	257	14	5.4%
Hazardous Material	56	0	0.0%
Health & Medical	47	0	0.0%
Safety & Security	46	0	0.0%
Transportation	131	2	1.5%
Total	**755**	**37**	**4.9%**

Critical facilities and community lifelines that are exposed to volcano are likely to experience functional downtime following these events, which could increase the net impact of these events in a region.

19.6.3. Estimates of Loss

As shown in Table 19-3, the analysis conducted for volcanic events identified 1,034 State-owned buildings and 45 State-leased buildings in the volcanic hazard area with a replacement cost value of $499.7 million. In addition to impacting State assets, volcanic events can have major economic impacts on a community from the loss of and damage to structures and subsequent economic losses.

19.6.4. Buildable Land

Throughout the State, there are over 11.7 million acres of land available for development. Of that, 9.5 percent (1.1 million acres) is within the volcanic hazard area. Any type of development in these areas will be susceptible to damages associated with volcanic hazards.

19.6.5. Equity Priority Communities

The communities and populations especially vulnerable to volcanic eruptions include low-income communities, migrant populations, populations whose primarily language is not English, Indigenous populations, communities of older adults, and those with respiratory and other health concerns. These populations may be more susceptible to transport and communication challenges.

Vulnerable populations may also be impacted by the effects of toxic volcanic ash and problems of the respiratory system, eyes, and skin. Psychological effects, injuries, waste disposal and water supplies issues, collapse of buildings and power outage are all likely to impact vulnerable populations (Zuskin, et al. 2007).

The risk analysis for volcano found that 11.5 percent of people exposed to the volcano hazard live in equity priority communities (24,595 people). A breakdown of exposed equity priority communities by county is included in Appendix I.

19.6.6. NRI Scores

According to the NRI, 16 of the State's counties have volcano risk, rated from very low to relatively high. Table 19-6 shows scores for the six counties with the highest rating. See Section 4.1.3 for a description of the components of the NRI.

Table 19-6. NRI Scoring of Counties for Volcano

County	Expected Annual Loss	Social Vulnerability Rating	Community Resilience Rating	Community Risk Factor	Risk Value	Score
Shasta	$3,913,963	Relatively High	Relatively Moderate	1.26	$5,031,894	87.64
Siskiyou	$1,146,556	Relatively High	Relatively Moderate	1.39	$1,534,741	78.65
Butte	$857,541	Very High	Relatively High	1.25	$1,075,947	71.91
Tehama	$360,874	Very High	Relatively Low	1.52	$537,733	67.42
Trinity	$181,623	Very High	Relatively Low	1.45	$270,985	64.04
Lassen	$192,884	Relatively High	Relatively Moderate	1.14	$221,510	60.67

19.7. MITIGATING THE HAZARD

19.7.1. Existing Measures to Mitigate the Hazard

The USGS California Volcano Observatory obtains and interprets data from real-time monitoring sensors installed on California's very high, high, and moderate threat volcanoes, although network coverage is minimal at some locations (USGS n.d.). Information is relayed to emergency response agencies and the public. The Volcano Notification Service is a free service that sends notification emails about volcanic activity to subscribers (USGS n.d.-b). Volcano monitoring networks and warning systems can save lives and reduce property losses.

19.7.2. Opportunities for Mitigating the Hazard

Volcanic events cannot be prevented, but there are mitigation measures the State can implement to reduce their severity. A range of potential opportunities to mitigate the volcano hazard is provided in Table 19-7. See Section 1.2.3 for a description of the different types of alternatives.

19.7.3. Selected Actions to Mitigate the Hazard

The mitigation strategy developed for this SHMP includes the following actions that address the volcano hazard:

- Action 2018-001: Support Legislative Efforts that Formalize California's Comprehensive Mitigation Program.
- Action 2018-006: Enhance Collaboration on the Development and Sharing of Data Systems and GIS Modeling.
- Action 2018-039: Volcano Hazard Vulnerability Assessment.

Table 19-7. Potential Opportunities to Mitigate the Volcano Hazard

Community-Scale	Organizational Scale	Government-Scale
Manipulate the hazard: ▪ None **Reduce exposure and vulnerability:** ▪ Locate outside of hazard area **Build local capacity:** ▪ Develop and practice a household evacuation plan	**Manipulate the hazard:** ▪ None **Reduce exposure and vulnerability:** ▪ Locate outside of hazard area ▪ Protect corporate critical facilities from potential impacts of severe ash fall (air filtration capability) **Build local capacity:** ▪ Develop and practice a corporate evacuation plan ▪ Inform employees through corporate sponsored outreach	**Manipulate the hazard:** ▪ Limited success has been experienced with lava flow diversion structures **Reduce exposure and vulnerability:** ▪ Locate outside of hazard area ▪ Protect critical facilities and utilities from potential problems associated with ash fall ▪ Build redundancy for critical facilities and functions **Build local capacity:** ▪ Public outreach, awareness ▪ Tap into State volcano warning system to provide early warning to residents of potential ash fall problems
Nature-based opportunities ▪ Volcanic ash could be used to supply nutrients and reduce carbon dioxide from the atmosphere		

20. RISK ASSESSMENT SUMMARY FOR NATURAL HAZARDS

This SHMP assessed 15 natural hazards of interest, which are the hazards that are typically assessed in local hazard mitigation planning efforts in California and that are eligible for mitigation grant funding under FEMA's Hazard Mitigation Assistance (HMA) programs. Identifying these hazards as a distinct category in the SHMP establishes those hazards as a baseline for local risk assessments and planning efforts. However, none of these hazards are binding on local planning efforts. Local communities should determine the hazards of concern to be addressed for their plans through a planning process. The role of the SHMP is to provide guidance and alternatives to support these planning processes.

Of the 15 natural hazards of interest assessed in this SHMP, eight were identified as high-impact hazards, six were identified as medium-impact, and one was identified as low-impact, as shown in Figure 20-1. The parameters for these ratings are discussed in detail in Appendix I.

These rankings are based on impacts on State-owned or -leased facilities or identified critical facilities and lifelines that are essential to the State's ability respond to and recover from hazard events. The rankings should not be interpreted as applicable locally. Local planning efforts should assess and rank risk individually, based on the impacts of these hazards on the defined planning areas for local planning efforts. The metrics to measure those impacts should be determined locally by the local hazard mitigation planning process.

Figure 20-1. Natural Hazards of Interest Hazard Impact Ratings