Sonoma County Multijurisdictional Hazard Mitigation Plan Update 2021

PART 2—RISK ASSESSMENT

6. IDENTIFIED HAZARDS OF CONCERN AND RISK ASSESSMENT METHODOLOGY

The risk assessments in this plan describe the risks associated with each identified hazard of concern. The following steps were used to define the risk of each hazard:

- **Identify and profile each hazard**—The following information is given for each hazard:
  - A summary of past events that have impacted the planning area
  - Geographic areas most affected by the hazard
  - Event frequency estimates
  - Severity descriptions
  - Warning time likely to be available for response.
- **Determine exposure to each hazard**—Exposure was assessed by overlaying hazard maps with an inventory of structures, facilities, and systems to decide which of them would be exposed to each hazard.
- **Assess the vulnerability of exposed facilities—**Vulnerability of exposed structures and infrastructure was evaluated by interpreting the probability of occurrence of each event and assessing structures, facilities, and systems that are exposed to each hazard. Tools such as GIS and Hazus were used for this assessment for the dam failure, earthquake, flood, and tsunami hazards. Outputs similar to those from Hazus were generated for other hazards, using data generated through GIS.

The risk assessments performed for this plan evaluated risk countywide and for individual incorporated areas.

6.1 IDENTIFIED HAZARDS OF CONCERN

The Steering Committee considered the full range of natural hazards that could affect the planning area and then listed hazards that present the greatest concern. The process incorporated a review of state and local hazard planning documents as well as information on the frequency of, magnitude of, and costs associated with hazards that have struck the planning area or could do so. Anecdotal information regarding natural hazards and the perceived vulnerability of the planning area's assets to them was also used. Based on the review, this plan addresses the following hazards of concern (presented in alphabetical order; the order of listing does not indicate the hazards' relative severity):

- Dam failure
- Drought
- Earthquake
- Flooding
- Landslide/mass movement

- Sea level rise
- Severe weather
- Tsunami
- Wildfire

The hazard mitigation plan includes a discussion of climate change, but it is not treated as a stand-alone hazard. Instead, a review is provided on the ways in which climate change could affect the planning area's exposure and vulnerability to the other identified hazards of concern.

An additional chapter provides a profile of "hazards of concern," defined as hazards that may impact the planning area but whose risk is difficult to quantify due to a lack of data or well-established assessment parameters. That chapter provides a profile of these hazards but does not assess them to the same level of detail as the primary hazards of concern. The hazards of interest are not included in the risk rating for this plan.

6.2 RISK ASSESSMENT TOOLS

6.2.1 Mapping

National, state, county, and city databases were reviewed to locate available spatially based data relevant to this planning effort. Maps were produced using geographic information system (GIS) software to show the spatial extent and location of hazards when such datasets were available. These maps are included in the hazard profile chapters of this document and the jurisdiction-specific annexes in Volume 2. Details regarding the data sources and methodologies employed in these mapping efforts is located in Appendix C.

6.2.2 Hazus

Overview

In 1997, FEMA developed the standardized Hazards U.S., or Hazus, model to estimate losses caused by earthquakes and identify areas that face the highest risk and potential for loss. Hazus was later expanded into a multi-hazard methodology with new models for estimating potential losses from hurricanes, floods, and tsunamis.

Hazus is a GIS-based software program used to support risk assessments, mitigation planning, and emergency planning and response. It provides a wide range of inventory data, such as demographics, building stock, community lifelines, and multiple models to estimate potential losses from natural disasters. The program maps and displays hazard data and the results of damage and economic loss estimates for buildings and infrastructure. Its advantages include the following:

- Provides a consistent methodology for assessing risk across geographic and political entities.
- Provides a way to save data so that it can readily be updated as population, inventory, and other factors change and as mitigation planning efforts evolve.
- Facilitates the review of mitigation plans because it helps to ensure that FEMA methodologies are incorporated.
- Supports grant applications by calculating benefits using FEMA definitions and terminology.
- Produces hazard data and loss estimates that can be used in communication with local stakeholders.

- Is administered by the local government and can be used to manage and update a hazard mitigation plan throughout its implementation.

Levels of Detail for Evaluation

Hazus provides default data for inventory and hazards; this default data can be supplemented with local data to provide a more refined analysis. The model can carry out three levels of analysis, depending on the format and level of detail of information about the planning area:

- **Level 1**—All of the information needed to produce an estimate of losses is included in the software's default data. This data is derived from national databases and describes in general terms the characteristic parameters of the planning area.
- **Level 2**—More accurate estimates of losses require more detailed information about the planning area. To produce Level 2 estimates of losses, detailed information is required about local geology, hydrology, hydraulics and building inventory, as well as data about utilities and critical facilities. This information is needed in a GIS format.
- **Level 3**—This level of analysis generates the most accurate estimate of losses. It requires detailed engineering and geotechnical information to customize it for the planning area.

6.3 RISK ASSESSMENT APPROACH

6.3.1 Hazard Profile Development

Hazard profiles were developed through web-based research and review of previously developed reports and plans, including community general plans and state and local hazard mitigation plans. Frequency and severity indicators include past events and the expert opinions of geologists, emergency management specialists, and others.

6.3.2 Exposure and Vulnerability

Dam Failure, Earthquake, and Flood

Community exposure and vulnerability to the following hazards were evaluated using Hazus:

- **Dam Failure and Flood**—A Level 2 user-defined analysis was performed for general building stock and for community lifelines using the flood module. Current mapping for the planning area was used to delineate hazard areas for flood and dam failure, and estimate potential losses. To estimate damage that would result from these inundation-based hazards, Hazus uses pre-defined relationships between water depth at a structure and resulting damage, with damage given as a percent of total replacement value. Curves defining these relationships have been developed for damage to structures and for damage to typical contents within a structure. By inputting inundation depth data and known property replacement cost values, dollar-value estimates of damage were generated.
- **Earthquake**—A Level 2 analysis was performed to assess earthquake exposure and vulnerability for four scenario events and one probabilistic event:
  - A Magnitude-7.57 event on the Hayward Fault with an epicenter 16 miles southeast of Petaluma.
  - A Magnitude-7.55 event on the Maacama Fault with an epicenter 26 miles north-northwest of Cloverdale.

- A Magnitude-7.19 event on the Rodgers Creek and Healdsburg Faults with an epicenter 3 miles north-northeast of Santa Rosa.
- A Magnitude-8.04 event on the San Andreas Fault with an epicenter 16 miles west of Sebastopol.
- The standard Hazus 100-year probabilistic event.

Landslide/Mass Movement, Sea Level Rise, Severe Weather, Tsunami, and Wildfire

Historical datasets were not adequate to model future losses for most of the hazards of concern. However, areas and inventory susceptible to some of the hazards of concern were mapped by other means to evaluate exposure. A qualitative analysis was conducted for other hazards using the best available data and professional judgment.

Drought

The risk assessment methodologies used for this update focus on damage to structures. Because drought does not impact structures, the risk assessment for this hazard was more limited and qualitative than the assessment for the other hazards of concern.

6.4 SOURCES OF DATA USED IN MODELING AND EXPOSURE ANALYSIS

6.4.1 Building and Cost Data

Replacement cost is the cost to replace the entire structure with one of equal quality and utility. Replacement cost is based on industry-standard cost-estimation models published in the 2020 *RS Means Square Foot Costs*. It is calculated using the RS Means square foot cost for a structure, which is based on the Hazus occupancy class (i.e., multi-family residential or commercial retail trade), multiplied by the square footage of the structure from the tax assessor data. The construction class and number of stories for single-family residential structures also factor into determining the square foot costs.

Replacement cost values and detailed structure information derived from parcel and tax assessor data provided by Sonoma County were loaded into Hazus. When available, an updated inventory was used in place of the Hazus defaults for community lifelines.

6.4.2 Hazus Data Inputs

The following hazard datasets were used for the Hazus Level 2 analysis conducted for the risk assessment:

- **Flood**—Flood hazards areas were delineated using a combination of the effective Digital Flood Insurance Rate Map (DFIRM), the preliminary FIRM, and the County's Russian River flood stage inundation areas. Potential losses for the FEMA 1-percent-annual-chance and 0.2-percent-annual-chance (100- and 500-year) flood events, and the equivalent stages in the Russian River data, were estimated. The 47-foot flood stage and the 51-foot flood stage, both as measured at the Guerneville stream gage, were considered equivalent to the FEMA 1-percent-annual chance and 0.2-percent-annual-chance events respectively. Using the DFIRM and preliminary FIRM floodplain boundaries and base flood elevation information, and the County's 3-foot digital elevation model (DEM), flood depth grids were generated and integrated into the Hazus model. The flood depth grids, included as part of the Russian River inundation areas were included as part of the County's original flood stage dataset.
- **Dam Failure**—Dam failure inundation area boundaries data for Annadel No. 1, Cook No. 2, Delta Pond, Dutcher Creek, Fern Lake, Foothill Regulating Park, Foss Creek North Area, Lagunita, Lake Helen,

Lytton, Mallacomes, Matanzas Creek, Merlo, Middle Fork Brush Creek, Piner Creek, Santa Rosa Creek Reservoir, and Suttenfield were provided by the California Department of Water Resources. Associated inundation depth grid data were also provided for all dams except Delta Pond. Inundation area boundaries data for Azalea, Fountaingrove, Lake Ralphine, and Warm Springs Dam provided by the County. Depth grids for Delta Pond and the dams provided by the County were created using the inundation area boundaries and the 3-foot DEM data. The individual dam depth grids were combined using the maximum depth where the dam inundation areas overlapped, and the combined depth grid was integrated into the Hazus model.

- **Earthquake**—Earthquake ShakeMaps and probabilistic data prepared by the U.S. Geological Survey (USGS) were used for the analysis of this hazard. A National Earthquake Hazard Reduction Program (NEHRP) soils map from the California Department of Conservation, the USGS's liquefaction susceptibility data, and susceptibility to deep-seated landslide data from the California Geological Survey were also integrated into the Hazus model.

6.4.3 Other Local Hazard Data

Locally relevant information on hazards was gathered from a variety of sources. Frequency and severity indicators include past events and the expert opinions of geologists, emergency management specialists, and others. Data sources for specific hazards were as follows:

- **Flood**—Additional areas called "flood awareness areas" were delineated using the County's "functional riparian channels and floodplains" data. The mapped areas overlap with the FEMA and Russian River data in some areas but also include streams not mapped by FEMA.
- **Landslide/Mass Movement—**Susceptibility to deep-seated landslides data were provided by the California Geological Survey. Areas categorized as very high and high susceptibility (categories X, XI, VIII, and VII) were used in the exposure analysis.
- **Sea Level Rise**—USGS's Coastal Storm Modeling System sea level rise data were provided by Our Coast Our Future. Sea level rises of 200 cm (no storm) and 200 cm with a 100-year storm were used for the exposure analysis.
- **Severe Weather**—No GIS format severe weather area datasets were identified for Sonoma County.
- **Tsunami—**Tsunami inundation area data were provided by the California Department of Conservation.
- **Wildfire**—Sonoma County Wildfire Hazard Index data were provided by Sonoma County. Areas categorized as very high and high relative hazard were used in the exposure analysis.

6.4.4 Data Source Summary

Table 6-1 summarizes the data sources used for the risk assessment for this plan.

Table 6-1. Hazus Model Data Documentation

Data	Source	Date	Format
Property parcel data including building information (use code, square footage, year built)	Sonoma County	2020	Digital (GIS)
Building footprints (Sonoma County Vegetation Mapping & LiDAR Program)	Sonoma County	Unknown	Digital (GIS)
Building replacement (square foot) costs	RS Means	2020	Digital (pdf)
Sonoma County Supervisorial District boundaries	Sonoma County	Downloaded 2021	Digital (GIS)
Population data	FEMA Hazus version 4.2 SP03	2010	Digital (GIS and tabular)
CA State dam breach inundation maps (inundation boundaries and depth grids)	California Department of Water Resources	2018-20	Digital (GIS)
Dam inundation areas	Sonoma County	Unknown	Digital (GIS)
ShakeMap—Hayward RC+HN+HS M7.57	USGS	2017	Digital (GIS)
ShakeMap—Maacama M7.55	USGS	2017	Digital (GIS)
ShakeMap—Rodgers Creek-Healdsburg M7.19	USGS	2017	Digital (GIS)
ShakeMap—San Andreas SAO+SAN+SAP+SAS M8.04	USGS	2017	Digital (GIS)
NEHRP soils (VsMapV3_Geology)	California Department of Conservation	2015	Digital (GIS)
Liquefaction susceptibility	USGS (provided by Sonoma County)	2006	Digital (GIS)
Digital Flood Insurance Rate Map (DFIRM)—Sonoma County effective 3/7/2017, latest Letter of Map Revision effective 6/19/2020	FEMA	2020	Digital (GIS)
Preliminary FIRM—Sonoma County dated 5/15/2020	FEMA	2020	Digital (GIS)
Russian River Flood Modeling (inundation boundaries and depth grids)	Sonoma County	2017	Digital (GIS)
Functional Riparian Channels and Floodplains	Sonoma County Agricultural Preservation & Open Space District	2020	Digital (GIS)
Susceptibility to deep-seated landslides	California Geological Survey	2011	Digital (GIS)
USGS Coastal Storm Modeling System (v. 2.0, v. 2.1, and v. 2.2) sea level rise data	Our Coast Our Future	2019	Digital (GIS)
Tsunami Inundation Map for Emergency Planning	California Emergency Management Agency, California Geological Survey, and University of Southern California—Tsunami Research Center	2009	Digital (GIS)
Sonoma County Wildfire Hazard Index	Permit Sonoma, Sonoma County, Fire Safe Sonoma, Tukman Geospatial, Digital Mapping Solutions, Wildland Res Mgt	2021	Digital (GIS)
Sonoma Veg Map LiDAR Hydro Flattened Bare Earth DEM (3-foot resolution)	Sonoma County	2013	Digital (GIS)
Critical Facilities			
Police stations	Sonoma County (original ArcGIS Online)	Provided 2020	Digital (GIS)
Fire stations	Sonoma County	Provided 2020	Digital (GIS)
Public lands (city, county, state buildings)	Sonoma County	Provided 2020	Digital (GIS)
County buildings	Sonoma County	Provided 2020	Digital (GIS)
County leased buildings	Sonoma County	Provided 2020	Digital (GIS)
Post offices	Sonoma County (original ArcGIS Online)	Provided 2020	Digital (GIS)

Data	Source	Date	Format
Public schools	Sonoma County	Provided 2020	Digital (GIS)
Private schools	Sonoma County	Provided 2020	Digital (GIS)
College and university parcels	Sonoma County	Provided 2020	Digital (GIS)
Emergency shelters	Sonoma County	Provided 2020	Digital (GIS)
Licensed and certified healthcare facilities	Sonoma County (original ArcGIS Online)	Provided 2020	Digital (GIS)
Convalescent hospital parcels	Sonoma County	Provided 2020	Digital (GIS)
Animal hospital parcels	Sonoma County	Provided 2020	Digital (GIS)
Emergency Medical Services stations	Sonoma County	Provided 2020	Digital (GIS)
Geothermal power plants	Sonoma County	Provided 2020	Digital (GIS)
Hydroelectric power plants	Sonoma County	Provided 2020	Digital (GIS)
Electric substations	Sonoma County (original ArcGIS Online)	Provided 2020	Digital (GIS)
Sonoma-Marin Area Rail Transit stations	Sonoma County	Provided 2020	Digital (GIS)
Airports	Sonoma County	Provided 2020	Digital (GIS)
Bus transit stops	Sonoma County	Provided 2020	Digital (GIS)
Bridges	Sonoma County	Provided 2020	Digital (GIS)
Hazmat facilities	Sonoma County	Provided 2020	Digital (GIS)
Certified Unified Program Agency facilities	Sonoma County	Provided 2020	Digital (GIS)
Natural gas stations	California Energy Commission	Downloaded 2018	Digital (GIS)
Power plants	California Energy Commission	Downloaded 2020	Digital (GIS)
Wastewater treatment plants	California Water Resources Control Board	Downloaded 2020	Digital (GIS)
Hospital heliports	California Department of Transportation	Downloaded 2020	Digital (GIS)
Local Emergency Operations Centers	Homeland Infrastructure Foundation-Level Data (HIFLD)	Downloaded 2020	Digital (GIS)
Veterans Health Administration medical facilities	HIFLD	Downloaded 2020	Digital (GIS)
FM transmission towers	HIFLD	Downloaded 2020	Digital (GIS)
AM transmission towers	HIFLD	Downloaded 2020	Digital (GIS)
TV digital station transmitters	HIFLD	Downloaded 2020	Digital (GIS)
TV analog station transmitters	HIFLD	Downloaded 2020	Digital (GIS)
FDIC insured banks	HIFLD	Downloaded 2020	Digital (GIS)
Port facilities	HIFLD	Downloaded 2020	Digital (GIS)

6.5 LIMITATIONS

Loss estimates, exposure assessments and hazard-specific vulnerability evaluations rely on the best available data and methodologies. Uncertainties are inherent in any loss estimation methodology and arise in part from incomplete scientific knowledge concerning natural hazards and their effects on the built environment. Uncertainties also result from the following:

- Approximations and simplifications necessary to conduct a study
- Incomplete or outdated inventory, demographic or economic parameter data
- The unique nature, geographic extent, and severity of each hazard
- Mitigation measures already employed
- The amount of advance notice residents have to prepare for a specific hazard event.

These factors can affect loss estimates by a factor of two or more. Therefore, potential exposure and loss estimates are approximate and should be used only to understand relative risk. Over the long term, the planning partners will collect additional data to assist in estimating potential losses associated with other hazards.

7. DAM FAILURE

7.1 GENERAL BACKGROUND

7.1.1 Definition and Classification of Dams

A dam is an artificial barrier that can store water, wastewater, or liquid-borne materials for many reasons—flood control, human water supply, irrigation, livestock water supply, energy generation, containment of mine tailings, recreation, or pollution control. Many dams fulfill a combination of these functions. They are an important resource in the United States (ASDSO, 2013). In California, dams are regulated by the State of California Division of Safety of Dams. Additional regulatory oversight of dams is cited in Chapter 5 and described in Appendix B.

The California Water Code (Division 3) defines a dam as any artificial barrier, together with appurtenant works, that does or may impound or divert water, and that meets either of the following conditions:

- Is 25 feet or more in height from the natural bed of the stream or watercourse at the downstream toe of the barrier (or from the lowest elevation of the outside limit of the barrier if it is not across a stream channel or watercourse) to the maximum possible water storage elevation
- Has an impounding capacity of 50 acre-feet or more

Dams can be classified according to their purpose, the construction material or methods used, their slope or cross-section, the way they resist the force of the water pressure, or the means used for controlling seepage. Materials used to construct dams include earth, rock, tailings from mining or milling, concrete, masonry, steel, timber, plastic, rubber, and combinations of these.

7.1.2 Causes of Dam Failure

Partial or full failure of dams has the potential to cause massive destruction to the ecosystems and communities located downstream. Partial or full failure can occur as a result of one or a combination of the following reasons (FEMA, 2015):

- Overtopping caused by floods that exceed the dam capacity (inadequate spillway capacity)
- Prolonged periods of rainfall and flooding
- Deliberate acts of sabotage (terrorism)
- Structural failure of materials used in dam construction
- Movement and/or failure of the foundation supporting the dam
- Settlement and cracking of concrete or embankment dams

- Piping and internal erosion of soil in embankment dams
- Inadequate or negligent operation, maintenance, and upkeep
- Failure of upstream dams on the same waterway
- Earthquake (liquefaction/landslides).

Many dam failures in the United States have been secondary results of other disasters. The most common causes are earthquakes, landslides, extreme storms, equipment malfunction, structural damage, foundation failures, and sabotage. Poor construction, lack of maintenance and repair, and deficient operational procedures are preventable or correctable by a program of regular inspections. Terrorism and vandalism are serious concerns that all operators of public facilities must plan for; these threats are under continuous review by public safety agencies.

7.1.3 Planning Requirements

State of California

All dams whose inundation areas may impact the planning area have emergency action plans (EAPs) on file. The EAPs must include the following (Cal OES, 2018):

- Emergency notification flow charts
- Information on a four-step response process
- Description of agencies' roles and actions in response to an emergency incident
- Description of actions to be taken in advance of an emergency
- Inundation maps
- Additional information such as revision records and distribution lists.

After the EAPs are approved by the state, the law requires dam owners to send the approved EAPs to relevant stakeholders. Local public agencies can then adopt emergency procedures that incorporate the information in the EAP in a manner that conforms to local needs and includes methods and procedures for alerting and warning the public and other response and preparedness related items (State of California, 2018).

Federal Energy Regulatory Commission

Dams that fall under the jurisdiction of the Federal Energy Regulatory Commission (FERC) also have specified planning requirements. FERC has the largest dam safety program in the United States. It cooperates with many federal and state agencies to ensure and promote dam safety and, more recently, homeland security. FERC requires licensees to prepare emergency action plans and conducts training sessions on how to develop and test these plans. The plans are designed to serve as an early warning system if there is a potential for, or a sudden release of water from, a dam failure or accident to the dam. The plans include operational procedures that may be used, such as reducing reservoir levels and reducing downstream flows and procedures for notifying affected residents and agencies responsible for emergency management. These plans are frequently updated and tested to ensure that in emergency situations everyone knows what to do, thus saving lives and minimizing property damage.

7.2 HAZARD PROFILE

7.2.1 Past Events

No known failures have occurred on dams that impact Sonoma County. However, according to the 2013 *State of California Multi-Hazard Mitigation Plan*, there have been nine failures of federally regulated dams elsewhere in the state since 1950. Overtopping caused two of the nine dam failures in the state, and the others were caused by seepage or leaks. The most catastrophic event was the failure of the St. Francis Dam in Los Angeles County, which failed in 1928 and killed an estimated 450 people.

The state's most recent dam emergency occurred in February 2017 when the Oroville Dam in Butte County was on the verge of overflow. The dam's concrete spillway was damaged by erosion and a massive hole developed. The auxiliary spillway was used to prevent overtopping of the dam, and it experienced erosion problems also. Evacuation orders were issued in advance of a potential large uncontrolled release of water from Lake Oroville, but such a release did not occur. After this incident, state officials ordered that flood-control spillways be re-inspected on 93 California dams with potential geologic, structural or performance issues that could jeopardize their ability to safely pass a flood event.

7.2.2 Location

List of High-Hazard Dams

According to the Army Corps of Engineers' National Inventory of Dams, there are 65 dams that are in the planning area or have inundation areas that extend into the planning area. Table 7-1 lists basic data about the 21 dams that are rated as high or extremely high risk. The locations of each dam are shown on Figure 7-1.

Warm Springs Dam

The largest dam in Sonoma County is the Warm Springs Dam that impounds Dry Creek and provides water supply and flood management. The dam was built in 1982 and forms Lake Sonoma Reservoir, which has a total storage capacity of 381,000 acre-feet: a water supply pool of 245,000 acre-feet and a flood pool of 136,000 acre-feet. The dam is owned by the U.S. Army Corps of Engineers. Water supply releases from this dam are controlled by the Sonoma County Water Agency. Water released for flood control is managed by the Corps (County of Sonoma 2017).

The Corps assessed the seismic integrity of the Warms Springs Dam in 2006. The assessment did not report any potential failure modes but did analyze the consequences of a failure. The occurrence of a seepage, overtopping, or a seismic event that could lead to a total breach of the dam could not entirely be ruled out due to the lack of updated studies. A breach could occur within a relatively short period of time, perhaps a few hours. The Corps categorized this dam as Dam Safety Action Class IV (considered marginally safe). This rating is based on probability of failure and on the population, residential and commercial structures, roads, farmland, bridge, and utilities downstream that could be damaged. The Corps plans to conduct additional safety assessment of the dam and appurtenant structures using the most recent information on seismic and flood conditions.

The Warm Springs Dam Failure Response Plan outlines the procedures and policy for potential failure of the Warm Springs Dam and possible impacts in the north central portion of the county. The plan identifies inundation areas, warning and evacuation procedures, and emergency contacts.

Table 7-1. High-Hazard Dams in the Planning Area or with Inundation Areas Extending into Planning Area

Name	Water Course	Owner	Year Built	Hazard Rating	Dam Type	Crest Length (feet)	Height (feet)	Storage Capacity (acre feet)	Condition Assessment
Fern Lake	Mill Cr. Trib.	Sonoma Developmental Center	1921	High	Earth	300	40	241	Satisfactory
Suttenfield	Sonoma Creek	Sonoma Developmental Center	1938	Extremely High	Earth	965	76	600	Satisfactory
Warm Springs[a]	Dry Creek	Corps of Engineers San Francisco District	1982	High	Earth	3000	319	130	n/a
Annadel No. 1	Spring Creek	California Department of Parks and Recreation	1956	Extremely High	Earth	400	67	395	Poor
Towibalyla	Franz Cr. Trib.	Kendall Jackson Wine Estates, LTD	1962	High	Earth	525	51	376	Satisfactory
Mallacomes	Foote Creek	Rancho Mallacomes	1951	High	Earth	940	57	225	Satisfactory
Piner Creek	Paulin Creek	Sonoma County Water Agency	1962	High	Earth	205	28	172	Satisfactory
Middle Fork Brush Creek	Middle Fk. Brush Cr.	Sonoma County Water Agency	1961	High	Earth	1100	37	138	Satisfactory
Matanzas Creek	Matanzas Creek	Sonoma County Water Agency	1963	Extremely High	Earth	685	95	1,500	Satisfactory
Santa Rosa Creek Reservoir	Santa Rosa Cr. Trib.	Sonoma County Water Agency	1963	Extremely High	Earth	1950	37	3,550	Satisfactory
Lake Ralphine	Santa Rosa Cr. Trib.	City of Santa Rosa	1882	Extremely High	Earth	700	35	387	Satisfactory
Fountaingrove	Mark West Cr. Trib.	City of Santa Rosa	1953	Extremely High	Earth	500	38	427	Satisfactory
Lagunita	Windsor Cr. Trib.	Private Entity	1954	Extremely High	Earth	308	49	133	Satisfactory
Azalea	N. Fk. Lancel Cr.	Silver Eagle Ranch, LLC	1955	High	Earth	140	44	85	Satisfactory
Lytton	Russian R. Trib.	Lytton Rancheria of California	1956	High	Earth	275	34	410	Satisfactory
Lowe	Franz Cr. Trib.	Ferrari-Carano Vineyards and Winery, LLC	1959	High	Earth	550	30	108	Satisfactory
Bosch No. 2	Windsor Cr. Trib.	Private Entity	1962	High	Earth	230	55	37	Satisfactory
Foothill Regulating Park	Windsor Cr. Trib.	County of Sonoma Regional Park	1963	High	Earth	274	51	109	Satisfactory
The Hill Ranch	Santa Rosa Cr.	Private Entity	1955	High	Earth	202	49	160	Satisfactory
Merlo	Fall Creek	Private Entity	1982	High	Earth	210	74	930	Satisfactory
La Crema Winery		Jackson Family Wines		High	Earth	1600	32	103	Fair

a. The Warm Springs Dam is a federal dam, not under the jurisdiction of the State of California. Data taken from U.S. Army Corps of Engineers' National Inventory of Dams

Source: California Department of Water Resources, Division of Safety of Dams, 2020

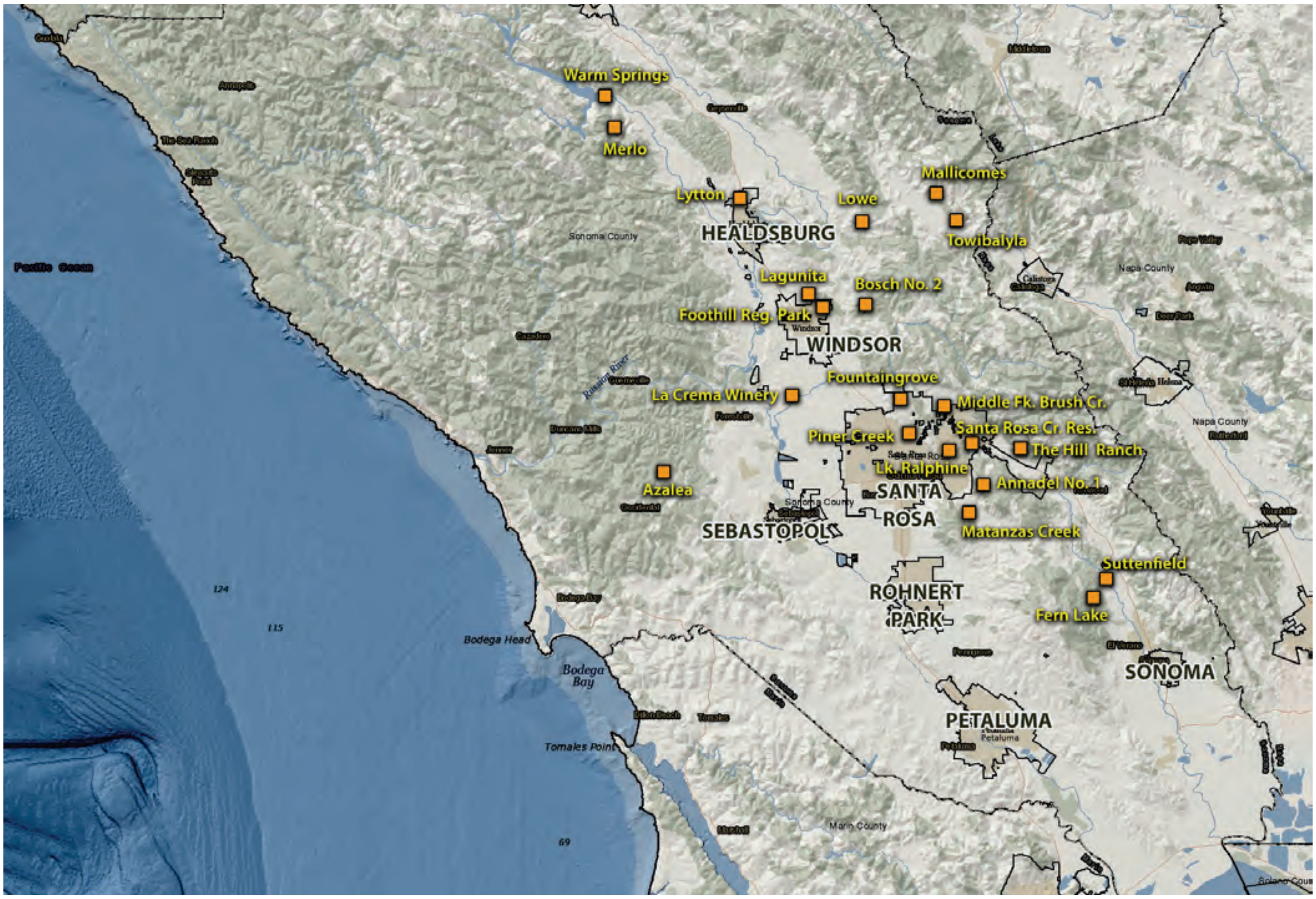


Figure 7-1. Locations of Dams in Sonoma County

Coyote Valley Dam

The Coyote Valley Dam in Mendocino County regulates the northern Russian River and was built in 1959. It forms the Lake Mendocino Reservoir, which holds 122,400 acre-feet. Failure of this dam could affect areas in Sonoma County. This dam is owned by the Corps of Engineers. Water releases are controlled in a manner similar to the approach for the Warm Springs Dam (County of Sonoma 2017).

The Corps assessed the seismic integrity of the Coyote Valley Dam in 2005 and categorized it as Dam Safety Action Class III. Dams in Class III, for confirmed and unconfirmed dam safety issues, are significantly inadequate or have moderate to high risk based on the combination of life or economic consequences and probability of failure. The assessment found that the following are the most likely modes of failure, in order of decreasing risk:

- Seepage along the conduit leading to the formation of piping, which can quickly progress to rapid breaching of the embankment.
- Tunnel/Conduit joint failure caused by significant displacements of the shells during both the operating base earthquake and maximum design earthquake, and intake tower stability and embankment/foundation liquefaction failures during a maximum design earthquake.
- The dam will be overtopped during the probable maximum flood event and will result in erosion of the crest and downstream slope leading to a complete breach.

The Corps plans to conduct additional safety assessment of the dam and appurtenant structures using the most recent information on seismic and flood conditions.

Other Dams in the County

There are 63 smaller dams throughout Sonoma County that are regulated by the Division of Safety of Dams. All are small and generally used for agricultural, drinking water, or stormwater management purposes. Failure of one of these dams could pose a significant threat to limited areas of the county. A dam inundation contingency plan for each dam is filed with the County.

Inundation Mapping

A key element for EAPs required for dams in California is a map defining the potential downstream inundation should the dam fail. For this risk assessment, digital data suitable for a quantitative assessment of dam failure risk was available for all high hazard dams listed in Table 7-1. To perform the risk assessment's evaluation of exposure and vulnerability, the dam failure inundation areas were combined into a single hazard area shown in Figure 7-2.

7.2.3 Frequency

Dam failure events are infrequent and usually coincide with or follow events such as earthquakes, landslides and excessive rainfall and snowmelt. Although the recent Oroville event raised public concern about dam failure, the probability of such failures remains low in today's regulatory environment. No recorded failures have occurred on dams that impact the planning area, so no estimate of frequency or probability of future occurrence can be developed based on the historical record.

All dams face a "residual risk" of failure, which represents the risk that conditions may exceed those for which the dam was designed. For example, dams may be designed to withstand a probable maximum precipitation, defined as "theoretically, the greatest depth of precipitation for a given duration that is physically possible over a given storm area at a particular geographical location at a certain time of the year" (Hansen 1982). The chance of occurrence of a precipitation event of a greater magnitude than that represents residual risk for such dams. This in turn represents a theoretical probability of future occurrence for a dam failure event, though the probability of an event exceeding the assumed maximum is not generally calculated as part of dam design.

7.2.4 Severity

Dam failure can be catastrophic to all life and property downstream. California's Division of Safety of Dams has developed a hazard potential classification system for state-jurisdiction dams, as shown on Table 7-2. This system is modified from federal guidelines, which recommend three-tier classification. The California system adds a fourth hazard classification of "extremely high." Dams classified as extremely high hazard may impact highly populated areas or critical infrastructure or have short evacuation warning times (California Division of Safety of Dams, 2017). All dams listed in Table 7-1 are classified as high hazard in this system.

Figure 7-2. Dam Failure Inundation Area Used for Risk Assessment

Data Sources: Sonoma Co., CA DWR

Table 7-2. State of California Downstream Hazard Potential Classification

Hazard Category	Direct Loss of Life	Economic, Environmental, and Lifeline Losses
Low	None expected	Low and principally limited to dam owner's property
Significant	None expected	Yes
High	Probable (one or more expected)	Yes, but not necessary for this classification
Extremely High	Considerable	Yes, major impacts to critical infrastructure or property

Source: California Division of Safety of Dams, 2017

7.2.5 Warning Time

Advance Warning of Failure

Warning time for dam failure varies depending on the cause of the failure. Events of extreme precipitation or massive snowmelt can be predicted in advance, so evacuations can be planned with sufficient time. In the event of a structural failure due to earthquake, there may be no or limited warning time. The USGS Earthquake Hazards Program has several dam-safety related earthquake programs, including dam-specific earthquake monitoring programs in California to help monitor safety concerns following seismic events.

Time for Failure to Occur

The process of the dam failure affects warning time. Earthen dams do not tend to fail completely or instantaneously. Once a breach is initiated, discharging water erodes the breach until either the reservoir water is depleted, or the breach resists further erosion. Concrete gravity dams also tend to have a partial breach as one or more monolith sections are forced apart by escaping water. The time of breach formation ranges from a few minutes to a few hours.

Time After Failure Before Downstream Areas Are Affected

The number of people to be alerted and evacuated in the event of impending dam failure can vary widely. There may be few people along the river in winter, when only permanent residents are apt to be present; but there may be many people in summer, when seasonal cabins are occupied and there are visitors along all the rivers.

Another factor that must be considered is the initial flow in the river when the failure occurs. The initial flow is normally very low on all the rivers from May through October. During the winter, the initial flow is much higher and at times may even be equal to or greater than flood stage. This wide variation in initial flow has a significant impact on the areas that must be evacuated.

If the Warm Springs Dam failed, portions of the communities of Healdsburg, Windsor, Santa Rosa, Sebastopol, and Guerneville, as well as some rural population areas in the floodplain immediately downstream of the dam, would be within the 1- to 24-hour flood wave travel time bracket. Half of the rural population immediately downstream of the dam are within a 15-minute flood wave travel time and all are within a 1-hour flood wave travel time (County of Sonoma 2017).

7.2.6 Secondary Hazards

Dam failure can cause landslides, bank erosion, and destruction of downstream habitat. Dam failure may worsen the severity of a drought by releasing water that might have been used as a potable water source.

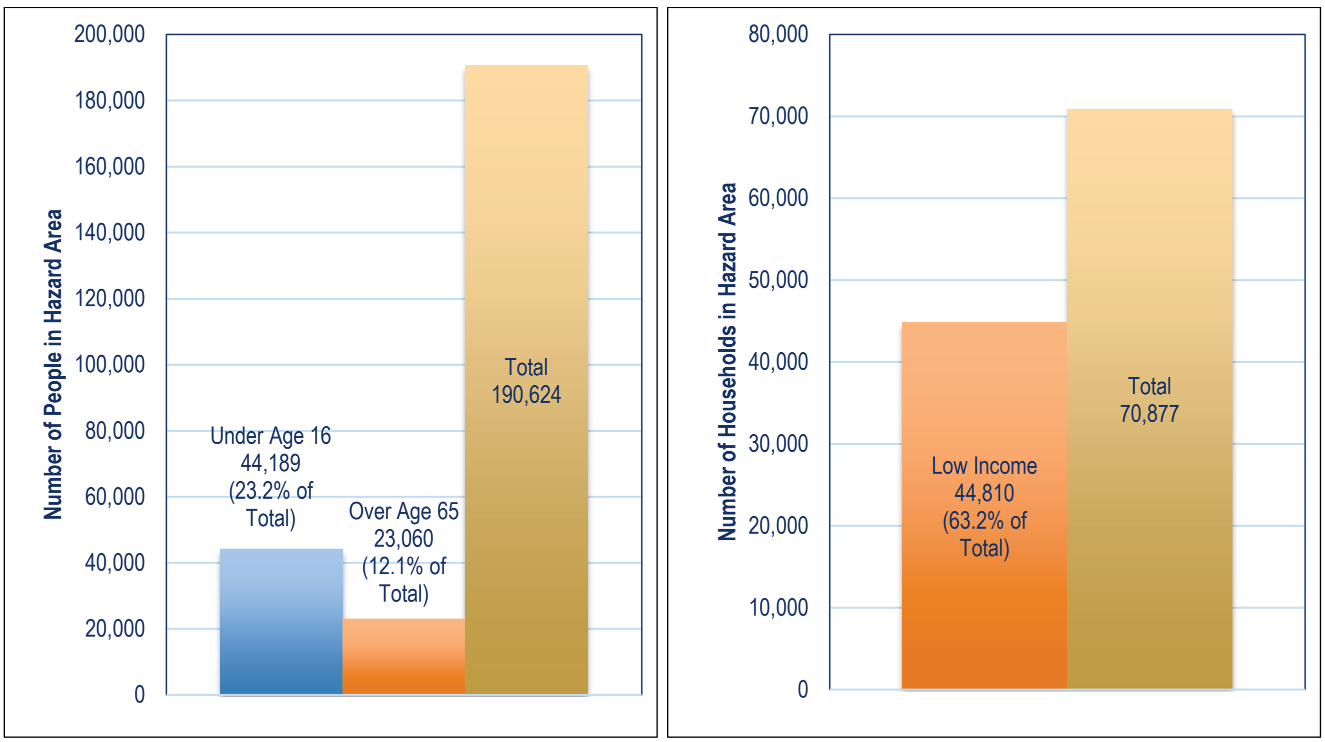
7.3 EXPOSURE

A quantitative assessment of exposure to the dam failure hazard was conducted using the inundation mapping (see Figure 7-2) and the asset inventory developed for this plan. Detailed results by jurisdiction are included in Appendix D; countywide summaries are provided below.

7.3.1 Population

The estimated total population living in the evaluated dam failure inundation zone is 72,953 (15.0 percent of the total planning area population).

Socially vulnerable populations exposed to the dam failure hazard were estimated based on data for the Census-defined blocks that lie at least partially within the mapped dam failure inundation zone. Because many of those Census blocks extend outside the inundation zone, the estimates are greater than the actual exposed populations, but they provide reasonable relative data for use in mitigation planning. Figure 7-3 summarizes the estimated exposure of socially vulnerable populations.



See Section 4.8.1 for the definition of "low income" used in this analysis

Figure 7-3. Socially Vulnerable Populations in Dam Failure Inundation Zone Census Blocks

7.3.2 Property

Table 7-3 summarizes the estimated property exposure in the evaluated dam failure inundation area. Figure 7-4 shows the Hazus-defined occupancy class of all buildings in the combined dam failure inundation area. These occupancy classes provide an indication of land use within the mapped hazard area. Some land uses are more vulnerable to dam failure inundation, such as single-family homes, while others are less vulnerable, such as agricultural land or parks.

Table 7-3. Exposed Property in Evaluated Dam Failure Inundation Area

Acres of inundation area	119,638
Number of Buildings Exposed	28,064
Value of Exposed Structures	$20,123,003,848
Value of Exposed Contents	$17,118,450,390
Total Exposed Property Value	$37,241,454,238
Total Exposed Value as % of Planning Area Total	17.0%

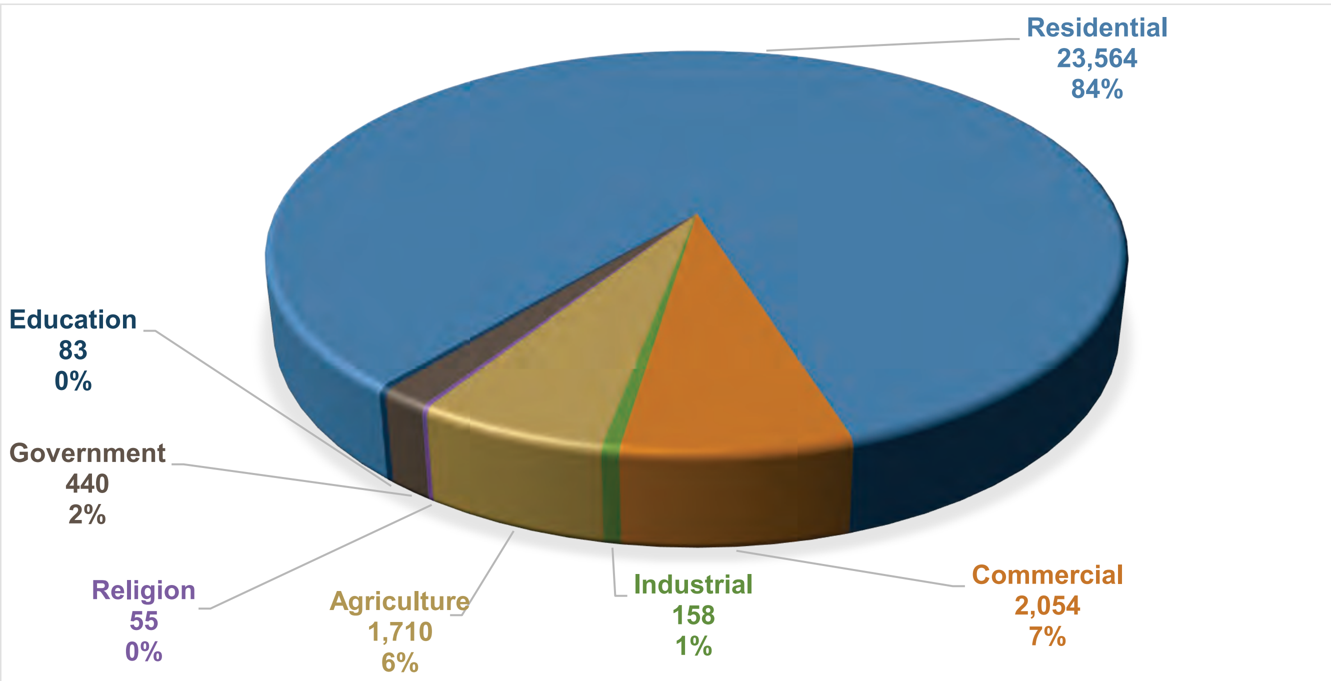


Figure 7-4. Building Occupancy Class Distribution in the Dam Failure Inundation Zone

7.3.3 Critical Facilities

Figure 7-5 shows critical facilities located in the dam inundation zone by facility type and river system. The total count of critical facilities in the dam failure inundation zone (1,059) represents 22 percent of the planning area total of 4,759. Significant facilities included in the mapped inundation zone include the following:

- **2 water treatment facilities**
- **12 wastewater treatment facilities**
- **660 hazardous material sites**
- **3 hospitals**
- **12 fire stations**
- **4 police stations**
- **49 schools**
- **111 road bridges**

7.3.4 Environment

All natural features and wildlife in the dam inundation zone are at risk from the dam failure hazard.

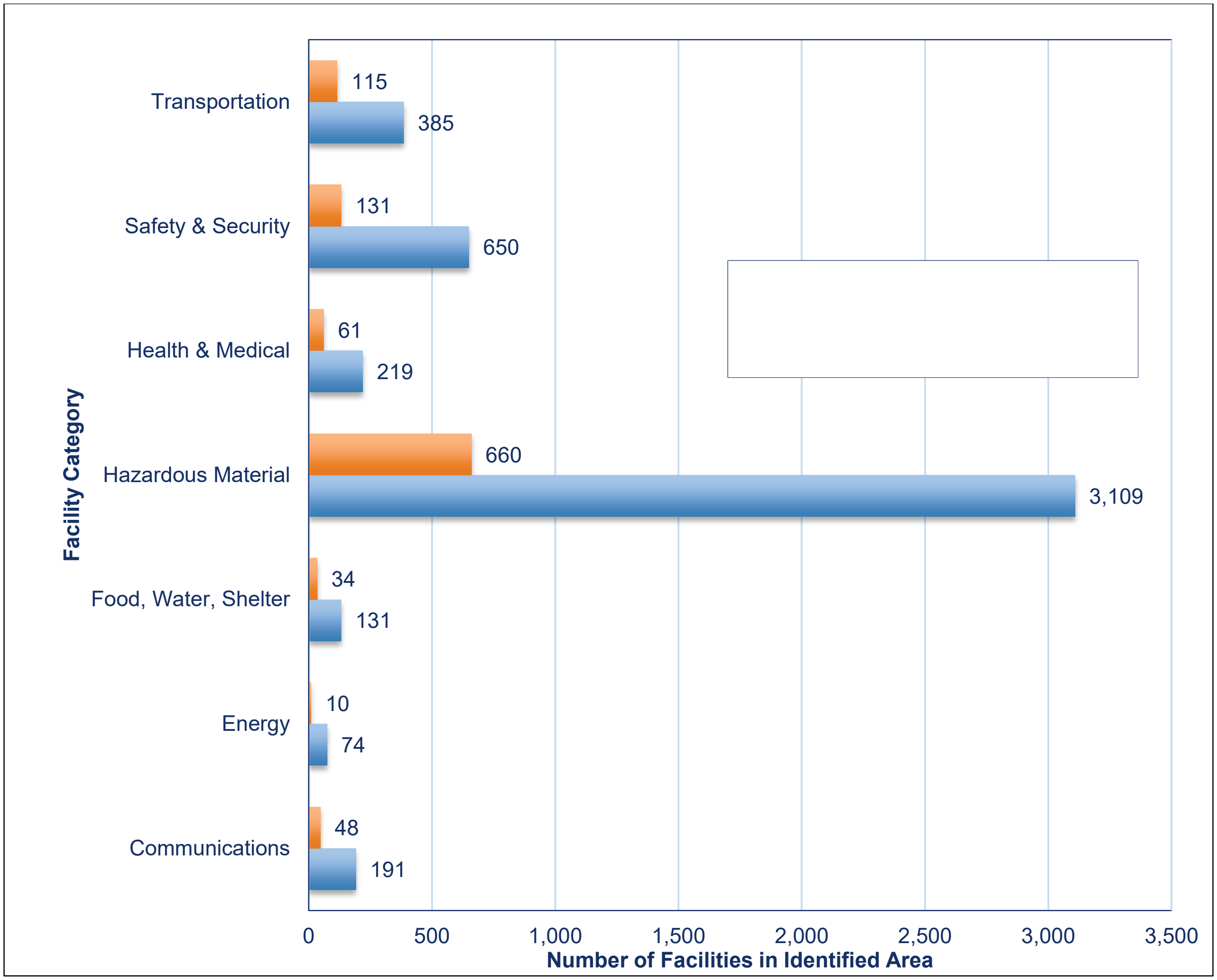


Figure 7-5. Critical Facilities in Dam Failure Inundation Zones and Countywide

7.4 VULNERABILITY

The vulnerability of people, property, and critical facilities was evaluated for the combined dam inundation area. Detailed results by jurisdiction are included in Appendix D; countywide summaries are provided below.

7.4.1 Population

Vulnerable populations are all populations downstream from dam failures that are incapable of escaping the area before floodwaters arrive. This population includes the elderly and young who may be unable to get themselves out of the inundation area. The vulnerable population also includes those who would not have adequate warning from a television, radio emergency warning system, siren, or cell phone alert. Impacts on persons and households for the five dams chosen for further analysis were estimated for each event through the Level 2 Hazus analysis. Table 7-4 summarizes the results.

Table 7-4. Estimated Dam Failure Impacts on Population

Number of Displaced Residents	44,359
Number of Residents Requiring Short Term Shelter	3,157

7.4.2 Property

Vulnerable properties are those closest to the dam inundation zone. These properties would experience the largest, most destructive surge of water. Low-lying areas are also vulnerable since they are where the dam waters would collect. Properties in the dam inundation zone that are built to National Flood Insurance Program (NFIP) minimum construction standards may have some level of protection against dam inundation, depending on the velocity and elevation of the inundation waters. These properties also are more likely to have flood insurance. Table 7-5 summarizes the loss estimates for dam failure.

Table 7-5. Estimated Impact of a Dam Failure in the Planning Area

Number of Buildings Impacted	25,402
Estimated Loss, Structures	$7,546,212,770
Estimated Loss, Contents	$7,923,438,235
Estimated Loss, Total	$15,469,651,005
Total Loss as % of Total Replacement Value	7.1%

7.4.3 Critical Facilities

Hazus estimated damage to critical facilities in the dam failure inundation zones as summarized in Figure 7-6. Typical vulnerabilities of these facilities include the following:

- Transportation routes are vulnerable to dam inundation and have the potential to be wiped out, creating isolation issues and significant disruption to travel. Those that are most vulnerable are those that are already in poor condition and would not be able to withstand a large water surge.
- Utilities such as overhead power lines, cable and phone lines in the inundation zone could also be vulnerable. If phone lines were lost, significant communication issues may occur in the planning area due to limited cell phone reception in many areas.
- In addition, emergency response would be hindered due to the loss of transportation routes as well as some protective-function facilities in the safety and security category located in the inundation zone. Recovery time to restore many critical functions after an event may be lengthy.

7.4.4 Environment

The environment would be vulnerable to a number of risks in the event of dam failure. The inundation could introduce foreign elements into local waterways, resulting in destruction of downstream habitat and detrimental effects on many species of animals, especially endangered species such as the tidewater goby.

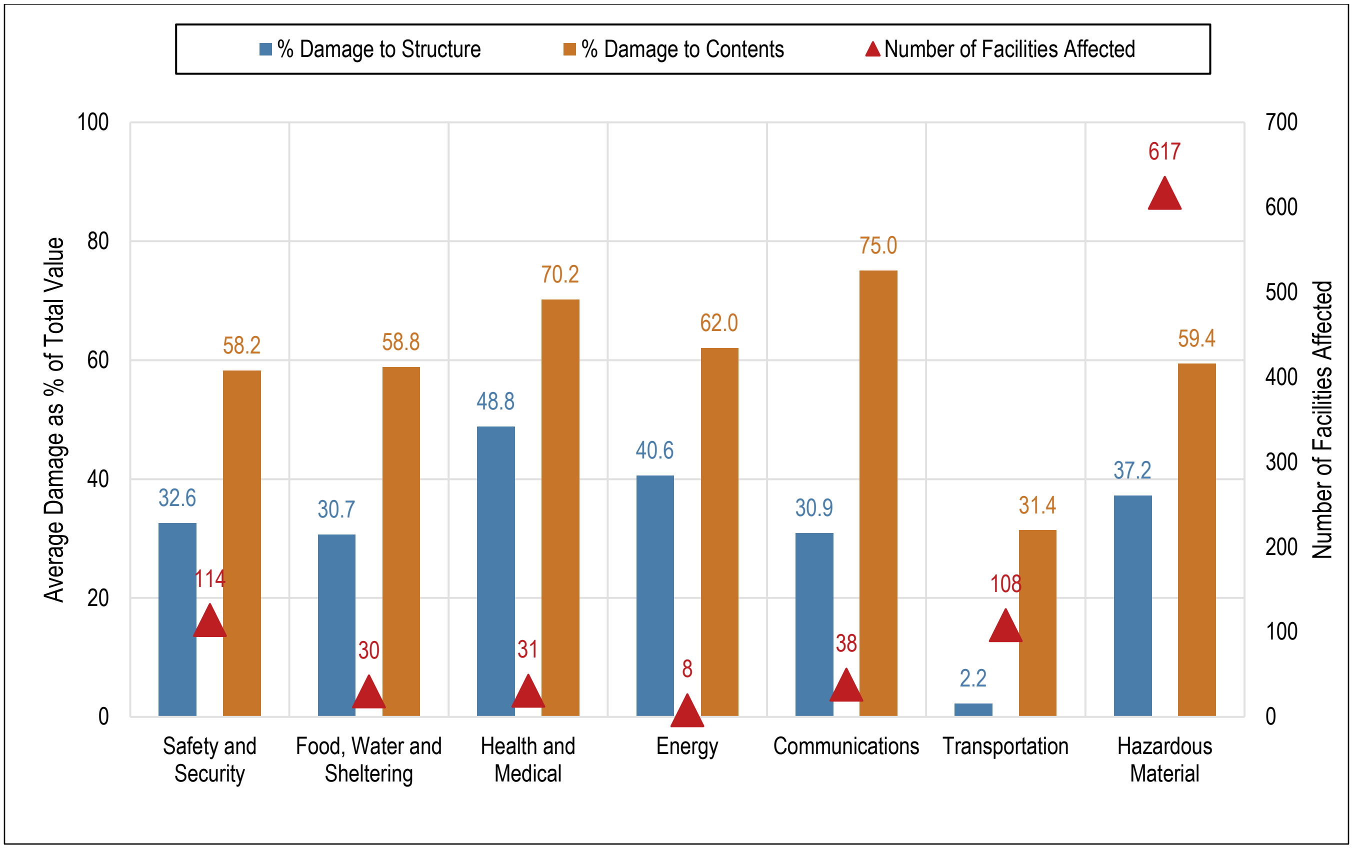


Figure 7-6. Estimated Damage to Critical Facilities from Dam Failure

7.5 FUTURE TRENDS IN DEVELOPMENT

Land use in the planning area will be directed by general plans adopted under state law. The safety elements of the general plans establish standards and plans for the protection of the community from hazards. Dam failure is currently not addressed as a stand-alone hazard in the safety elements, but flooding is. Municipalities participating in this plan have established comprehensive policies regarding sound land use in identified flood hazard areas. Any structures that are built in the dam failure inundation area outside of the regulated floodplain will not be subject to floodplain management codes and standards. These structures would be more vulnerable than those constructed with floodplain codes and standards. Flood-related policies in the general plans will help to reduce the risk associated with dam failure for all future development in the planning area.

7.6 SCENARIO

In a worst-case scenario, an earthquake could lead to liquefaction of the ground soils where the dams that impact the planning area are located, causing the dams to fail. This could occur without warning in the middle of the night when downstream residents are asleep and unprepared to evacuate. A human-caused failure such as a terrorist attack also could trigger a catastrophic failure of one of the dams.

7.7 ISSUES

The most significant issue associated with dam failure involves the properties and populations in the inundation zone. Flooding as a result of a dam failure would significantly impact these areas. There is often limited warning time for dam failures, which are frequently associated with other natural hazard events such as earthquakes, landslides, or severe weather. Important issues associated with the dam failure hazard include the following:

- Dam infrastructure may require repair and improvement to withstand climate change impacts, such as changing in the timing and intensity of rain events.
- Structures located in the dam inundation zone may be located outside of special flood hazard areas, meaning that they are not constructed to withstand floodwaters and are less likely to be covered by flood insurance. Even structures that have been designed with flood hazards in mind may not be able to withstand the height and velocity of flow from a dam failure event.
- California law requires that a property's location in a dam inundation area be disclosed to a seller if the seller or the seller's agent has knowledge of the property's location within the hazard area or if the local jurisdiction has compiled a list of parcels that are in the inundation area and has posted at the offices of the county recorder, county assessor, and county planning agency a notice that identifies the location of the list. It is unknown if this list has been compiled for the planning area.
- The concept of residual risk associated with structural flood control projects should be considered in the design of capital projects and the application of land use regulations.
- Federally regulated dams have an adequate level of oversight and sophistication in the development of emergency action plans for public notification in the unlikely event of failure. However, the protocol for notification of downstream citizens of imminent failure needs to be tied to local emergency response planning.

8. DROUGHT

8.1 GENERAL BACKGROUND

Drought is a significant decrease in water supply relative to what is needed to sufficiently meet typical demand in each location. It is a normal phase in the Mediterranean climate cycle, originating from a deficiency of precipitation over an extended period, usually a season or more. This leads to a water shortage for some activity, group, or environmental sector. Drought is generally defined based on four ways of measuring it (National Drought Mitigation Center, 2021):

- **Meteorological drought**—Based on measurements such as precipitation deficit compared to normal or expected precipitation. Anomalies of precipitation and temperature may last from several months to several decades. How long they last depend on interactions between the atmosphere and the oceans, soil moisture and land surface processes, topography, internal dynamics, and the accumulated influence of global weather systems.
- **Agricultural drought**—Based on impacts due to reduced precipitation and water supply (e.g., crop loss, herd culling, etc.)
- **Hydrological drought**—Based on measurements of stream flows, groundwater, and reservoir levels relative to normal conditions
- **Socioeconomic drought**—Based on direct and indirect socio-economic impacts on society and the economy. Socioeconomic drought occurs when the demand for an economic good exceeds supply as a result of a weather-related shortfall in water supply. If a community has stored enough water to meet its needs in the event of a shortage of rainfall, then it may not experience socioeconomic drought even though its geographic area experiences meteorological drought.

8.1.1 Monitoring and Categorizing Drought

<u>NOAA Drought Indices</u>

The National Oceanic and Atmospheric Administration (NOAA) has developed several indices to measure the impacts and severity of meteorological, agricultural, and hydrological drought and to map their extent and locations:

- The ***Crop Moisture Index*** measures short-term drought weekly to assess impacts on agriculture.
- The ***Palmer Z Index*** measures short-term drought on a monthly scale.
- The ***Palmer Drought Severity Index*** is based on long-term weather patterns. The intensity of drought in a given month is dependent on current weather plus the cumulative patterns of previous months. Weather patterns can change quickly, and the Palmer Drought Severity Index can respond fairly rapidly.

- The ***Palmer Hydrological Drought Index*** quantifies hydrological effects (reservoir levels, groundwater levels, etc.), which take longer to develop and last longer. This index responds more slowly to changing conditions than the Palmer Drought Index.
- The ***Standardized Precipitation Index*** considers only precipitation. A value of zero indicates the median precipitation amount; the index is negative for drought and positive for wet conditions. The Standardized Precipitation Index is computed for time scales ranging from one month to 24 months.

Each of these indices is meaningful for different sectors of society and the economy. For example an urbanized areas that uses water from reservoirs would be sensitive to hydrological drought characterized by the Palmer Hydrological Drought Index, while unirrigated grazing land would be sensitive to meteorological drought characterized by the Crop Moisture Index. Maps of these indices show drought conditions nationwide at a given point in time. They are not necessarily indicators of any given area's long-term susceptibility to drought. Recent examples of these maps are shown on Figure 8-1.

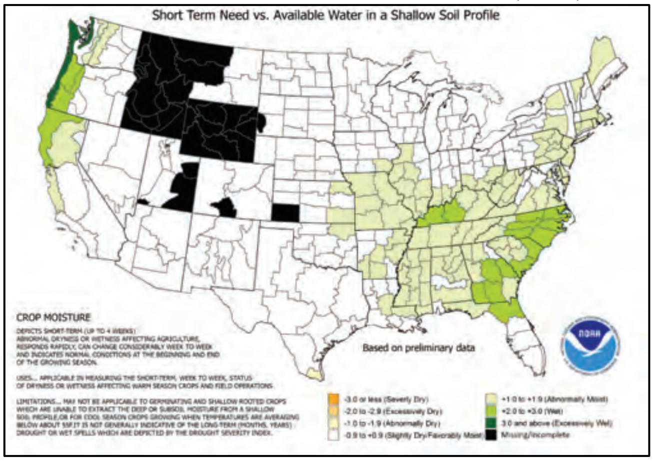
U.S. Drought Monitor

The U.S. Drought Monitor (USDM) is a map that is updated weekly to show the location and intensity of drought across the country. The USDM uses a five-category system (USDM, 2021):

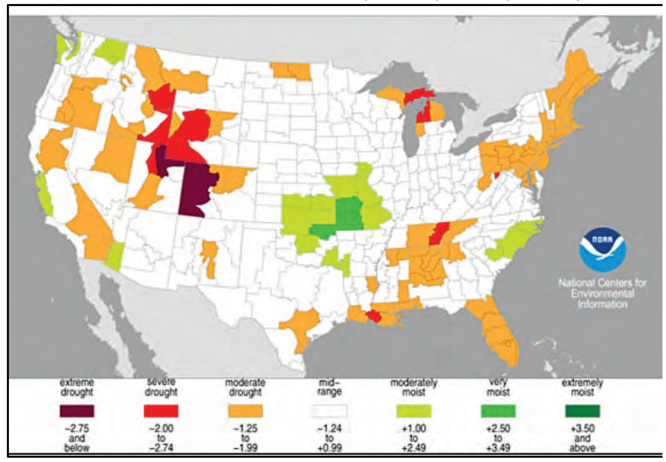
- D0—Abnormally Dry
  - Short-term dryness slowing planting, growth of crops
  - Some lingering water deficits
  - Pastures or crops not fully recovered
- D1—Moderate Drought
  - Some damage to crops, pastures
  - Some water shortages developing
  - Voluntary water-use restrictions requested
- D2—Severe 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

The USDM categories show experts' assessments of conditions related to drought. These experts check variables including temperature, soil moisture, stream flow, water levels in reservoirs and lakes, snow cover, and meltwater runoff. They also check whether areas are showing drought impacts such as water shortages and business interruptions. Associated statistics show what proportion of various geographic areas are in each category of dryness or drought, and how many people are affected. U.S. Drought Monitor data go back to 2000.

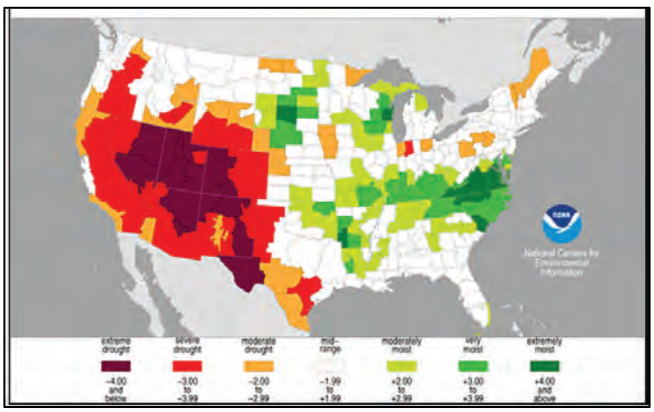
Sources: National Weather Service, 2021; National Centers for Environmental Information, 2021a, 2021b, 2021c, 2021d



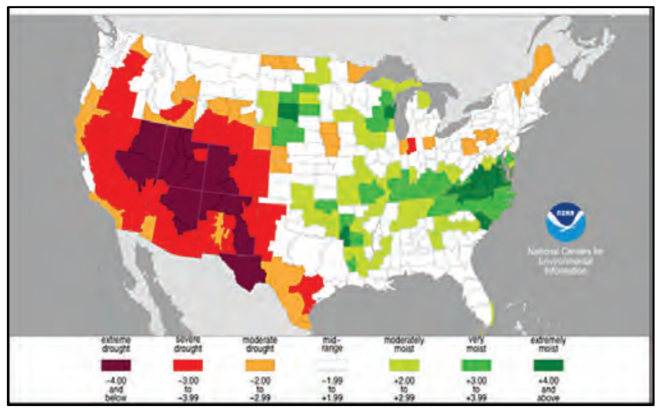
Crop Moisture Index (Week Ending February 06, 2020)



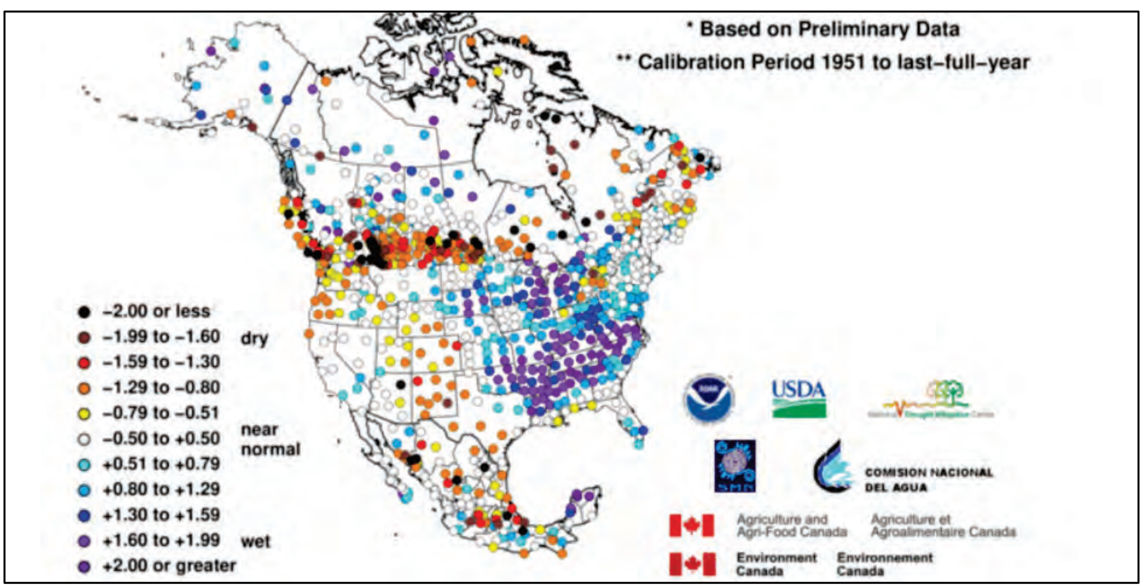
Palmer Z Index Short-Term Drought Conditions (January 2021)



Palmer Drought Severity Index (January 2021)



Palmer Hydrological Drought Index (January 2021)



Standardized Precipitation Index (24-Months Ending December 2020)

Figure 8-1. Standard National Drought and Precipitation Indices

8.1.2 Drought Impacts

Drought can have a widespread impact on the environment and the economy, although it typically does not result in loss of life or damage to structures, as do other natural disasters. The National Drought Mitigation Center uses three categories to describe likely drought impacts:

- **Economic Impacts**—These impacts of drought cost people (or businesses) money. Farmers' crops are destroyed; low water supply necessitates spending on irrigation system modifications, drilling of new wells, and/or trucking in water; water-related businesses (such as sales of boats and fishing equipment) may experience reduced revenue.
- **Environmental Impacts**—Plants and animals depend on water. When a drought occurs, their food supply can shrink, and their habitat can be damaged.
- **Social Impacts**—Social impacts include public safety, health, conflicts between people when there is not enough water to go around, and changes in lifestyle.

The demand that society places on water systems and supplies—such as expanding populations, irrigation, and environmental needs—contributes to drought impacts. Drought can lead to difficult decisions regarding the allocation of water, as well as stringent water use restrictions, water quality problems, and inadequate water supplies for fire suppression. There are also issues such as growing conflicts between agricultural uses of surface water and in-stream uses, surface water and groundwater interrelationships, and the effects of growing water demand on uses of water.

Vulnerability of an activity to drought depends on its water demand and the water supplies available to meet the demand. The impacts of drought vary between sectors of the community in both timing and severity:

- **Water supply—**The water supply sector encompasses urban and rural drinking water systems that are affected when a drought depletes surface and groundwater supplies due to reduced runoff and recharge from precipitation.
- **Agriculture and commerce—**Impacts on agriculture and associated commerce include the reduction of crop yield and livestock sizes due to insufficient water supply for crop irrigation and maintenance of ground cover for grazing.
- **Environment, public health, and safety—**Impacts on the environmental, public health, and safety sectors include wildfires that are both detrimental to the forest ecosystem and hazardous to the public. The impacts also includes the desiccation of streams, resulting in the reduction of in-stream habitats for native species.

8.1.3 California Drought Response

During critically dry years, the California State Water Resources Control Board can mandate conservation by water users and agencies to address statewide water shortages. Table 8-1 lists State Drought Management Program stages mandated to water right holders.

Table 8-1. State Drought Management Program

Drought Stage	State Mandated Customer Demand Reduction	Rate Impacts
Stage 0 or 1	<10%	Normal rates
Stage 2	10 to 15%	Normal rates; Drought surcharge
Stage 3	15 to 20%	Normal rates; Drought surcharge
Stage 4	>20%	Normal rates, Drought surcharge

8.2 HAZARD PROFILE

8.2.1 Local Water Use and Supply

Sonoma County has two principal sources of water for residential, commercial, industrial, and agricultural use: the Russian River and groundwater. Additional water sources include diversions from small streams and springs and numerous reservoirs. Major users of Russian River water in Sonoma County are the cities of Cloverdale and Healdsburg, numerous individual diverters along the main stem of the Russian River and Dry Creek, and the Sonoma County Water Agency (Sonoma Water). About 73 percent of Sonoma County residents live in cities served by public water systems. Most residents of the unincorporated rural areas are outside urban service areas and are dependent on individual onsite wells or small-scale shared water supply systems.

Sonoma Water

Infrastructure

Sonoma Water serves the urbanized areas of Sonoma County and northern Marin County with water from the Russian River. The agency's extensive water supply infrastructure generally mitigates the effects of short-term dry periods for most water users (see Figure 8-2):

- Two major reservoirs regulate flow on the Russian River:
    - Sonoma Water and the Mendocino County Russian River Flood Control and Water Conservation Improvement District have water right permits authorizing storage up to the design capacity of 122,500 acre-feet per year in the Lake Mendocino reservoir (Coyote Valley Dam) in Mendocino County. Sonoma Water controls releases from the water supply pool in Lake Mendocino. However, the Corps manages flood control releases when the water level exceeds the top of the water supply pool elevation.
    - The Warm Springs Dam impounds water on Dry creek in Sonoma County forming Lake Sonoma, which has a total water supply capacity of 245,000 acre-feet (Sonoma Water, 2021a). Sonoma Water controls water supply releases from Lake Sonoma and the Corps manages flood control releases.
- Sonoma Water diverts water from the Russian River near Forestville and conveys the water via its transmission system (including diversion facilities, treatment facilities, aqueducts, pipelines, water storage tanks, and booster pump stations) to its customers.

Source: (Sonoma Water n.d.)

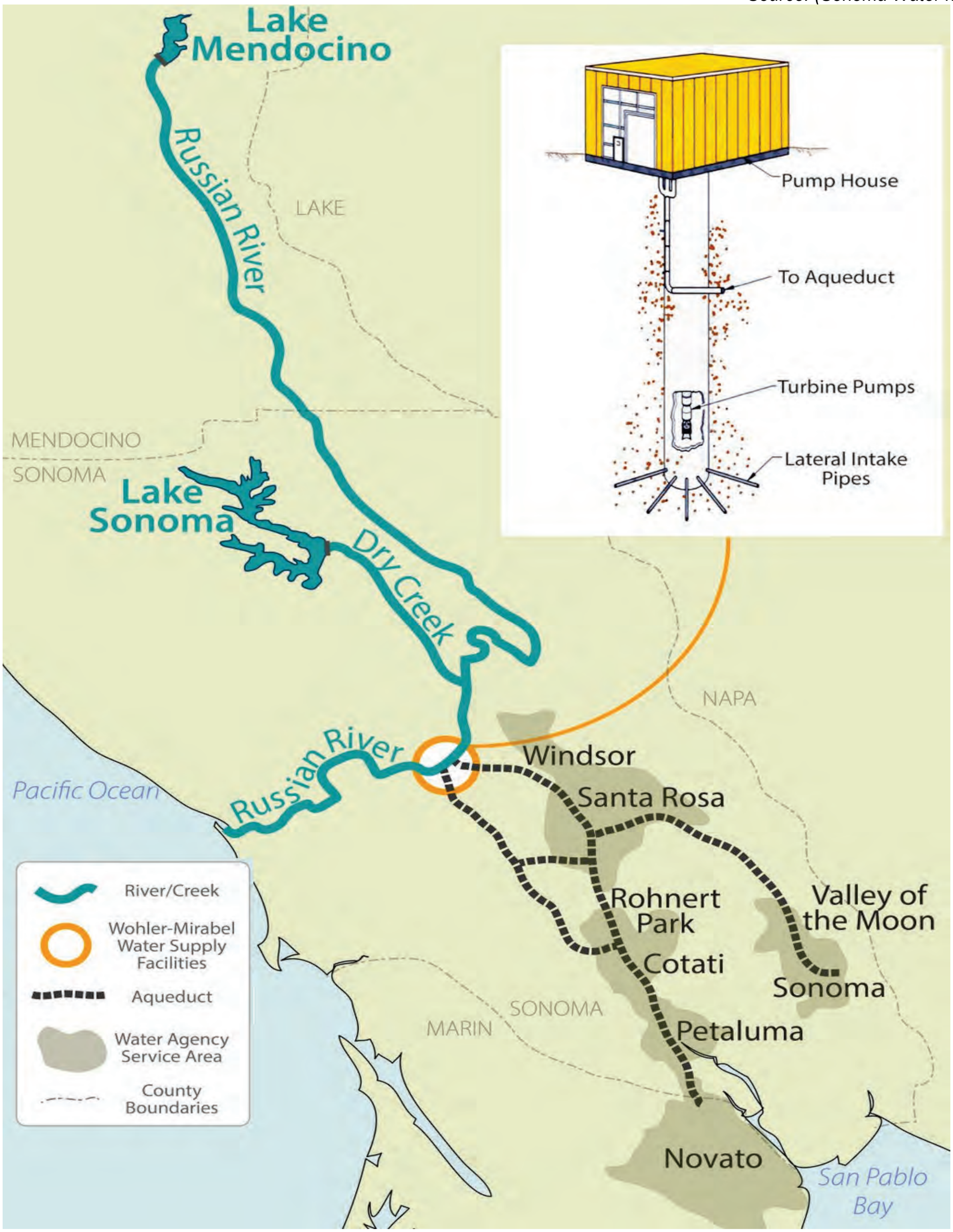


Figure 8-2. Russian River Watershed and the Sonoma Water Supply System

Planning Efforts

In accordance with California's Urban Water Management Planning Act, Sonoma Water is updating its *Urban Water Management Plan* and *Water Shortage Contingency Plan*. The updated plan will describe the following (Sonoma Water 2021):

- Existing water supplies and transmission system facilities
- Projected water demand in Sonoma Water's service area over the next 25 years
- Projected water supplies available to Sonoma Water over the next 25 years, the reliability of that supply, and general schedules for water supply projects
- Climate change impacts on the water supply
- Energy intensity
- Current and planned water conservation activities
- A comparison of water supply and water demand over the next 25 years under different hydrological assumptions (normal year, single dry year, multiple dry years).

Some municipalities in Sonoma County receive water deliveries from Sonoma Water and augment these with local supply, such as municipal groundwater supply wells. Most municipalities are currently updating their urban water management plans and water storage contingency plans to estimate projected water demand and water supply to ensure adequate drinking water is available for all users.

Sonoma Water's 2018 *Water Supply Strategies Action Plan*, a regional planning document to increase water supply system reliability, reported the following progress on water efficiency goals and new plans for the future (Sonoma Water 2018).

- Groundwater Sustainability Plans are being developed.
- Two Stormwater Resource Plans increase the region's ability to leverage grant funding and prioritize multi-beneficial projects.
- Continued development of forecast-informed reservoir operation strategies
- Following a multi-year drought in which water demands were significantly reduced, the region committed to extending the Sonoma Marin Saving Water Partnership memorandum or understanding.
- Advanced quantitative precipitation information from radar units that can provide critical information on location, timing, and intensity of precipitation throughout the Bay Area.
- Increased coordination with Lake Mendocino water users including Potter Valley Project relicensing activities.
- Climate adaptation planning to identify strategies to address climate risks and vulnerabilities to ensure an increased understanding of water supply reliability impacts.

Other Public Water Systems

In addition to Sonoma Water, municipalities and water districts provide water to customers throughout Sonoma County. About two dozen such systems serve 1,000 customers or more. The City of Santa Rosa serves nearly 180,000 customers. The cities of Petaluma, Rohnert Park, Healdsburg, and Sonoma, and the Town of Windsor, serve between 10,000 and 60,000 customers. Some of the public systems in the county are entirely reliant on groundwater; others have a mix of sources. Some purchase Russian River water through Sonoma Water or have separate surface water rights.

Small Water Systems

About 70 small water systems (defined as having between 5 to 14 service connections) supply water in Sonoma County, serving campgrounds, small commercial establishments, mobile home parks, isolated rural residences and subdivisions, and small unincorporated communities. Permitting, inspecting, and monitoring are conducted through County Department of Health Services, Division of Environmental Health. The vulnerability of these systems varies, depending on their location, water supply, and available storage and demand (County of Sonoma 2017).

Private Wells

Private wells are vulnerable wherever limited recharge and excessive withdrawals lead to a decline in groundwater levels. Groundwater availability and aquifer conditions vary widely in the county, but shallow wells and wells in upland areas may be particularly vulnerable. Private wells considered most vulnerable to drought are located in the marginal groundwater areas (Class 3 and 4 on Figure 8-3), though groundwater levels can be adversely affected in major (Class 1) groundwater basins as well (County of Sonoma 2017).

Surface Water

Users who are reliant on surface water are most vulnerable to drought. This includes water right holders along the upper Russian River, and small reservoirs throughout the County that are reliant on each season's rainfall to fill the reservoir. The west Petaluma area has been severely impacted when ponds and reservoirs do not fill.

8.2.2 Past Events

Periods of Drought in California

The following sections describe prolonged droughts in California that have impacted the planning area.

2012 to 2017 Drought

California's last drought set several records for the state. The period from 2012 to 2014 ranked as the driest three consecutive years for statewide precipitation. Calendar year 2014 set new records for statewide average temperatures and for record-low water allocations from the State Water Project and the federal Central Valley Project. Calendar year 2013 set minimum annual precipitation records for many communities. Detailed executive orders and regulations addressed water conservation and management. The statewide drought emergency was lifted in April 2017. In Sonoma County, the Board of Supervisors proclaimed a local emergency due to drought conditions on February 25, 2014. That proclamation covered all of Sonoma County, including all nine cities and special districts and was continued until March 1, 2016. This proclamation was guided by mandatory state emergency conservation regulations issued to all water providers in California (County of Sonoma 2017).

Source: Sonoma County 2021b

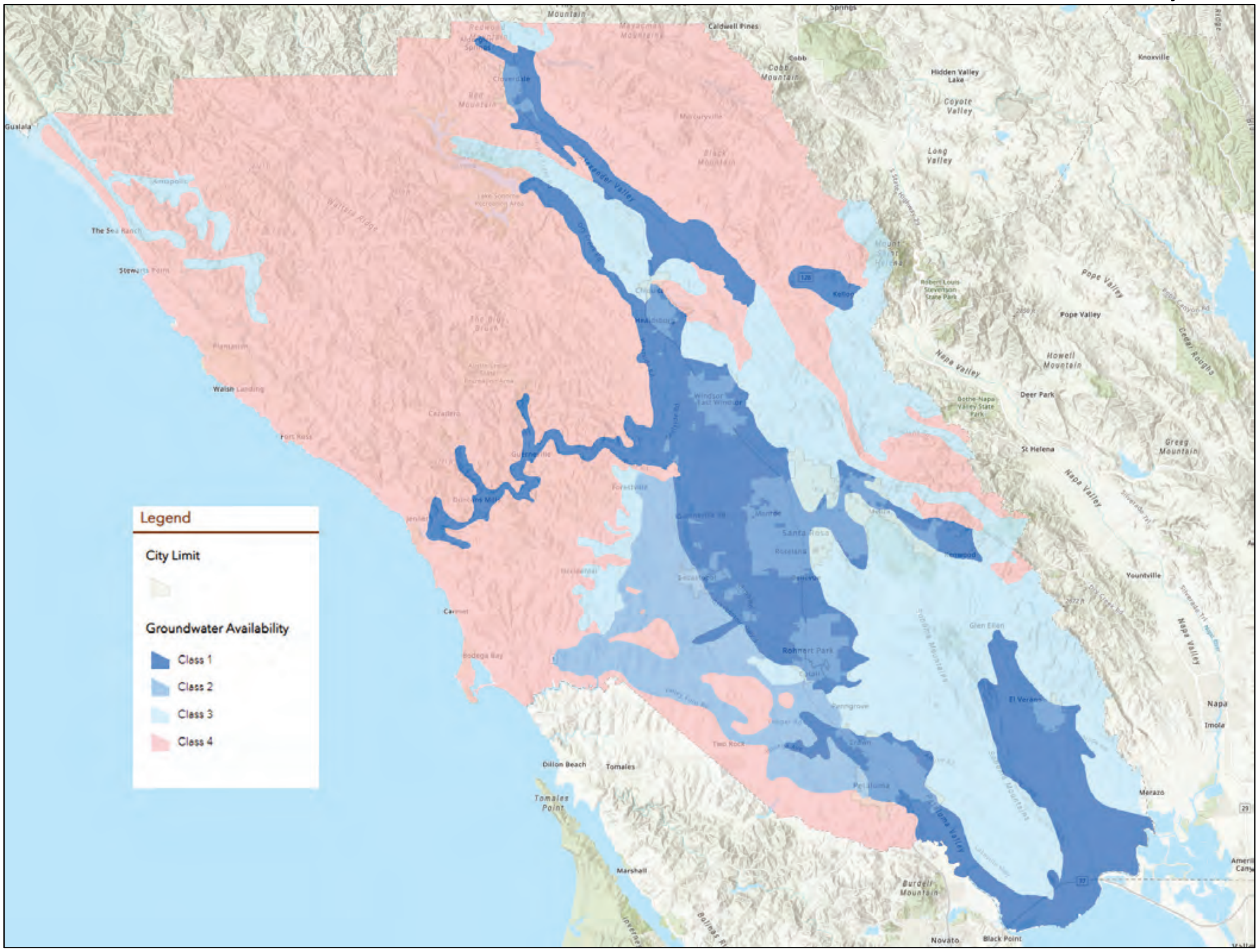


Figure 8-3. Groundwater Availability in Sonoma County

2007 to 2009 Drought

The state proclaimed a statewide drought emergency on June 4, 2008 after spring 2008 was the driest spring on record, with low snowmelt runoff. On February 27, 2009, the state proclaimed a state of emergency for the entire state as severe drought continued. The largest court-ordered water restriction in state history (at the time) was imposed. In Sonoma County, abnormally dry to extreme drought conditions occurred from April 2007 to January 2012. At the height of drought severity in 2009, Lake Sonoma was 74 percent full. Lake Mendocino was 38 percent full in 2009. After two dry years, and only 7.28 inches of rain—compared to 15.5 inches in 2008—the area was listed by the U.S. Drought Monitor as in a D2 (severe drought) condition (County of Sonoma 2017).

1987 to 1992 Drought

California received precipitation well below average levels for four consecutive years. While the Central Coast was most affected, the Sierra Nevada range in Northern California and the Central Valley counties were also affected. During this drought, only 56 percent of average runoff for the Sacramento Valley was received. In 1991, the State Water Project sharply decreased deliveries to water suppliers. By February 1991, all 58 counties in California were experiencing drought. Urban areas as well as agricultural areas were impacted.

1976 to 1977 Drought

California had a severe drought due to lack of precipitation in the winters of 1976 and 1977. 1977 was the driest period on record in California at that time,. The cumulative impact led to widespread water shortages and severe water conservation measures statewide. Over $2.6 billion in crop damage was recorded in 31 counties. FEMA declared a drought emergency (Declaration 3023-EM) on January 20, 1977 for 58 California counties. In Sonoma County, the Russian River saw only 6 percent of its normal runoff in 1977. The reduction of flow from this water source significantly impacted communities throughout Sonoma, Marin, and Mendocino counties. The Sonoma Water Board of Directors proclaimed an emergency for the Russian River Water Supply in February 1976 and the County Board of Supervisors proclaimed a local emergency in July 1976. The response required implementation of water conservation measures and construction of emergency wells to augment supplies (County of Sonoma 2017).

Agriculture-Related Drought Disasters

The U.S. Department of Agriculture (USDA) Farm Service Agency provides assistance for agriculture-related losses resulting from drought, flood, fire, freeze, tornadoes, pest infestation, and other natural disasters. The U.S. Secretary of Agriculture is authorized to designate counties as disaster areas to make emergency loans to producers suffering losses in those counties and in counties that are contiguous to them. Between 2012 and 2020, the period for which data is available, Sonoma County was included in drought-related USDA declarations in 2012, 2013, 2014, 2015, 2016, 2017, and 2020 (USDA Farm Services Agency, 2021).

8.2.3 Location

Drought is a regional phenomenon that has the potential to impact the entire planning area. A drought affects all aspects of the environment and the community simultaneously and has the potential to directly or indirectly impact every person in the planning area as well as adversely affect the local economy.

8.2.4 Frequency

Drought has a high probability of occurrence in the planning area. From January 2000 to May 2020, some part of Sonoma County experienced a USDM rating of D1 or higher in 370 out of 1,065 weeks—slightly more than one out of every three weeks (see Figure 8-4). Sonoma County has also been included in USDA drought disaster declarations seven times since 2012. Historical drought data for the planning area indicate there have been four significant multi-year droughts in the last 40 years (1980 to 2020), amounting to a severe drought every 10 to 11 years on average.

8.2.5 Severity

The severity of any given drought depends on many factors. Driving factors are the amount and timing of precipitation, duration of below average rainfall, and the size and location of the affected area. The longer the duration of the drought and the larger the area impacted, the more severe the potential impacts.

Source: U.S. Drought Monitor, 2020

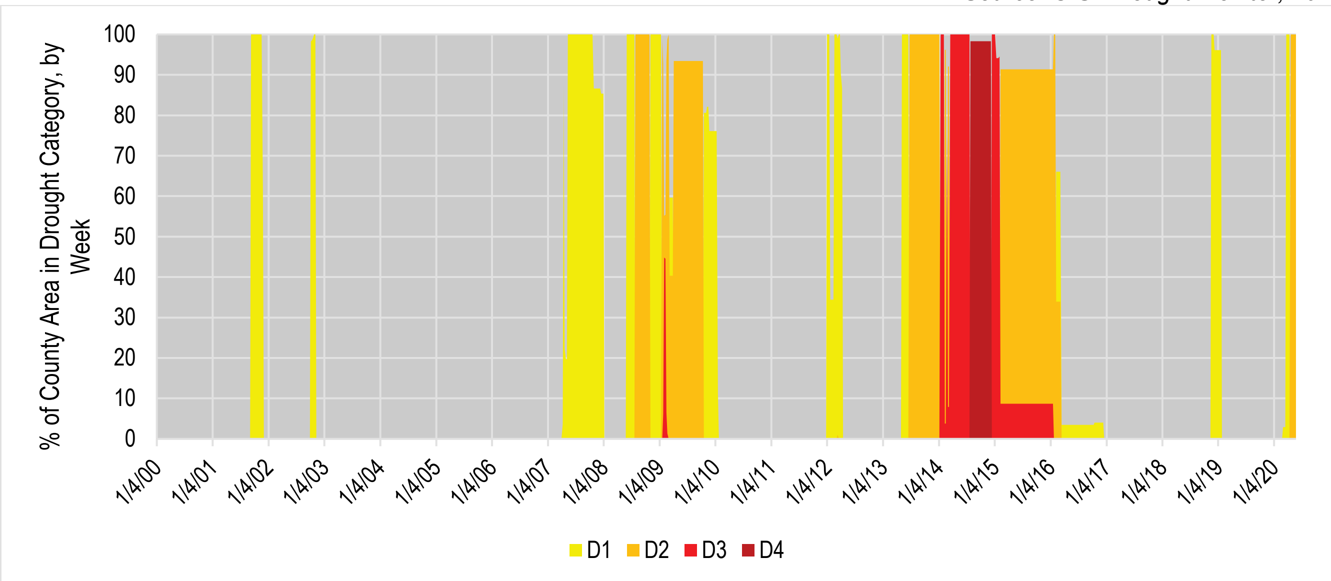


Figure 8-4. Percent of Sonoma County Affected by Each USDM Rating, 2000 – 2020

U.S. Drought Monitor Ratings

Sonoma County has a history of severe droughts. As shown in Figure 8-4, at least part of the county has experienced extreme (D3) or exceptional (D4) droughts more than once since 2000.

Drought Impact Reporter

The National Drought Mitigation Center developed the Drought Impact Reporter in response to the need for a national drought impact database for the United States. Information comes from a variety of sources: on-line, drought-related news stories and scientific publications, members of the public who visit the website and submit a drought-related impact for their region, members of the media, and staff of government agencies. The database is being populated beginning with the most recent impacts and working backward in time.

The Drought Impact Reporter indicates 149 impacts from drought that specifically affected Sonoma County from January 2010 through December 2019 (Drought Impact Reporter, 2020). Most (88.5 percent) are based on media reports. The following are the reported numbers of impacts by category (some incidents are assigned to more than one impact category):

- Agriculture—43
- Business and Industry—11
- Energy—6
- Fire—18
- Plants and Wildlife—49
- Relief, Response, and Restrictions—70
- Society and Public Health—54

- Tourism and Recreation—13
- Water Supply and Quality—82

Potential Agricultural Impact

The agricultural industry's dependency upon water for production and processing makes it vulnerable to drought conditions. For example, the 2014 Sonoma County Crop Report indicated that field crops saw significant damage due to drought. Many of the crops produced one third of their normal yield; volunteer hay yield was 37 percent of the five-year average and grain oats produced just 33 percent. Pasture and rangeland were severely impacted, with yields of 38 percent and 26 percent of normal. The 2019 Sonoma County Crop Report indicated record rainfall in the winter and growth in the value of nursery product due to landscape and lawn replacement efforts. Since this nursery increase was largely of drought-resistant plants, decreased water availability remains an issue of concern.

8.2.6 Warning Time

Predicting drought depends on the ability to forecast precipitation and temperature. Only generalized warning can take place due to the numerous variables that scientists have not pieced together well enough to make accurate and precise predictions.

Determination of when drought begins is based on impacts on water users and assessments of available water supply, including water stored in reservoirs or groundwater basins. Different water agencies have different criteria for defining drought. Some issue drought watch or drought warning announcements.

8.2.7 Secondary Hazards

The secondary hazard most associated with drought is wildfire. A prolonged lack of precipitation dries out vegetation, which becomes increasingly susceptible to ignition as the duration of the drought extends. In addition, lack of sufficient water resources can stress trees and other vegetation, making them more vulnerable to infestation from pests, which in turn, can make them more vulnerable to ignition. Millions of board feet of timber have been lost, and in many cases erosion occurred, which caused serious damage to aquatic life, irrigation, and power production by heavy silting of streams, reservoirs, and rivers.

8.3 EXPOSURE

All people, property and environments in the planning area would be exposed to some degree to the impacts of moderate to extreme drought conditions.

8.4 VULNERABILITY

8.4.1 Population

The entire population of the county is vulnerable to drought events. Drought can affect people's health and safety, including health problems related to low water flows, poor water quality, or dust. Droughts can also lead to loss of human life. Other possible impacts include recreational risks; effects on air quality; diminished living conditions related to energy, air quality, and hygiene; compromised food and nutrition; and increased incidence of illness and disease (Centers for Disease Control and Prevention, 2012). A secondary, indirect impact from drought is an increase in wildfire risk. The vulnerability of the planning area population to the wildfire risk is discussed in Chapter 15.

8.4.2 Property

No structures will be directly affected by drought conditions, though some structures may become vulnerable to wildfires, which are more likely following years of drought. Droughts can have significant impacts on other types of property such as landscaped areas and economically important natural resources. Drought causes the most significant economic impacts on industries that use water or depend on water for their business, most notably agriculture and related sectors (forestry, fisheries, and waterborne activities), power plants (including geothermal power production), and oil refineries. In addition to losses in yields in crop and livestock production, drought is associated with increased insect infestations, plant diseases, and wind erosion. Drought can lead to other losses because so many sectors are affected - losses that include reduced income for farmers and reduced business for retailers and others who provide goods and services to farmers. This leads to unemployment, increased credit risk for financial institutions, capital shortfalls, and loss of tax revenue. Prices for food, energy, and other products may also increase as supplies decrease.

8.4.3 Critical Facilities

Critical facilities as defined for this plan will continue to be operational during a drought. Critical facility features such as landscaping may not be maintained due to limited water resources, but the risk to critical facility core functions is low.

8.4.4 Environment

Groundwater and Streams

Drought generally does not affect groundwater sources as quickly as surface water supplies, but groundwater supplies generally take longer to recover. Reduced precipitation during a drought means that groundwater supplies are not replenished at a normal rate. This can lead to a reduction in groundwater levels and problems such as reduced pumping capacity or wells going dry. Shallow wells are more susceptible than deep wells. Reduced replenishment of groundwater affects streams, especially during the summer when there is little or no precipitation. Reduced groundwater levels mean that even less water will enter streams when stream flows are lowest. Where stream flows are reduced, development that relies on surface water may seek to establish new groundwater wells, which could further increase groundwater depletion.

Other Potential Losses

Environmental losses from drought are associated with damage to plants, animals, wildlife habitat, and air and water quality; forest and range fires; degradation of landscape quality; loss of biodiversity; and soil erosion. Some of the effects are short-term and conditions quickly return to normal following the end of the drought. Other environmental effects linger for some time or may even become permanent. Although environmental losses are difficult to quantify, growing public awareness and concern for environmental quality has forced public officials to focus greater attention and resources on these effects. The following are potential impacts of drought:

- Wildlife habitat may be degraded through the loss of wetlands, lakes and vegetation. The degradation of landscape quality, including increased soil erosion, may lead to a more permanent loss of biological productivity.

- Drought conditions greatly increase the likelihood of wildfires, a major threat to timber resources, structures, and other property.
- Water shortages and severe drought conditions would have a significant impact on Native American tribes' way of life in fishing and farming subsistence.
- Scenic resources in the county are vulnerable to the increased likelihood of wildfires associated with droughts.
- Drying up or dying off of forests could reduce ecological and eco-tourist values.
- Shortage of water supply can have significant economic impacts.
- Drought conditions often are associated with harmful algal blooms—specifically cyanobacteria that can cause severe illness and death in mammals.

8.5 FUTURE TRENDS IN DEVELOPMENT

All municipal planning partners in this effort have established general plans that include policies directing land use. They also have adopted local urban water management plans and water shortage contingency plans dealing with issues of long-term water supply planning and the protection of water resources. These plans provide the capability at the local municipal level to protect future development from the impacts of drought. All planning partners reviewed these plans under the capability assessments performed for this effort. Deficiencies identified by these reviews can be identified as mitigation actions to increase the capability to deal with future trends in development. In addition, water providers in the planning area have plans and programs in place to balance competing needs for water resources within the planning area.

Sonoma Water and its water contractors participate in the Sonoma Marin Water Saving Partnership to develop, fund, and implement water conservation to ensure careful use of water as a precious resource. Measures to promote water conservation and provide incentives for investment in long-term water savings are developed, funded, and implemented.

8.6 SCENARIO

A multi-year drought that impacts the entire west or the State of California is the worst-case scenario for the planning area. In the past, such droughts and the wildfires and floods that followed them have caused extensive damage to natural systems. If another severe drought occurs before these systems have a chance to recover, it could exacerbate the stress already placed on existing planning area water resources.

8.7 ISSUES

The planning team has identified the following drought-related issues:

- The promotion of additional demand management and water conservation efforts even during non-drought periods should be encouraged.
- The planning area should plan for frequent droughts or multi-year droughts that can limit the ability to successfully recover from one drought and prepare for the next—particularly considering the longevity of the 2012 to 2017 drought.

- Water planning should consider impacts of additional drawn downs on groundwater supplies as pressure on surface water increases during drought.
- Drought in the county will increase and expand fire-prone areas and adversely affect the timber economy.
- With the possibility of climate change, drought may become a more pervasive issue due to warming trends and wider fluctuations in precipitation patterns. The probability of drought frequencies and durations may increase.
- Alternative water supplies or increased use of recycled water will need to be identified and developed, as well as alternative strategies to allocate and distribute existing water sources.
- Groundwater recharge techniques can be used to increase available water in storage and stabilize the groundwater supply.

9. EARTHQUAKE

9.1 GENERAL BACKGROUND

An earthquake is the vibration of the earth's surface following a release of energy in the earth's crust. This energy can be generated by a sudden dislocation of the crust or by a volcanic eruption. Most destructive quakes are caused by dislocations of the crust. The crust may first bend and then, when the stress exceeds the strength of the rocks, break and snap to a new position. In the process of breaking, vibrations called "seismic waves" are generated. These waves travel outward from the source of the earthquake at varying speeds.

9.1.1 Earthquake Location

The location of an earthquake is commonly described by its focal depth and the geographic position of its epicenter. The focal depth of an earthquake is the depth from the Earth's surface to the region where an earthquake's energy originates (the focus or hypocenter). The epicenter of an earthquake is the point on the Earth's surface directly above the hypocenter.

9.1.2 Earthquake Geology

Tectonic Plates

The Earth's crust, which is the rigid outermost shell of the planet, is broken into seven or eight major tectonic plates (depending on how they are defined) and many minor plates. Where the plates meet, they move in one of three ways along their mutual boundary: convergent (two plates moving together), divergent (two plates moving apart), or transform (two plates moving parallel to one another). Earthquakes, volcanic activity, mountain-building, and oceanic trench formation occur along plate boundaries. Subduction is a geological process that takes place at convergent boundaries of tectonic plate, in which one plate moves under another. Regions where this process occurs are known as subduction zones, and they have the potential to generate highly damaging earthquakes.

California is seismically active because of movement of the North American Plate, east of the San Andreas Fault, and the Pacific Plate to the west, which includes the state's coastal communities. The transform (parallel) movement of these tectonic plates against one another creates stresses that build as the rocks are gradually deformed. The rock deformation, or strain, is stored in the rocks as elastic strain energy. When the strength of the rock is exceeded, rupture occurs along a fault. The rocks on opposite sides of the fault slide past each other as they spring back into a more relaxed position. The strain energy is released partly as heat and partly as elastic waves called seismic waves. The passage of these seismic waves produces the ground shaking in earthquakes.

Faults

Geologists have found that earthquakes reoccur along faults, which are zones of weakness in the earth's crust. When a fault experiences an earthquake, there is no guarantee that all the stress has been relieved. Another earthquake can still occur. In fact, relieving stress along one part of a fault may increase it in another part.

Faults are more likely to have future earthquakes on them if they have more rapid rates of movement, have had recent earthquakes along them, experience greater total displacements, and are aligned so that movement can relieve the accumulating tectonic stresses. Geologists classify faults by their relative hazards. "Active" faults, which represent the highest hazard, are those that have ruptured to the ground surface during the Holocene period (about the last 11,000 years). "Potentially active" faults are those that displaced layers of rock from the Quaternary period (the last 1,800,000 years) (California Department of Conservation, 2003).

Determining if a fault is "active" or "potentially active" depends on geologic evidence, which may not be available for every fault. Most of the seismic hazards are associated with well-known active faults. However, inactive faults or concealed faults (referred to as "blind-thrust" faults), where no displacements have been recorded, also have the potential to reactivate or experience displacement along a branch sometime in the future. An example of a fault zone that has been reactivated is the Foothills Fault Zone. The zone was considered inactive until evidence of an earthquake (approximately 1.6 million years ago) was found near Spenceville, California. Then, in 1975, an earthquake occurred on another branch of the zone near Oroville, California (now known as the Cleveland Hills Fault). The State Division of Mines and Geology indicates that increased earthquake activity throughout California may cause tectonic movement along currently inactive fault systems.

9.1.3 Earthquake-Related Hazards

According to the U.S. Geological Survey (USGS) Earthquake Hazards Program, an earthquake hazard is anything associated with an earthquake that may affect resident's normal activities. This includes the following:

- **Surface Faulting**—Displacement that reaches the earth's surface during slip along a fault. Commonly occurs with shallow earthquakes, those with an epicenter less than 20 kilometers.
- **Ground Motion (shaking)**—The movement of the earth's surface from earthquakes or explosions. Ground motion or shaking is produced by waves that are generated by sudden slip on a fault or sudden pressure at the explosive source and travel through the earth and along its surface.
- **Mass Movement—**A movement of surface material down a slope.
- **Liquefaction**—A process by which water-saturated sediment temporarily loses strength and acts as a fluid. Earthquake shaking can cause this effect.
- **Tectonic Deformation**—A change in the original shape of a material due to stress and strain.
- **Tsunami**—A sea wave of local or distant origin that results from large-scale seafloor displacements associated with large earthquakes, major submarine slides, or violent underwater volcanic eruptions.

9.1.4 Earthquake Classifications

Earthquakes are typically classified in one of two ways: By the amount of energy released, measured as magnitude; or by the impact on people and structures, measured as intensity.

Magnitude

An earthquake's magnitude is a measure of the energy released at the source of the earthquake. Magnitude is commonly expressed by ratings on the moment magnitude scale (M_W), the most common scale used today (USGS, 2017). This scale is based on the total moment release of the earthquake (the product of the 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

Intensity

The most used intensity scale is the modified Mercalli intensity scale. Ratings of the scale as well as the perceived shaking and damage potential for structures are shown in Table 9-1. The modified Mercalli intensity scale is generally represented visually using shake maps, which show the expected ground shaking at any given location produced by an earthquake with a specified magnitude and epicenter. An earthquake has only one magnitude and one epicenter, but it produces a range of ground shaking at sites throughout the region, depending on the distance from the earthquake, the rock and soil conditions at sites, and variations in the propagation of seismic waves from the earthquake due to complexities in the structure of the earth's crust. A shake map shows the variation of ground shaking in a region immediately following significant earthquakes (for technical information about shake maps see USGS, 2018).

Table 9-1. Mercalli Scale and Peak Ground Acceleration Comparison

Modified Mercalli Scale	Perceived Shaking	Potential Structure Damage		Estimated PGA[a] (%g)
		Resistant Buildings	Vulnerable Buildings	
I	Not Felt	None	None	<0.17%
II-III	Weak	None	None	0.17% - 1.4%
IV	Light	None	None	1.4% - 3.9%
V	Moderate	Very Light	Light	3.9% - 9.2%
VI	Strong	Light	Moderate	9.2% - 18%
VII	Very Strong	Moderate	Moderate/Heavy	18% - 34%
VIII	Severe	Moderate/Heavy	Heavy	34% - 65%
IX	Violent	Heavy	Very Heavy	65% - 124%
X – XII	Extreme	Very Heavy	Very Heavy	>124%

a. PGA = peak ground acceleration. Measured in percent of g, where g is the acceleration of gravity

Sources: USGS, 2008; USGS, 2010

9.1.5 Ground Motion

Earthquake hazard assessment is based on expected ground motion. During an earthquake when the ground is shaking, it also experiences acceleration. The peak acceleration is the largest increase in velocity recorded by a particular station during an earthquake. Estimates are developed of the annual probability that certain ground motion accelerations will be exceeded; the annual probabilities can then be summed over a time period of interest.

The most commonly mapped ground motion parameters are horizontal and vertical peak ground accelerations (PGA) for a given soil type. PGA is a measure of how hard the earth shakes, or accelerates, in a given geographic area. Instruments called accelerographs record levels of ground motion due to earthquakes at stations throughout a region. PGA is measured in g (the acceleration due to gravity) or expressed as a percent acceleration force of gravity (%g). These readings are recorded by state and federal agencies that monitor and predict seismic activity.

Maps of PGA values form the basis of seismic zone maps that are included in building codes such as the International Building Code. Building codes that include seismic provisions specify the horizontal force due to lateral acceleration that a building should be able to withstand during an earthquake. PGA values are directly related to these lateral forces that could damage “short period structures” (e.g. single-family dwellings). Longer period response components determine the lateral forces that damage larger structures with longer natural periods (apartment buildings, factories, high-rises, bridges). Table 9-1 lists damage potential and perceived shaking by PGA factors, compared to the Mercalli scale.

9.1.6 USGS Earthquake Mapping Programs

ShakeMaps

The USGS Earthquake Hazards Program produces maps called ShakeMaps that map ground motion and shaking intensity following significant earthquakes. ShakeMaps focus on the ground shaking caused by the earthquake, rather than on characteristics of the earthquake source, such as magnitude and epicenter. An earthquake has only one magnitude and one epicenter, but it produces a range of ground shaking at sites throughout the region, depending on the distance from the earthquake, the rock and soil conditions at sites, and variations in the propagation of seismic waves from the earthquake due to complexities in the structure of the earth’s crust.

A ShakeMap shows the extent and variation of ground shaking immediately across the surrounding region following significant earthquakes. Such mapping is derived from peak ground motion amplitudes recorded on seismic sensors, with interpolation where data are lacking based on estimated amplitudes. Color-coded instrumental intensity maps are derived from empirical relations between peak ground motions and Modified Mercalli intensity. In addition to the maps of recorded events, the USGS creates the following:

- Scenario ShakeMaps of hypothetical earthquakes of an assumed magnitude on known faults
- Probabilistic ShakeMaps, based on predicted shaking from all possible earthquakes over a 10,000-year period. In a probabilistic map, information from millions of scenario maps are combined to make a forecast for the future. The maps indicate the ground motion at any given point that has a given probability of being exceeded in a given timeframe, such as a 100-year (1-percent-annual chance) event.

National Seismic Hazard Map

National maps of earthquake shaking hazards provide information for creating and updating seismic design requirements for building codes, insurance rate structures, earthquake loss studies, retrofit priorities and land use planning. After thorough review of the studies, professional organizations of engineers update the seismic-risk maps and seismic design requirements contained in building codes (Brown et al., 2001). The USGS updated the National Seismic Hazard Maps in 2018. New seismic, geologic, and geodetic information on earthquake rates and associated ground shaking were incorporated into these revised maps. The 2018 map, shown in Figure 9-1, represents the best available data as determined by the USGS.

Source: (U.S. Geological Survey n.d.)

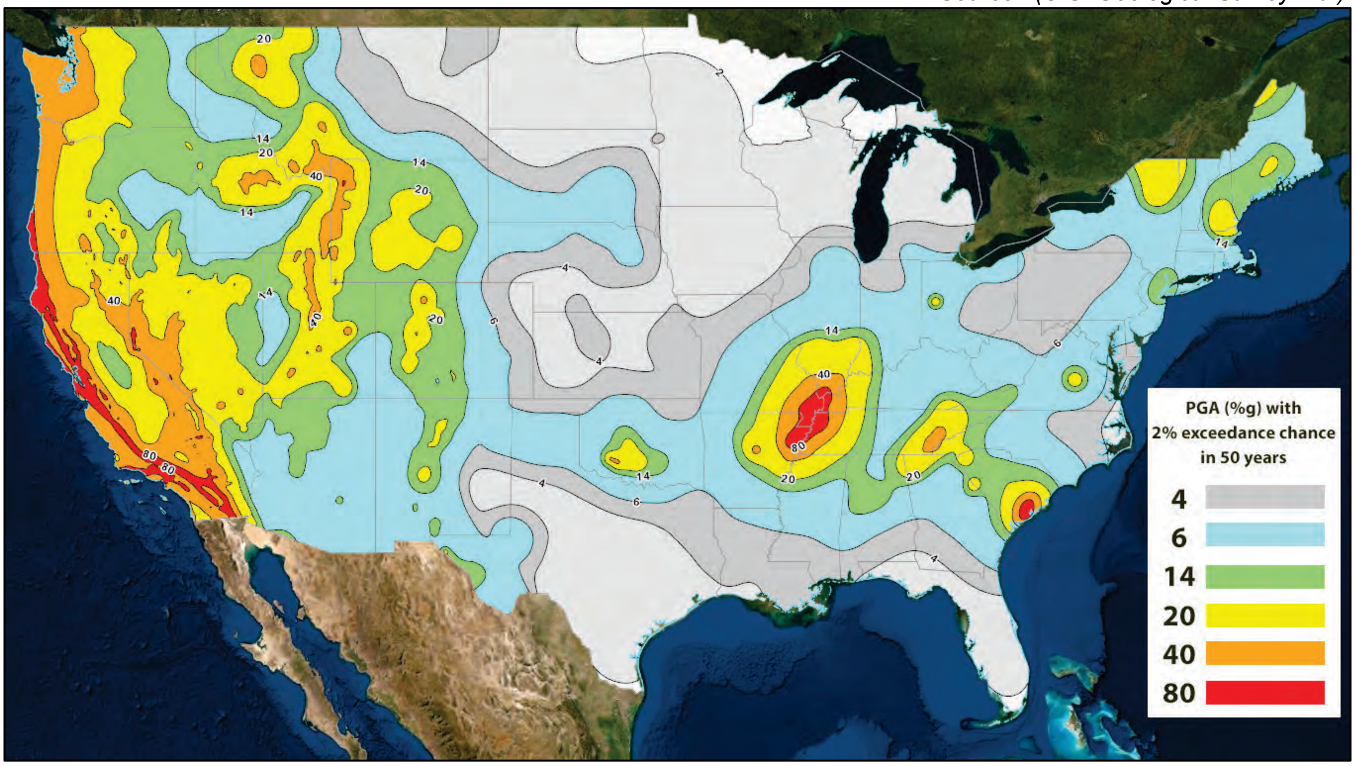


Figure 9-1. Peak Acceleration (%g) with 2% Probability of Exceedance in 50 Years

9.1.7 Liquefaction and Soil Types

Soil liquefaction occurs when water-saturated sands, silts or gravelly soils are shaken so violently that the individual grains lose contact with one another and float freely in the water, turning the ground into a pudding-like liquid. Building and road foundations lose load-bearing strength and may sink into what was previously solid ground. Unless properly secured, hazardous materials can be released, causing significant damage to the environment and people.

A program called the National Earthquake Hazard Reduction Program (NEHRP) creates maps based on soil characteristics to help identify locations subject to liquefaction. NEHRP soil types define the locations that will be significantly impacted by an earthquake. Table 9-2 summarizes NEHRP soil classifications. NEHRP Soils B and C typically can sustain ground shaking without much effect, dependent on the earthquake magnitude. The areas that are commonly most affected by ground shaking have NEHRP Soils D, E and F (Southern California Earthquake Center, 2018). In general, these areas are also most susceptible to liquefaction. The areas that are most affected by ground shaking have NEHRP Soils D, E and F.

Table 9-2. NEHRP Soil Classification System

NEHRP Soil Type	Description	Mean Shear Velocity to 30 m (m/s)
A	Hard Rock	1,500
B	Firm to Hard Rock	760-1,500
C	Dense Soil/Soft Rock	360-760
D	Stiff Soil	180-360
E	Soft Clays	< 180
F	Special Study Soils (liquefiable soils, sensitive clays, organic soils, soft clays >36 m thick)	

9.2 HAZARD PROFILE

9.2.1 Past Events

The Bay Area has experienced significant, well-documented earthquakes. Since 1855, more than 140 earthquakes have been felt in the Santa Rosa area (County of Sonoma 2017). According to the Northern California Earthquake Data Center, two earthquakes of magnitude 5.0 or greater have been felt in Sonoma County since 2000:

- December 14, 2016—A 5.01 magnitude event near The Geysers
- August 24, 2014—A 6.02 magnitude event near South Napa

The sections below describe major recorded historical earthquakes that have affected Sonoma County.

Pre-1900 Earthquakes

Seven earthquakes are believed to have caused damage to structures in Sonoma County in the 19th century. Reported damage from these earthquakes indicates a Modified Mercalli rating of VI to VIII. Notable events were the 1868 magnitude 7.2 earthquake on the Hayward Fault and the 1898 magnitude 6.7 earthquake on the Rodgers Creek Fault. Although damage from these two events was limited due to the area's sparse population at the time, a recurrence of either of these events would result in significant damage today (County of Sonoma 2017).

1906 San Francisco Earthquake

The April 18, 1906, magnitude 8.3 earthquake on the northern segment of the San Andreas Fault caused major damage in Santa Rosa, Sebastopol, Healdsburg, Petaluma and other communities. Santa Rosa is said to have suffered more damage proportionally to its size than any other Bay Area city. The only reported casualties in Sonoma County were in Santa Rosa, where 65 died. The shaking lasted for about 50 seconds. The Santa Rosa Courthouse was totally destroyed by the shaking and ensuing fire, as were approximately eight blocks of commercial buildings. It was reported that almost all non-wood buildings were destroyed by the shaking alone (County of Sonoma 2017).

1969 Rodgers Creek / Healdsburg Fault Earthquake

The last major earthquakes with an epicenter in Sonoma County occurred on October 1, 1969. Two earthquakes of magnitudes 5.6 and 5.7 originated 2 miles north of Santa Rosa. Damage was concentrated in Santa Rosa and principally confined to the partial collapse of unreinforced masonry buildings and wood frame buildings. In all, 99 structures were significantly damaged, approximately half in the business district and half in residential areas.

Total building damage was estimated at $6 million, with dwelling contents losses at $1.25 million. Several County buildings suffered damage, including the library, post office, and veterans memorial building. There was no loss of life from these earthquakes. The mayor of Santa Rosa sought state and federal disaster assistance, but there was not enough damage to public facilities to warrant a declaration. Small Business Administration loans were made available to commercial and residential property owners (County of Sonoma 2017).

1989 Loma Prieta Earthquake

This magnitude 6.9 earthquake was caused by slip along the San Andreas Fault. Damage in Sonoma County was minor (only five dwellings were yellow tagged), but the quake killed 63 people and injured 3,757 throughout Northern California and caused an estimated $6 billion in property damage. It was the largest earthquake to occur on the San Andreas Fault since the 1906 San Francisco earthquake (County of Sonoma 2017).

2014 South Napa Earthquake

On August 24, 2014, a magnitude 6.0 earthquake shook Napa, Solano, and Sonoma County. The epicenter was 9 miles southeast of the City of Sonoma. The earthquake occurred on the West Napa Fault, a fault that was not mapped under the Alquist-Priolo earthquake fault hazard zone. It was the largest event in the Bay Area since the 1989 Loma Prieta earthquake. At least 12 aftershocks followed. The quake injured 257 people and killed one. Several structures in eastern Sonoma County were severely damaged. The governor issued an emergency proclamation for this event and a federal disaster was declared on September 11, 2014. The total economic loss was estimated at $400 million (County of Sonoma 2017).

2016 The Geysers Earthquake

A 5.0 magnitude earthquake occurred 4 miles west of The Geysers and 14 miles southwest of Clearlake on December 14, 2016, following a series of medium size earthquakes in Mammoth Lakes and the Central Coast. This event was primarily felt in the Clearlake and Santa Rosa areas but was also felt throughout the Bay Area.

9.2.2 Location

The Mendocino Triple Junction, in the Pacific Ocean near Cape Mendocino, is the point where the Gorda plate, the North American plate, and the Pacific plate meet. This is the location of a change in the broad plate motions that dominate the west coast of North America, linking the convergence boundary of the Cascadia subduction zone, the transform boundary of the San Andreas Fault system, and the Gorda plate’s subduction under the North American plate and simultaneous converging against the Pacific plate.

Fault Locations

Several major faults traverse Sonoma County. The Alquist-Priolo Earthquake Fault Maps identify the following earthquake faults running through or near the county (see Figure 9-2):

- **San Andreas Fault—**The San Andreas Fault intersects land in Sonoma County at Doran Beach and Bodega Bay as well as south of Fort Ross, traveling north to the county line just east of the coastline. Studies of the North Coast section of the San Andreas Fault suggest an average recurrence interval of 200 to 300 years, although studies indicate a long interval between the 1906 earthquake and the previous earthquake, which occurred around 1300. Prior to 1300, the intervals were about 200 years (USGS n.d.).

Source: (U.S. Geological Survey 2016)

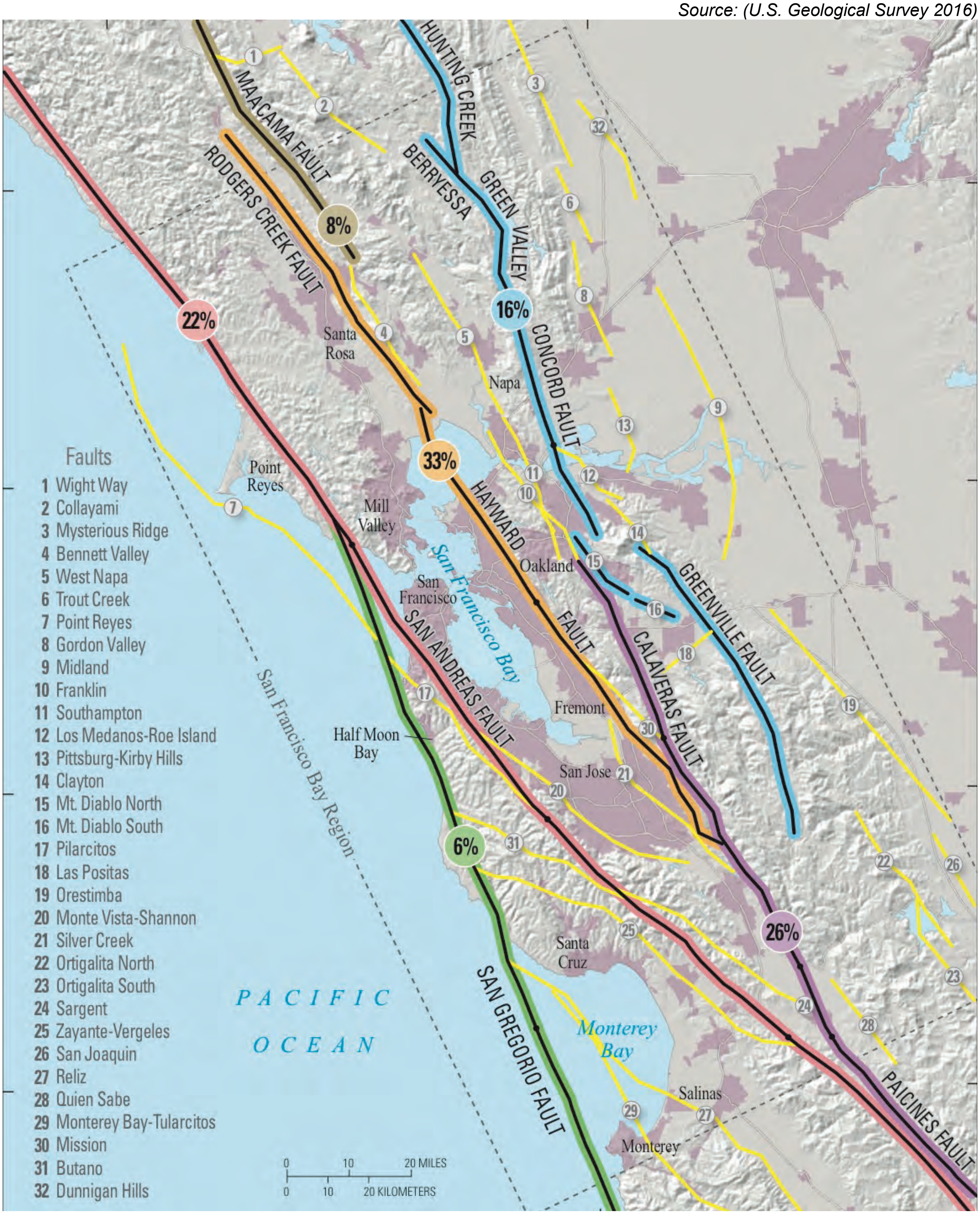


Figure 9-2. Mapped Faults in Sonoma County

- **Rodgers Creek Fault—**The Rodgers Creek Fault, which lies east of the San Andreas Fault, is the main strand of the North American-Pacific Plate boundary north of San Francisco Bay. The two sides of the fault slip past each other at a rate of 6 to 10 millimeters per year. It is estimated that there is a 33 percent chance of an earthquake of magnitude 6.7 or greater on the combined Rodgers Creek-Hayward fault system over the 30-year period from 2014 through 2043. In 2018, USGS released a more detailed and higher resolution map of the Rodgers Creek Fault. The new map shows the Rodgers Creek Fault extending about 11 miles farther north than previously thought and flanking the east side of the town of Healdsburg. It also showed an overall increase in the known width and complexity of the fault zone. These new findings indicate a greater hazard than previously thought (U.S. Geological Survey 2018).
- **Hayward Fault—**The Hayward Fault runs along the foot of the East Bay Hills. Its last major earthquake occurred on October 21, 1868, destroying downtown Hayward, killing 5 people, and injuring 30. It had an estimated magnitude of 6.8 and was considered the "Great Earthquake" until 1906. Scientists have found that the most recent five major earthquakes on this fault happened on average every 140 years. It is very likely that the Hayward fault will rupture and produce a significant earthquake within the next 30 years (Berkeley Seismology Lab 2018).
- **Maacama Fault—**The Maacama Fault passes east of the City of Cloverdale. The Maacama fault zone is one of three major fault zones that make up the San Andreas fault system in northern California. The fault is creeping near the town of Willits. Preliminary studies indicate that over the last 700 years, only fault creep has occurred at the site; however, over the last 3,500 years, slip has been accommodate by both creep and earthquakes with surface rupture. The preliminary minimum long-term slip rate at Haehl Creek on the Maacama fault of greater than or equal to 8 millimeters per year is consistent with rates found on the Hayward and Rodgers Creek segments of this fault system and is consistent with the notion that the fault zone is capable of producing large earthquakes (Larsen 2005).

Faults outside the planning area also can impact its people, property, and economy. A rupture in the Cascadia subduction zone, for example, would have considerable impacts on the planning area (Pacific Northwest Seismic Network, 2018). This is the 600-mile-long offshore zone, from northern Vancouver Island to Cape Mendocino, where the Juan de Fuca plate is being subducted below the North American plate.

NEHRP Soil Type and Liquefaction Mapping

Figure 9-3 shows NEHRP soil classifications in Sonoma County. Figure 9-4 shows areas in that have moderate, high, or very high susceptibility to liquefaction.

9.2.3 Frequency

Historic records of earthquake occurrences may give some indication of future probabilities. Seismic activity was more frequent from 1830 to 1930 than it has been since. This leads some scientists to suspect that pressure is building up along the faults in the Bay Area that can result in a large quake. Such a quake could have dramatic and devastating effects throughout the Bay Area. The USGS reports the following earthquake probabilities for the Bay Area over next 30 years (U.S. Geological Survey n.d.):

- 72 percent probability of an earthquake measuring magnitude 6.7
- 51 percent probability of an earthquake measuring magnitude 7
- 20 percent probability of an earthquake measuring magnitude 7.5

Figure 9-3. NEHRP Soil Class

C (Dense soil/soft rock)
D (Stiff soil)
E (Soft clay)
Cities
County Boundary
Highways

N
0 5 10 Miles

Data Sources: Sonoma Co, CGS

Figure 9-4. Liquefaction Susceptibility

9.2.4 Severity

The severity of an earthquake can be expressed in terms of intensity or magnitude (see Section 0). The State of California Department of Conservation probabilistic ground shaking maps, based on current information about fault zones, show the PGA that has a certain probability of being exceeded in a 50-year period. Sonoma County is in a high-risk area, with a 10-percent probability in a 50-year period of ground shaking from a seismic event exceeding 40 to 60 percent of gravity in most parts of the county. Figure 9-5 shows the expected peak horizontal ground accelerations for this probability.

Source: (U.S. Geological Survey n.d.)

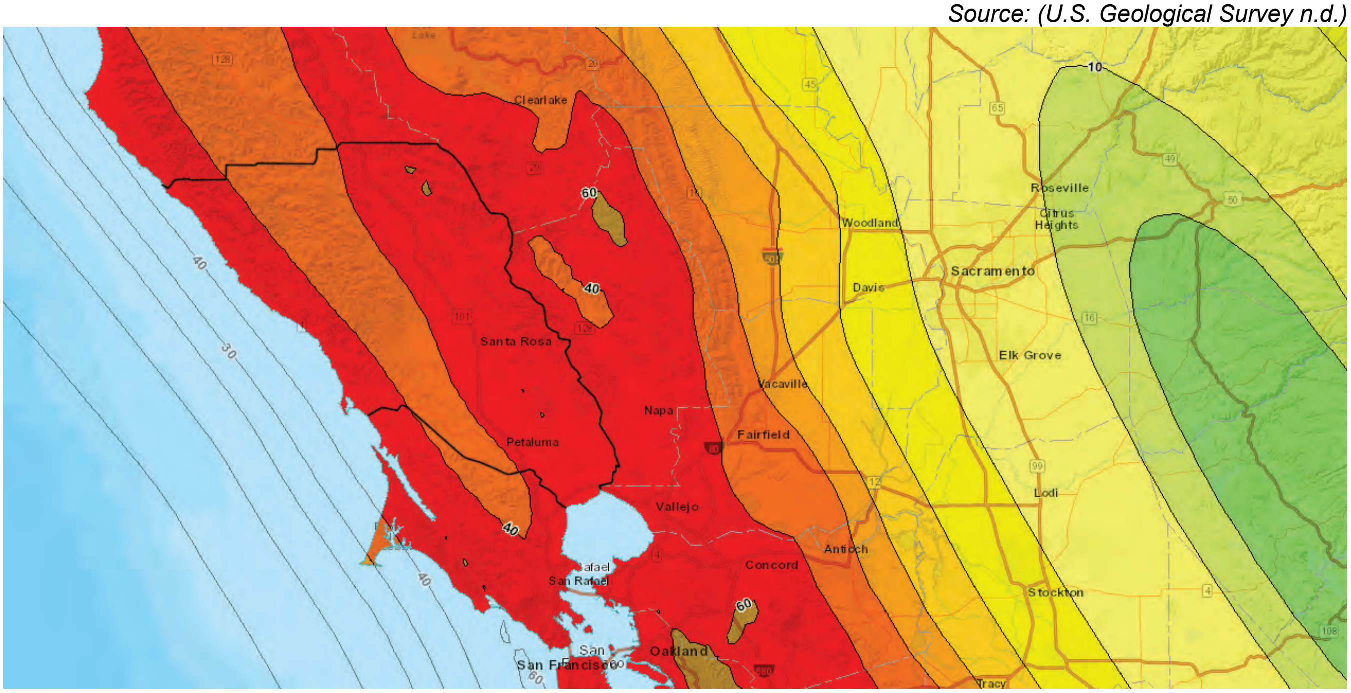


Figure 9-5. Peak Horizontal Acceleration (%g) with 10% Probability of Exceedance in 50 Years

9.2.5 Warning Time

There is no current reliable way to predict the day or month that an earthquake will occur at any given location. Research is being done with warning systems that detect the lower energy compressional waves (P waves) that precede the secondary waves (S waves) experienced as an earthquake. Earthquake early warning systems may provide a few seconds' or a few minutes' notice that a major earthquake is about to occur. The warning time is very short, but it could allow for someone to get under a desk, pause hazardous or high-risk work, or initiate protective automated systems in structures or critical infrastructure.

9.2.6 Secondary Hazards

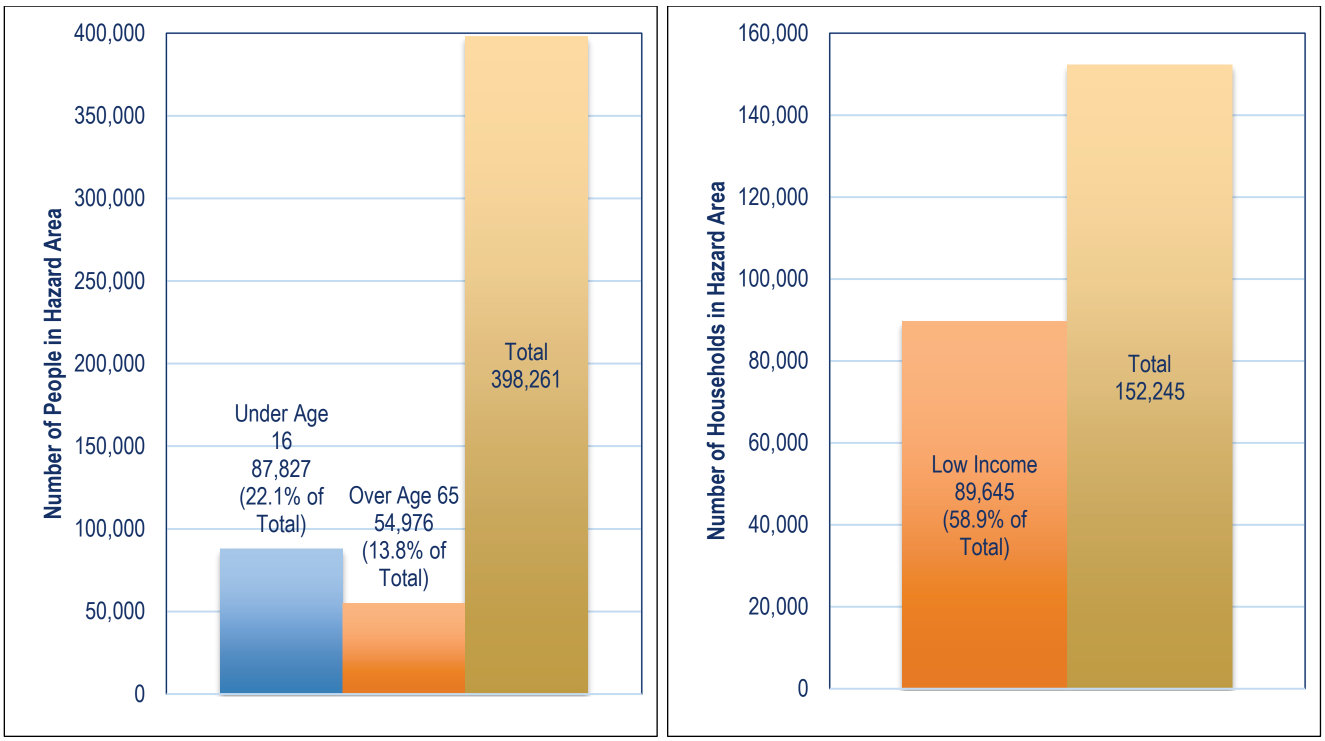
Earthquakes can cause landslides, often as a result of loss of cohesion in clay-rich soils. Earthen dams and levees are highly susceptible to seismic events, and the impacts of their eventual failures can be considered secondary risk exposure to earthquakes. Depending on the location, earthquakes can also trigger tsunamis. Additionally, fires can result from gas lines or power lines that are broken or downed during the earthquake. It may be difficult to control a fire, particularly if the water lines feeding fire hydrants are also broken.

9.3 EXPOSURE

9.3.1 Population

The entire population of the planning area (490,000) is potentially exposed to direct damage from earthquakes or indirect impacts such as business interruption, road closures, and loss of function of utilities.

Socially vulnerable populations living on NEHRP D or E soils were estimated based on data for the Census-defined blocks that lie at least partially within the mapped soil zones. Because many of those Census blocks extend outside the define soils zones, the estimates are greater than the actual exposed populations, but they provide reasonable relative data for use in mitigation planning. Figure 9-6 summarizes the estimated exposure of socially vulnerable populations.



See Section 4.8.1 for the definition of "low income" used in this analysis

Figure 9-6. Socially Vulnerable Populations Living on NEHRP D or E Soils Census Blocks

9.3.2 Property

According to County Assessor records, there are 173,000 buildings in the planning area, most of them residential. All buildings are considered to be exposed to the earthquake hazard.

9.3.3 Critical Facilities

Since the entire planning area has exposure to the earthquake hazard, all critical facilities components are considered to be exposed. The breakdown of the numbers and types of facilities is presented in Table 4-4. Critical facilities constructed on NEHRP Type D and E soils are particularly at risk from seismic events. Figure 9-7 shows the number of critical facilities built on these soils in the planning area, by type of facility.

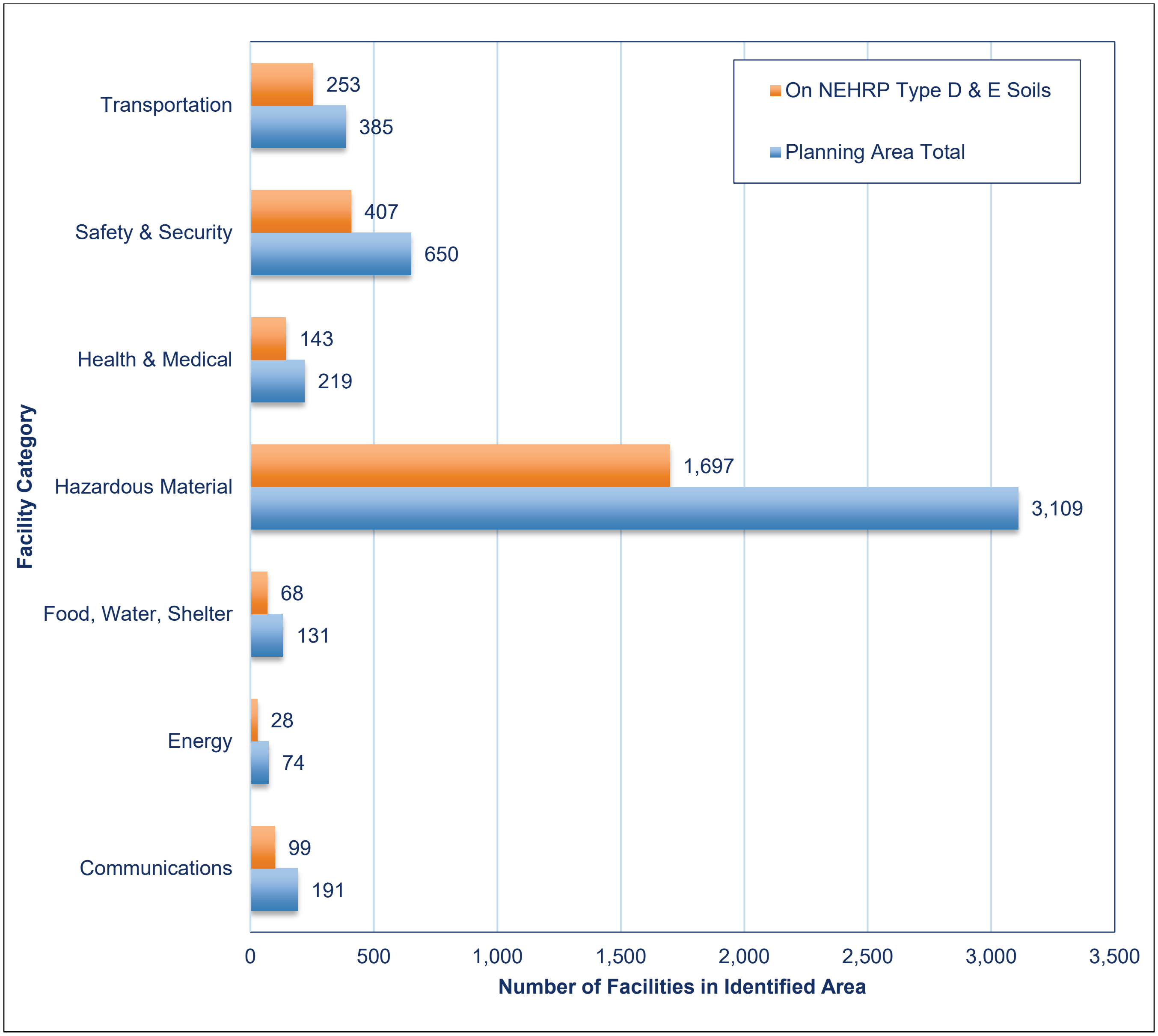


Figure 9-7. Critical Facilities Constructed on NEHRP Type D and E Soils, and Countywide

Significant facilities included in the mapped areas of NEHRP Type D and E soils include the following:

- 2 water treatment facilities
- 20 wastewater treatment facilities
- 1,697 hazardous material sites
- 4 hospitals
- 43 fire stations
- 8 police stations
- 206 school buildings
- 230 road bridges
- 10 port facilities
- 3 airports

9.3.4 Environment

The entire planning area is exposed to the earthquake hazard, including all natural resources, habitat, and wildlife.

9.4 VULNERABILITY

Earthquake vulnerability data for the risk assessment was generated using a Hazus Level 2 (user-defined) analysis for the for the events listed in Table 9-3. The countywide analysis results are summarized in the sections below. Detailed information, broken down by municipality, can be found in Appendix D.

Table 9-3. Earthquakes Modeled for Risk Assessment

Event	Magnitude	Epicenter Location	PGA
100-Year Probabilistic Earthquake	N/A	N/A	Figure 9-8
Hayward Fault Scenario	7.57	16 miles southeast of Petaluma	Figure 9-9
Maacama Fault Scenario	7.55	26 miles north-northwest of Cloverdale	Figure 9-10
Rodgers Creek – Healdsburg Fault Scenario	7.19	3 miles north-northeast of Santa Rosa	Figure 9-11
San Andreas Fault Scenario	8.04	16 miles west of Sebastopol	Figure 9-12

9.4.1 Population

Hazus estimated impacts on persons and households in the planning area for the selected earthquake scenarios as summarized in Table 9-4.

Table 9-4. Estimated Earthquake Impact on Persons

Scenario	Displaced Households	Persons Requiring Short Term Shelter
100-Year Probabilistic Earthquake	874	558
Hayward Fault Scenario	5,020	3,250
Maacama Fault Scenario	1,663	1,072
Rodgers Creek – Healdsburg Fault Scenario	3,792	2,466
San Andreas Fault Scenario	584	370

9.4.2 Property

Building Age

Table 9-5 identifies significant milestones in building and seismic code requirements that directly affect the structural integrity of development. Using U.S. Census estimates of housing stock age, estimates were developed of the number of housing units constructed before each of these dates. About a quarter of the planning area's housing units were constructed after the Uniform Building Code was amended in 1994 to include seismic safety provisions. Housing units built before 1933 when there were no building permits, inspections, or seismic standards, account for only about 3 percent.

Loss Potential

Table 9-6 summarizes Hazus estimates of earthquake damage in the planning area for the evaluated scenarios. The debris estimate includes only structural debris; it does not include additional debris that may accumulate, such as from trees. In addition, these estimates do not include losses that would occur from any local tsunamis or fires stemming from an earthquake.

Figure 9-8. 100-Year Probabilistic Earthquake

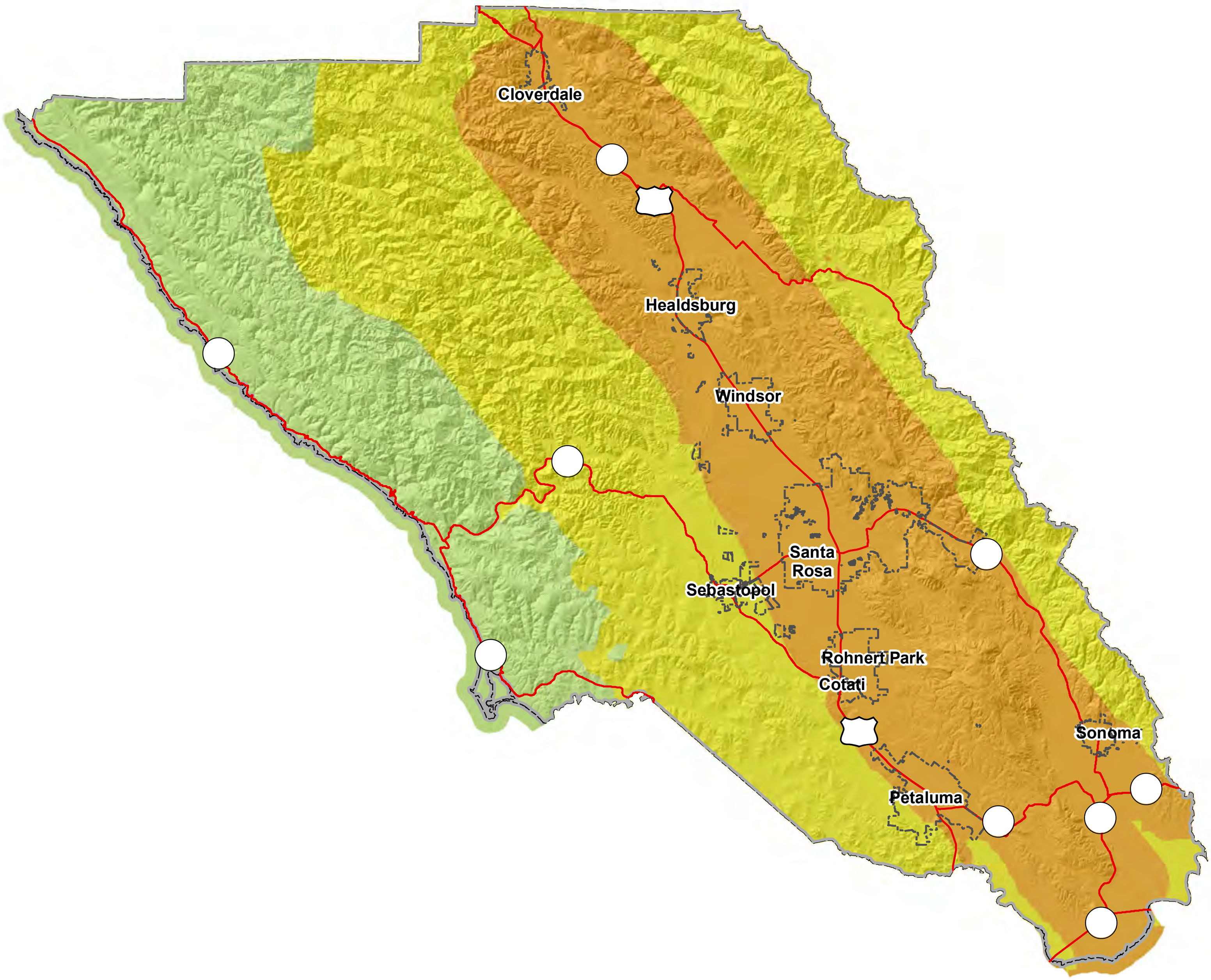


Figure 9-9. Hayward M7.57 Earthquake Scenario

Mercalli Intensity Scale

- VI (Strong/Light)
- VII (Very Strong/Moderate)
- VIII (Severe/Moderate-Heavy)

Intensity scale described as: (perceived shaking / potential damage)

- Cities
- County Boundary
- Highways

N

0 5 10 Miles

Data Sources: Sonoma Co., USGS

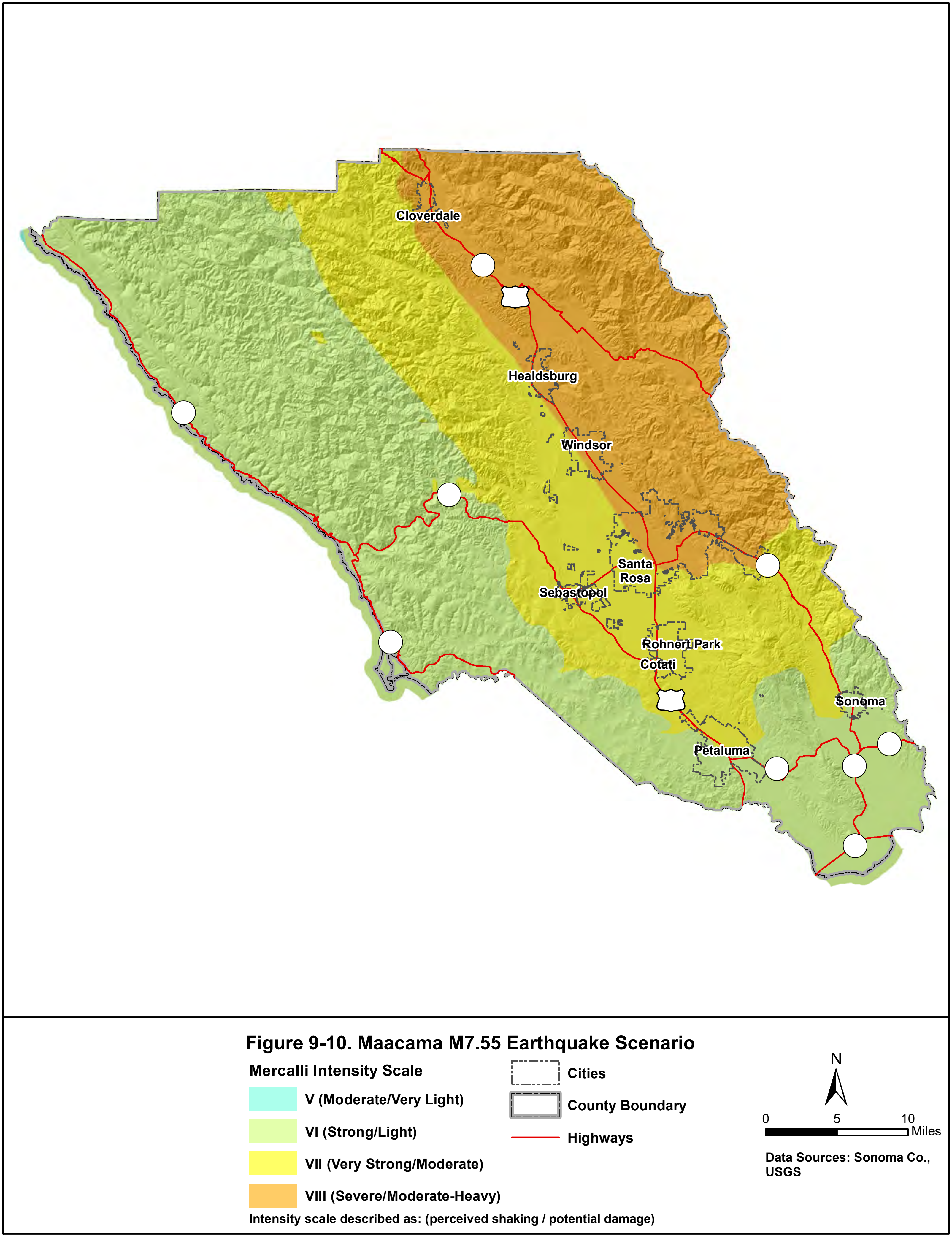


Figure 9-10. Maacama M7.55 Earthquake Scenario

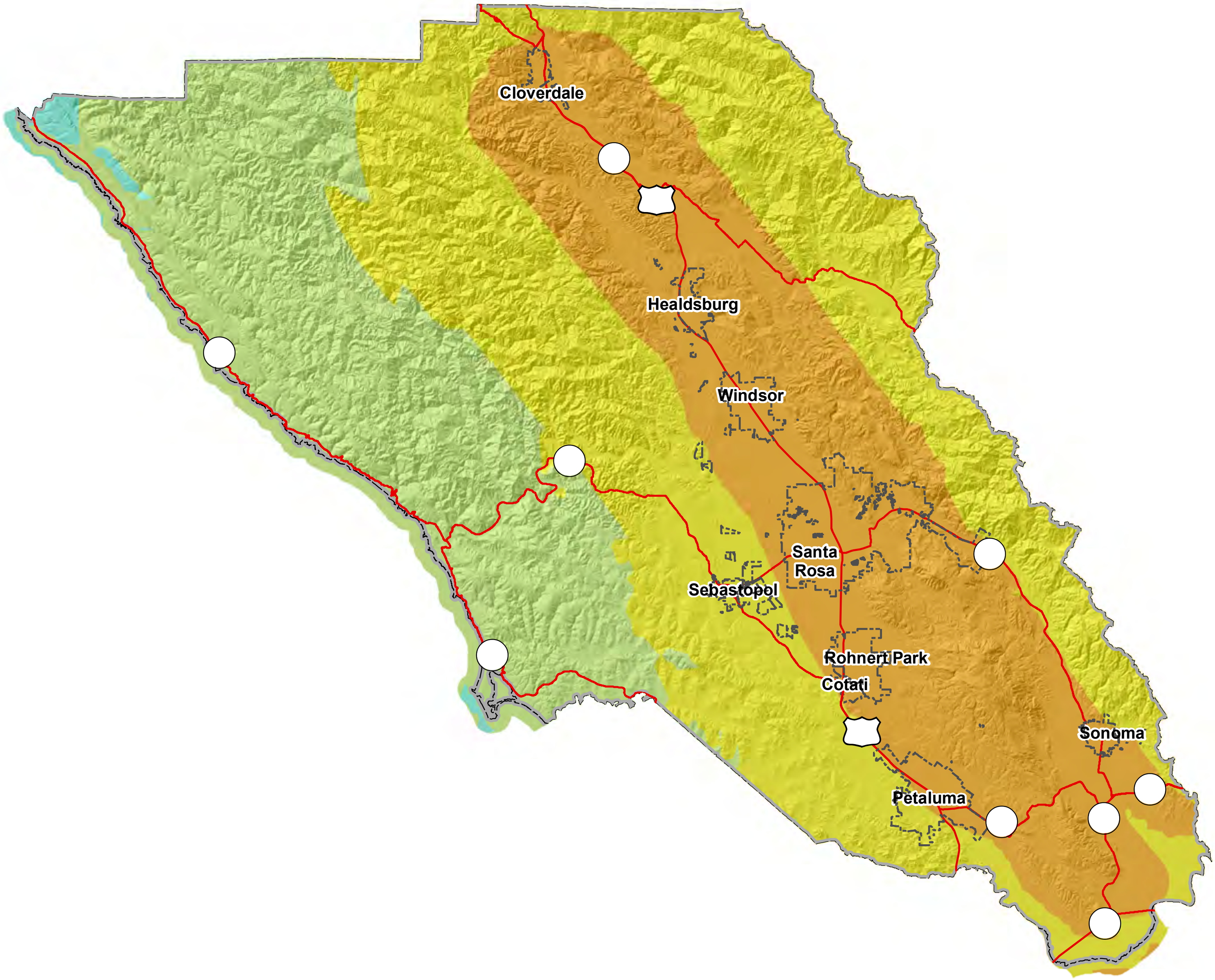


Figure 9-11. Rodgers Creek – Healdsburg M7.19

Mercalli Intensity Scale

- V (Moderate/Very Light)
- VI (Strong/Light)
- VII (Very Strong/Moderate)
- VIII (Severe/Moderate-Heavy)

Intensity scale described as: (perceived shaking / potential damage)

- Cities
- County Boundary
- Highways

N

0 5 10 Miles

Data Sources: Sonoma Co., USGS

Figure 9-12. San Andreas M8.04 Earthquake Scenario

Mercalli Intensity Scale

- VI (Strong/Light)
- VII (Very Strong/Moderate)
- VIII (Severe/Moderate-Heavy)

Intensity scale described as:
(perceived shaking / potential damage)

- Cities
- County Boundary
- Highways

N

0 5 10 Miles

Data Sources: Sonoma Co., USGS

Table 9-5. Age of Housing Units in Planning Area

Time Period	Number of Current Planning Area Housing Units Built in Period	% of Total Housing Units	Significance of Time Frame
Pre-1933	5,640	3.3%	Before 1933, there were no explicit earthquake requirements in building codes. State law did not require local governments to have building officials or issue building permits.
1933-1940	2,980	1.7%	In 1940, the first strong motion recording was made.
1941-1960	21,917	12.6%	In 1960, the Structural Engineers Association of California published guidelines on recommended earthquake provisions.
1961-1975	35,516	20.5%	In 1975, significant improvements were made to lateral force requirements.
1976-1994	66,594	38.4%	In 1994, the Uniform Building Code was amended to include provisions for seismic safety.
1995 – present	40,837	23.5%	Seismic code is currently enforced.
Total	**173,484**	**100.0%**	

Note: Number and percent estimates are approximation as housing unit age information does not correspond directly with the time periods indicated. In addition, there are significant margins of error associated with the Census estimates.

Table 9-6. Estimated Impact of Earthquake Scenario Events in the Planning Area

Earthquake Scenario Event	Structure Debris		Structure + Contents Damage	
	Tons	Truckloads	Value	% of Total Value
100-Year Probabilistic Earthquake	836,820	33,473	$14,392,110,613	6.6%
Hayward Fault Scenario	4,117,150	164,686	$31,275,029,312	14.3%
Maacama Fault Scenario	1,862,920	74,517	$18,535,479,687	8.5%
Rodgers Creek – Healdsburg Fault Scenario	2,592,600	103,704	$24,448,538,642	11.2%
San Andreas Fault Scenario	995,710	39,828	$14,504,660,400	6.6%

9.4.3 Critical Facilities

Level of Damage

Hazus classifies the vulnerability of critical facilities to earthquake as no damage, slight damage, moderate damage, extensive damage, or complete damage. Hazus was used to assign a category to each critical facility in the planning area for the assessed earthquake scenarios. Summary results are shown in Figure 9-13 through Figure 9-17.

Time to Restore Critical Facilities to Functionality

Hazus estimates the time to restore critical facilities to fully functional use. Results are presented as probability of being functional at specified time increments: 1, 3, 7, 14, 30 and 90 days after the event. For example, Hazus may estimate that a facility has 5 percent chance of being fully functional at Day 3, and a 95 percent chance of being fully functional at Day 90. The analysis of critical facilities in the planning area was performed for the assessed earthquake scenarios. The results are summarized in Figure 9-18 through Figure 9-22. These figures show the average functionality for all critical facilities in each category.

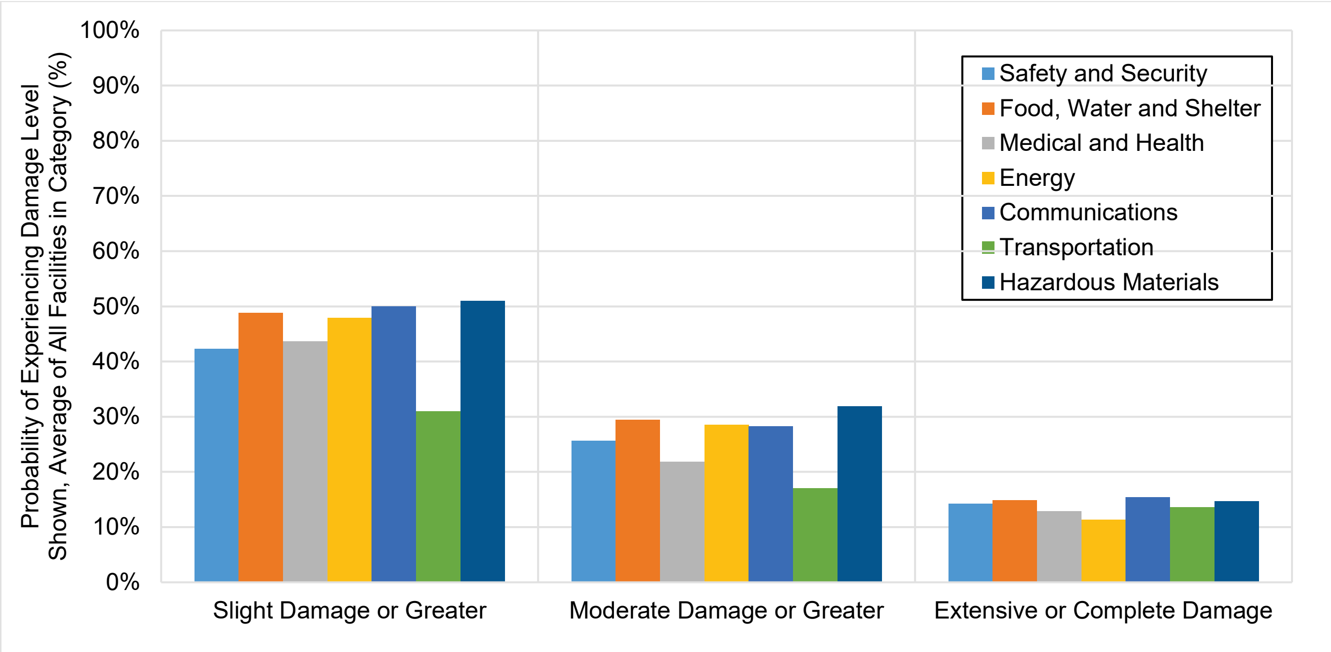


Figure 9-13. Critical Facility Damage Potential, 100-Year Probabilistic Earthquake

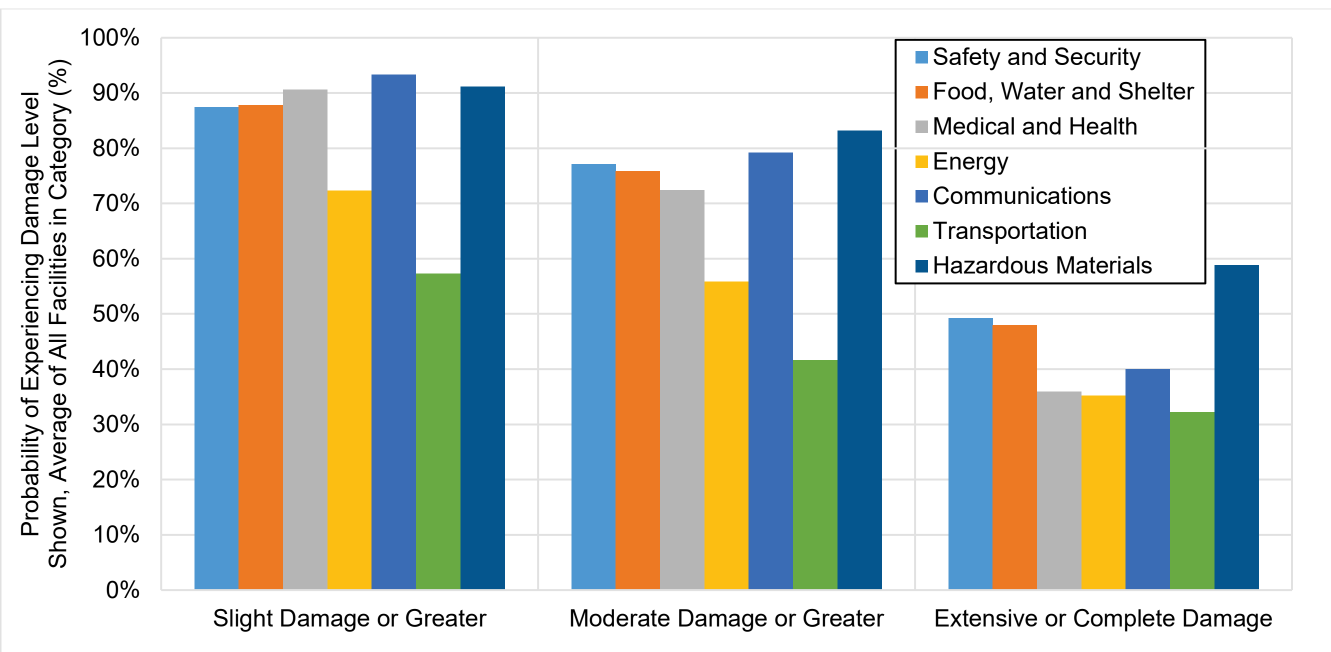


Figure 9-14. Critical Facility Damage Potential, Hayward Fault Scenario

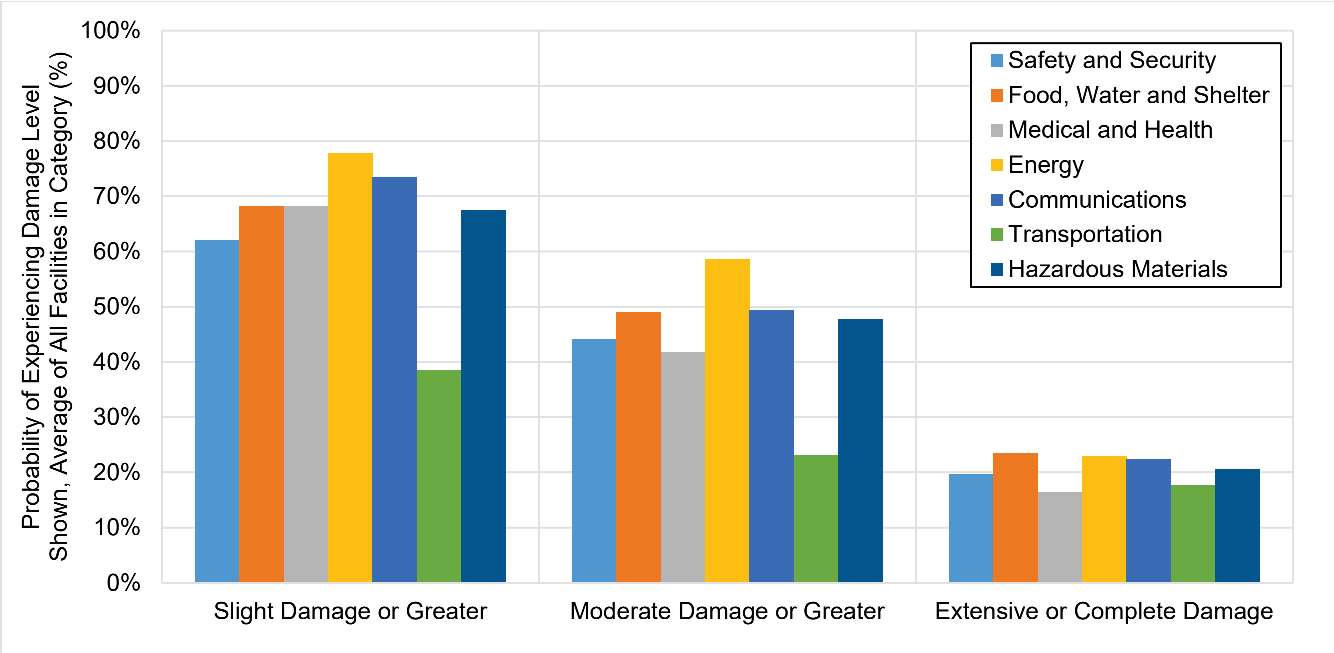


Figure 9-15. Critical Facility Damage Potential, Maacama Fault Scenario

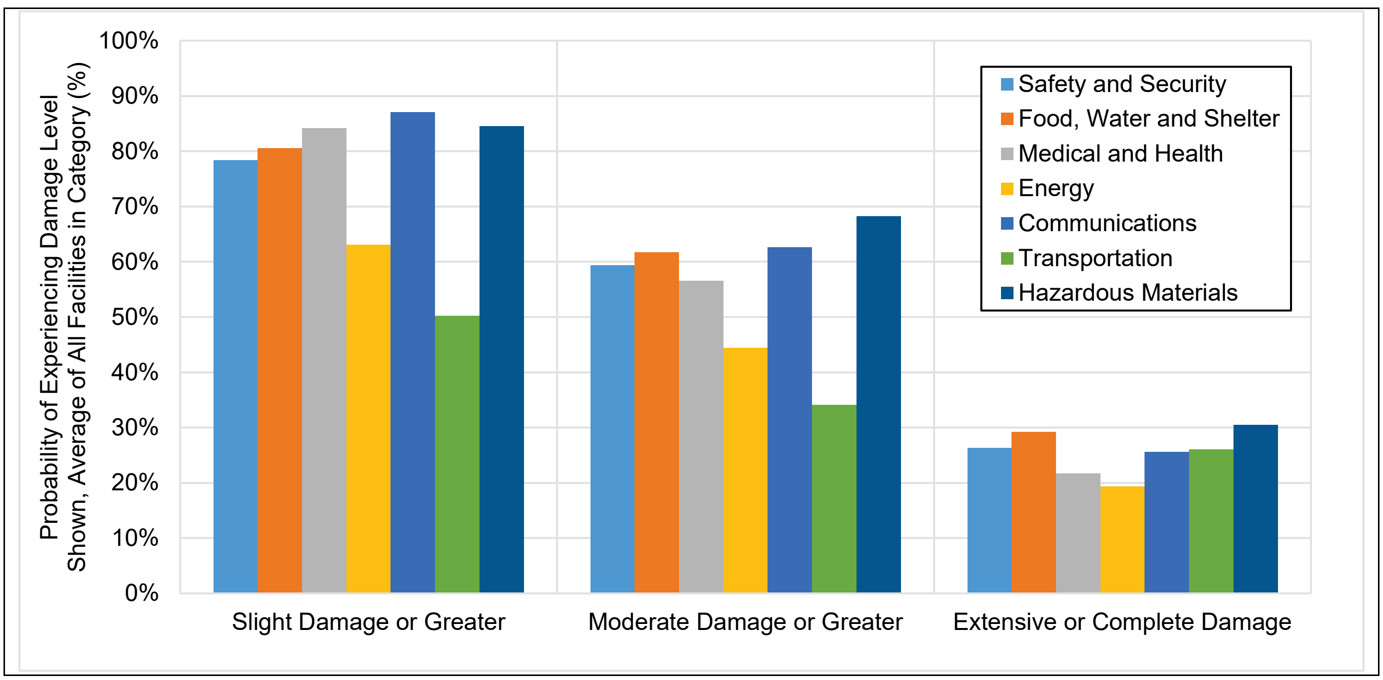


Figure 9-16. Critical Facility Damage Potential, Rodgers Creek – Healdsburg Fault Scenario

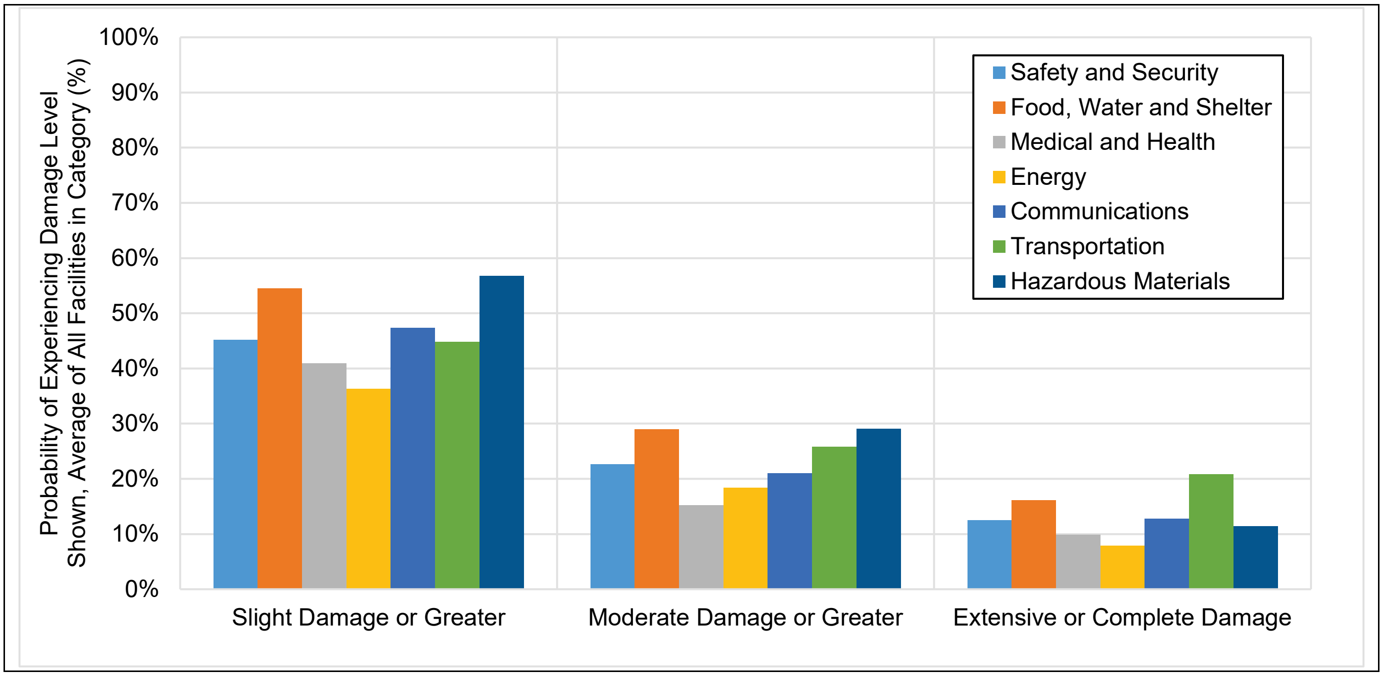


Figure 9-17. Critical Facility Damage Potential, San Andreas Scenario

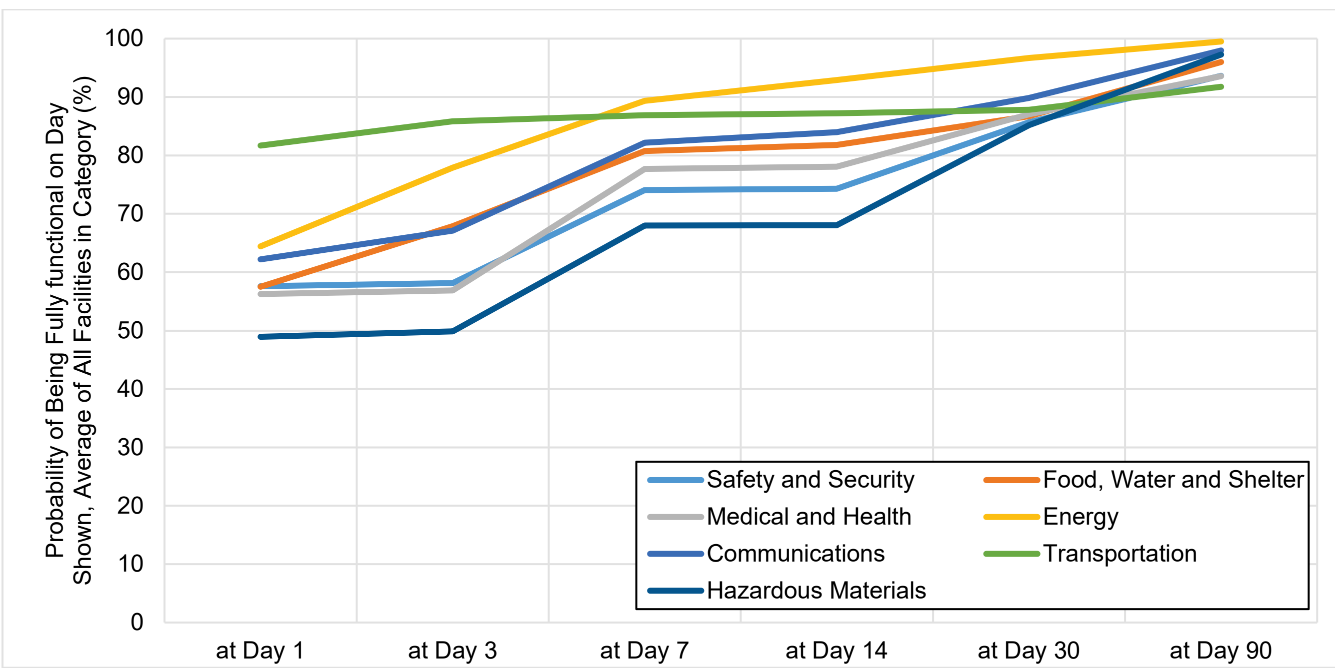


Figure 9-18. Critical Facility Functionality, 100-Year Probabilistic Earthquake

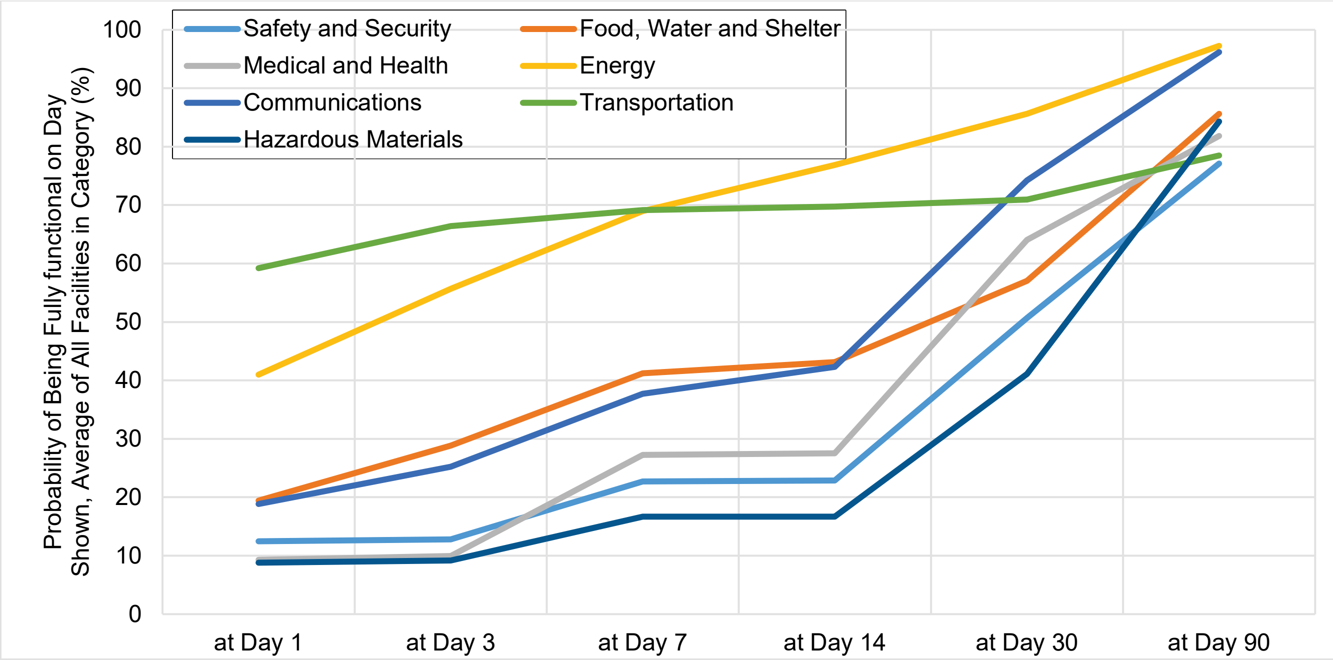


Figure 9-19. Critical Facility Functionality, Hayward Fault Scenario

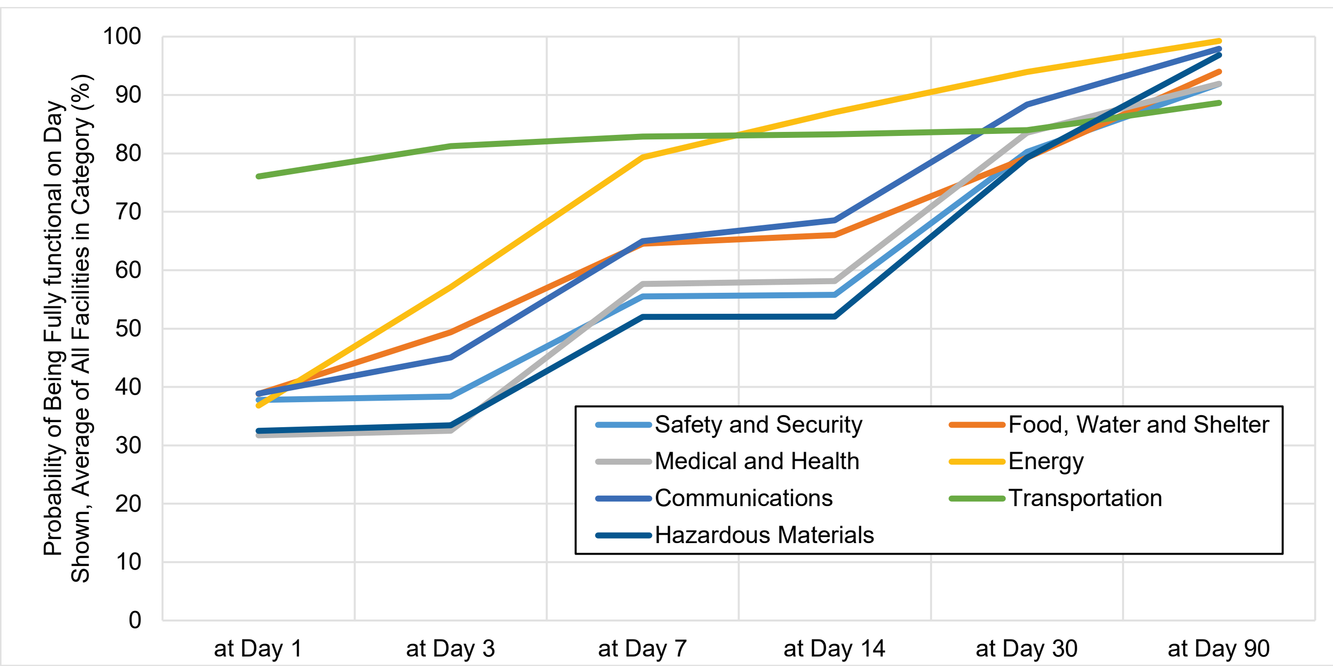


Figure 9-20. Critical Facility Functionality, Maacama Fault Scenario

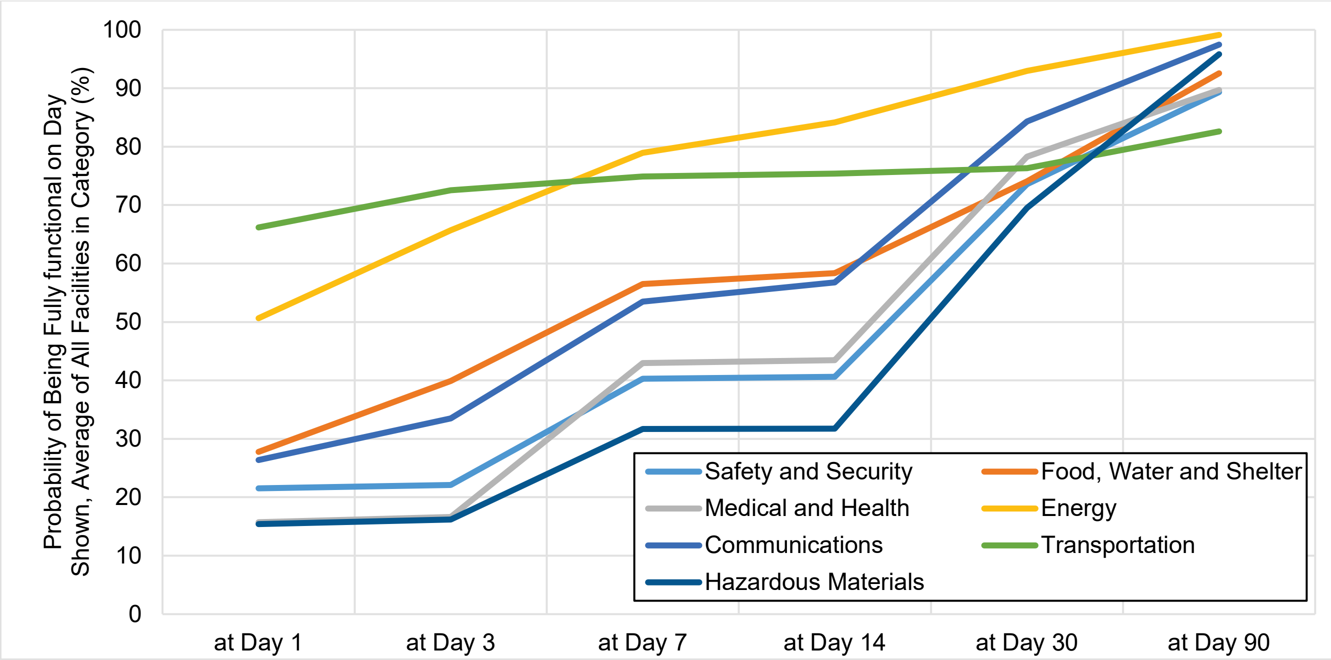


Figure 9-21. Critical Facility Functionality, Rodgers Creek – Healdsburg Fault Scenario

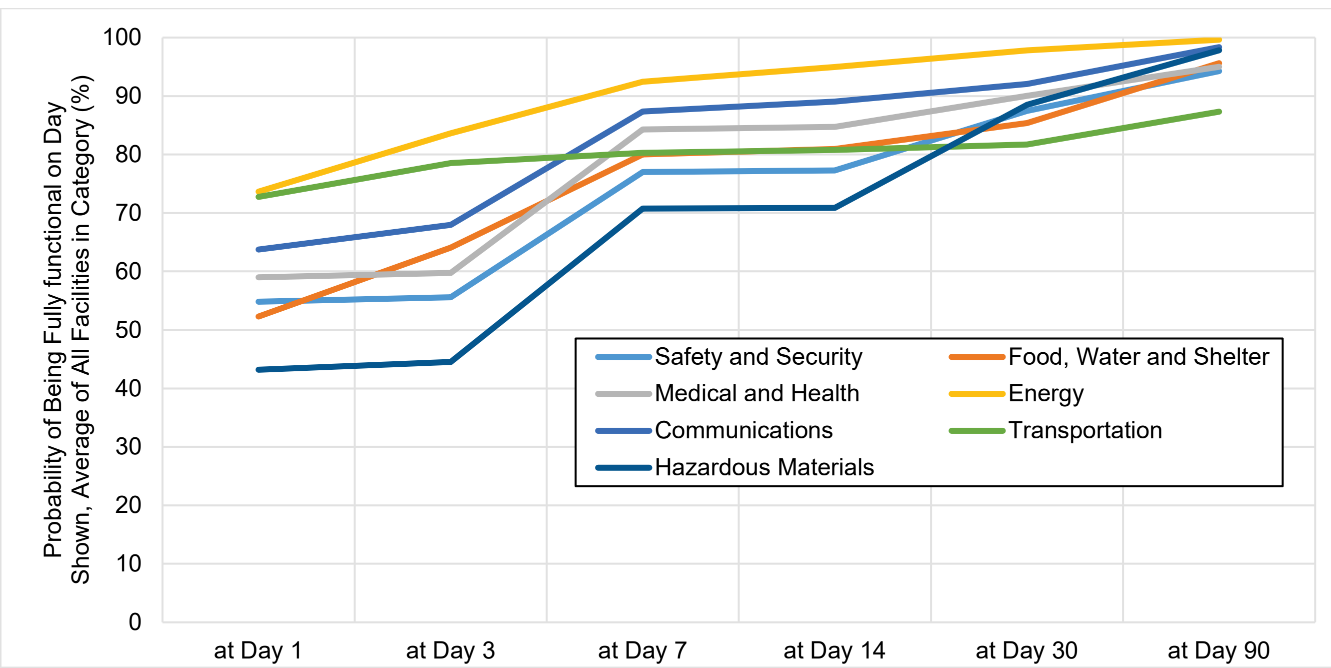


Figure 9-22. Critical Facility Functionality, San Andreas Fault Scenario

9.4.4 Environment

Environmental problems as a result of an earthquake can be numerous. Secondary hazards will likely have some of the most damaging effects on the environment. Earthquake-induced landslides can significantly damage surrounding habitat. It is also possible for streams to be rerouted after an earthquake. Rerouting can change the water quality, possibly damaging habitat and feeding areas. Streams fed by groundwater wells can dry up because of changes in underlying geology.

9.5 FUTURE TRENDS IN DEVELOPMENT

As populations grow, it is critical that the services supporting these communities—such as water, sewer, power, roads, hospitals, and public safety agencies—are able to maintain or quickly resume functionality after a disaster. Land use in the planning area will be directed by general plans adopted under California's General Planning Law. The safety elements of the general plans establish standards and plans for the protection of the community from hazards, including seismic hazards. The information in this plan provides a tool to ensure that there is no increase in exposure in areas of high seismic risk. Development in the planning area will be regulated through building standards and performance measures so that the degree of risk will be reduced. Geologic hazard areas are heavily regulated under California's General Planning Law. The International Building Code establishes provisions to address seismic risk.

9.6 SCENARIO

Based on history and geology, the planning area will be frequently impacted by earthquakes. The worst-case scenario is a higher-magnitude event (7.5 or higher) with an epicenter within 50 miles of the county. Earthquakes of this magnitude or higher could lead to massive structural failure of property on soils prone to liquefaction. Building and road foundations would lose load-bearing strength. Injuries could occur from debris, such as parapets and chimneys that could topple or be shaken loose and fall on those walking or driving below. Levees and revetments built on these poor soils would likely fail, representing a loss of critical infrastructure. An earthquake event of this magnitude located off the coast could cause a significant local tsunami that would further damage structures and jeopardize lives. An earthquake may also cause minor landslides along unstable slopes, which put at risk major roads and highways that act as sole evacuation routes. This would be even more likely if the earthquake occurred during the winter or early spring.

9.7 ISSUES

Important issues associated with an earthquake include the following:

- A large percentage of the planning area is located on NEHRP D soils, which are prone to liquefaction. Structures on these soils may experience significant structural damage.
- It is estimated more than a third of the planning area's building stock was built prior to 1975, when seismic provisions became uniformly applied through building code applications. Many structures may need seismic retrofits in order to withstand a moderate earthquake. Residential retrofit programs, such as Earthquake Brace+Bolt, may be able to assist in the costs of these efforts.
- Due to limitations in current modeling abilities, the risk to critical facilities in the planning area from the earthquake hazard is likely understated. A more thorough review of the age of critical facilities, codes they were built to, and location on liquefiable soils should be conducted.

- Damage to transportation systems in the planning area after an earthquake has the potential to significantly disrupt response and recovery efforts and lead to isolation of populations.
- Earthquakes can cause fires in wooden homes and collapse of essential buildings such as fire stations.
- Landslides and tsunamis are major secondary hazards that could have a widespread effect on the county.
- Citizens are expected to be self-sufficient up to two weeks after a major earthquake without government response agencies, utilities, private-sector services, and infrastructure components. Education programs are currently in place to facilitate development of individual, family, neighborhood, and business earthquake preparedness. It takes individuals, families, and communities working in concert with one another to be prepared for disaster.
- After a major seismic event, the planning area is likely to experience disruptions in the flow of goods and services resulting from the destruction of major transportation infrastructure across the broader region.
- A seismic event can damage communication systems, complicating efforts to coordinate response to the event.

10. FLOODING

10.1 GENERAL BACKGROUND

10.1.1 Types of Floodplains in the Planning Area

A floodplain is the area adjacent to a river, creek, lake, or the ocean that becomes inundated during a flood. In general, there are two types of floodplains in the planning area: riverine and coastal.

Riverine Floodplains

Riverine floodplains may be broad, as when a river crosses an extensive flat landscape, or narrow, as when a river is confined in a canyon.

When floodwaters recede after a flood event, they leave behind layers of rock and mud. These gradually build up to create a new floor of the floodplain. Floodplains generally contain unconsolidated sediments (accumulations of sand, gravel, loam, silt, and/or clay), often extending below the bed of the stream. These sediments provide a natural filtering system, with water percolating back into the ground and replenishing groundwater. These are often important aquifers, the water drawn from them being filtered compared to the water in the stream. Fertile, flat reclaimed floodplain lands are commonly used for agriculture, commerce, and residential development.

Connections between a river and its floodplain are most apparent during and after major flood events. These areas form a complex physical and biological system that not only supports a variety of natural resources but also provides natural flood and erosion control. When a river is separated from its floodplain with levees and other flood control facilities, natural, built-in benefits can be lost, altered, or significantly reduced.

The frequency and severity of flooding for river systems are based on discharge probability. The discharge probability is 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 different discharge levels and storm surge levels. These measurements reflect statistical averages only; it is possible for multiple floods with a low probability of occurrence (such as a 1-percent-annual-chance flood) to occur in a short time period. For riverine flooding, the same flood event can have flows at different points on a river that correspond to different probabilities of occurrence.

Coastal Floodplains

Coastal floodplains are adjacent to the ocean and other tidally influenced areas. Like riverine floodplains, coastal floodplains may be broad or narrow, depending on local topography and natural flood defenses such as dune systems or tidal wetlands. Coastal floods are usually caused by coastal storms that, when combined with normal tides, push water toward the shore. This is commonly referred to as storm surge. The result can be waves that extend further inland, causing damage to development that would not normally be subject to wave action.

10.1.2 FEMA Regulatory Flood Zones

The extent of flooding associated with a 1-percent annual probability of occurrence (also called the base flood) is used as the regulatory boundary by many agencies. Also referred to as the special flood hazard area (SFHA), this boundary is a convenient tool for assessing vulnerability and risk in flood-prone communities. Many communities have maps that show the extent and likely depth of flooding for the base flood. Corresponding water-surface elevations describe the elevation of water that will result from a given discharge level, which is one of the most important factors used in estimating flood damage.

FEMA defines flood hazard areas as areas expected to be inundated by a flood of a given magnitude. These areas are determined via statistical analyses of records of river flow, storm tides, and rainfall; information obtained through consultation with the community; floodplain topographic surveys; and hydrologic and hydraulic analyses. Flood hazard areas are delineated on DFIRMs (Digital Flood Insurance Rate Maps), which provide the following information:

- Locations of specific properties in relation to special flood hazard areas
- Base flood elevations (1-percent-annual-chance) at specific sites
- Magnitudes of flood in specific areas
- Undeveloped coastal barriers where flood insurance is not available
- Regulatory floodways and floodplain boundaries (1-percent and 0.2-percent-annual-chance floodplains).

Land covered by floodwaters of the base flood is the special flood hazard area on a DFIRM—an area where NFIP floodplain management regulations must be enforced, and where mandatory purchase of flood insurance applies. This regulatory boundary is a convenient tool for assessing vulnerability and risk in flood-prone communities, because many communities have maps showing the extent of the base flood and likely depths that will occur.

The base flood elevation (the water elevation of a flood that has a 1-percent chance of occurring in any given year) is one of the most important factors in estimating potential damage from flooding. A structure within a 1-percent-annual-chance floodplain has a 26-percent chance of undergoing flood damage during the term of a 30-year mortgage. The 1-percent-annual-chance flood is used by the NFIP as the basis for insurance requirements nationwide. DFIRMs also depict 0.2-percent-annual-chance flood designations.

DFIRMs and other flood hazard information can be used to identify the expected spatial extent of flooding from a 1-percent and 0.2-percent annual chance event. They depict the following SFHAs and other areas:

- **Zone A (Also known as Unnumbered A-zones**)—SFHAs where no base flood elevations or depths are shown because detailed hydraulic analyses have not been performed.
- **Zones A1-30 and AE—**SFHAs that are subject to inundation by the base flood, determined using detailed hydraulic analysis. Base flood elevations are shown within these zones.
- **Zone AH—**SFHAs that are subject to shallow flooding, usually in the form of a pond, with an average depth ranging from 1 to 3 feet. Base flood elevations derived from detailed analyses are shown at selected intervals within these zones.

- **Zone AO—**SFHAs subject to inundation by types of shallow flooding where average depths are between 1 and 3 feet. These are normally areas prone to shallow sheet flow flooding on sloping terrain.
- **Zone AR—**Areas with a temporarily increased flood risk due to the building or restoration of flood control system (such as a levee or a dam). Mandatory flood insurance purchase requirements apply, but rates do not exceed the rates for unnumbered A zones if the structure is built or restored in compliance with Zone AR floodplain management regulations.
- **Zone A99—**Areas with a 1 percent annual chance of flooding that will be protected by a federal flood control system where construction has reached specified legal requirements. No depths or base flood elevations are shown within these zones.
- **Zone VE, V1-30—**SFHAs along coasts that are subject to inundation by the base flood with additional hazards due to waves with heights of 3 feet or greater. Base flood elevations derived from detailed hydraulic analysis are shown within these zones.
- **Zone B and X (shaded)—**Zones where the land elevation as been determined to be above the base flood elevation, but below the 500-year flood elevation. These zones are not SFHAs.
- **Zones C and X (unshaded)—**Zones where the land elevation has been determined to be above both the base flood elevation and the 500-year flood elevation. These zones are not SFHAs.

The FEMA designated floodway is the channel of a water course and portion of the adjacent floodplain that is needed to convey the base flood without increasing flood levels by more than a specified amount (typically, 1 foot). A floodway may be designated within the SFHA where the deepest, highest velocity flow is expected and any infrastructure will be at risk. Floodways should be kept free of obstructions and development to allow floodwaters to move downstream unobstructed. Any development in a floodway is subject to severe damage and high risks for occupants and emergency responders.

Flood damage may occur outside of SFHAs. FEMA typically does not designate SFHAs for areas subject to flooding from local drainage problems, particularly in urban areas; drainage basins of less than 1 square mile in area; or hillside areas subject to runoff, erosion, and mudflow. FEMA does not map flooding along the length of all streams or in areas that are undeveloped.

According to FEMA, the coastal high hazard area (or "V zone," where V stands for velocity wave action) is the most hazardous part of the coastal floodplain, due to its exposure to wave effects. The V zone has an increased degree of flood risk compared to coastal flood areas not within the coastal high hazard area (A zones), and is subject to more stringent regulatory requirements. Figure 10-1 is a typical transect illustrating the coastal V and A zones and the effects of energy dissipation and regeneration of a wave as it moves inland. Wave elevations are decreased by obstructions such as buildings, vegetation, and rising ground surface.

10.1.3 Floodplain Ecosystems and Beneficial Functions

Floodplains can support ecosystems that are rich in plant and animal species. Wetting of the floodplain soil releases a surge of nutrients left over from the last flood or caused by the rapid decomposition of organic matter accumulated since then. Microscopic organisms thrive, and larger species enter a rapid breeding cycle. Opportunistic feeders (particularly birds) move in to take advantage. The production of nutrients falls away quickly, but the surge of new growth endures. Species growing in floodplains are markedly different from those that grow outside floodplains. For instance, trees that grow in floodplains tend to be very tolerant of root disturbance and very quick-growing compared to non-riparian trees.

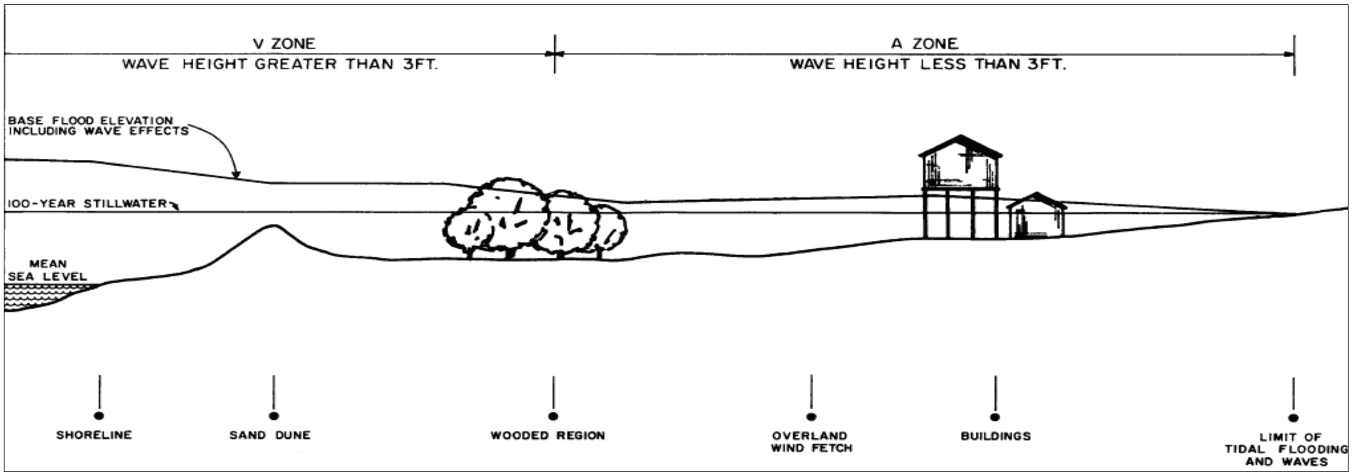


Figure 10-1. Typical Transect Schematic

Floodplains have many natural beneficial functions, and disruption of them can have long-term consequences for entire regions. Some well-known, water-related functions of floodplains (noted by FEMA) include:

- Natural flood and erosion control
- Provide flood storage and conveyance
- Reduce flood velocities
- Reduce flood peaks
- Reduce sedimentation
- Surface water quality maintenance
- Filter nutrients and impurities from runoff
- Process organic wastes
- Moderate temperatures of water
- Provide groundwater recharge
- Promote infiltration and aquifer recharge
- Reduce frequency and duration of low surface flows

Areas in the floodplain that typically provide these natural functions are wetlands, riparian areas, sensitive areas, and habitats for rare and endangered species.

10.1.4 Effects of Human Activities

Because they border water bodies, floodplains have historically been popular sites to establish settlements. Human activities tend to concentrate in floodplains for a number of reasons: water is readily available; riverine floodplain land is fertile and suitable for farming; transportation by water is easily accessible; land is flatter and easier to develop; and there is value placed in ocean views. But human activity in floodplains frequently interferes with the natural function of floodplains. It can affect the distribution and timing of drainage, thereby increasing flood problems. Human development can create local flooding problems by altering or confining drainage channels or causing erosion of natural flood protection systems such as dunes. Flood potential can be increased in several ways: reducing a stream's capacity to contain flows; increasing flow rates or velocities downstream; and allowing waves to extend further inland. Human activities can interface effectively with a floodplain as long as steps are taken to mitigate the activities' adverse impacts on floodplain functions.

10.2 HAZARD PROFILE

10.2.1 Federal Flood Program Participation

National Flood Insurance Program

The most vulnerable structures in the planning area are those that are not constructed to standards to withstand the impacts of a flood. Such structures may have been built before flood damage prevention regulations were in effect or may not be subject to flood-related building codes because they are outside mapped flood hazard areas. Table 10-1 summarizes planning area participation in the National Flood Insurance Program (NFIP). The average flood insurance claim paid out in the planning area since participation in NFIP began is $38,200.

Table 10-1. Flood Insurance Statistics

Jurisdiction	Initial FIRM Effective Date	# of Flood Insurance Policies as of 03/31/2021	Insurance In Force	Total Written Premium + Federal Policy Fee	Claims through 03/31/2021	
					Number	Value
Cloverdale	09/27/1985	35	$9,048,600	$8,766	9	$327,240
Cotati	04/15/1980	72	$22,529,500	$7,412	0	$2,275
Healdsburg	03/04/1980	115	$39,433,000	$11,673	42	$759,335
Petaluma	02/15/1980	362	$128,484,100	$35,705	280	$8,643,392
Rohnert Park	06/01/1981	46	$15,456,500	$9,095	5	$3,639
Santa Rosa	08/03/1981	145	$47,368,200	$12,478	21	$465,602
Sebastopol	06/18/1980	37	$15,563,600	$420	21	$1,602,797
City of Sonoma	01/17/1979	79	$21,724,100	$8,679	28	$683,642
Sonoma County	01/20/1982	2,183	$557,908,100	$804,699	2,986	$116,859,702
Town of Windsor	12/02/2008	62	$19,496,400	$10,270	0	$45,252
Total		**3,136**	**$877,012,100**	**$909,197**	**3,392**	**$129,392,876**

Levee Accreditation

For the NFIP, FEMA only recognizes levee systems that meet minimum design, operation, and maintenance standards. CFR 44 (Section 65.10) describes the information needed for FEMA to determine if a levee system provides protection from the 1 percent annual chance flood. This information must be supplied to FEMA by the community or other party when a flood risk study or restudy is conducted, when FIRMs are revised, or upon FEMA request. FEMA reviews the information for the purpose of establishing the appropriate FIRM flood zone.

FEMA coordinates its programs with the U.S. Army Corps of Engineers, who may inspect, maintain, and repair levee systems. The Corps has authority under Public Law 84-99 to supplement local efforts to repair flood control projects that are damaged by floods. Like FEMA, the Corps provides a program to allow public sponsors or operators to address levee system maintenance deficiencies. Failure to do so within the required timeframe results in the levee system being placed in an inactive status in the Corps’ Rehabilitation and Inspection Program. Levee systems in an inactive status are ineligible for rehabilitation assistance under Public Law 84-99.

There are about 60 levees in Sonoma County. Table 10-2 lists the 29 levees shown on the FEMA FIRM, all of which protect population, structures, and/or valuable property from riverine flooding.

Table 10-2. Levees Shown on FIRM for Sonoma County

Levee Name	Population	Structures	Property Value	Length (miles)	FIRM Status
All Coast Lumber Company and Cloverdale Water Treatment Plan	51	3	$5.29 million	1.24	Non-Accredited
J. Black #3	6	4	$2.27 million	0.99	Non-Accredited
Petaluma River Left Bank	508	213	$140 million	0.83	Non-Accredited
Petaluma River Right Bank	567	176	$104 million	0.89	A99
Sonoma County Levee 106	2	1	$327,000	0.26	Non-Accredited
Sonoma County Levee 111	1	1	$595,000	0.09	Non-Accredited
Sonoma County Levee 12	121	44	$23 million	2.58	Non-Accredited
Sonoma County Levee 13	124	13	$106 million	0.59	Non-Accredited
Sonoma County Levee 16	14	7	$9.28 million	1.08	Non-Accredited
Sonoma County Levee 17	25	14	$8.33 million	0.7	Non-Accredited
Sonoma County Levee 18	18	2	$16.2 million	0.07	Non-Accredited
Sonoma County Levee 21	0	2	$4.11 million	1.31	Non-Accredited
Sonoma County Levee 25	307	24	$88.8 million	0.24	Non-Accredited
Sonoma County Levee 29	102	16	$29.9 million	0.9	Non-Accredited
Sonoma County Levee 30	5	2	$844,000	1.93	Non-Accredited
Sonoma County Levee 32	63	17	$4.78 million	0.23	Non-Accredited
Sonoma County Levee 33	62	21	$13.3 million	0.85	Non-Accredited
Sonoma County Levee 34	477	1	$4.47 million	1.39	Non-Accredited
Sonoma County Levee 37	4	1	$358,000	0.21	Non-Accredited
Sonoma County Levee 38	154	3	$11.8 million	1.47	Non-Accredited
Sonoma County Levee 39	4	1	$391,000	0.45	Non-Accredited
Sonoma County Levee 4	4	3	$2.04 million	0.39	Non-Accredited
Sonoma County Levee 46	12	3	$1.85 million	1.76	Non-Accredited
Sonoma County Levee 48	2	2	$2.6 million	0.62	Non-Accredited
Sonoma County Levee 50	2	1	$1.03 million	4.82	Non-Accredited
Sonoma County Levee 62	0	3	$3.41 million	7.91	Non-Accredited
Sonoma County Levee 65	7	4	$5.24 million	5.62	Non-Accredited
Sonoma County Levee 67	0	4	$2.16 million	9.56	Non-Accredited
Sonoma County Levee 80	13	4	$2.38 million	1.11	Non-Accredited

The Community Rating System

Sonoma County and the City of Petaluma currently participate in the CRS program. Table 10-3 summarizes the CRS status of each. Many of the mitigation actions identified in this plan are creditable activities under the CRS program. Therefore, successful implementation of this plan offers the potential to enhance the CRS classification.

Table 10-3. CRS Status of Participating Jurisdictions

Jurisdiction	NFIP Community #	CRS Entry Date	Current CRS Classification	Premium Discount	
				SFHA	Non SFHA
City of Petaluma	060379	10/01/1991	6	20%	10%
Sonoma County	060375	10/01/1991	10	0%	0%

Repetitive Loss

A repetitive loss property is defined by FEMA as an NFIP-insured property that has experienced any of the following since 1978, regardless of any changes in ownership:

- Four or more paid losses more than $1,000
- Two paid losses 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.

The government has instituted programs encouraging communities to identify and mitigate the causes of repetitive losses. Studies have found that many of these properties are outside any mapped 1 percent annual chance (100-year) floodplain. The key identifiers for repetitive loss properties are the existence of NFIP insurance policies and claims paid by the policies.

FEMA further 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 claims 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, and claims made within 10 days of each other are counted as one claim. 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-sponsored programs, such as the CRS, require participating communities to identify repetitive loss areas. A repetitive loss area is the portion of a floodplain holding structures that FEMA has identified as meeting the definition of repetitive loss. Identifying repetitive loss areas helps to identify structures that are at risk but are not on FEMA's list of repetitive loss structures because no flood insurance policy was in force at the time of loss.

FEMA's list of repetitive loss properties identifies 969 such properties in the Sonoma County planning area, as of March 28, 2021, as summarized in Table 10-4. These properties likely were flooded by flood events typical for the floodplain reflected in the current mapping. Note that special purpose district planning partners to this plan have no identified repetitive loss properties because districts are not eligible participants in the NFIP.

FEMA recently changed its policies on providing repetitive loss properties information due to implications of the Privacy Act. The "routine use" provision for acquiring the data, which requires certifications on how the data will be used, was not well-defined at the time of this plan update. Repetitive loss data for all planning partners could not be acquired in time for analysis and assessment for this plan. Therefore, the resolution of the repetitive loss data available to support this plan update is limited to property counts only. No location or dates of loss data was available. As the State of California's largest repetitive loss community, Sonoma County and its planning partners understand the importance of a thorough understanding of the repetitive flood loss problem. The County and its planning partners will seek to meet FEMA requirements for access to this data through plan implementation. Future updates to this plan will seek to have enhanced resolution for more detailed analysis.

Table 10-4. Repetitive Loss Properties in Sonoma County

Jurisdiction	Repetitive Loss Properties	Total Number of Losses	Payment Made for Losses		
			Building Payments	Contents Payments	Total Payments
Healdsburg	8	25	$305,938.77	$52,298.70	$358,237.47
Morro Bay	3	6	$107,144.24	$.00	$107,144.24
Petaluma	39	108	$2,750,657.29	$668,253.68	$3,418,910.97
Santa Rosa	2	4	$27,134.97	$.00	$27,134.97
Sebastopol	9	23	$654,611.00	$665,023.72	$1,319,634.72
Sonoma (City)	4	10	$167,180.17	$40,134.26	$207,314.43
Sonoma County	904	3,217	$69,494,790.53	$15,992,640.94	$85,487,431.47
Total	**969**	**3,393**	**$73,507,456.97**	**$17,418,351.30**	**$90,925,808.27**

Source: March 28, 2021 FEMA Repetitive Loss Summary

10.2.2 Typical Flood-Causing Events

There are six types of flood events that can impact the planning area: riverine flooding, urban flooding, coastal flooding, tsunami flooding, flooding from sea level rise, and flooding from a dam failure. This hazard profile focuses on the coastal, riverine, and urban flood hazards. Floods resulting from a dam failure are discussed in Chapter 7. Tsunami flooding is discussed in Chapter 14. Floods from sea level rise are discussed in Chapter 12

10.2.3 Flooding Sources

River Systems

Riverine floods in Sonoma County occur during winter. Typically, they develop within 24 to 48 hours after a storm event and recede within three days after the end of the storm. Damaging floods in the county occur most frequently along the Russian River, Petaluma River, Sonoma Creek, Laguna De Santa Rosa, and their tributaries.

Russian River

The Russian River watershed is the largest in Sonoma County, draining a total of 1,485 square miles. It originates in Mendocino County, flows southward through eastern Sonoma County to Healdsburg, where it turns west; then flows into the Pacific Ocean at Jenner. Nearly 90 percent of the drainage basis lies upstream of the flood-prone areas of the Russian River which includes the unincorporated communities of Monte Rio, Guerneville, Rio Nido and Forestville. The watershed comprises much of the county's prime agricultural land and has been greatly influenced by urbanization in the vicinity of Windsor and Santa Rosa. West of Forestville, the river's floodplain narrows significantly as it flows through the Coast Range to the Pacific.

Along the lower Russian River, floods are characterized by high velocity and significant depth of flow due to the relatively narrow floodplain. The frequency of flooding in this portion of the river causes repetitive flood losses in the residential and commercial districts of Mirabel Park, Duncans Mills, Monte Rio, Rio Nido and Guerneville. The National Weather Service considers the Russian River at flood stage when it reaches a height of 32 feet at the Guerneville Bridge. Floods reaching a gauge height of less than 34 feet at the Guerneville Bridge are common during a typical winter but do not usually present significant problems for the community.

The USGS has maintained stream-gaging stations to record flow levels on the Russian River since 1911. The gages are located in the communities of Cloverdale (USGS gauge #11463000), Healdsburg (USGS gauge

#11464000), and Guerneville (USGS gauge # 11467000). The drainage area monitored by these gaging station is about 1,340 square miles, of which 235 square miles are in the drainage areas behind either the Warm Springs Dam or the Coyote Valley Dam. The Guerneville gauge monitors peak discharge 4.3 miles upstream from the Guerneville Bridge and 20.8 miles upstream from the mouth of the Russian River. For County emergency response purposes, a staff gauge on the Guerneville Bridge is used to monitor flood elevation levels and risk to the community of Guerneville. This gauge does not measure or record flow levels and is not an official USGS gaging station (County of Sonoma 2017).

Sonoma Creek

Sonoma Creek frequently floods during relatively small winter storm events that cause flows to overtop the banks. The flooding is of short duration, but may last several days. The bordering low lands are most impacted, as a result of storm water runoff from the upper watershed (County of Sonoma 2017).

Petaluma River

Petaluma River floods after multi-day storm events due to inadequate storm water infrastructure. Flooding along this river mainly occurs in the Payran area, between Denman Flat and the confluence of Lynch Creek; and the Penngrove area. Between 1997 and 2008, the City of Petaluma significantly reduced its flood exposure in the Payran area by completing $40 million in improvements to flood control infrastructure, including 3,600 feet of channel widening and floodwalls, pump stations, two vehicular bridge replacements, and two railroad bridge replacements (County of Sonoma 2017).

Laguna De Santa Rosa

The Laguna De Santa Rosa is a freshwater estuary that receives stormwater from southern Santa Rosa, Rohnert Park, Cotati, Sebastopol, and large unincorporated areas. Many portions of these cities were developed in or near the Laguna's historical flood inundation area. The most significant flood impacts along the Laguna and its tributaries occur in western Rohnert Park, Cotati, and eastern Sebastopol. The City of Santa Rosa's Laguna Treatment Plant has experienced significant flooding on numerous occasions.

Urban Flooding

Urban flooding occurs when available stormwater conveyance systems lack the capacity to convey rainfall runoff to nearby creeks, streams, and rivers. As drainage facilities are overwhelmed, roads and transportation corridors become conveyance facilities. Urban floods can be a great disturbance of daily life in urban areas. Roads can be blocked, and people may be unable to go to work or school. Economic damage can be high, but the number of casualties is usually limited, because of the nature of the flood.

The two key factors that contribute to urban flooding are rainfall intensity and duration. Topography, soil conditions, urbanization and groundcover also play an important role. On flat terrain, the flow speed is low and people can still drive through flooded areas. The water rises relatively slowly and usually does not reach life endangering depths. Risks are much greater where conditions cause floodwaters to flow at higher velocity.

Coastal Flooding

Coastal flooding occurs when intense, offshore low-pressure systems drive ocean water inland. The water pushed ashore is called storm surge. Flooding along the Pacific coast is often associated with the simultaneous occurrence of very high tides, large waves, and storm swells during the winter. Though at lower risk, the San Pablo Bay shoreline also can be affected by storm surges and tidal actions.

Most flood damage along the California coast is due to the confluence of large waves, storm surges, and high tides during strong El Niño events. These storm events can result in coastal bluff erosion. Much of the Sonoma County coastline is elevated above sea level with dramatic coastal bluffs. The bluffs are subject to erosion from winter storms, wave action, wind, and stormwater runoff and can become unstable. Bluff erosion or retreat may occur suddenly and catastrophically through slope failure due to heavy rain, high wave action, and high tides.

According to the National Academy of Sciences, storms and sea level rise are causing California coastal bluffs, beaches, and dunes to retreat at rates from a few inches to several feet per year. The Academy projects that California coastal bluffs could retreat more than 100 feet by 2100. The ability of coastal bluffs to withstand continuous erosive forces over time depends on the relative resistance of the shoreline rocks. Factors that determine rock resistance are the type of rock, extent of shearing and fracturing, and inclination of the rock layers. Coastal bluffs consisting of native materials from the Franciscan or Merced geologic formations are the most affected by erosion (County of Sonoma 2017).

Coastal bluff erosion has threatened development in some areas west of State Highway 1, such as Gleason Beach. Structures and septic systems in these areas were built on or near the edge of coastal bluffs and on steep slopes, which are eroding. Landslides, in conjunction with wave action, failure of shoreline protection measures, and changes in drainage have resulted in severe erosion, bluff failure, and loss of bluff top area. Some houses have been demolished and removed because they posed a public safety risk, and several other houses have been damaged to the extent that they are no longer habitable. Caltrans investigations in 1998 and 2003 determined that coastal erosion rates near Gleason Beach were about 1 foot per year. Coastal erosion threatens the stability of State Highway 1, and Caltrans developed a project to relocate State Highway 1 at Gleason Beach. The project is scheduled to begin in mid-2021.

10.2.4 Past Events

Significant floods occurred on the Russian River in 1955, 1964, 1986, 1995, 1997, 2006, and 2017. The earliest major flood recorded on the Russian River occurred in 1862. This flood predated gauge measurements of river flow, but is estimated to have had a discharge of about 100,000 cubic feet per second. The Petaluma River has also had a history of flooding. According to the Corps of Engineers, floods in 1982, 1986, and 1998 caused over $34 million in damage within the City of Petaluma, particularly in the Payran area. These flood hazards have been significantly reduced by construction of flood control channels and flood walls, completed in 2008 (County of Sonoma 2017). Table 10-5 summarizes the 15 federally declared flood disasters in Sonoma County related to flooding between 1960 and 2020.

The largest flood in recent history occurred between February 14 and 18, 1986, when a peak discharge of 102,000 cubic feet per second was recorded and the flood reached a gage height of 48.6 feet at Guerneville. Heavy rains from December 26, 2005, to January 3, 2006. The Russian River rose above flood stage at all USGS gaging stations in Sonoma County. Significant flooding also occurred on the Petaluma River and Sonoma Creek. At Guerneville, the river crested at 41.6 feet. The rainfall measured in the City of Santa Rosa during this storm was near record-setting at 17.6 inches. A federal disaster declaration was issued for this event, and more than 100 roadways were blocked due to flooding or landslides. Some 2,100 business and residential properties were inundated, and 50,000 residents were without power. Sonoma County business and residential damages were estimated at $104 million (County of Sonoma 2017).

Table 10-5. Declared Sonoma County Flood Disaster Events

Date	Declaration #	Type of event	Assistance Type[a]	Estimated Damage
February 24 – March 1, 2019	4434	Severe winter storms, flooding, landslides, mudslides	PA	$155 million
February 1 – 23, 2017	4308	Severe winter storms, flooding, mudslides	PA	$537.1 million
January 3 – 12, 2017	4301	Severe winter storms, flooding, and mudslides	PA	$162.3 million
March 29 – April 16, 2006	1646	Severe storms, flooding, landslides, and mudslides	PA	
December 17 – January 3, 2006	1628	Severe storms, flooding, mudslides, and landslides	IA & PA	$163.2 million
February 2 – April 30, 1998	1203	Severe winter storms and flooding	IA & PA	
December 28, 1996 – April 1, 1997	1155	Severe storms/flooding	IA & PA	
February 13 – April 19, 1995	1046	Severe winter storms, flooding, landslides, mud flows	IA & PA	
January 3 – February 10, 1995	1044	Severe winter storms, flooding, landslides, mud flows	IA & PA	
January 5 – March 20, 1993	979	Severe storm, winter storm, mud & landslides, flooding	IA & PA	
February 12 – March 10, 1986	758	Severe storms, flooding	IA & PA	
January 21 – March 30, 1983	677	Coastal storms, floods, slides, tornadoes	IA & PA	
December 19, 1981 – January 8, 1983	651	Severe storms, flood, mudslides, high tide	IA & PA	
January 16, 1969	253	Severe storms, flooding	IA & PA	
December 24, 1964	183	Heavy rains & flooding	IA & PA	

a. IA = Individual Assistance; PA = Public Assistance; HMGP = Hazard Mitigation Grant Program; N/A = Information not available or applicable

10.2.5 Location

FEMA-generated FIRMs (Flood Insurance Rate Maps) are the principle tool used to identify the extent and location of the flood hazard. FEMA last updated a FIRM for the County of Sonoma on March 7, 2017. Flood hazard zones from that mapping are shown on Figure 10-2. Preliminary data were released in May 2020 for additional FIRM updates, but those changes have not yet become effective.

Additional areas called “flood awareness areas” were delineated using the County’s “functional riparian channels and floodplains” data (see Figure 10-3). The mapped areas overlap with the FEMA and Russian River data in some areas but also include streams not mapped by FEMA.

10.2.6 Frequency

Riverine Flooding

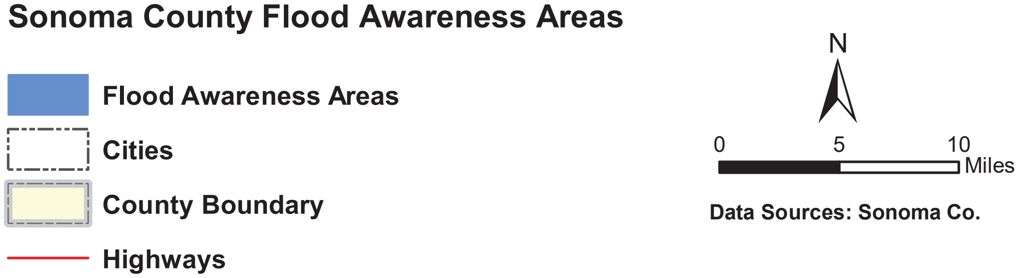
Annual peak gauge heights and discharges for the Russian River at the USGS Guerneville gage indicate that peak flows exceeded flood stage at Guerneville in 34 of 59 years. The number of floods experienced may be greater as some years had more than one high flow event. The future potential for flood frequency and intensity in the near term is expected to be similar to the observed historic probabilities. Based on this, the planning area can expect at least one episode of minor river flooding most winters. In the longer term, the effects of development and of climate change storm intensity, frequency and flooding are unknown (County of Sonoma 2017).

Figure 10-2. FEMA FIRM Flood Hazard Areas

1% Annual Chance Flood (100-Year)
0.2% Annual Chance Flood (500-Year)
Cities
County Boundary
Highways

Data Sources: Sonoma Co., FEMA

Figure 10-3. Sonoma County Flood Awareness Areas



Flood frequency for riverine flooding is often evaluated by examining peak discharges; Table 10-6 lists peak flows on the Petaluma and Russian Rivers used in FEMA's flood insurance study to define flows with a 10 percent, 2 percent, 1 percent, and 0.2 percent probability of occurring in any given years. These values are often referred to a flows likely to occur once every 10, 50, 100, or 500 years, respectively. FEMA's peak flows for all surface waters in the county are included in Appendix E.

Table 10-6. Peak Riverine Discharges on the Petaluma and Russian Rivers

Source/Location	Discharge (cubic feet/second)			
	10 Percent Annual Chance	2 Percent Annual Chance	1 Percent Annual Chance	0.2 Percent Annual Chance
Petaluma River				
Downstream of confluence with Adobe Creek	8,672	11,034	11,910	15,044
At Highway 101 bridge	6,675	9,149	10,494	13,694
Downstream of confluence of Washington Creek	5,758	8,459	9,757	13,056
Downstream of confluence of Lynch Creek	5,246	7,492	8,671	11,563
Downstream of confluence of Capri Creek	4,653	6,583	7,728	10,523
Downstream of confluence of Willow Brook	3,587	4,825	5,360	6,733
Upstream of confluence of Willow Brook	1,701	2,947	3,529	4,801
Russian River				
At Pacific Ocean	76,000	102,000	114,000	135,000
Upstream of Duncan Mills	75,000	100,000	112,000	133,000
Upstream of confluence of Austin Creek	74,000	98,000	107,000	131,000
Upstream of Summerhome Gage	73,000	97,000	106,000	130,000
Downstream of confluence of Mark West Creek	67,000	92,000	97,000	126,000
Upstream of confluence of Mark West Creek	60,000	88,000	103,000	140,000
Upstream of confluence of Dry Creek	56,000	79,000	90,000	129,000
Upstream of confluence of Brooks Creek	55,000	78,000	88,000	127,000
Upstream of confluence of Maacama Canal	51,000	73,000	82,000	115,000
Upstream of confluence of Sausal Creek	50,000	71,000	81,000	111,000
Upstream of confluence of Lytton Creek	50,000	70,000	80,000	110,000
Upstream of confluence of Miller Creek	48,000	68,000	79,000	106,000
Upstream of confluence of Gill Creek	47,000	67,000	76,000	105,000
Upstream of confluence of Big Sulphur Creek	46,000	58,000	73,000	100,000
Upstream of confluence of Oat Valley Creek	40,000	56,000	64,000	85,000
Russian River Split Flow				
At Healdsburg Avenue	*	215	640	9,140

* Data not available
Source: FEMA Flood Insurance Study Number 06097CV001E, Sonoma County, California and Incorporated Areas, March 7, 2017

Coastal Flooding

The frequency and severity of coastal flooding are based on storm surge height, which is the height of water accounting for waves. Table 10-7 summarizes the still-water elevations along the San Pablo Bay coastline, representing the steady state water depth not accounting for breaking waves. These are the projected elevations of floodwaters in the absence of waves resulting from wind or seismic effects. Table 10-8 shows the storm surge water levels used for mapping the coastal floodplains in the planning area.

Low	8.4	9.8	10.6	10.9
High	15.7	15.1	17.2	16.5

a. Elevation in 1988 North American Vertical Datum

Source: FEMA Flood Insurance Study Number 06097CV001E, Sonoma County, California and Incorporated Areas, March 7, 2017

Table 10-8. Regional Storm Surge Water Elevations

	Regional Storm Surge Water Elevations (feet, North American Vertical Datum)		
	Point Reyes	Bodega Harbor	Arena Cove
50-percent	7.6	7.6	7.8
20-percent	7.9	7.9	8.2
10-percent	8.2	8.2	8.4
4-percent	8.5	8.5	8.8
2-percent	8.8	8.8	9.0
1-percent	9.1	9.1	9.3
0.2 percent	9.8	9.8	10.1

Source: FEMA Flood Insurance Study Number 06097CV001E, Sonoma County, California and Incorporated Areas, March 7, 2017

10.2.7 Severity

The principal factors affecting flood damage are flood depth and velocity. The deeper and faster flood flows become, the more damage they can cause. Shallow flooding with high velocities can cause as much damage as deep flooding with slow velocity. Wave action has significant velocity, and waves as small as 1.5 feet can cause substantial damage to structures and other development. Table 10-9 summarizes impacts and estimated costs of recent federally declared flood disasters in Sonoma County.

10.2.8 Warning Time

Due to the sequential pattern of meteorological conditions needed to cause serious flooding, it is unusual for a flood to occur without warning. Warning times for floods can be between 24 and 48 hours. Flash flooding can be less predictable, but potential hazard areas can be warned in advanced of potential flash flooding danger. Flash flooding is infrequent in the planning area.

As major storm systems approach, the National Weather Service, in coordination with the California Department of Water Resources, monitors weather conditions and real-time precipitation and river stage data; forecasts the amount and timing of expected precipitation; and issues official river forecasts and hydrologic statements. Updated a minimum of twice daily, these river forecasts are available as both text products and as graphical river guidance plots, which provide river stage information for each official forecast point for the next five days following the forecast issuance. As storm events continue with streams and rivers rising to threatening levels, these forecasts may be updated more frequently if needed.

Table 10-9. Damage and Estimated Losses from Recent Floods in Sonoma County

Date	Loss Estimates[a]	Damage
January 8-31, 1995	$21 million	• Over 50 roads closed • 15,000 residents without power • Total displaced persons exceeded 2,000, of which 456 flood victims were evacuated by air • 13 medical cases were treated and 2 flood-related fatalities occurred
March 7-15, 1995	$13.3 million	• Over 100 roads closed • 45,000 residents without power At least 3,000 residents displaced • Up to 30 containers of possible toxic materials identified in the flood zone
December 30, 1996 – January 4, 1997	$31 million	• Up to 200 roads were closed or damaged temporarily 463 homes damaged • 12,000 residents without power • Over 1,200 victims evacuated their residences and 2 storm-related deaths occurred • Sewage and treatment plants overflowed
February 2, 1998	$28 million	• 200 roads were listed as flooded or closed 6,400 residents without power • 250+ homes were inundated • 1,200 residents voluntarily evacuated 4 storm-related deaths
December 30, 2005 – January 3, 2006	$104 million	• Over 100 roads closed due to flooding and landslides Approximately 50,000 county residents without power 2106 properties inundated, 67 declared uninhabitable Unknown number of self-evacuations • Laguna Wastewater Treatment Plant flooded with partially treated sewage spill
December 2014	$1.1 million	• 48 businesses and single-family dwellings damaged along Foss Creek
January – February 2017	$155 million	• 1,900 homes (1,760 with major damage) and 578 businesses damaged by flood waters • Emergency operations center activated
February 2019	$155 million	• 2,000 buildings damaged and 1 fatality • 3,500 evacuated • Emergency operations center activated

a. Dollar amounts in the year of occurrence

Graphical river guidance plots can be accessed at these websites:

- http://www.cnrfc.noaa.gov
- http://cdec.water.ca.gov/guidance_plots/

10.2.9 Secondary Hazards

The most problematic secondary hazard for flooding is bank or coastal erosion. In many cases the threat and effects of erosion are worse than actual flooding. This is especially true on the upper courses of rivers where there are steep gradients. Floodwaters in these reaches may pass quickly and without much damage, but scour the banks, edging properties closer to the floodplain or causing them to fall in. Flooding is also responsible for hazards such as landslides when high flows over-saturate soils on steep slopes, causing them to fail. Hazardous materials spills are also a secondary hazard of flooding if storage tanks rupture and spill into streams, rivers or drainage sewers.

10.3 EXPOSURE

A quantitative assessment of exposure to the dam failure hazard was conducted using the asset inventory developed for this plan, flood mapping by FEMA for the most recent Sonoma County FIRM (see Figure 10-2), and Sonoma County's mapped flood awareness areas (see Figure 10-3). Detailed results by jurisdiction are included in Appendix D; countywide summaries are provided below.

10.3.1 Population

Table 10-10 summarizes the estimated population living in the evaluated flood hazard areas.

Table 10-10. Exposed Population in Evaluated Flood Hazard Zones

	1% Annual Chance Flood Zone	0.2% Annual Chance Flood Zone	Flood Awareness Areas
Population Exposed	7,768	17,861	7,524
% of Total Planning Area Population	1.6%	3.7%	1.55%

Socially vulnerable populations living in the mapped flood zones were estimated based on data for the Census-defined blocks that lie at least partially within the mapped flood zone. Because many of those Census blocks extend outside the flood zone, the estimates are greater than the actual exposed populations, but they provide reasonable relative data for use in mitigation planning. Figure 10-4 summarizes the estimated exposure of socially vulnerable populations.

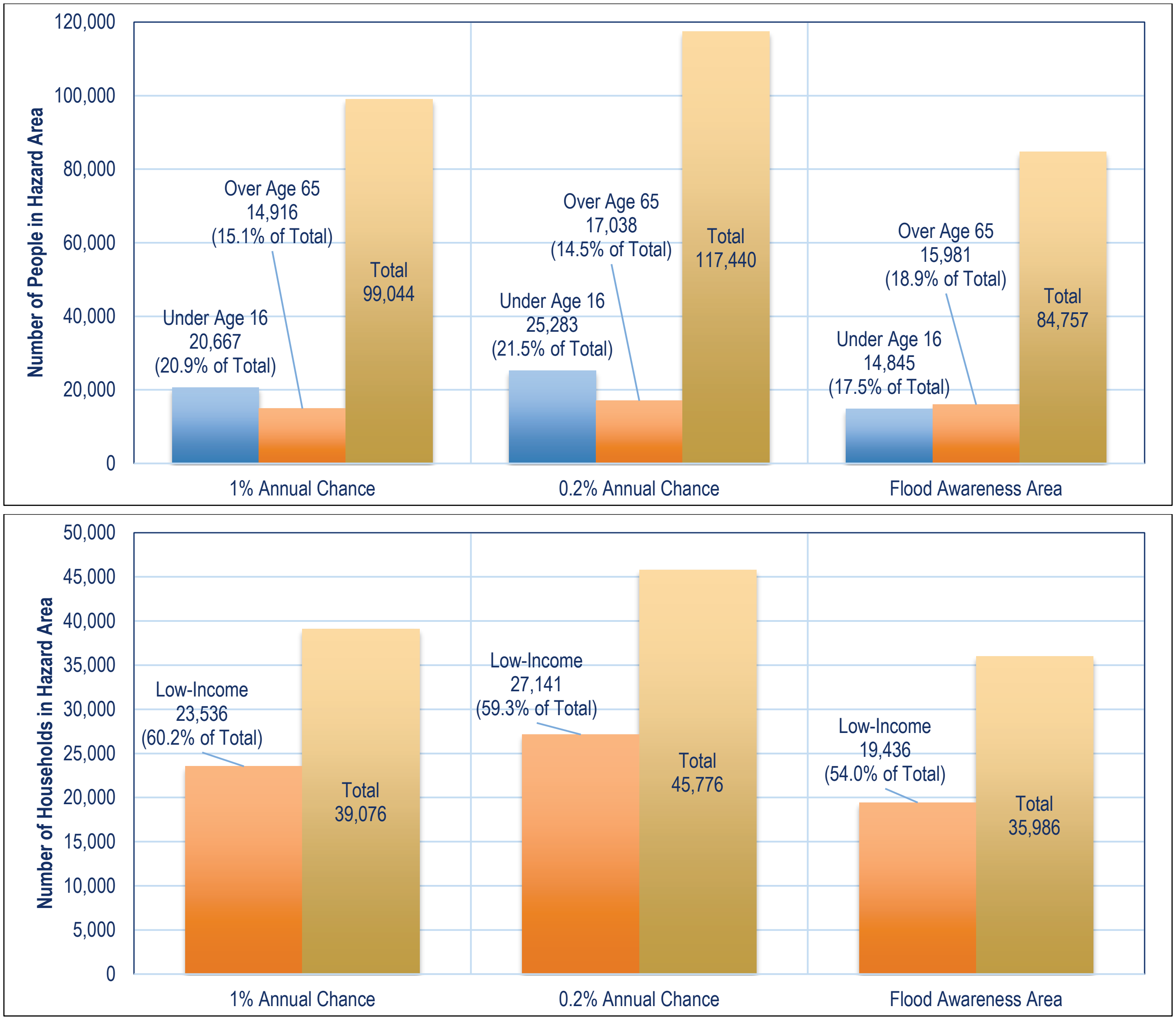
10.3.2 Property

Table 10-11 summarizes the estimated property exposure in the evaluated flood hazard areas. Figure 10-5 shows the occupancy class defined by Hazus for all buildings in the mapped floodplains. These occupancy classes provide an indication of land use within the mapped hazard area. Some land uses are more vulnerable to flood risks, such as single-family homes, while others are less vulnerable, such as agricultural land or parks.

10.3.3 Critical Facilities

The breakdown of critical facility exposure by facility type is shown in Figure 10-6. Critical facilities exposed to the flood hazard represent the following percentages of all critical facilities in the planning area:

- 7.9 percent (377 facilities) of all critical facilities are in the 1-percent-annual-chance flood hazard area.
- 11.6 percent (550 facilities) of all critical facilities are in the 0.2-percent-annual-chance flood hazard area.
- 8.8 percent (418 facilities) of all critical facilities are in the flood awareness area.



See Section 4.8.1 for the definition of "low income" used in this analysis

Figure 10-4. Socially Vulnerable Populations in Flood Zone Census Blocks

Table 10-11. Exposed Property in Evaluated Flood Hazard Zones

	1% Annual Chance Flood Zone	0.2% Annual Chance Flood Zone	Flood Awareness Areas
Acres of inundation area	58,495	64,542	—
Number of Buildings Exposed	4,570	8,416	4,654
Value of Exposed Structures	$6,282,146,827	$9,094,421,934	$5,241,949,336
Value of Exposed Contents	$6,062,349,168	$8,493,127,383	$4,978,042,951
Total Exposed Property Value	**$12,344,495,994**	**$17,587,549,317**	**$10,219,992,287**
Total Exposed Value as % of Planning Area Total	***5.6%***	***8.0%***	***4.68%***

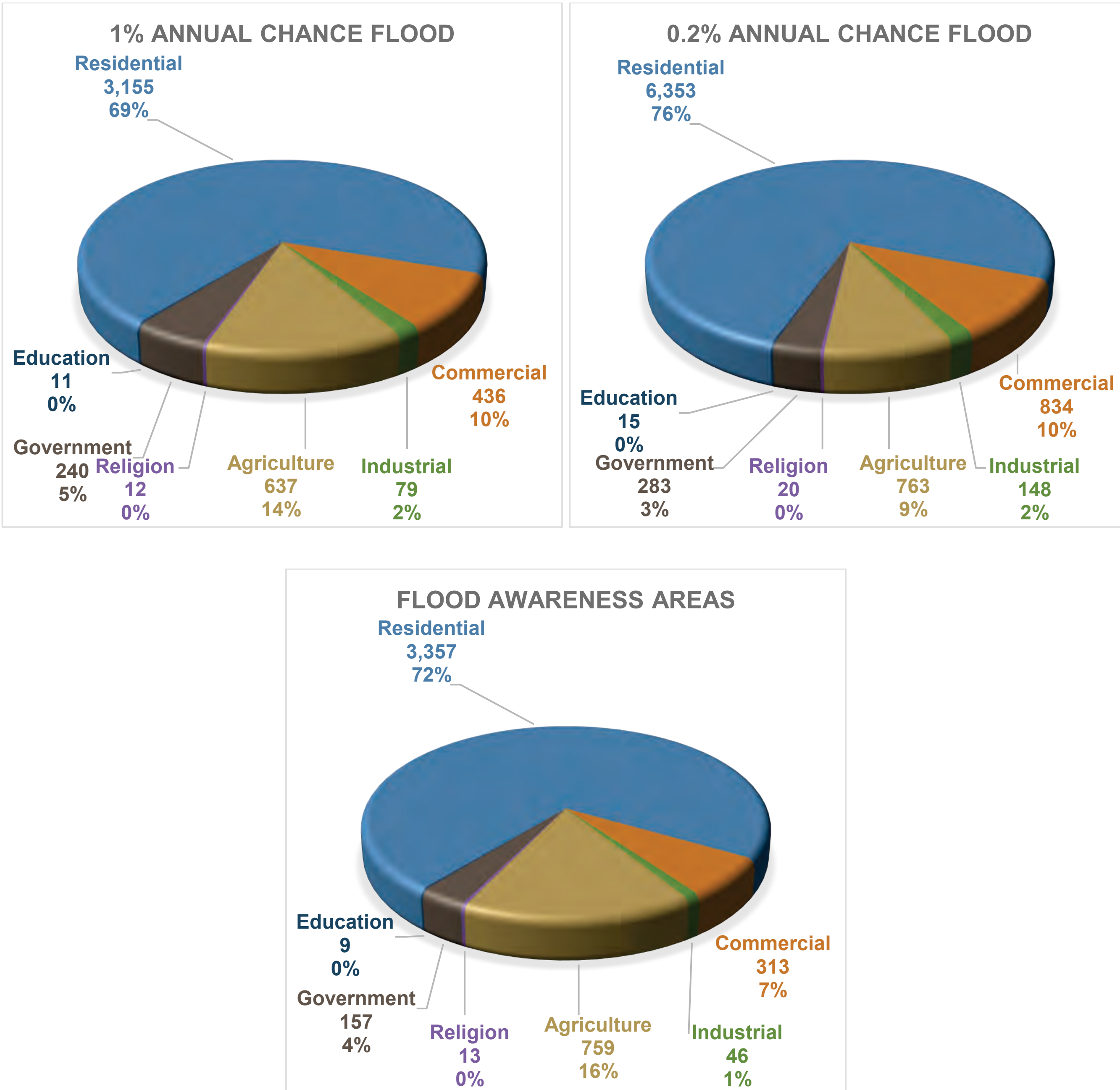


Figure 10-5. Building Occupancy Classes in the Mapped Flood Zones

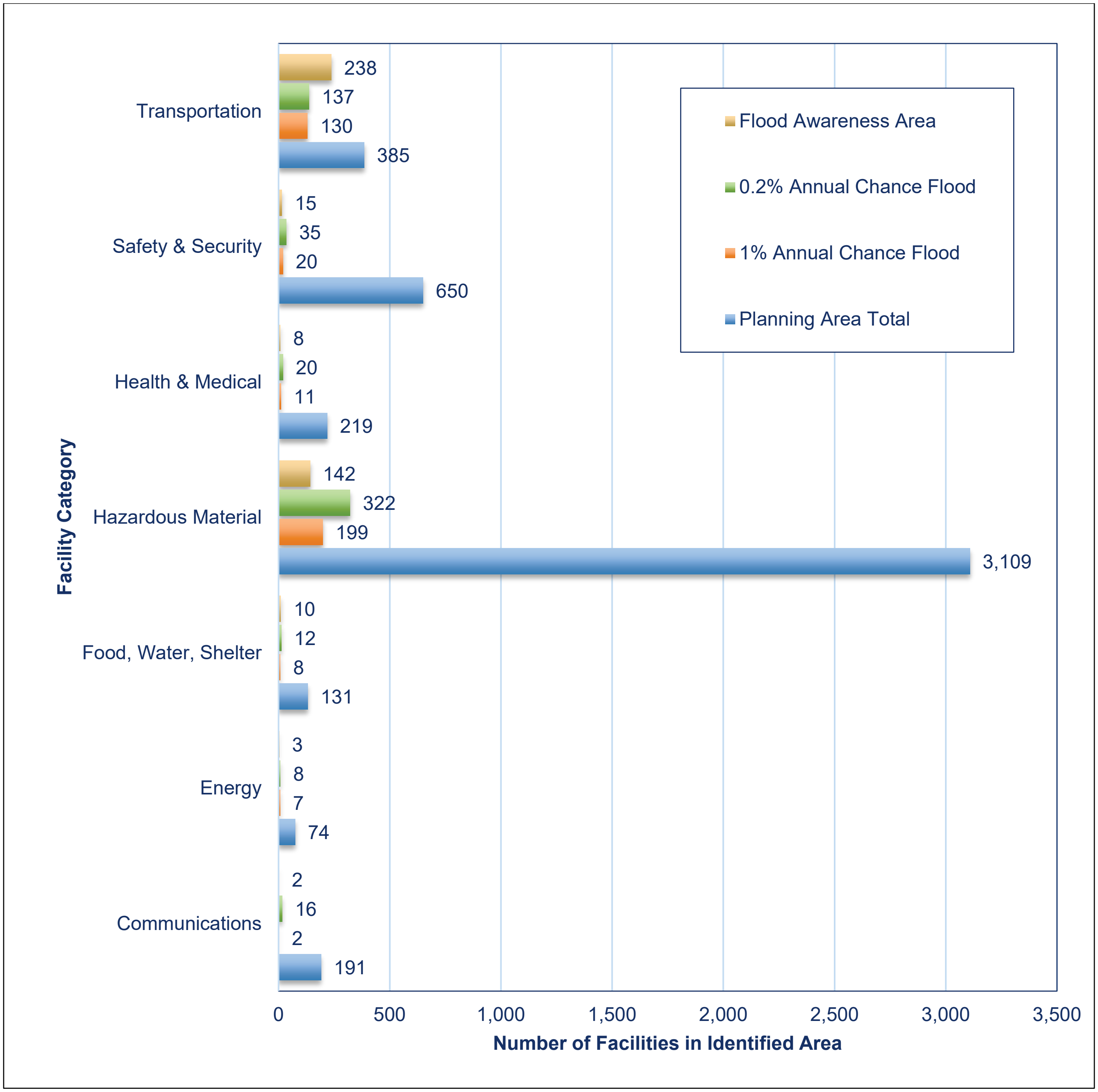


Figure 10-6. Critical Facilities in Mapped Flood Hazard Areas and Countywide

Significant facilities included in the 1 percent annual chance flood zone include the following:

- 4 wastewater treatment facilities
- 199 hazardous material sites
- 5 schools
- 1 airport
- 5 fire stations
- 115 road bridges
- 14 port facilities

All levees line flood-prone rivers and are therefore exposed to the flood hazard. This includes the 29 levees, totaling 50 miles in length, listed in Table 10-2, which have been identified as protecting people and valuable assets from floodwaters.

10.3.4 Environment

Because floodplain management measures place restrictions on development in areas affected by flooding, floodplains often have a higher portion of area that is undeveloped open space or natural area. These undeveloped areas represent environment exposed to the flood hazard.

10.4 VULNERABILITY

The results of the vulnerability assessment indicate estimated damage for the 1-percent and 0.2-percent-annual-chance flood hazards. Detailed results by jurisdiction are included in Appendix D; countywide summaries are provided below.

10.4.1 Population

Impacts on persons and households for evaluated flood events were estimated for each event through the Level 2 Hazus analysis. Table 10-12 summarizes the results.

Table 10-12. Estimated Flood Impacts on Residents

	Displaced Population	Number of Residents Requiring Short Term Shelter
1% Annual Chance Flood Zone	1,684	85
0.2% Annual Chance Flood Zone	4,802	273

10.4.2 Property

Table 10-13 summarizes Hazus estimates of flood damage in the planning area. The debris estimate includes only structural debris and building finishes; it does not include additional debris that may result from a flood event, such as from trees, sediment, building contents, bridges or utility lines.

Table 10-13. Estimated Impact of a Flood Event in the Planning Area

Damage Type	1% Annual Chance Event	0.2% Annual Chance Event
Structure Debris (Tons)	657,111	784,257
Buildings Impacted	3,594	5,264
Total Value (Structure + Contents) Damaged	$3,890,916,991	$4,480,381,334
Damage as % of Total Value	1.8%	2.0%

10.4.3 Critical Facilities

Estimated Damage

Hazus was used to estimate the percent of damage to the building and contents of critical facilities, using depth/damage function curves. The results are summarized in Figure 10-7 and Figure 10-8.

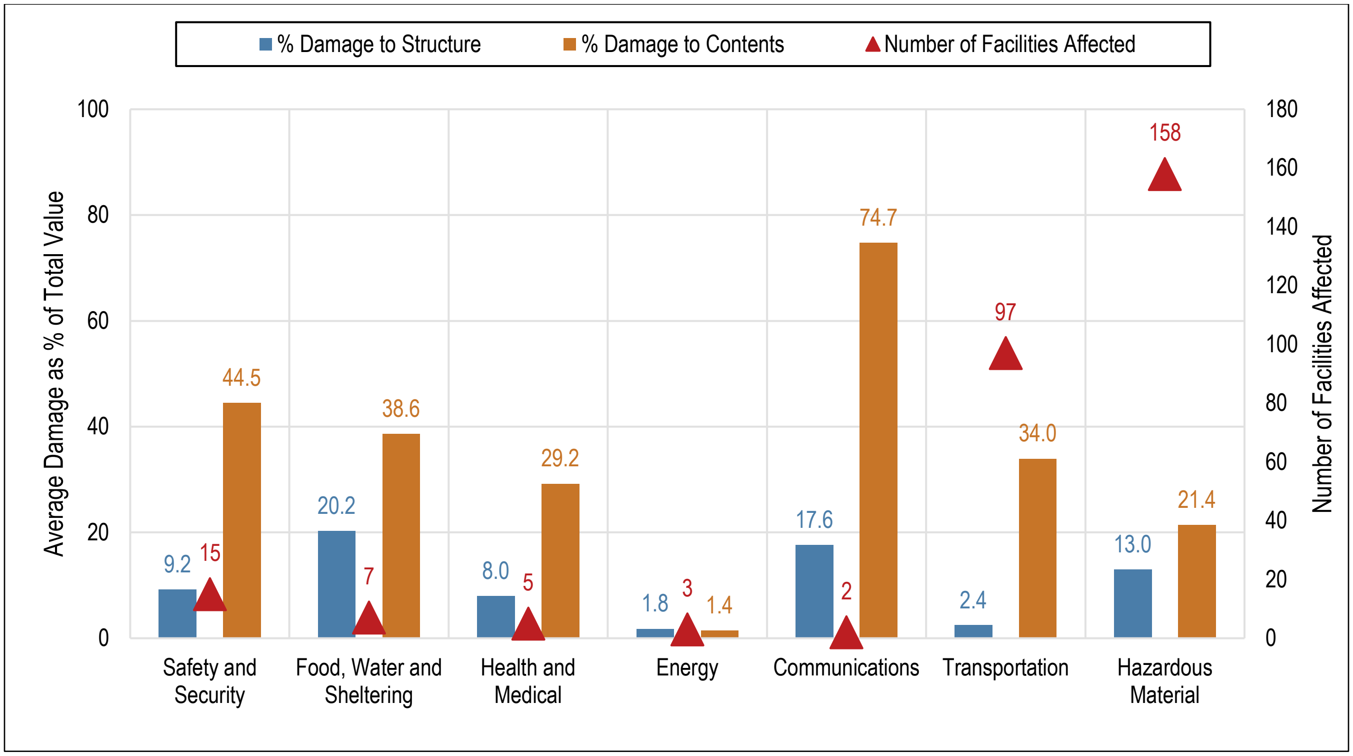


Figure 10-7. Estimated Damage to Critical Facilities from 1% Annual Chance Flood

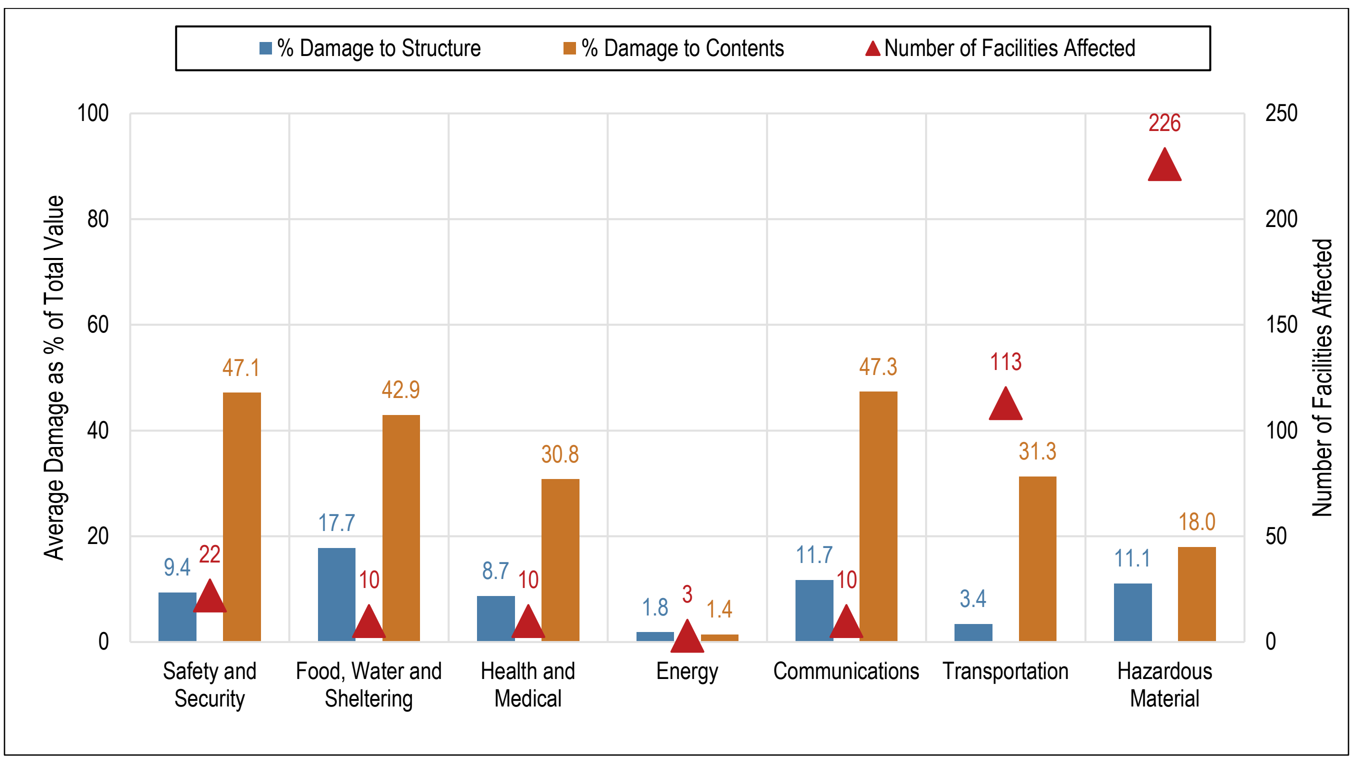


Figure 10-8. Estimated Damage to Critical Facilities from 0.2% Annual Chance Flood

Impacts on Hazardous Materials

During a flood event, containers holding hazardous materials can rupture and leak into the surrounding area. These facilities could release chemicals that cause cancer or other human health effects, significant adverse acute human health effects, or significant adverse environmental effects.

Impacts on Utilities and Infrastructure

Roads that are blocked or damaged can isolate residents and can prevent access throughout the planning area, including for emergency service providers needing to get to vulnerable populations or to make repairs. Bridges washed out or blocked by floods or debris also can cause isolation. Underground utilities can be damaged. Levees can fail or be overtopped, inundating the land that they protect. Floodwaters can back up drainage systems, causing localized flooding. Culverts can be blocked by debris from flood events, also causing localized urban flooding. Floodwaters can get into drinking water supplies, causing contamination. Sewer systems can be backed up, causing wastewater to spill into homes, neighborhoods, rivers and streams.

10.4.4 Environment

Flooding is a natural event, and floodplains provide many natural and beneficial functions. Nonetheless, 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 and levees, and logjams from timber harvesting can increase stream bank erosion, causing rivers and streams to migrate into non-natural courses.

Loss estimation platforms such as Hazus are not currently equipped to measure environmental impacts of flood hazards. The best gauge of vulnerability of the environment would be a review of damage from past flood events. Capturing loss data from future events that segregates damage to the environment could be beneficial in measuring the vulnerability of the environment for future updates.

10.5 FUTURE TRENDS IN DEVELOPMENT

The County and its planning partners are equipped to handle future growth within flood hazard areas. All municipal planning partners have general plans that address frequently flooded areas in their safety elements. All partners have committed to linking their general plans to this hazard mitigation plan update. This will create an opportunity for wise land use decisions as future growth impacts flood hazard areas. In addition, partners who are participating in good standing in the NFIP have agreed to regulate new development in the mapped floodplain according to standards that equal or exceed those specified under 44 CFR Section 60.3. This will ensure that any development allowed in the floodplain will be constructed such that the flood risk exposure is eliminated or significantly reduced.

Development in floodplain areas outside of an urban service area is generally constrained by septic requirements. New standards of onsite wastewater treatment (septic) systems became effective in May 2016 pursuant to new regulations adopted by the State Water Resources Control Board. These standards establish a risk-based, tiered approach for the management of septic system installations and replacements. They mandate that these systems meet increasing levels of performance and protection if they are adversely affecting water quality in nearby water bodies. These higher standards may limit development on some parcels in the floodplain. The County Riparian

Corridor Zoning combining district further restricts development in many portions of the floodplain (County of Sonoma 2017).

10.6 SCENARIO

The major river systems in Sonoma County flood at irregular intervals, but generally in response to a succession of intense winter rainstorms. Storm patterns of warm, moist air usually occur between early November and late March. A series of such storms can cause severe flooding in Sonoma County. The worst-case scenario is a series of storms that flood numerous drainage basins in a short time. This would overwhelm city and County response and floodplain management departments. Major roads would be blocked, preventing access for many residents and critical functions. High river flows could cause rivers to scour, possibly washing out roads and creating more isolation problems. In the case of multi-basin flooding, the County would not be able to make repairs quickly enough to restore critical facilities.

10.7 ISSUES

The planning team has identified the following flood-related issues relevant to the planning area:

- Structures in the planning area built before any regulations existed on floodplain development may be particularly vulnerable to the flood hazard.
- The accuracy of the existing flood hazard mapping produced by FEMA in reflecting the true flood risk within the planning area is questionable, especially along the Russian River.
- The extent of the flood-protection currently provided by flood control facilities (dams, dikes and levees) is not known due to the lack of an established national policy on flood protection standards.
- Older levees are subject to failure or do not meet current building practices for flood protection.
- The risk associated with the flood hazard overlaps the risk associated with other hazards such as earthquake, landslide, and severe weather. This provides an opportunity to seek mitigation alternatives with multiple objectives that can reduce risk for multiple hazards.
- There is no area-wide degree of consistency in land-use and floodplain management practices.
- Climate change may cause more extensive flood problems due to possible sea level rise and more severe weather patterns. The 0.2 percent-annual-chance floodplain inundation area may become a higher probability risk. Coastal flood hazard ratings may also need to be reviewed.
- More information is needed on flood risk to support the concept of risk-based analysis of capital projects.
- There needs to be a sustained effort to gather historical damage data, such as high-water marks on structures and damage reports, to measure the cost-effectiveness of future mitigation projects.
- Ongoing flood hazard mitigation will require funding from multiple sources.
- Coordinated hazard mitigation efforts among jurisdictions affected by flood hazards in the county are recommended.
- Floodplain residents should continue to be educated about flood preparedness and the resources available during and after floods.
- The concept of residual risk should be considered in the design of future capital flood control projects and should be communicated with residents living in the floodplain.

- The promotion of flood insurance as a means of protecting private property owners from the economic impacts of frequent flood events should continue.
- The economy affects a jurisdiction's ability to manage its floodplains. Budget cuts and personnel losses can strain resources needed to support floodplain management.
- Sonoma County is the State of California largest "repetitive loss" community. Challenges in the acquisition of repetitive loss data from FEMA have made it difficult to acquire data necessary to study the repetitive flood loss problem in depth.

11. LANDSLIDE/MASS MOVEMENT

11.1 GENERAL BACKGROUND

11.1.1 Mass Movement Types

Mass movement is the movement of rock and soil down slope under the influence of gravity. Landslides are the most commonly recognized type of mass movement. Other common mass movement types include the following:

- **Block slides**—Blocks of rock that slide along a slip plane as a unit down a slope.
- **Coastal bluff erosion—**The collapse of coastal bluffs due to undercutting erosive forces of wave action.
- **Creep**—A slow-moving landslide often only noticed through crooked trees and disturbed structures.
- **Debris avalanche**—A debris flow that travels faster than about 10 miles per hour (mph). Speeds in excess of 20 mph are not uncommon, and speeds in excess of 100 mph, although rare, can occur. The slurry can travel miles from its source, growing as it descends, picking up trees, boulders, cars, and anything else in its path.
- **Earth flows**—Fine-grained sediments that flow downhill and typically form a fan structure.
- **Mudslides or Debris Flows**—Rivers of rock, earth, organic matter and other soil materials saturated with water. They develop in the soil overlying bedrock on sloping surfaces when water rapidly accumulates in the ground, such as during heavy rainfall or rapid snowmelt.
- **Rock falls**—Blocks of rock that fall away from a bedrock unit without a rotational component.
- **Rock topples**—Blocks of rock that fall away from a bedrock unit with a rotational component.
- **Rotational slumps**—Blocks of fine-grained sediment that rotate and move down slope.
- **Transitional slides**—Sediments that move along a flat surface without a rotational component.

11.1.2 Factors Causing Mass Movements

Mass movements are caused by a combination of geological and climate conditions, as well as encroaching urbanization. Vulnerable areas are affected by residential, agricultural, commercial, and industrial development and the infrastructure that supports it.

Factors causing mass movements fall into two categories:

- Factors that increase driving forces:
  - ➢ Steepening the slope
  - ➢ Adding weight to (loading) the slope, especially the upper parts

- Increasing the height of a slope (either by human or natural downcutting)
- Seismic shaking

- Factors that reduce resisting forces:
  - Adding water to the slope, which causes increased pore pressure, which reduces frictional strength
  - Steepening the slope, which reduces normal stress, and thus reduces internal friction
  - Bedding, jointing, or foliation parallel to slope or dipping out of slope—these discontinuities are low-strength zones along which the rock can fail and slide out of the slope
  - Intrinsically weak materials (e.g., deeply weathered, sheared, unconsolidated, or clay-rich materials)
  - Undercutting the slope, which reduces support
  - Removing vegetation, especially trees, which reduces root strength and leads to increased water in soil due to reduced evaporation losses
  - Seismic shaking
  - Coastal bluff erosion caused by wave action

11.2 HAZARD PROFILE

11.2.1 Past Events

Table 11-1 lists the known damage-causing mass movements that have occurred in the county. The following sections describe specific past significant events.

Table 11-1. Landslide/Mass Movement Events in Sonoma County

Dates of Event	Primary Event Type	FEMA Disaster #	Losses/Impacts
February 24 – March 1, 2019	Severe Winter Storms, Flooding, Landslides, and Mudslides	4434	
February 1 – 23, 2017	Severe Winter Storms, Flooding, Mudslides	4308	
January 3 – 12, 2017	Severe Winter Storms, Flooding, and Mudslides	4301	
December 23, 2012	Debris Flow		Mudslides closed Annapolis Road for several hours, east of Highway 1. $1,000 in property damage
December 5, 2012	Debris Flow		Highway 1 was closed north of Jenner due to a significant mud and rockslide blocking the lanes of the road. $15,000 in property damage.
March 29 – April 16, 2006	Severe Storms, Flooding, Landslides, and Mudslides	1646	
December 17, 2005 – January 3, 2006	Severe Storms, Flooding, Mudslides, and Landslides	1628	

Sources: FEMA 2020, National Centers for Environmental Information Storm Events Database, 2020

April 2006

One of the most recent and most destructive mass movements in Sonoma County occurred in April 2006. Persistent heavy rainfall caused a massive number of landslides across the Sonoma and Marin County valleys area during the first half of April. About $20 million of damage was done to agriculture, with over $9 million spent in road repair damage in Sonoma County alone. Over $5 million worth of damage was done to single family dwellings in Sonoma - with lesser (but still substantial) amounts of damage experienced to businesses and public buildings. In Marin County the hardest hit areas were Mill Valley, Fairfax, and San Rafael. In Mill Valley, a man was killed after he was buried in a mudslide in his backyard.

January – March 1998

Another example of Sonoma County's landslide risk occurred during the El Niño winter storms of January 6 – 7, 1998, in the community of Rio Nido. The upper portion of the slide consisted of a large rotational block failure that occurred near the top of the ridge, approximately 600 feet above the elevation of the canyon floor. Two debris flow failures, which are characterized by fluid and high speed downhill flows, were initiated from the face of the block. The southern debris flow traveled 1,500 feet down a narrow ravine, causing the destruction of three homes and damaging four others in Upper Canyon Three. The northern debris flow traveled down an adjacent drainage ravine north of the homes and came to rest within a long-jam 15 to 20 feet high, located about 800 feet from the canyon floor. Additional debris flows occurred in the same area on February 21 and March 12, 1998 as a result of additional moderate rainfall.

Residents were evacuated until the stability of the slides could be determined. Geologic studies were performed and movement of the slides monitored for years. Evacuation zones maps were periodically revised and residents gradually permitted to return to some areas. Other damaging slides occurred in the communities of Monte Rio, Gold Ridge, Hidden Acres, Blucher Valley, Fitch Mountain, and the coastal community of Gleason's Beach.

The widespread damage caused across the state by these storms prompted FEMA and Cal OES to initiate the first federally funded landslide acquisition program. The program was designed to permanently remove the properties destroyed, damaged, or still at risk from the landslides. Sonoma County received funds for the acquisition of 45 properties in the four communities that suffered the greatest damage.

11.2.2 Location

Dormant Sites of Previous Mass Movements

One of the best predictors of where mass movements might occur is the location of past landslides, which can be recognized by distinctive topographic shapes that can remain in place for thousands of years. Such sites range from a few acres to several square miles. Many show no evidence of recent movement and are not currently active. A few may become active in any given year. The recognition of ancient dormant landslide sites is important in the identification of areas susceptible to landslides because they can be reactivated by earthquakes or by exceptionally wet weather. These dormant sites are also vulnerable to construction-triggered sliding. The shoreline contains many large, deep-seated dormant landslides.

Landslide Susceptibility Mapping

In 2011, the California Geological Survey conducted a statewide analysis using a combination of regional rock strength and slope data to create classes of susceptibility to deep-seated landslides. The analysis assumed, in general, that susceptibility to deep-seated landslides is low on very low slopes in all rock materials and increases with slope and in weak rocks. The analysis also factored in locations of past landslides. Figure 11-1 shows deep-seated landslide susceptibility classes (none, low, moderate, high, and very high).

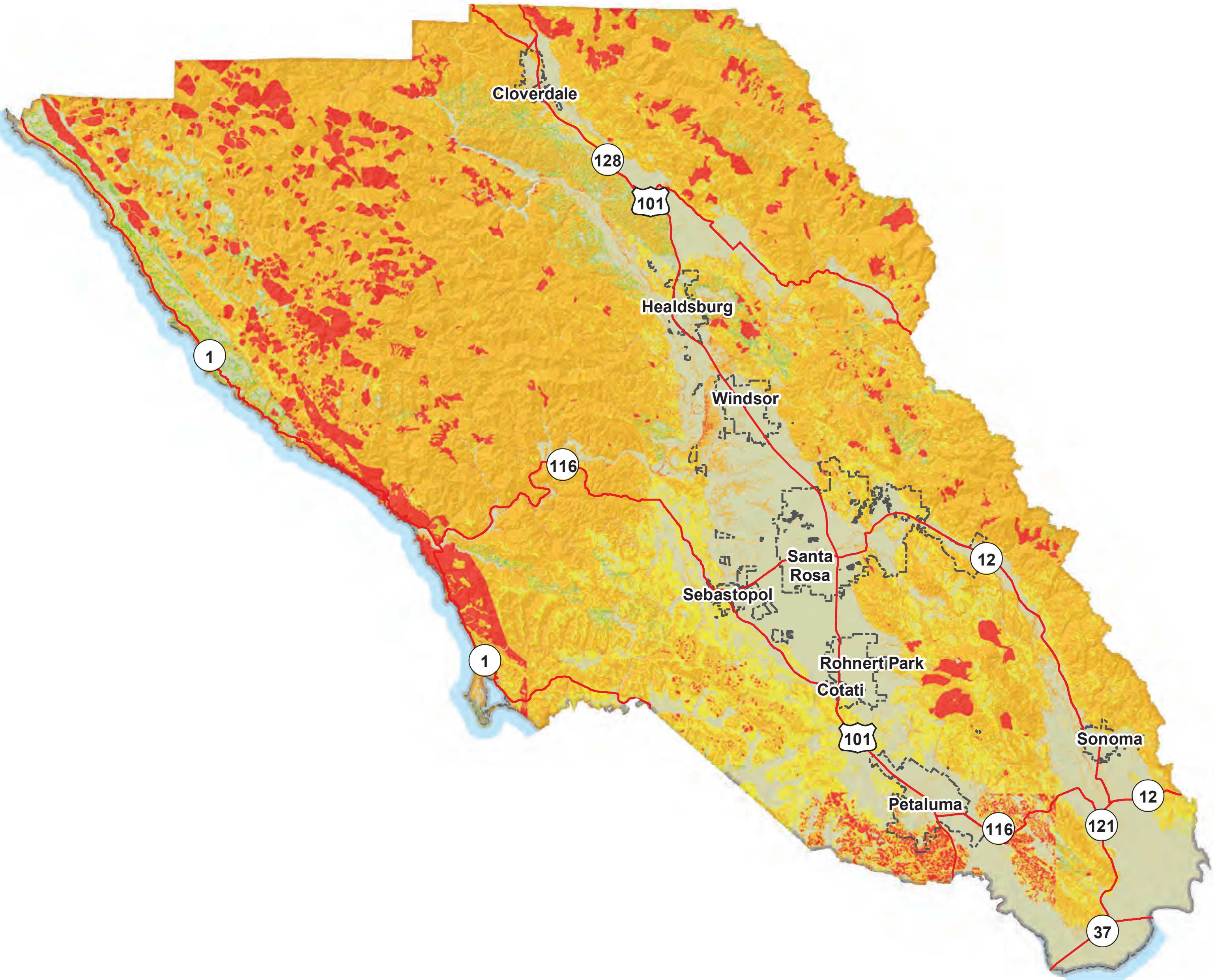
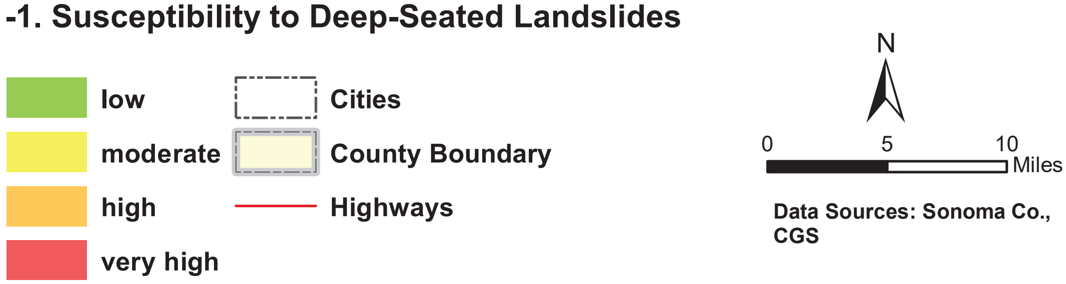


Figure 11-1. Susceptibility to Deep-Seated Landslides



11.2.3 Frequency

Mass movements are often triggered by other natural hazards such as earthquakes, heavy rain, floods or wildfires, so their frequency is often related to the frequency of the precipitating hazards. In Sonoma County, landslides typically occur during and after severe storms, so the potential for landslides largely coincides with the potential for sequential severe storms that saturate steep, vulnerable soils. Most weather-induced landslides in the county occur in the winter after the water table has risen. Landslides that result from earthquakes can occur at any time.

The probability of a landslide event occurring in the county in any given year is high. Approximately 50 landslides occur each winter that block county roads (County of Sonoma 2017). Table 11-1 lists five landslide events in the county for which federal disaster declarations were issued between 2006 and 2019, an average of one such major event every three years.

11.2.4 Severity

Mass movements destroy property and infrastructure and can claim human lives. They have the potential of destabilizing the foundation of structures, which may result in monetary loss for residents. Slope failures in the United States result in an average of 25 to 50 lives lost per year (USGS, 2020). Movements can pose a serious hazard to properties on or below hillsides. They can cause block access to roads, which can isolate residents and businesses and delay commercial, public and private transportation. This can result in economic losses for businesses. Vegetation or poles on slopes can be knocked over, resulting in possible losses to power and communication lines. Mass movements also can damage rivers or streams, potentially harming water quality, fisheries, and spawning habitat.

Landslides along the county’s coastline, in conjunction with wave action, have resulted in seawall failure, severe erosion, cliff failure, and loss of bluff top area that threatens development. Lots have been significantly reduced in size in the last 25 years, and several houses have been damaged to the extent that they are no longer habitable. Poor road design and construction can contribute to landslide hazards through side-casting on sloping lands, over steepened cut slopes and inadequate drainage facilities (County of Sonoma 2017).

11.2.5 Warning Time

The velocity of landslides ranges from a slow creep of inches per year to many feet per second, 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 the geology, vegetation and amount of predicted precipitation for an area can help in these predictions. However, there is no practical warning system for individual landslides. The current standard operating procedure is to monitor situations on a case-by-case basis, and respond after the event has occurred. Generally accepted warning signs for landslide activity include the following:

- Springs, seeps, or saturated ground in areas that have not typically been wet before
- New cracks or unusual bulges in the ground, street pavements or sidewalks
- Soil moving away from foundations
- Ancillary structures such as decks and patios tilting and/or moving relative to the main house
- Tilting or cracking of concrete floors and foundations
- Broken water lines and other underground utilities

- Leaning telephone poles, trees, retaining walls or fences
- Offset fence lines
- Sunken or down-dropped road beds
- Rapid increase in creek water levels, possibly accompanied by increased turbidity (soil content)
- Sudden decrease in creek water levels though rain is still falling or just recently stopped
- Sticking doors and windows, and visible open spaces indicating jambs and frames out of plumb
- A faint rumbling sound that increases in volume as the landslide nears
- Unusual sounds, such as trees cracking or boulders knocking together.

11.2.6 Secondary Hazards

Mass movements are not generally known to result in secondary hazards. A landslide that blocks a river or stream does have the potential to cause flooding.

11.3 EXPOSURE

A quantitative assessment of exposure to the mass movement/landslide hazard was conducted using the landslide hazard mapping and the asset inventory developed for this plan, with an emphasis on the zones with the highest degree of susceptibility (Zones V through X). Detailed results by jurisdiction are provided in Appendix D. Results for the whole planning area are presented in the sections below.

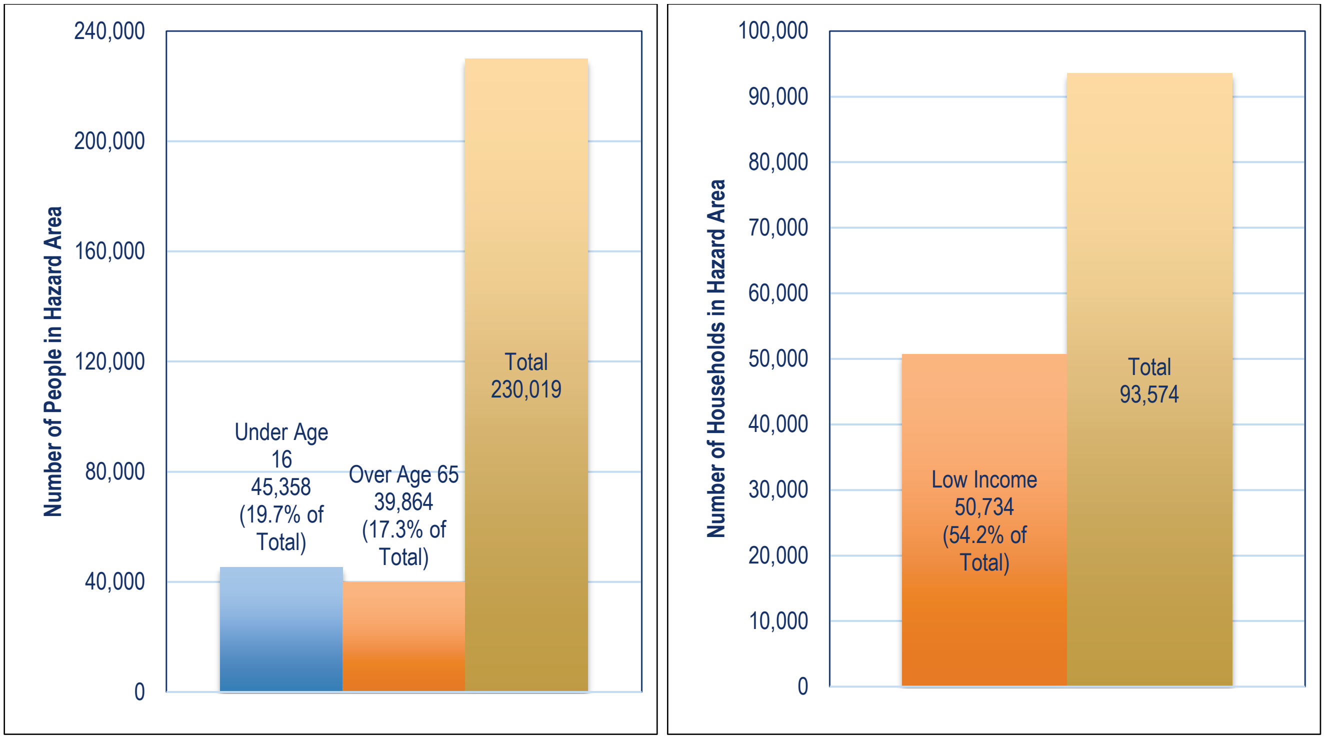
11.3.1 Population

Population exposure was estimated by calculating the number of buildings in each hazard area as a percent of total planning area buildings, and then applying this percentage to the estimated planning area population. Table 11-2 summarizes the estimated countywide population living in the mapped landslide risk areas.

Table 11-2. Exposed Population in Mapped Landslide Hazard Zones

	Moderate Landslide Risk (Susceptibility Categories V and VI)	High Landslide Risk (Susceptibility Categories VII, VIII, IX)	Very High Landslide Risk (Susceptibility Category X; Includes existing landslides)
Population Exposed	54,240	51,796	6,919
% of Total Planning Area Population	11.2%	10.7%	1.4%

Socially vulnerable populations exposed to the landslide hazard were estimated based on data for the Census-defined blocks that lie at least partially within the mapped high and very high landslide hazard zones. Because many of those Census blocks extend outside the mapped hazard zones, the estimates are greater than the actual exposed populations, but they provide reasonable relative data for use in mitigation planning. Figure 11-2 summarizes the estimated exposure of socially vulnerable populations.



See Section 4.8.1 for the definition of "low income" used in this analysis

Figure 11-2. Socially Vulnerable Populations in High and Very High Landslide Risk Zones Census Blocks

11.3.2 Property

Table 11-3 summarizes the estimated property exposure in the evaluated landslide hazard areas. Figure 11-3 shows the occupancy class defined by Hazus for all buildings in the mapped landslide hazard areas. These occupancy classes provide an indication of land use within the mapped hazard area. Some land uses are more vulnerable to landslides, such as single-family homes, while others are less vulnerable, such as agricultural land or parks.

Table 11-3. Exposed Property in Mapped Landslide Hazard Zones

	Moderate Landslide Risk (Susceptibility Categories V and VI)	High Landslide Risk (Susceptibility Categories VII, VIII, IX)	Very High Landslide Risk (Susceptibility Category X; Includes existing landslides)
Number of Buildings Exposed	21,473	24,283	3,173
Value of Exposed Structures	$16,099,740,155	$27,506,743,592	$3,361,526,190
Value of Exposed Contents	$12,591,969,732	$24,546,419,412	$2,936,809,711
Total Exposed Property Value	$28,691,709,887	$52,053,163,004	$6,298,335,902
Total Exposed Value as % of Planning Area Total	*13.1%*	*23.8%*	*2.9%*

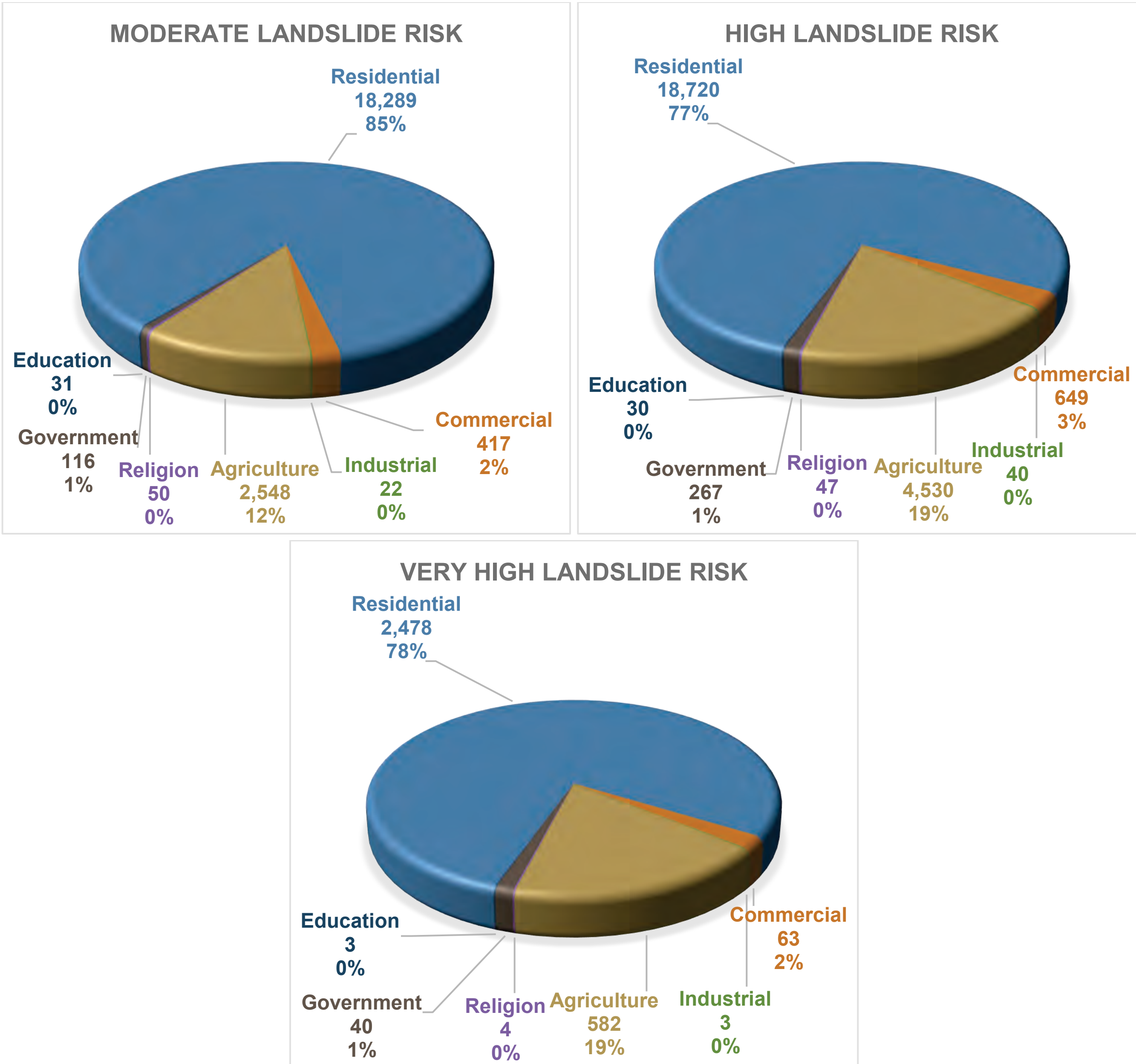


Figure 11-3. Building Occupancy Classes in the Mapped Landslide Hazard Zones

11.3.3 Critical Facilities

The breakdown of exposure of critical facilities by susceptibility class and facility type is shown in Figure 11-4.

11.3.4 Environment

All natural areas within the high susceptibility zones for landslide are considered to be exposed to the hazard.

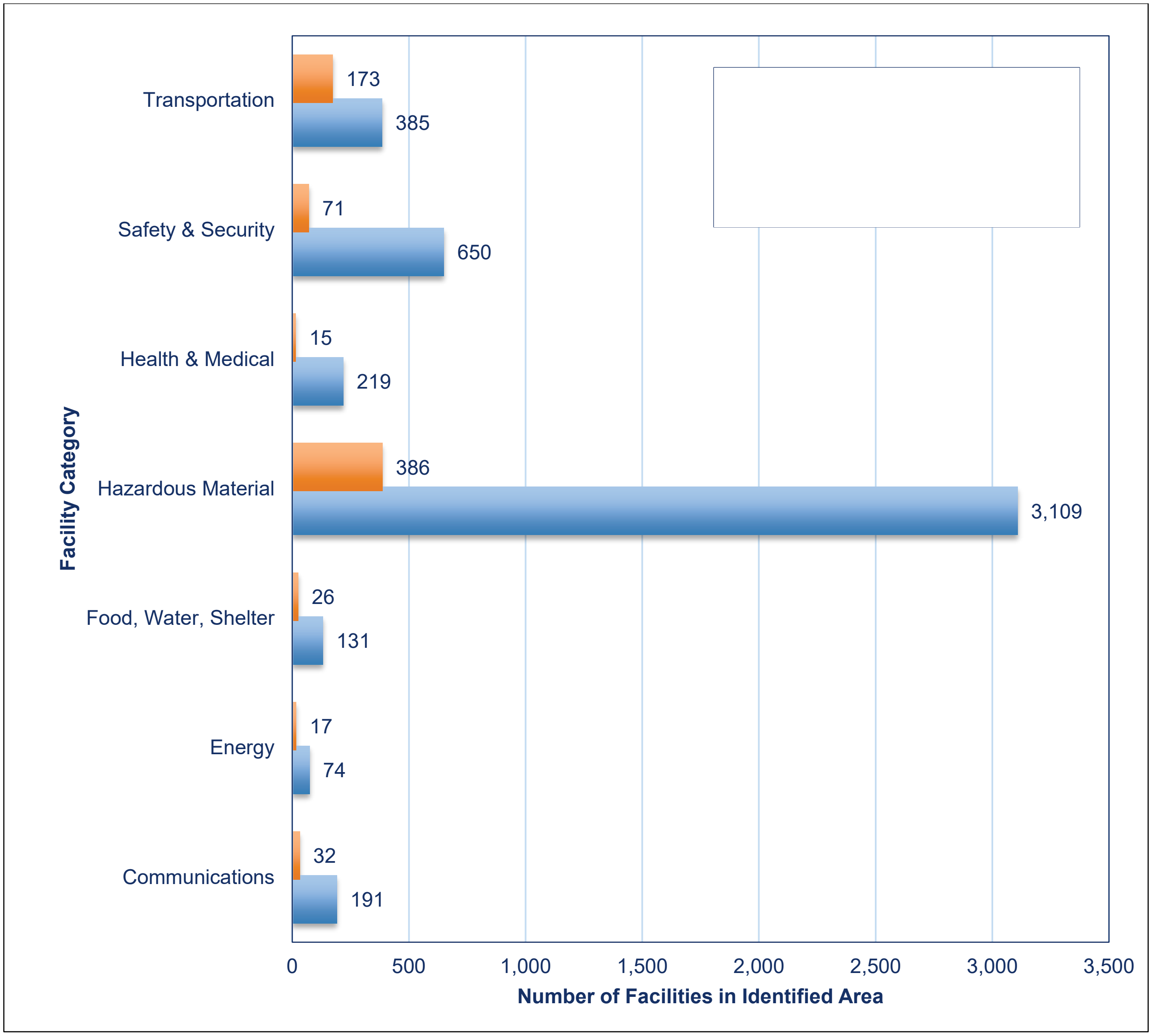


Figure 11-4. Critical Facilities in Mapped Landslide Susceptibility Classes and Countywide

11.4 VULNERABILITY

Vulnerability estimates for the landslide hazard are described qualitatively. No loss estimation of these facilities was performed because damage functions have not been established for the landslide hazard.

11.4.1 Population

All people exposed the landslide hazard are potentially vulnerable to landslide impacts. Populations with access and functional needs as well as elderly populations and the very young are more vulnerable to the landslide hazards as they may not be able to evacuate quickly enough to avoid the impacts of a landslide.

11.4.2 Property

Loss estimations for the landslide hazard are not based on modeling utilizing damage functions, because no such damage functions have been generated. Instead, loss estimates were developed representing 1, 10, 30, and 50 percent of the replacement value of exposed structures. This allows emergency managers to select a range of economic impact based on an estimate of the percent of damage to the general building stock. Damage in excess of 50 percent is considered to be substantial by most building codes and typically requires total reconstruction of the structure. Table 11-4 shows potential losses in the areas with the highest degree of landslide susceptibility.

Table 11-4. Loss Estimation for Mass Movement

	Exposed Value	Loss Value	Loss as % of Total Planning Area Replacement Value
Moderate Landslide Susceptibility Zone			
Loss = 1% of Exposed Value	$28.7 billion	$287 million	less than 1%
Loss = 10% of Exposed Value		$2.9 billion	1.3%
Loss = 30% of Exposed Value		$8.7 billion	3.9%
Loss = 50% of Exposed Value		$14.4 billion	6.6%
High Landslide Susceptibility Zone			
Loss = 1% of Exposed Value	$52.0 billion	$520 million	less than 1%
Loss = 10% of Exposed Value		$5.2 billion	2.4%
Loss = 30% of Exposed Value		$15.6 billion	7.1%
Loss = 50% of Exposed Value		$26.0 billion	11.9%
Very High Landslide Susceptibility Zone			
Loss = 1% of Exposed Value	$6.3 billion	$63 million	less than 1%
Loss = 10% of Exposed Value		$630 million	less than 1%
Loss = 30% of Exposed Value		$1.9 billion	less than 1%
Loss = 50% of Exposed Value		$3.2 billion	1.5%

11.4.3 Critical Facilities

Highly susceptible areas of the county include mountain and coastal roads and transportation infrastructure. At this time all infrastructure and transportation corridors identified as exposed to the landslide hazard are considered vulnerable until more information becomes available. A more in-depth analysis of the mitigation measures taken by landslide-exposed critical facilities to prevent damage from landslides should be done to determine if they could withstand impacts of a mass movement.

11.4.4 Environment

Natural Resources

Landslides can destroy natural assets that are highly valued by the community:

- Landslides that fall into streams may significantly impact fish and wildlife habitat, as well as affecting water quality.
- Hillsides that provide wildlife habitat can be lost due to landslides.
- Endangered species and their critical habitat in the planning area may be located in landslide hazard areas.

Agricultural and Timber Resources

Agricultural resources include rangelands, timberlands, cultivated farmlands and dairy lands. Landslides can have major consequences to such resources, primarily timberland, due to the large percentage of such land in remote locations on steep slopes. Roads accessing timberlands are often susceptible to slides and frequently are contributing factors to landslides. Mass movement activity on these roads can remove them from production.

Cultural Resources

Many cultural sites are at risk from landslides, which can destroy artifacts and structures.

Scenic Resources

Sonoma County features a broad range of scenic resources, including the coastline and Pacific Ocean, mountains, hills, ridgelines, inland water features, forests, agricultural features, and distinctive rural communities. Many of these resources or access routes to them are vulnerable to landslides.

11.5 FUTURE TRENDS IN DEVELOPMENT

Land use controls (such as prohibiting development on unstable soils or steep slopes) are the most cost effective way to prevent loss of life and property. The County and its planning partners are equipped to handle future growth within landslide hazard areas. All municipal planning partners have general plans that address landslide risk areas in their safety elements. All partners have committed to linking their general plans to this hazard mitigation plan update. This will create an opportunity for wise land use decisions as future growth impacts landslide hazard areas.

The California Building Standards Code has adopted the International Building Code (IBC) by reference. The IBC includes provisions for geotechnical analyses in steep slope areas that have soil types considered susceptible to landslide hazards. These provisions assure that new construction is built to standards that reduce the vulnerability to landslide risk. Building construction and grading activities are subject to County code that require a geotechnical report or slope stability analysis under specific slope conditions. The County requires a site evaluation prior to building plan check. Geologic maps are reviewed during the site evaluation and where building or grading is proposed in areas mapped with landslides, expansive soils, liquefaction potential, or fault rupture hazards, a geotechnical report is required and design mitigations identified.

11.6 SCENARIO

Major landslides in Sonoma County occur as a result of soil conditions that have been affected by severe storms, groundwater or human development. Landslides are most likely during late winter when the water table is high. After heavy rains, soils become saturated with water. As water seeps downward through upper soils that may consist of permeable sands and gravels and accumulates on impermeable silt, it will cause weakness and destabilization in the slope. The worst-case scenario for landslide hazards in the planning area would generally correspond to a severe storm with heavy rain and flooding and/or high ocean waves, followed by a damaging earthquake. An earthquake that occurs when water tables are high and soils are saturated has the potential to trigger a significant number of landslides in the planning area.

11.7 ISSUES

Important issues associated with landslides in the planning area include the following:

- An accurate picture of where landslides occurred during previous storms is vital in making intelligent land use planning and mitigation decisions.
- Landslides may result in isolation of neighborhoods and communities, due to the fact that large portions of the transportation infrastructure are in areas of high and moderate slope instability. Isolation may result in food shortages, loss of power, and severely reduced economic productivity.
- There are critical facilities in areas of unstable slopes that could result in interruption to utility services, particularly water and power. This creates a need for mitigation and for continuity of operations planning to develop procedures for providing services without access to essential facilities.
- Landslides may result in loss of water quality to the environment and for drinking purposes, due to increased sediment delivery into surface waterways.
- There are existing homes in landslide hazard areas throughout the planning area. The degree of vulnerability of these structures depends on the codes and standards the structures were constructed to. Information to this level of detail is not currently available.
- The impact of climate change on landslides is uncertain. If climate change impacts the timing and intensity of rain event, then the frequency of landslide events may increase.
- The risk associated with the landslide hazard overlaps the risk associated with other hazards such as earthquake, flood, and wildfire. This provides an opportunity to seek mitigation alternatives with multiple objectives that can reduce risk for multiple hazards.
- California’s Disclosures in Real Property Transactions law requires disclosure if a property is in a landslide hazard area. Such disclosure is dependent upon knowledge by the seller or the seller’s real estate agent or the posting of a landslide hazard map at the offices of the County recorder, County assessor, and County planning agency and a notice identifying the location of the map and any changes to it.
- Future development could lead to more homes in landslide risk areas.
- Mapping and assessment of landslide hazards are constantly evolving. As new data and science become available, assessments of landslide risk should be reevaluated.
- Coastal bluff erosion is particularly susceptible to ocean wave height and the direction of wave approach. El Niño conditions often result in substantial increases in the of coastal bluff retreat. Roads and residential developments are most exposed to these hazards.

12. SEA LEVEL RISE

12.1 GENERAL BACKGROUND

In the past century, global mean sea level has increased by 7 to 8 inches. The two major causes of global sea level rise are thermal expansion of warming oceans and the melting of land-based glaciers and polar ice caps. Given current trends in greenhouse gas emissions and increasing global temperatures, sea level rise is expected to accelerate in the coming decades, with scientists projecting as much as a 66-inch increase in sea level along segments of California's coast by 2100. While over the next few decades, the most damaging events are likely to be dominated by large El Niño - driven storm events in combination with high tides and large waves, impacts will generally become more frequent and more severe in the latter half of this century (California Coastal Commission 2019).

Approximately 85 percent of California's population live and work in coastal counties. The sea level along California's coasts has risen nearly 8 inches in the past century and is projected to rise by as much as 20 to 55 inches by the end of the century. A 55-inch sea level rise could put nearly half a million people at risk of flooding by 2100, and threaten $100 billion in property and infrastructure, including roadways, buildings, hazardous waste sites, power plants, and parks and tourist destinations. Coastal erosion could have a significant impact on California's ocean-dependent economy, which is estimated to be $46 billion per year.

As sea levels rise, saltwater contamination of the State's delta and levee systems will increase. Saltwater contamination of the Sacramento/San Joaquin Delta will threaten wildlife and the source of drinking water for 20 million Californians. Farmland in low areas may also be harmed by salt-contaminated water (California Office of the Attorney General 2021). The third National Climate Assessment cites strong evidence showing that the cost of doing nothing exceeds the costs associated with adapting to sea level rise by 4 to 10 times.

12.2 HAZARD PROFILE

Sonoma County's ocean coast regularly experiences erosion, flooding, and significant storm events, and sea level rise would exacerbate these processes. Sea level at the San Francisco tide gauge has risen 8 inches over the past century, and the National Research Council projects that by 2100 sea level in California south of Cape Mendocino may rise 66 inches. It is critically important that Sonoma County plan and prepare to adapt to sea level rise to ensure public resources and coastal communities are resilient for present and future generations. Future development considerations should include future vulnerabilities to sea level rise and corresponding habitat migration (County of Sonoma, 2019).

The 2018 report *Conserving California's Coastal Habitats: A Legacy and a Future with Sea Level Rise* identifies numerous potential impacts of sea level rise on coastal and bay land natural resources and natural protections in Sonoma County (Heady et al. 2018):

- As sea levels rise, coastal habitats may be squeezed into an ever-shrinking area between rising seas and human development and infrastructure. Coastal habitats are at risk of being submerged, and their associated species will be lost without immediate conservation and management actions to give them the space and ability to move inland.
- Natural land and open space may become inundated, including important undeveloped areas that serve as protection of developed areas from flooding.
- Higher seas will mean a higher reach for storm surge, which will increase coastal flooding.
- Saltwater intrusion into surface and groundwater aquifers will push further and further inland, potentially altering natural habitat communities and impacting agricultural practices.
- Currently protected and conserved coastal areas in California and their habitat value, which represents a real and substantial investment for the future, may be impacted or lost.

The report highlights recommendations to conserve California's coastal habitats in the face of rising sea levels by maintaining resilient conservation lands, conserving resilient landscapes, and managing in place for resilience.

12.2.1 Previous Assessments

Sonoma County Local Coastal Plan

First mandated in 1979 by the California Coastal Act, the *Sonoma County Local Coastal Plan* is an important planning document in managing the conservation and development of the county's coastal regions. The current Local Coastal Plan was written in 1981 and amended in 2001. The County is currently in the process of updating the plan. General findings of the plan are as follows (County of Sonoma 2019):

- Rising seas increase the risk of coastal flooding, storm surge inundation, bluff and coastal erosion, shoreline retreat, saltwater intrusion, and wetland loss or migration.
- The net result of coastal storms and sea level rise is coastline retreat, ranging from a few centimeters per year for bluffs made of resistant bedrock to several meters for beaches and dunes. These rates of coastline retreat will increase with rising sea levels and are likely to further increase if waves become higher.
- The impacts of sea level rise will vary according to local factors such as shoreline characteristics and topography, the location and extent of development, and local drainage and wind patterns.
- Sea level rise will result in more frequent flooding and gradual inundation, as well as increased bluff, dune, and shoreline erosion. This flooding and erosion will affect transportation facilities, utility systems, storm water systems, ports and harbors, large wetland areas, and coastal development (i.e., homes and businesses).

Bodega Bay Vulnerability Assessment, Sonoma County Local Coastal Plan

Sonoma County's *Bodega Bay Focused Sea Level Rise Vulnerability Assessment and Adaptation Strategies* is an appendix to that Local Coastal Plan that focuses on Bodega Bay, the coastal community most at risk from the impacts of sea level rise. The Bodega Bay vulnerability assessment identifies coastal areas and assets in Bodega Bay exposed to sea level rise and storm events. It analyzes the location and extent of assets projected to be inundated by sea level rise and flooded by storm events and assesses the impacts of inundation and flooding. The assessment also identifies potential adaptation measures to minimize the risks and impacts of inundation and flooding. The sea level rise and storm scenarios used in the analysis are based California sea level rise projections adopted by the National Research Council in 2012 and the Our Coast Our Future website. The assessment selected five sea level rise and storm scenarios that cover a full range of impact to affected coastal communities by the end of the century. Its findings by area are as follows (Permit Sonoma 2017):

- The northern section of Bodega Bay—the Bodega Harbor area—contains all the marinas, the only rural residential development, and the largest area of urban residential development in the Bodega Bay study area. By 2100 under the worst-case scenario, permanent inundation from sea level rise would affect 59 to 99 percent of marinas; 28 to 76 percent of County roads; 53 percent of a coastal wetland, and up to 14 percent of residential areas.
- The eastern section of Bodega Bay—the Highway 1 area—contains all the commercial development and the only public utility (Bodega Bay PUD Wastewater Treatment Plant) in the Bodega Bay study area. By 2100 under the worst case scenario, permanent inundation from sea level rise would affect 9 to 70 percent of commercial areas, 51 percent of the Bodega Harbour Yacht Club, 13 to 22 percent of residential areas, and 2 percent of a public access and recreation area.
- The southern section of Bodega Bay—the County Regional Parks Area—contains the only County parks (Westside and Doran Beach Regional Parks) and institutional development (U.C. Davis Bodega Marine Laboratory) in the Bodega Bay study area. By 2100 under the worst case scenario, permanent inundation from sea level rise would affect 20 to 73 percent of coastal wetlands, almost 100 percent of Westside Regional Park and 36 percent of Doran Beach Regional Park, 26 to 39 percent of County roads, and 23 percent of the Links at Bodega Harbor Golf Course.

12.2.2 Location

Sea level rise is likely to affect all coastal areas of Sonoma County. The habitats fringing a coastline attenuate waves and thus reduce storm-related damage to shorelines from erosion and inundation. North of the Russian River mouth to the northern extent of Sonoma County, kelp forest habitat backed by rocky cliffs dominate the landscape and are generally low exposure. In contrast, south of the Russian River mouth, a greater diversity of habitats (e.g., wetlands, beaches, dune systems) are present and are habitats that are highly exposed to erosion and inundation during storms compared to north of the river mouth. As coastal development and rising sea levels alter or damage these habitats, coastlines and nearby infrastructure become increasingly vulnerable to storms (County of Sonoma 2019).

The USGS's Coastal Storm Modeling System sea level rise data were used in the risk assessment for this hazard mitigation plan. The data indicate sea-level rise inundation areas for a sea-level rise of 200 centimeters with and without a 100-year storm event. The mapped inundation areas for these two scenarios (200-cm SLR and 200-cm SLR + 100-Yr) are shown on Figure 12-1 and Figure 12-2.

12.2.3 Frequency

Sea level rise is an ongoing phenomenon that will likely impact the frequency and severity of coastal storms. Storms and flooding in California typically occur during the winter from November to April and are influenced by several climate patterns, most prominently the El Niño Southern Oscillation. Every two to seven years, the Southern Oscillation alternates between two phases—La Niña and El Niño. El Niño years generally result in persistently low air pressure, greater rainfall, and high winds. The water levels reached during these large, short-term events have exceeded mean sea levels projected for 2100, so understanding their additive effects is crucial for coastal planning (County of Sonoma 2019).

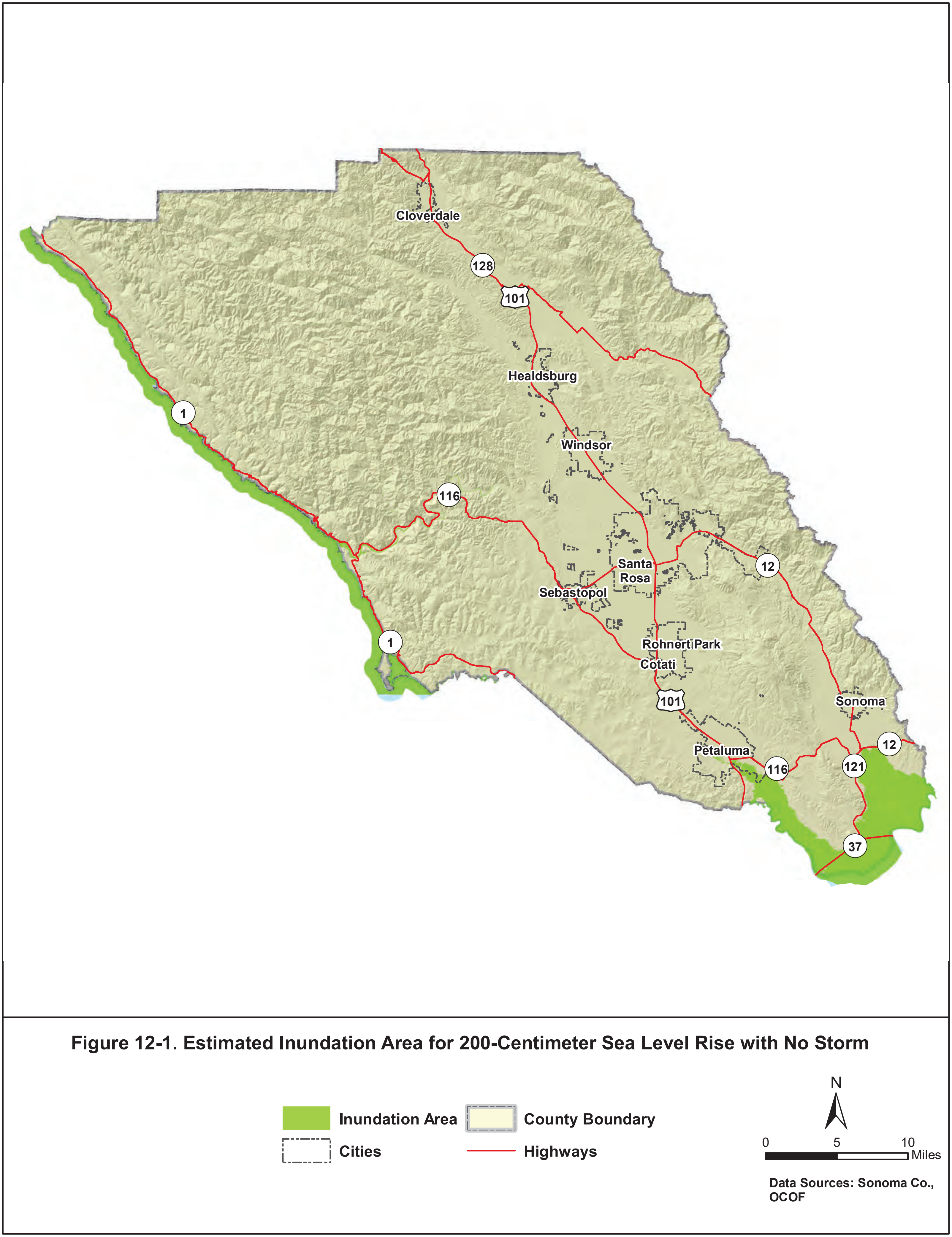


Figure 12-1. Estimated Inundation Area for 200-Centimeter Sea Level Rise with No Storm

Figure 12-2. Estimated Inundation Area for 200-Centimeter Sea Level Rise with a 100-Year Storm Event

Inundation Area
County Boundary
Cities
Highways

N
0 5 10 Miles

Data Sources: Sonoma Co., OCOF

Low air pressure during a storm causes an immediate rise in sea level above predicted tides, referred to as storm surge. It also increases wind activity, generating erosive waves on top of the already high sea level. This combination of factors during an El Niño event can cause widespread damage in coastal areas. As sea level rises, flooding from storms will become more frequent and potentially more hazardous (County of Sonoma 2019).

Severity

Models projecting sea level rise provide a range of severity scenarios based on assumptions about the rate of climate change. One medium-rate sea level rise scenario for Sonoma County predicts increases from the 1992 baseline sea level as shown in Figure 12-3. While Sonoma County's ocean coast regularly experiences erosion, flooding, and significant storm events, sea level rise would exacerbate these natural processes and lead to significant social, environmental, and economic impacts. The third National Climate Assessment cites strong evidence showing that the cost of doing nothing exceeds the costs associated with adapting to sea level rise by 4 to 10 times (County of Sonoma 2019).

Source: Climate Central, 2021

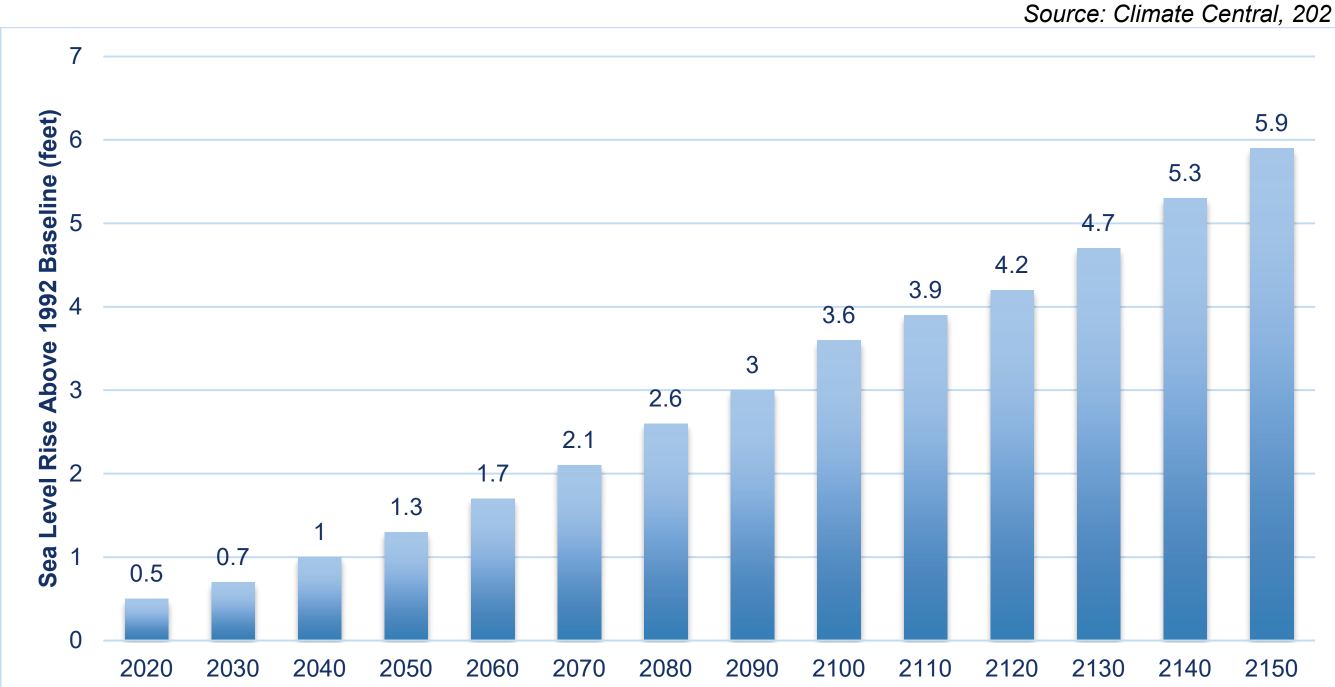


Figure 12-3. Medium Projection for Sonoma County Sea Level Rise Above 1992 Baseline

12.3 EXPOSURE

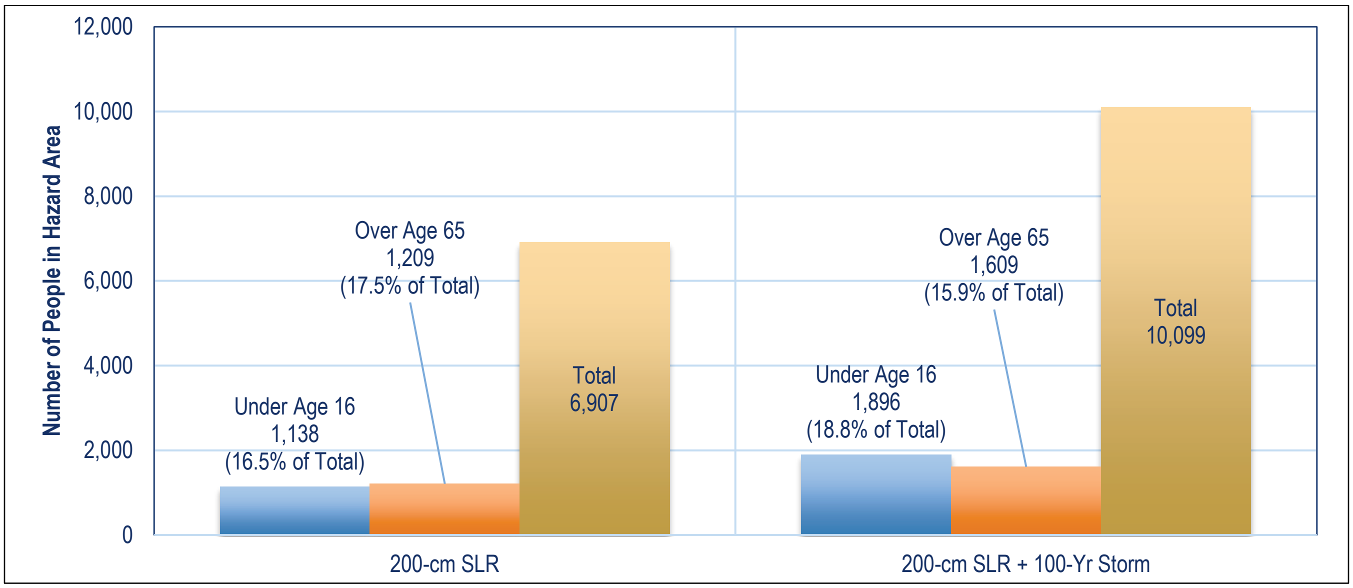
12.3.1 Population

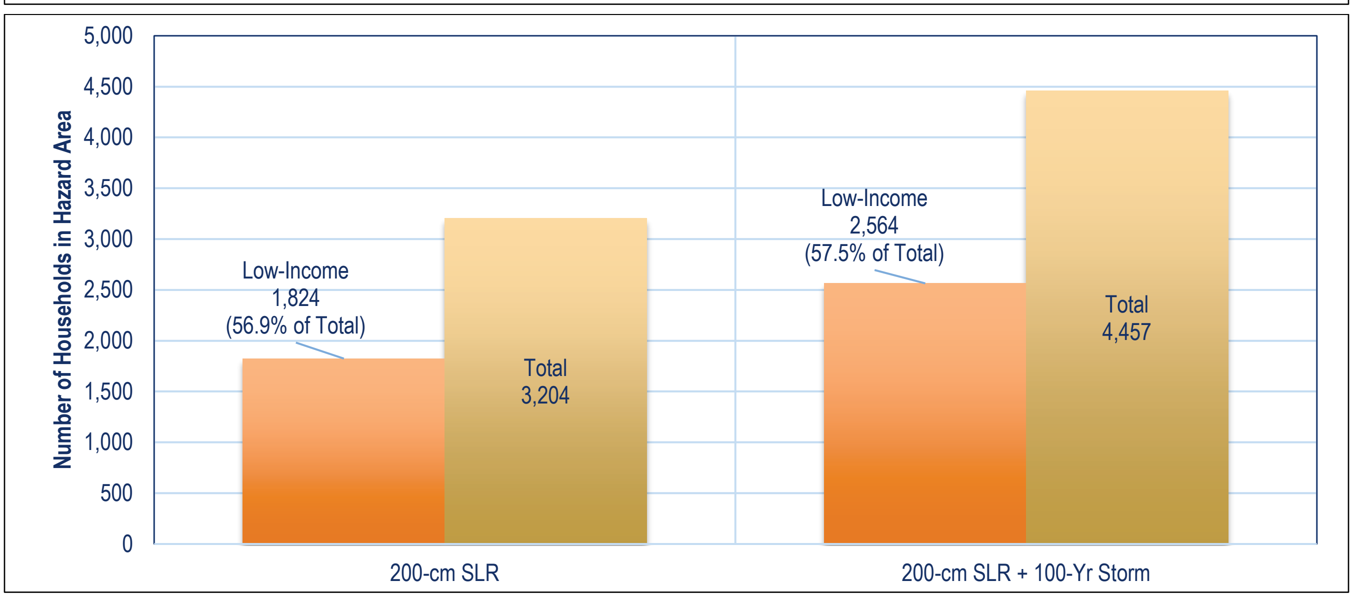
The planning team overlaid the sea-level-rise projection data on the population and asset data developed for the hazard risk assessment for this plan. Detailed results by district are provided in Appendix D; results for the total planning area are presented in Table 12-1.

Table 12-1. Estimated Population Exposure for Sea Level Rise

	200 cm SLR	200 cm SLR + 100 Yr
Population Exposed	356	1,106
% of Total Planning Area Population	0.07%	0.23%

Socially vulnerable populations exposed to the sea level rise hazard were estimated based on data for the Census-defined blocks that lie at least partially within the mapped 200-cm SLR + 100-Yr inundation zone. Because many of those Census blocks extend outside the mapped inundation zone, the estimates are greater than the actual exposed populations, but they provide reasonable relative data for use in mitigation planning. Figure 12-4 summarizes the estimated exposure of socially vulnerable populations.





See Section 4.8.1 for the definition of "low income" used in this analysis

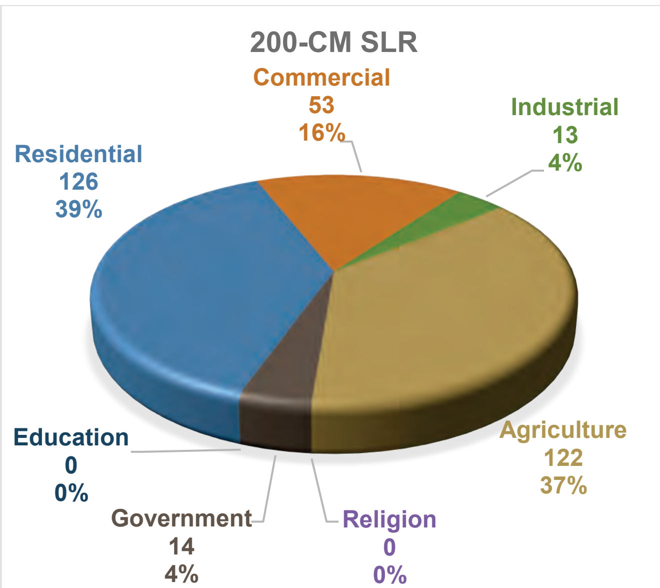
Figure 12-4. Socially Vulnerable Populations in 200-cm SLR + 100-Yr Inundation Zone Census Blocks

12.3.2 Property

Detailed results for property exposed to the sea-level rise hazard by district are provided in Appendix D; results for the total planning area are presented in Table 12-2. Current land use distribution, as represented by building occupancy class, in the areas affected by sea level rise is shown in Figure 12-5 for the 200-centimeter sea level rise scenarios with and without a 100-year storm event.

Table 12-2. Estimated Property Exposure for Sea Level Rise

	200 cm SLR	200 cm SLR + 100 Yr
Number of Buildings Exposed	328	737
Value of Exposed Structures	$871,633,025	$1,487,128,142
Value of Exposed Contents	$832,486,802	$1,434,604,620
Total Exposed Property Value	**$1,704,119,828**	**$2,921,732,763**
Total Exposed Value as % of Planning Area Total	***0.78%***	***1.34%***



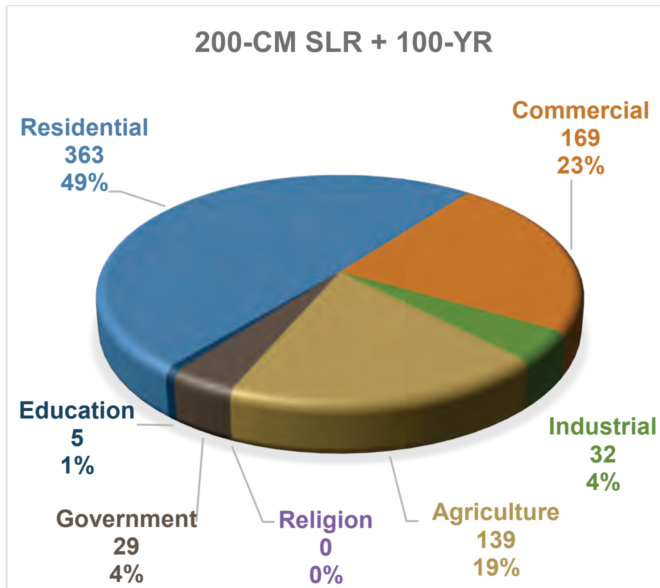


Figure 12-5. Building Occupancy Classes in the Mapped Flood Zones

12.3.3 Critical Facilities

The exposure of critical facilities by sea level rise inundation zone and facility type is shown in Figure 12-6. There are over 50 hazardous waste facilities in the 200-Centimeter SLR + 100-Year Storm inundation zone. Inundation of hazardous waste facilities poses a number of important risks to the immediate community, including public health concerns.

12.3.4 Environment

All sea level rise inundation areas are exposed and vulnerable to impacts. Many of the SLR inundation areas include important environmental and natural resources, which are often important elements in nature-based SLR and flooding strategies.

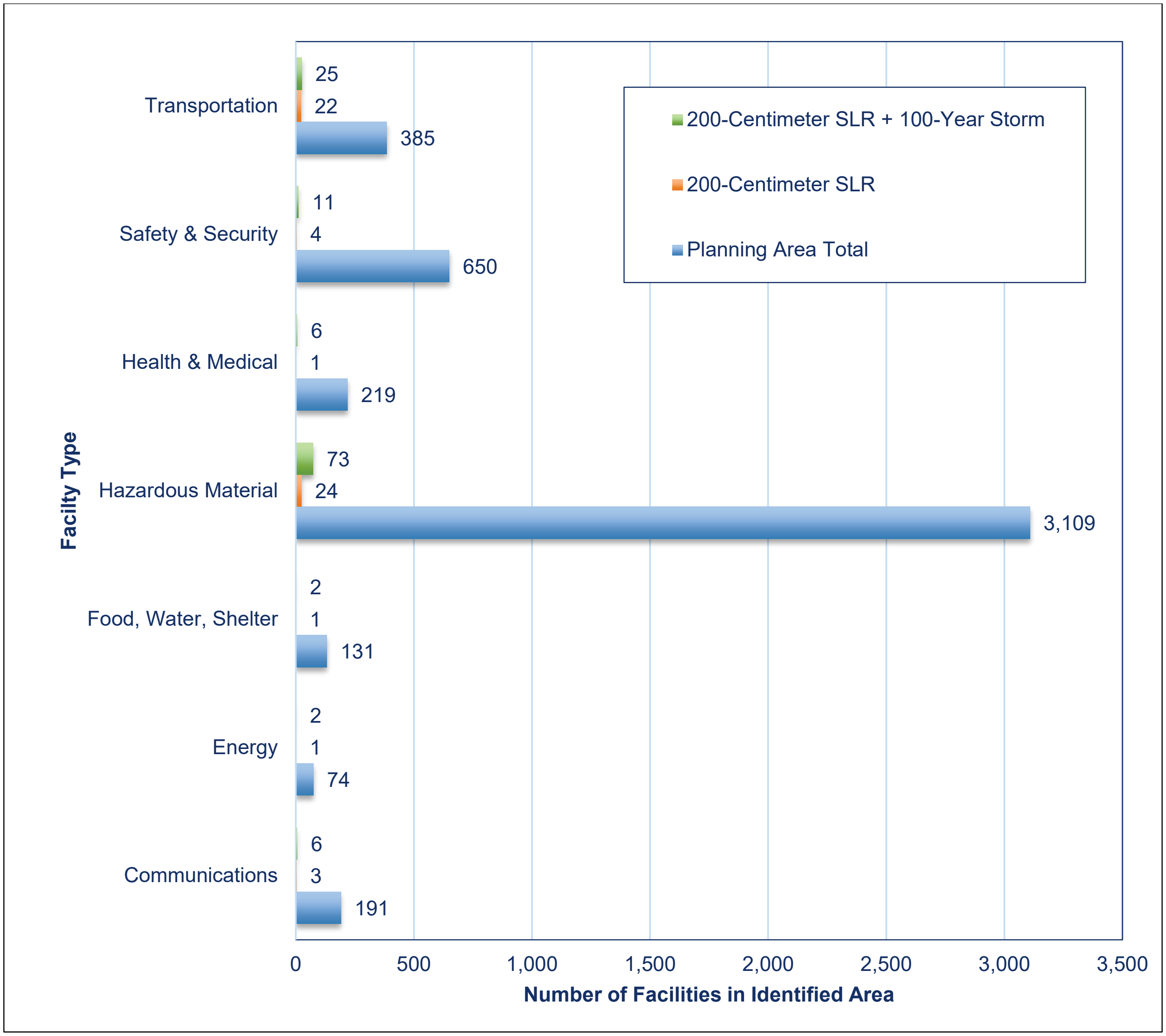


Figure 12-6. Critical Facilities in Sea-Level Rise Inundation Areas

12.4 VULNERABILITY

No quantitative vulnerability analysis was performed for the sea level rise hazard, as no hazard mitigation models for quantitative analysis have yet been developed or validated. The vulnerability analysis for this hazard is based on qualitative projections. The following potential and critical impacts were identified in a qualitative review of recent scientific research on the topic of sea level rise in California:

- Storm drainage systems may experience backups as a result of higher level of daily tidal flooding, especially if outfalls are located within sea level rise inundation areas.
- Important coastal habitat may be lost as sea level rise permanently inundates areas, or it may be damaged due to extreme tide and storm surge events.

- Saltwater intrusion into freshwater resources may occur, further altering habitat and ecosystems. Protective ecosystem services may be lost as land area and wetlands are permanently inundated.

Residents, businesses, and industries that currently thrive on the shoreline will be at risk of flooding by the middle of the century if nothing is done to protect, elevate or relocate them. A 16-inch sea level rise (relative to sea level in 2000) could expose 281 square miles of Bay shoreline to flooding, and a 55-inch rise could expose 333 square miles. If no adaptation measures were taken, a 55-inch rise would place an estimated 270,000 people in the Bay Area at risk from flooding, 98 percent more than are currently at risk. The estimated value of Bay Area shoreline development at risk from a 55-inch rise in sea level is $62 billion—two-thirds of all the estimated value of development vulnerable to sea level rise along California's entire coastline. Any increased storm activity resulting from climate change, in combination with higher sea level, could cause even greater flooding (San Francisco Bay Conversation and Development Commission, 2011).

Populations seeking areas to relocate as they retreat from rising sea levels could significantly affect Sonoma County. This could impact housing needs, thus increasing exposure within Sonoma County to the other hazards profiled in this plan (San Francisco Bay Conversation and Development Commission, 2011).

12.5 FUTURE TRENDS IN DEVELOPMENT

The overall land area of Sonoma County will decrease as sea level rise permanently inundates the County's lowest areas. This will have significant impacts on land use and planning in local communities. Local general plans as well as climate action/adaptation plans in the planning area will guide this future development. State mandates have sought to strengthen land use application in areas impacted by sea level rise. Local general plans should be referenced and cross-referenced with the results of this Plan to mitigate future development in areas most vulnerable to sea level rise.

12.6 SCENARIO

Sea levels along the Sonoma County coast will rise over the next 80 years and beyond, and the county and coastal cities will be adversely impacted by that rise. The impacts are already happening and will progress over time. The planning partners are already preparing for these impacts using programs such as the Local Coastal Plan and other current projections customized for the immediate region. Mitigating the impacts from sea-level rise will take resources and tough land use decisions over the next 30 years, starting immediately.

12.7 ISSUES

The planning team has identified the following sea-level-rise-related issues:

- Available funding is not adequate to mitigate the impacts from sea level rise.
- The County should consider the adoption of higher regulatory standards to mitigate impacts of sea-level rise on redevelopment.
- The data and science that measure sea-level rise impacts progress rapidly. The County should commit to staying in line with the best available data and science on sea-level rise as it evolves.
- The costs to mitigate impacts from sea-level rise will be extensive and potentially beyond the County's means.

- There needs to be a determination of where people can go when the only option to mitigate the impacts from sea-level rise is to retreat.
- The County will need to find ways to equitably mitigate impacts from sea-level rise.
- Risk communication will be crucial to the successful mitigation of this hazard.

13. SEVERE WEATHER

13.1 GENERAL BACKGROUND

Severe weather refers to any dangerous meteorological phenomena with the potential to cause damage, serious social disruption, or loss of human life. The most common severe weather events to impact the planning area are thunderstorms, damaging winds and extreme heat. For this risk assessment, the term "severe weather" refers to these three event types in aggregate. They are assessed as a single hazard for the following reasons:

- Records indicate that each of these weather event types has impacted the planning area to some degree, and all have similar frequencies of occurrence.
- None of these weather event types have a clearly defined extent or location. Therefore, no quantitative, geospatial analysis is available to support exposure or vulnerability analysis; the analyses for this hazard are qualitative.

13.1.1 Thunderstorms, Lightning and Hail

NOAA classifies a thunderstorm as a storm with lightning and thunder produced by cumulonimbus clouds, usually producing gusty winds, heavy rain, and sometimes hail. Thunderstorms are usually short in duration (seldom more than two hours), but they may deliver enough rainfall to cause urban or flash flooding.

Lightning is an electrical discharge that results from the buildup of positive and negative charges within a thunderstorm. When the buildup becomes strong enough, lightning appears as a "bolt." This flash of light usually occurs within the clouds or between the clouds and the ground. A bolt of lightning instantaneously reaches temperatures approaching 50,000 ºF. The rapid heating and cooling of air near the lightning causes thunder.

Hail occurs when updrafts in thunderstorms carry raindrops upward into extremely cold areas of the atmosphere where they freeze into ice. Eventually, the hailstones encounter downdraft air and fall to the ground. Hailstones can begin to melt and then re-freeze together, forming large and very irregularly shaped hail.

13.1.2 Damaging Winds

Straight-Line Winds

Straight-line wind is a general term used to describe damaging winds that are not tornadoes. They are many different types of straight-line winds. Most damaging straight-line winds are generated by thunderstorm systems, although some result from other types of weather phenomena. Damaging winds are those that exceed 50 to 60 mph. The Beaufort Wind Chart (Table 13-1) provides terminology and a description of potential impacts at different levels (National Severe Storms Laboratory, 2018).

Table 13-1. Beaufort Wind Chart

Beaufort Number	Range (mph)	Terminology	Description
0	0	Calm	Calm. Smoke rises vertically.
1	1-3	Light air	Wind motion visible in smoke.
2	4-7	Light breeze	Wind felt on exposed skin. Leaves rustle.
3	8-12	Gentle breeze	Leaves and smaller twigs in constant motion.
4	13-18	Moderate breeze	Dust and loose paper is raised. Small branches begin to move.
5	19-24	Fresh breeze	Smaller trees sway
6	25-31	Strong breeze	Large branches in motion. Whistling heard in overhead wires. Umbrella use is difficult.
7	32-38	Near gale	Whole trees in motion. Some difficulty when walking into the wind.
8	39-46	Gale	Twigs broken from trees. Cars veer on road.
9	47-54	Sever gale	Light structure damage.
10	55-63	Storm	Trees uprooted. Considerable structural damage.
11	64-73	Violent storm	Widespread structural damage.
12	74-95	Hurricane	Considerable and widespread damage to structures.

Source: Lewis, n.d.

Tornado

A tornado is a violently rotating column of air with circulation reaching the ground. It almost always starts as a funnel cloud and may be accompanied by a loud roaring noise. Tornadoes are extremely destructive on a local scale (NOAA, NWS, 2009). A tornado is the smallest and potentially most dangerous of local storms. It is formed by the turbulent mixing of layers of air with contrasting temperature, moisture, density, and wind flow. The mixing layers of air account for most of the tornadoes occurring in April, May, and June, when cold, dry air meets warm, moister air moving up from the south. Tornado severity classified on the Fujita Tornado Damage Scale is shown in Table 13-2.

Table 13-2. Operational Enhanced Fujita Scale

Enhanced Fujita Number	3 Second Gust (mph)
0	65-85
1	86-110
2	111-135
3	136-165
4	166-200
5	Over 200

Source: NOAA, 2018a

13.1.3 Extreme Heat

Extreme heat is defined as temperatures that hover 10 ºF 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, cause drought, and impact water supplies. Such 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..

Extreme heat is the primary weather-related cause of death in the United States. In a 10-year record of weather fatalities across the nation (2006 – 2015), excessive heat claimed more lives each year than floods, lightning, tornadoes, and hurricanes. According to the *California Climate Adaptation Strategy*, heat waves have claimed more lives in California than all other declared disaster events combined. Despite this history, not a single heat emergency was proclaimed in California at the state or federal level between 1960 and 2016. Heat waves do not strike victims immediately, but their cumulative effects slowly cause harm to vulnerable populations. Older adults, children, and sick or overweight individuals are at greater risk from extreme heat.

13.1.4 Public Safety Power Shutoff Events

Some combinations of weather conditions—particularly high winds, extreme heat, and low humidity—pose increased risks of wildfire. In 2012, the California Public Utilities Commission ruled that California Public Utilities Code gives electric utilities authority to shut off electric power to protect public safety, since power supply systems have the potential ignite wildfires (California Public Utilities Commission 2021). Such shutoffs are referred to as public safety power shutoff events. Given the long, connected nature of power supply systems, a shutoff event targeted to a small at-risk area can affect a larger area outside the risk zone. The duration of a shutoff is tied directly to the severe weather that triggers it; the shutoff typically ends within 24 hours after the severe weather has passed (Pacific Gas & Electric n.d.).

13.2 HAZARD PROFILE

13.2.1 Past Events

Table 13-3 summarizes severe storm, wind, and heat events in the planning area since 2020 with recorded deaths, injuries, or property damage.

Table 13-3. Recorded Past Severe Weather Events in the Planning Area

Date	Event Type	Deaths (Direct or Indirect)	Injuries (Direct or Indirect)	Property or Crop Damage
10/27/2019	Strong Wind	0	0	$3,000
6/11/2019	Heat	1	0	$0
5/16/2019	Strong Wind	0	0	$1,000
4/16/2019	Strong Wind	0	4	$0
1/16/2019	Heavy Rain	1	0	$0
1/16/2019	Strong Wind	1	0	$0
12/31/2018	Strong Wind	1	0	$0
11/29/2018	Strong Wind	0	0	$10,000
2/8/2015	Heavy Rain	0	0	$25,000
2/6/2015	High Wind	0	0	$23,500
12/30/2014	Strong Wind	0	0	$70,600
2/28/2014	Strong Wind	0	0	$5,000
11/21/2013	Strong Wind	0	1	$35,000
10/4/2013	Strong Wind	0	0	$2,000
5/1/2013	Strong Wind	0	0	$80,000
4/8/2013	Strong Wind	0	0	$9,500
12/23/2012	Strong Wind	0	0	$13,000

Date	Event Type	Deaths (Direct or Indirect)	Injuries (Direct or Indirect)	Property or Crop Damage
12/22/2012	Heavy Rain	1	2	$30,000
12/5/2012	Strong Wind	0	0	$5,000
12/2/2012	Strong Wind	0	0	$134,000
11/30/2012	Strong Wind	1	0	$50,100
11/28/2012	Strong Wind	0	0	$1,000
3/27/2012	Strong Wind	0	0	$150,000
3/16/2012	Strong Wind	0	0	$412,500
3/14/2012	Strong Wind	0	0	$24,000
3/13/2012	Strong Wind	0	0	$65,000
1/23/2012	Strong Wind	0	0	$22,500
1/21/2012	Strong Wind	0	0	$60,000
1/20/2012	Strong Wind	0	0	$4,500
12/3/2011	Strong Wind	0	0	$200,000
11/30/2011	Strong Wind	0	0	$62,000
11/1/2011	Strong Wind	0	0	$17,000
10/5/2011	Strong Wind	0	0	$500
6/4/2011	Heavy Rain	0	0	$20,015,000
3/24/2011	Heavy Rain	0	0	$43,500
3/19/2011	High Wind	1	0	$35,000
3/18/2011	Tornado	0	0	$50,000
2/17/2011	Strong Wind	0	0	$35,000
2/16/2011	Heavy Rain	0	0	$25,000
2/15/2011	High Wind	0	0	$250,000
12/28/2010	Strong Wind	1	0	$85,000
12/20/2010	Strong Wind	0	0	$25,000
12/6/2010	Strong Wind	0	0	$45,000
10/24/2010	Strong Wind	0	0	$85,000
2/23/2010	Strong Wind	0	0	$15,000
1/25/2010	Strong Wind	0	0	$50,000
1/20/2010	Strong Wind	0	0	$435,000
1/19/2010	High Wind	0	0	$225,000
1/18/2010	Strong Wind	0	0	$110,000
11/28/2009	Strong Wind	0	0	$85,000
10/13/2009	High Wind	0	0	$160,000
5/5/2009	Heavy Rain	1	1	$50,000
4/14/2009	Strong Wind	0	0	$140,000
3/22/2009	Strong Wind	0	0	$2,000
2/26/2009	Strong Wind	0	0	$15,000
2/22/2009	Strong Wind	1	0	$5,000
2/15/2009	High Wind	0	0	$50,000
12/16/2008	Heavy Rain	1	0	$25,000
11/1/2008	Strong Wind	0	0	$16,000
12/27/2006	Strong Wind	1	0	$500,000

Date	Event Type	Deaths (Direct or Indirect)	Injuries (Direct or Indirect)	Property or Crop Damage
7/21/2006	Heat	1	0	$0
1/27/2005	Tornado	0	0	$150,000
12/29/2004	Tornado	0	0	$3,000
1/1/2002	Heavy Rain	0	0	$200,000
1/25/2001	Lightning	0	1	$1,000,000
Total		**13**	**9**	**$25,445,200**

Source: NOAA Storm Events Database, 2021

13.2.2 Location

Severe weather events have the potential to happen anywhere in the planning area. Mountainous regions experience heavier snowfall and a greater risk of road closures. Wind events are most damaging to areas that are heavily wooded. Under most conditions, the planning area's highest winds come from the southwest.

13.2.3 Frequency

Table 13-3 lists 65 storm, wind, or heat severe weather events in the planning area since 2000 that caused death, injury or property damage. This amounts to a little more than three damaging severe weather events every year on average. The probability of a severe weather event impacting the planning area is high.

13.2.4 Severity

Of the 65 damaging weather events listed in Table 13-3:

- 53 were associated with high winds, including three tornadoes. These events caused seven deaths and five injuries, and resulted in $4 million in property or crop damage.
- Two deaths were caused by extreme heat.
- One injury was caused by lightning. Lightning also caused $1 million in property or crop damage.
- Nine heavy rain events caused four deaths, three injuries, and $20.4 million in property or crop damage.

13.2.5 Warning Time

Meteorologists can often predict the likelihood of a severe weather event. This can give several days of warning time. However, meteorologists cannot predict the exact time of onset or severity of a storm. Some storms may come on quickly, with only a few hours of warning time.

13.2.6 Secondary Hazards

Major riverine or urban flooding can result from heavy rain. Rain falling on saturated soils on slopes or on areas recently burned by wildfire may lead to landslides. Lightning during thunderstorms presents a risk of starting a wildfire. Extreme heat can contribute to fire-prone dry vegetation.

13.3 EXPOSURE

All people and property and the entire environment of the planning area is exposed to some degree to the severe weather hazard.

13.4 VULNERABILITY

13.4.1 Population

The most common problems associated with severe weather events are immobility and loss of utilities. Although all populations in the planning area are exposed to severe weather events, some populations are more vulnerable. Vulnerable populations are the elderly, low income or linguistically isolated populations, people with life-threatening illnesses, and residents living in areas that are isolated from major roads. Power outages can be life threatening to those dependent on electricity for life support. Populations living at higher elevations with large stands of trees or power lines may be more susceptible to wind damage and black out, while populations in low-lying areas are at risk for possible flooding. In general, populations who lack adequate shelter during severe weather events, those who are reliant on sustained sources of power in order to survive, and those who live in isolated areas with limited ingress and egress options are the most vulnerable. The most common impacts of specific weather event types on people are as follows:

- **Thunderstorms, Lightning and Hail**—California and the planning area are not particularly prone to thunderstorm events and there are no recorded fatalities from lightning within the planning area. Thunderstorm-related deaths and injuries in the planning area are most likely to result from accompanying wind and heavy rain.
- **Damaging Winds**—Damaging winds can cause injuries and fatalities in a number of ways. Downed trees may fall on homes or cars, killing or injuring those inside. Objects that are not secured can be picked up in wind events and become projectiles. Structures that collapse or blow over during damaging wind events, especially tornadoes, may kill or injure those inside.
- **Extreme Heat**—Individuals with physical or mobility constraints, cognitive impairments, economic constraints, or social isolation are typically at greater risk from the adverse effects of excessive heat events. The average summertime mortality for excessive heat events is dependent upon the methodology used to derive such estimates. Certain medical conditions, such as heat stroke, can be directly attributable to excessive heat, while others may be exacerbated by excessive heat, resulting in medical emergencies. Individuals who lack shelter and heating are particularly vulnerable to extreme cold and wind chill.

13.4.2 Property

All property is vulnerable during severe weather events, but properties in poor condition or in particularly vulnerable locations may risk the most damage. The most common impacts of specific weather event types on property are as follows:

- **Thunderstorms, Lightning and Hail**—Damage from thunderstorms in the planning area is most likely to be related to secondary hazards accompanying the event, such as flooding, landslides or damaging winds. If lightning directly strikes a building, it may cause substantial damage and may even set the structure on fire.
- **Damaging Winds**—Mobile homes can be seriously damaged by wind gusts over 80 mph, even if they are anchored (National Severe Storms Laboratory, 2018). Properties at higher elevations or on ridges may be

more prone to wind damage. Falling trees can result in significant damage to structures. A major tornado could cause widespread damage to property in the planning area, but such an event is unlikely.

- **Extreme Heat**—Extreme heat is generally not a threat to damage property.

No modeling is available for quantitative loss estimations for the severe weather hazard. Instead, loss estimates were developed representing 1 percent, 3 percent and 5 percent of the replacement value of exposed structures:

- Loss of 1 percent of planning area replacement value—$2.2 billion
- Loss of 3 percent of planning area replacement value—$6.6 billion
- Loss of 5 percent of planning area replacement value—$11 billion

13.4.3 Critical Facilities

All critical facilities are vulnerable during severe weather events, especially those that lack backup power generation capabilities. When facilities supplying power to planning area land line telephone systems are frequently disrupted, significant issues arise with communication in the planning area. In addition, some facilities are particularly vulnerable to specific types of severe weather events:

- **Thunderstorms**—Facilities located in areas prone to localized or major flooding are vulnerable. Transportation systems are vulnerable to disruption from flooding or secondary hazard such as landslides.
- **Damaging Winds—**Critical facilities in the direct path of a tornado would be particularly vulnerable. Facilities located near trees or power lines that are likely to fall are also vulnerable. Roads and other transportation infrastructure could be blocked by downed trees or other debris.
- **Extreme Heat**— Extreme heat is generally not a threat to damage facilities or infrastructure.

13.4.4 Environment

The environment is highly vulnerable to severe weather events. Natural habitats such as streams and trees exposed to the elements during a severe storm risk major damage. Prolonged rains can saturate soils and lead to slope failure. Flood events caused by severe weather or snowmelt can produce river channel migration or damage riparian habitat. Storm surges can erode beachfront bluffs and redistribute sediment loads.

13.5 FUTURE TRENDS IN DEVELOPMENT

All future development will be affected by severe weather events. The ability to withstand impacts lies in sound land use practices and consistent enforcement of codes and regulations for new construction. The planning partners have adopted the International Building Code in response to California mandates. This code is equipped to deal with the impacts of severe weather events. Land use policies identified in general plans within the planning area also address many of the secondary impacts (flood and landslide) of the severe weather hazard. With these tools, the planning partners are well equipped to deal with future growth and the associated impacts of severe weather.

13.6 SCENARIO

A worst-case severe-weather event would involve prolonged high winds during a thunderstorm with large amounts of precipitation after soils are already saturated. Such an event would have both short-term and long-term effects. Initially, schools and roads would be closed due to power outages caused by high winds and downed tree obstructions. Some areas of the county could experience limited ingress and egress. Prolonged rain could produce flooding, overtopped culverts with ponded water on roads, mud over roadways, and landslides on steep slopes. Floods and landslides could further obstruct roads and bridges, further isolating residents. If major landslides impact major highways in the planning area, significant transportation disruption could result.

13.7 ISSUES

Important issues associated with severe weather in the planning area include the following:

- The most common direct impact from severe weather events is loss of power. Power outages that disrupt land line service could cause significant communication disruption.
- Older building stock in the planning area is built to low code standards or none at all. These structures could be highly vulnerable to severe weather events such as damaging winds.
- Redundancy of power supply must be evaluated, especially for critical facilities.
- Those residing in higher elevations with limited transportation routes may have the greatest vulnerability to isolation from storms. Another group at risk is the portion of the county population that is over the age of 65.
- Climate change may cause more severe weather patterns that could impact vulnerable populations within the planning area. Increased frequency and intensity of storms may result in greater damage.
- Detailed spatial analysis is needed to locate the most vulnerable populations, followed by focused public education and outreach mitigation activities for these populations.
- The risk associated with the severe weather hazard overlaps the risk associated with other hazards such as earthquake, landslide, and flood. This provides an opportunity to seek mitigation alternatives with multiple objectives that can reduce risk for multiple hazards.
- Isolated population centers are most vulnerable to the severe weather hazard. Rural areas frequently experience extended power outages, loss of communications, and damage to roads due to severe weather.

14. TSUNAMI

14.1 GENERAL BACKGROUND

A tsunami is a series of high-energy waves that radiate outward like pond ripples from an area where a generating event occurs, arriving at shorelines over an extended period. Tsunamis can be induced by earthquakes, landslides and submarine volcanic explosions (see Figure 14-1). Tsunamis are typically classified as local or distant, depending on the location of their source in comparison to where waves occur:

- The waves nearest to the generating source represent a local tsunami. Such events have minimal warning time, leaving few options except to run to high ground after a strong, prolonged local earthquake. Damage from the tsunami adds to damage from the triggering earthquake due to ground shaking, surface faulting, liquefaction, and landslides.
- The waves far from the generating source represent a distant tsunami. Distant tsunamis may travel for hours before striking a coastline, giving a community a chance to implement evacuation plans if a warning is received.

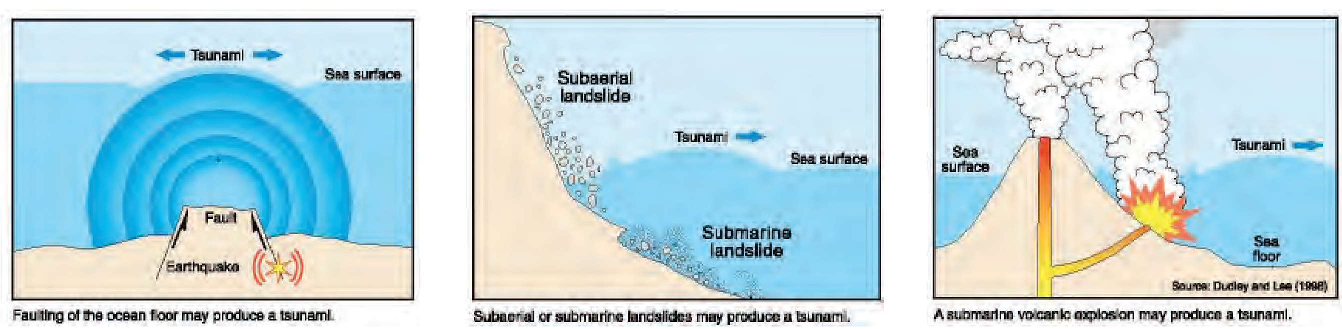


Figure 14-1. Common Sources of Tsunamis

In the open ocean, a tsunami may be only a few inches or feet high, but it can travel with speeds approaching 600 miles per hour. As a tsunami enters the shoaling waters near a coastline, its speed diminishes, its wavelength decreases, and its height increases greatly. At the shoreline, tsunamis may take the form of a fast-rising tide, a cresting wave, or a bore (a large, turbulent wall-like wave). The bore phenomenon resembles a step-like change in the water level that advances rapidly (from 10 to 60 miles per hour). The first wave is usually followed by several larger and more destructive waves.

The configuration of the coastline, the shape of the ocean floor, and the characteristics of advancing waves play important roles in the destructiveness of the waves. Bays, sounds, inlets, rivers, streams, offshore canyons, islands, and flood control channels may cause various effects that alter the level of damage. Offshore canyons can focus tsunami wave energy, and islands can filter the energy. It has been estimated that a tsunami wave entering a flood control channel could reach a mile or more inland, especially if it enters at high tide. The orientation of the coastline determines whether the waves strike head-on or are refracted from other parts of the coastline. A wave may be small at one point on a coast and much larger at other points. The inundation area for a tsunami event is often described as runup as illustrated in Figure 14-2.

Source: UNESCO, Retrieved from Different Directions: Tsunami, n.d.

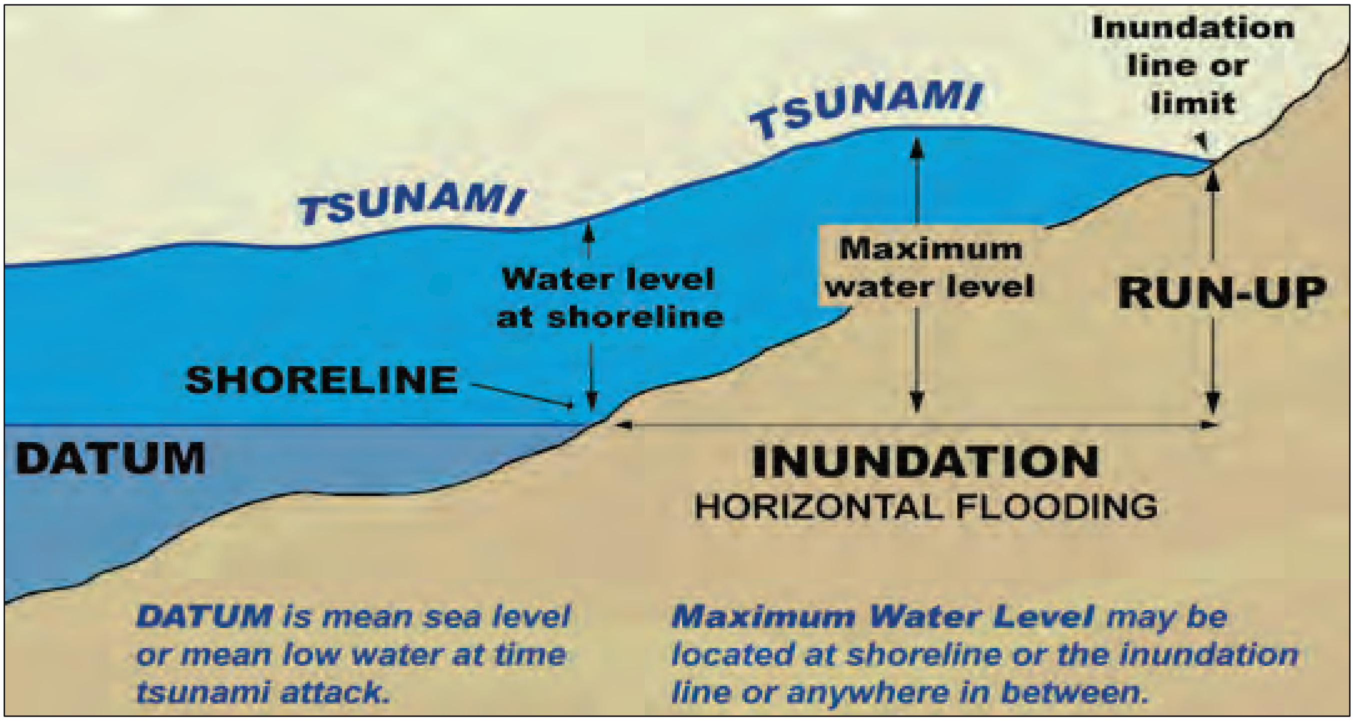


Figure 14-2. Runup Distance and Height in Relation to the Datum and Shoreline

14.2 HAZARD PROFILE

14.2.1 Past Events

California is at risk from both local and distant tsunamis. About 80 possible or confirmed tsunamis in California have been observed or recorded, including the following:

- The most recent recorded tsunamis affecting California were the March 11, 2011 tsunami caused by an earthquake near Japan, which resulted in nearly $100 million in damage to the California maritime community, and the February 27, 2010 minor recorded tsunami inundation in California caused by an earthquake near Chile.
- A 1960 Chilean earthquake produced a tsunami that impacted the entire Pacific basin. Damage was reported in California ports and harbors from San Diego to Crescent City and losses exceeded $1 million.
- A 1964 tsunami generated by a Magnitude-9.2 Alaska earthquake (see Figure 14-3) killed 12 in Northern California and caused over $15 million in damage. Wave oscillations in San Francisco Bay lasted more than 12 hours, causing nearly $200,000 in damage to boats and harbor structures. Sonoma County experienced slight tsunami impacts from this event.

Source: National Centers for Environmental Information, 2018

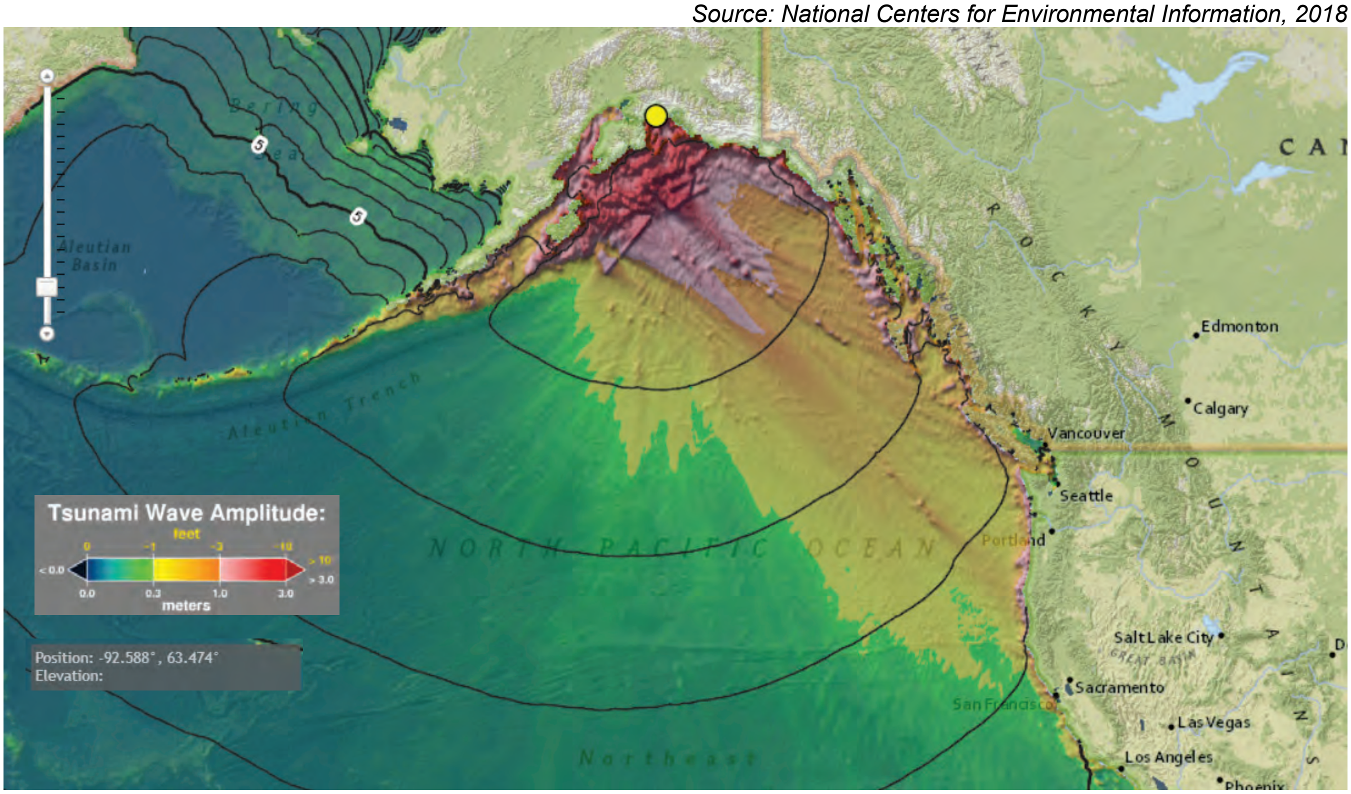


Figure 14-3. 1964 Alaska Earthquake Tsunami Event

14.2.2 Location

Sonoma County's rugged cliffs and generally elevated coastline reduces its exposure and vulnerability to tsunamis. The areas in Sonoma County that have the greatest exposure to potential damages by a tsunami are those coastal communities along the southern Sonoma County coast from Jenner to Bodega Bay. Tsunami inundation maps for the Sonoma Coast area near Jenner, Bodega Bay, and the San Pablo Bay were released in 2009 and form the basis for the County's Tsunami Response Plan.

Spud Point Marina is on the coast in Bodega Bay near the San Andreas Fault. Port Sonoma Marina is at the mouth of the Petaluma River in an area of potentially high liquefaction 3 miles west of the Rodgers Creek Fault. Both of these facilities face a potential risk from earthquake-induced tsunamis.

Figure 14-4 shows the mapped extent of the tsunami inundation areas for the Sonoma County planning area used for this risk assessment, as developed by the California Department of Conservation.

14.2.3 Frequency

The National Tsunami Hazard Mitigation Program rates the risk from the tsunami hazard to the U.S. west coast as a whole as high to very high (Dunbar and Weaver 2015). However, the historical record of tsunami events in Sonoma County includes only one minor event. The frequency of tsunami events in the planning area can be assumed to be low.

Figure 14-4. Tsunami Inundation Zones

14.2.4 Severity

In 2009 Cal OES, the California Geological Survey, and the University of Southern California mapped the tsunami run-up zone for the maximum credible earthquake along the Sonoma Coast, using NOAA's National Tsunami Hazard Mitigation Program. The modeling projected that a tsunami of 25 feet could occur in the coastal areas of Sonoma County, and that areas off San Pablo Bay could experience a 5 foot tsunami. According to the National Tsunami Hazard Mitigation Program, tsunami events with runups of more than 3 feet are the most likely to be dangerous to people and property.

A tsunami's size and speed, as well as the coastal area's form and depth, affect the impact of the tsunami. At some locations, the advancing turbulent wave front will be the most destructive part of the tsunami wave. In other situations, the greatest damage will be 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 withdrawal of the seawater (National Tsunami Hazard Mitigation Program, 2001).

14.2.5 Warning Time

Visible Indications

Tsunamis are difficult to detect in the open ocean; with waves generally less than 3 feet high. The first visible indication of an approaching tsunami may be either a rise or drop in water surface levels (National Tsunami Hazard Mitigation Program, 2001):

- A drop in water level (draw down) can be caused by the trough preceding the advancing, large inbound wave crest. Rapid draw down can create strong currents in harbor inlets and channels that can severely damage coastal structures due to erosive scour around piers and pilings. As the water's surface drops, piers can be damaged by boats or ships straining at or breaking their mooring lines. The vessels can overturn or sink due to strong currents, collisions with other objects, or impact with the harbor bottom.
- The advancing tsunami may initially arrive as a strong surge increasing the sea level. This can be similar to the rising tide, but the tsunami surge rises faster and does not stop at the shoreline. Even if the wave height appears to be small, 3 to 6 feet for example, the strength of the accompanying surge can be deadly. Waist-high surges can cause strong currents that float cars, small structures, other debris, and hazardous materials. Boats and debris are often carried inland by the surge and left stranded when the water recedes.

Warning System

Tsunami Warning System for the Pacific Ocean

The tsunami warning system for the Pacific Ocean evolved from a program initiated in 1946. It is a cooperative effort involving 26 countries along with numerous seismic stations, water level stations and information distribution centers. The National Weather Service operates two regional information distribution centers: The Pacific Tsunami Warning Center in Ewa Beach, Hawaii; and the National Tsunami Warning Center covering the California coast in Palmer, Alaska. The warning centers issue tsunami watches, warnings, and advisories. A watch is issued when a large earthquake has occurred far away from the region and the threat is still being determined. A warning is issued when damaging tsunami waves inundating dry land are expected. An advisory is issued when tsunami waves less than 1 meter high and dangerous strong currents will occur in harbors. The warning system is activated when a Pacific basin earthquake of magnitude 6.5 occurs or an earthquake is widely felt along the North American coast. When this occurs, the following sequence of actions occurs:

- Data is interpolated to determine epicenter and magnitude of the event.
- If the earthquake is of the right type, depth, magnitude, and is far away from California coast, a TSUNAMI WATCH is typically issued for the California coastline.
- A TSUNAMI WATCH is upgraded to a TSUNAMI WARNING if tsunami wave heights are forecast to be 1 meter or larger. A TSUNAMI ADVISORY is issued if tsunami wave heights are forecast to be 0.3 meters to less than 1 meter.
- Tsunami travel times are calculated, and the warning is transmitted to disseminating agencies who relay it to the public.
- The National Tsunami Warning Center will cancel/expire watches, warnings, or advisories if tide gauges and buoys indicate no significant tsunami was generated or if tsunami waves no longer meet the criteria for at least 3 hours.

This system is not considered to be effective for communities close to the tsunami source, because the first wave would arrive before the data can be processed and analyzed, and communications systems may be impacted by the precipitating event. In this case, strong ground shaking would provide the first warning of a potential tsunami and evacuations should begin immediately.

2010 Sonoma County Operational Area Tsunami Response Plan

Sonoma County's 2010 Tsunami Response Plan incorporates the 2009 mapping of the tsunami run-up zone for the maximum credible earthquake along the Sonoma Coast. The plan establishes notification and evacuation response procedures to help minimize casualties from tsunamis.

NOAA, Cal OES, and local emergency managers coordinate tsunami warning communications for the planning area. This emergency notification system is routinely tested and includes broadcasts on NOAA Weather Radio All Hazards, social media, local television and radio stations, sirens, and aircraft public address system. The Wireless Emergency Alert System will also be activated during a real event.

Estimated Travel Times

The NOAA National Centers for Environmental Information website provides maps that show estimated travel times to coastal locations for various tsunami-generating events. Figure 14-5 shows one example of the travel time for a tsunami generated in Aburatsu, Japan to reach the planning area—approximately 11 hours.

14.2.6 Secondary Hazards

Wherever water transport is a vital means of supply, disruption of coastal systems caused by tsunamis can have far-reaching economic effects.

Source: National Centers for Environmental Information, 2018c

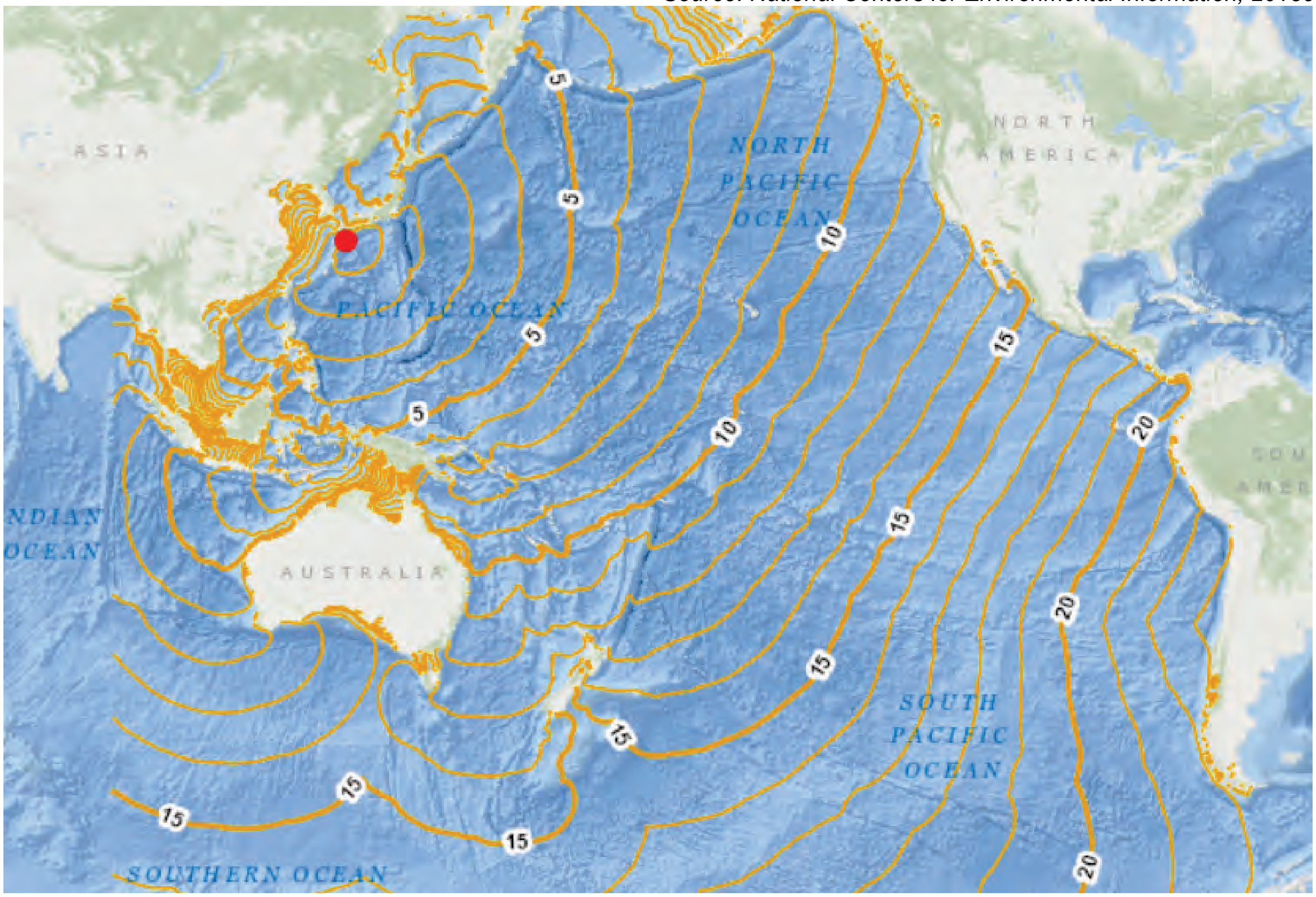


Figure 14-5. Potential Tsunami Travel Times in the Pacific Ocean, in Hours

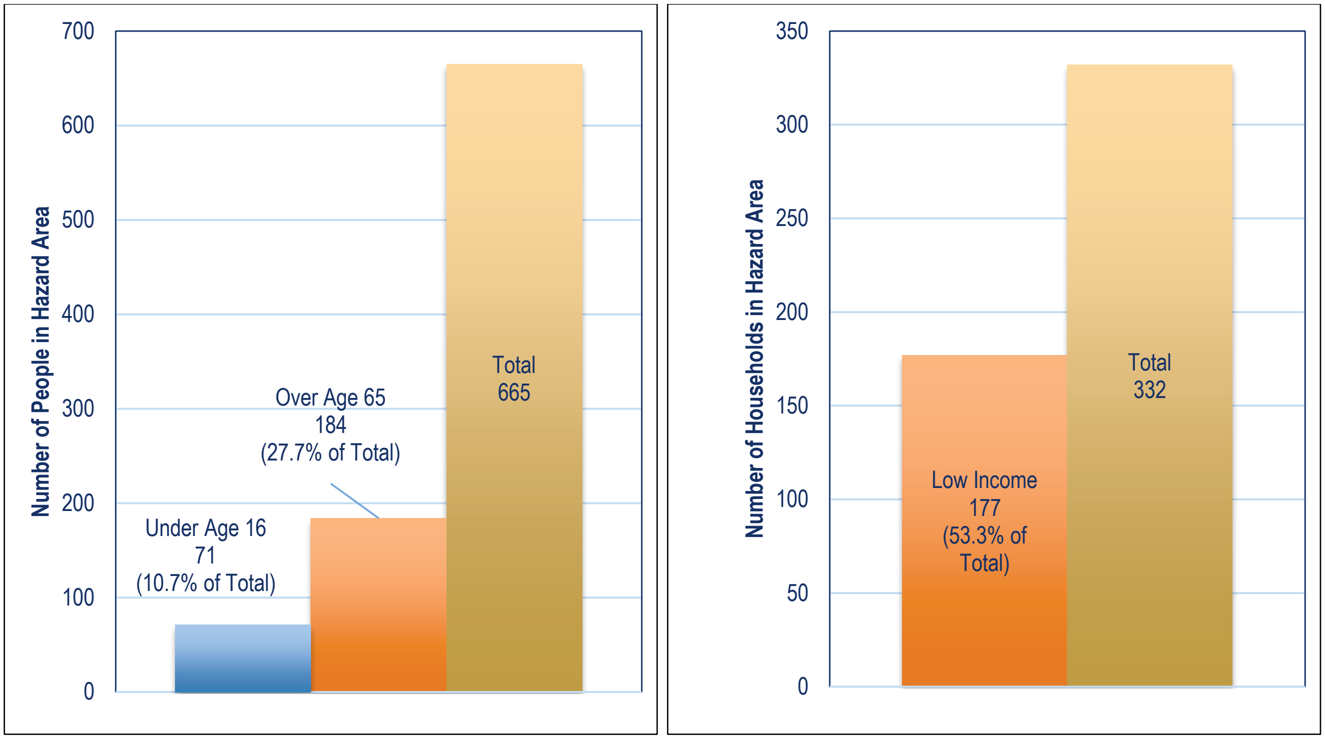
14.3 EXPOSURE

Exposure and vulnerability estimates are based on tsunami inundation maps. The value of exposed buildings in the tsunami inundation zone was generated by overlaying the inundation areas on the general building stock. The population living in tsunami hazard zones was estimated using the percent of buildings within the tsunami inundation areas and applying this percent to the estimated planning area population. Detailed results by jurisdiction are provided in Appendix D; results for the total planning area are presented below.

14.3.1 Population

The estimated total population living in the evaluated dam failure inundation zone is 102 (0.02 percent of the total planning area population). People recreating along beaches, low-lying coastal areas, tidal flats, and stream deltas that empty into ocean-going waters also would be exposed.

Socially vulnerable populations exposed to the tsunami hazard were estimated based on data for the Census-defined blocks that lie at least partially within the mapped inundation zone. Because many of those Census blocks extend outside the mapped inundation zone, the estimates are greater than the actual exposed populations, but they provide reasonable relative data for use in mitigation planning. Figure 14-6 summarizes the estimated exposure of socially vulnerable populations.



See Section 4.8.1 for the definition of "low income" used in this analysis

Figure 14-6. Socially Vulnerable Populations in the Mapped Tsunami Inundation Zone Census Blocks

14.3.2 Property

Table 14-1 summarizes the estimated property exposure in the evaluated tsunami inundation areas. Figure 14-7 shows the Hazus-defined occupancy class of all buildings in the tsunami inundation areas. These occupancy classes provide an indication of land use within the mapped hazard area. Some land uses are more vulnerable to inundation, such as single-family homes, while others are less vulnerable, such as agricultural land or parks.

Table 14-1. Exposed Property in the Tsunami Inundation Zone

Number of Buildings Exposed	77
Value of Exposed Structures	$41,894,144
Value of Exposed Contents	$44,710,276
Total Exposed Property Value	**$86,604,420**
Total Exposed Value as % of Planning Area Total	***0.04%***

14.3.3 Critical Facilities

The breakdown of critical facility exposure by facility type is shown in Figure 14-8. The total exposed facilities (22) is a very small percentage of total critical facilities in the planning area. They include two wastewater treatment facilities, one fire station, one school, one bridge and 14 port facilities.

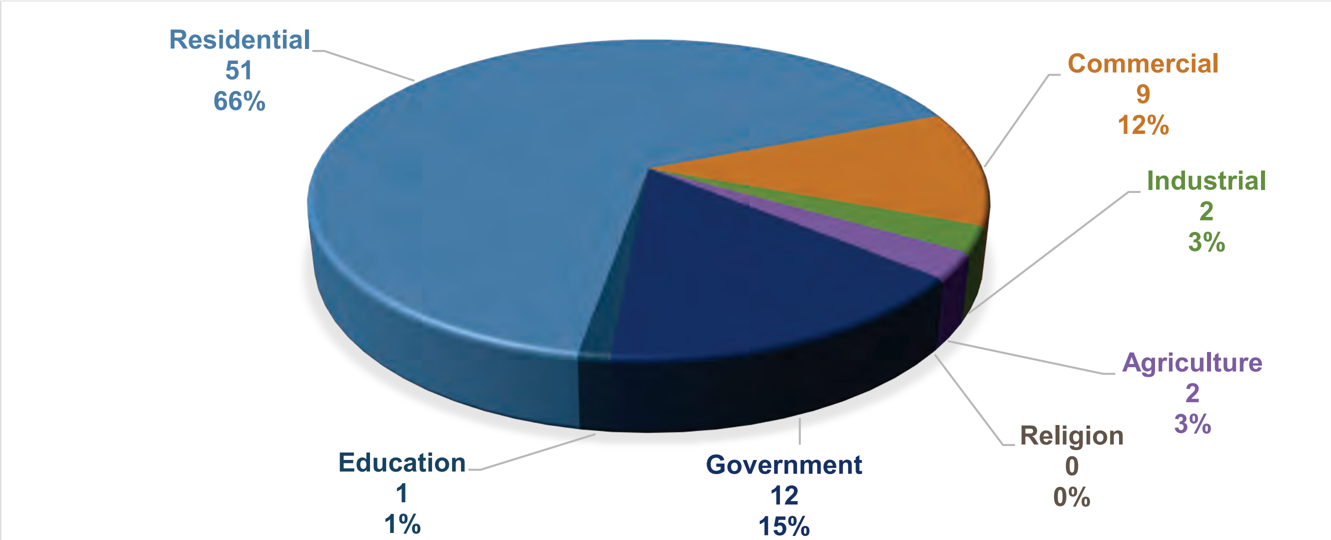


Figure 14-7. Structures in the Tsunami Inundation Zone, by Building Occupancy Class

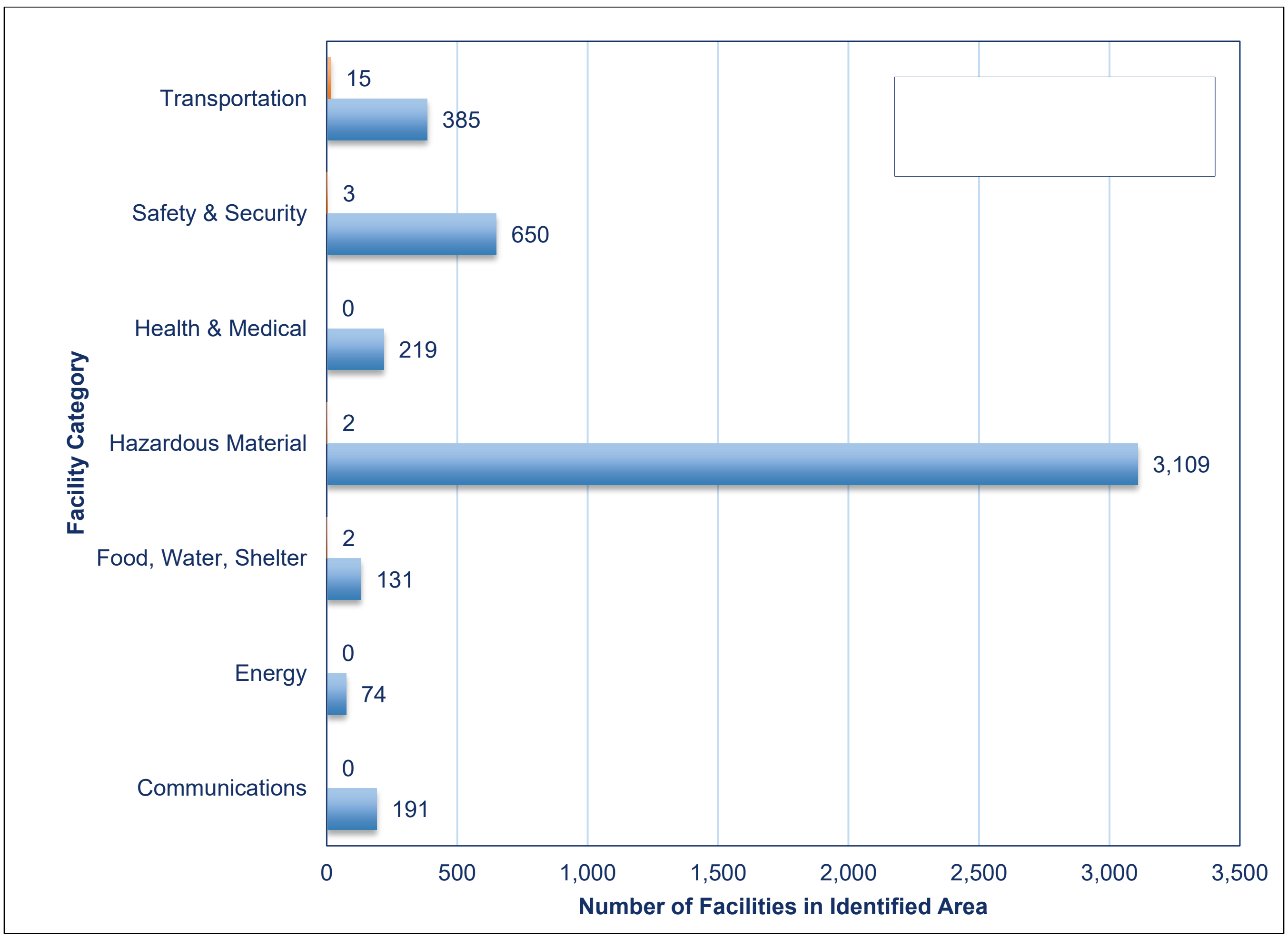


Figure 14-8. Critical Facilities in Mapped Tsunami Inundation Zone and Countywide

14.3.4 Environment

All waterways and beaches would be exposed to the effects of a tsunami; inundation of water and introduction of foreign debris could be hazardous to the environment. All wildlife inhabiting the area also is exposed.

14.4 VULNERABILITY

No quantitative vulnerability analysis was performed for the tsunami hazard. The following potential impacts were identified:

- The populations most vulnerable to the tsunami hazard are the elderly, disabled and very young who reside near beaches, low-lying coastal areas, tidal flats, and river deltas that empty into ocean going waters.
- In the event of a local tsunami generated in or near the planning area, there would be little warning time, so more of the population would be vulnerable.
- The impact of tsunami waves and the scouring associated with debris that may be carried in the water could be damaging to all structures along beaches, low-lying coastal areas, tidal flats and river deltas. The most vulnerable are those in the front line of tsunami impact and those that are structurally unsound.
- Structures that were built to current floodplain regulations in the tsunami inundation area may have some level of protection, particularly if they were built to withstand wave action. In addition to structure damage, ships moored at piers and in harbors often are swamped and sunk or are left battered and stranded high on the shore.
- The following infrastructure is vulnerable to damage:
  - **Water Proximate Infrastructure**—Breakwaters and piers collapse, sometimes because of scouring actions that sweep away their foundation material and sometimes because of the sheer impact of the tsunami waves.
  - **Flood Control Systems**—Floodwaters can back up drainage systems, causing localized flooding. Culverts can be blocked by debris from tsunami events, also causing localized urban flooding.
  - **Utility Systems—**Floodwaters can get into drinking water supplies, causing contamination. Sewer systems can be backed up, causing waste to spill into homes, neighborhoods, rivers and streams. Tsunami waves can knock down power lines and radio/cellular communication towers. Power generation facilities can be severely impacted by wave action and by inundation from floodwater.
- Tsunami waves can carry destructive debris and pollutants that can have devastating impacts on all facets of the environment. Environmental impacts on local waterways and wildlife would be most significant in areas closest to the point of impact. The vulnerability of aquatic habit and associated ecosystems in low-lying areas close to the coastline is high.

14.5 FUTURE TRENDS IN DEVELOPMENT

According to population projections by the California Department of Finance, Sonoma County’s population should decrease to 485,017 by 2040. This represents a 3.8 percent decrease from the 2018 population. Though new development will continue, the rate of development to accommodate future county growth will not be high. The County is subject to state general planning laws and the California Coastal Act. The County and its cities have adopted critical areas and resources lands regulations pursuant to these laws. The information in this plan provides the planning partners a tool to ensure that there is no increase in exposure within the mapped tsunami inundation area of the planning area.

The County of Sonoma was officially recognized as a TsunamiReady community in March 2016 by National Weather Service representatives. This designation recognizes voluntary community programs that promote collaborative tsunami hazard preparedness efforts. In order to become a TsunamiReady community, the County developed a local Tsunami Response Plan, mapped inundation areas along the coast, identified evacuation routes, established refuge areas, installed over 160 tsunami signs in the hazard zones, provided education to the public, deployed and maintained redundant and reliable means to disseminate tsunami warnings and participated in readiness exercises (County of Sonoma 2017).

14.6 SCENARIO

The tsunami scenario with the greatest potential impact on the planning area is a tsunami triggered by a major seismic event along the Cascadia subduction zone. Historical records suggest that tsunami wave heights on the order of 15 to 60 feet could be generated by a Cascadia subduction event (see Figure 14-9). The most destructive tsunami will be associated with a local source Cascadia event and will be preceded by strong ground shaking. Significant damage will result from the ground shaking, tsunami wave forces, and impacts associated with debris. A major tsunami event in the region would have devastating impacts on the people, property, and economy of the planning area.

Source: National Centers for Environmental Information, 2018

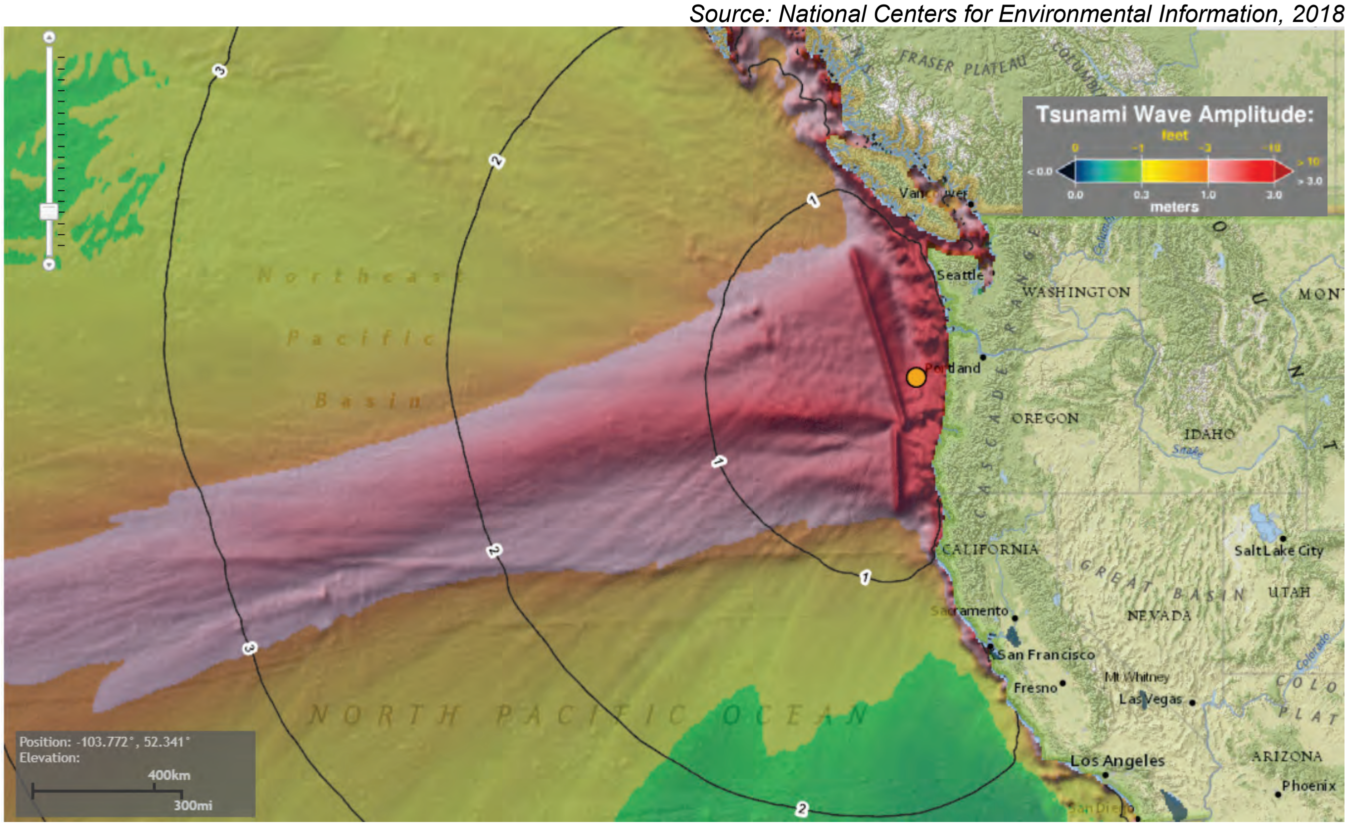


Figure 14-9. 1700 Cascadia Subduction zone Earthquake Tsunami Event

A tsunami from a more local earthquake, such along the San Andreas fault, might be less severe than a Cascadia subduction event. Tsunamis are less commonly associated with strike-slip faults such as the San Andreas system (County of Sonoma 2017). However, a local source tsunami presents a high risk to people, as there would not be time to initiate evacuation; the first surge could arrive in as few as 10 minutes. Strong ground shaking preceding the tsunami could damage buildings, communications and electric utility infrastructure, roads, and bridges, further impairing the community's ability to evacuate safely.

14.7 ISSUES

Important issues associated with a tsunami in the planning area include the following:

- Risk from tsunami inundation is not subject to the State of California real estate disclosure law at this time.
- Structures in the planning area built before the cities and County entered the NFIP may not be designed to resist tsunami forces.
- Present building codes and guidelines do not adequately address the impacts of tsunamis on structures. It is anticipated that future updates to the California Building Code will include amendments that address these issues.
- As tsunami warning technologies evolve, the tsunami warning capability within the planning area will need to be enhanced to provide the highest degree of warning to planning partners with tsunami risk exposure.
- With the future impacts from climate change, the issue of sea level rise may become an important consideration as probable tsunami inundation areas are identified through future studies.
- Special attention will be focused on vulnerable communities and tourists in the tsunami zone and on hazard mitigation through public education and outreach.

15. WILDFIRE

15.1 GENERAL BACKGROUND

A wildfire is an unplanned, unwanted, uncontrolled fire in an area of combustible vegetation. Wildfires typically start in rural areas but can burn into urban areas. A wildfire requires fire suppression to prevent damage to the natural or human environment. Though most wildfires are started by humans, they can occur naturally, and are important to many ecosystem processes.

15.1.1 Factors Affecting Fire Behavior

Fire behavior is based on factors such as the following:

- **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 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 can be more susceptible to wildfire. Structures in the human-built environment also represent a fuel component.
- **Weather—**Relevant weather conditions include temperature, relative humidity, wind speed and direction, cloud cover, precipitation amount and duration, and the stability of the atmosphere. 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, conditions are very favorable for extensive and severe wildfires. These conditions occur more frequently inland where temperatures are higher and fog is less prevalent.
- **Topography**—Topography includes slope and elevation. The topography of a region influences the amount of moisture retained in fuels; the impact of weather conditions such as temperature and wind; potential barriers to fire spread, such as roads, vineyards, and lakes; and elevation and slope of landforms (fire spreads more easily uphill than downhill). In steep terrain, common geographic features such as drainages, gulches and canyons can funnel air to act as chimneys, pulling hot air, gases, and embers ahead or outside of the main fire. The direction that a slope faces also has a major influence on fire behavior. South-facing slopes receive heating and drying solar radiation from early in the morning until sunset, whereas north-facing slopes only receive solar radiation during a short period of the day when the sun is high in the sky.

15.1.2 Secondary Hazards

Wildfires can generate a range of secondary effects, which in some cases may cause more widespread and prolonged damage than the fire itself. Fires can cause direct economic losses in the reduction of harvestable timber and indirect economic losses in reduced tourism. Wildfires cause the contamination of reservoirs, destroy transmission lines and contribute to flooding. They strip slopes of vegetation, exposing them to greater amounts of runoff. This in turn can weaken soils and cause failures on slopes. Major landslides can occur several years after a wildfire. 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. This increases the runoff generated by storm events, thus increasing the chance of flooding. These secondary impacts of wildfire can also affect the quantity and quality of water, which can pose a significant challenge to drinking water utilities.

15.2 HAZARD PROFILE

Virtually all of Sonoma County is at risk to wildfire. Risks include, but are not limited to, the following:

- Extensive building in wildland urban interface/intermix (WUI) areas
- Lack of vegetation management near homes and in wildland areas
- Structures not built or retrofitted with ignition-resistant building materials that can increase resistance to a wildfire's heat and embers
- A significant likelihood of high wind events during the dry fall months

Common fire causes in Sonoma County include electrical transmission line failures, equipment use, vehicle fires spreading into wildlands, and accidental starts from warming or debris fires. Due to heavy fuel loading, when fires start during high wind conditions, rapid rates of wildfire spread can result.

15.2.1 Wildfire Factors for the Planning area

Topography

Two steep ranges dominate the western and eastern lengths of Sonoma County, and most of the county's wildland-urban interface is in the hills and valleys of these two ranges. The hills of the Coastal Range rise abruptly from the Pacific shoreline to over 2,000 feet. The slopes of the Mayacamas Mountains on the county's eastern boundary rise from sea level valleys, including the Santa Rosa Plain, up to 4,500 feet on the slopes of Mount St. Helena. Sonoma County's valleys and foothills are predominantly devoted to agriculture but also contain most of the urbanized areas and population.

Weather

Sonoma County's primary wildland fire season typically spans the months May through November, with possible extension on both ends. In the fall, strong and dry northeast "Foehn" or "Diablo" winds significantly increase the likelihood and severity of wildland fires across California. With the exception of areas immediately along the coast, the weather during fire season is generally warm and dry during the day. Gradient winds, generally out of the south/southwest, typically strengthen in the late afternoon and diminish by dark.

Vegetation and Fuels

According to Sonoma County's 2016 *Community Wildfire Protection Plan*, there were 513,388 acres of coniferous forests and oak woodlands in Sonoma County at that time—more than 50.5 percent of county land area. Most of the oak woodland, and over 68 percent of the coniferous forestland (132,000 acres), is in private ownerships of 50 acres and less. Much of this forest acreage is not regularly maintained and contains dry/dead material and overcrowded trees and brush. The wide variation of ecosystems and microclimates in Sonoma

County make for a wide variety of vegetative fuels. In cooler climates there are redwood ecosystems as well as coastal prairie grasses. In the hills of the Mayacamas, chaparral, Douglas fir and other conifers, as well as oak grass lands, dominate (Fire Safe Sonoma 2016).

Firefighting Resources

A planning area's ability to suppress or fight fires when they start is a key factor affecting wildfire impacts. Federal, state, and local fire protection agencies that share resources and knowledge experience more effective and coordinated outcomes. Initial response to all fire, medical, and similar emergencies is the responsibility of 23 local fire departments in the Sonoma County Operational Area (FireDepartment.net, 2021). The County is divided into two types of responsibility areas:

- Local Responsibility Areas (LRA) and municipalities, where a local agency has primary responsibility for fire and emergency response. In LRA areas, local agencies have primary command, though they may request support from CAL FIRE.
- State Responsibility Areas (SRA), where the state firefighting agency, CAL FIRE, has primary responsibility for wildland fires and fires that pose a threat of spreading into the wildland. CAL FIRE has primary command of SRA fires as soon as their units arrive on the scene. SRAs cover 793,793 acres in Sonoma County—78 percent of the county.

Sonoma County is in CAL FIRE's Sonoma-Lake-Napa Unit, one of 21 CAL FIRE administrative units statewide. This unit covers 2.1 million acres in Sonoma, Lake, Napa, Yolo, Colusa, and Solano counties. It is served by three divisions and 10 field battalions. Sonoma County is the West Division, which contains four battalions and covers 793,793 acres.

The 23 local fire agencies in Sonoma County include fire protection districts, community services districts, and municipal fire departments. The City of Santa Rosa has its own fire department. The cities of Sonoma and Cotati and the Town of Windsor are served by local fire districts. Many of the fire districts in unincorporated areas are staffed by paid firefighters and supplemented by volunteers. In the areas most prone to wildland fires, fire suppression services are highly dependent on part-time and volunteer fire-fighting personnel, and the number of volunteer fire fighters has decreased in recent years. Volume 2 of this plan provides more information on the local fire protection districts participating in this multi-jurisdictional hazard mitigation planning effort.

15.2.2 Past Events

Wildland fires, particularly wildland/urban interface fires, have historically occurred in Sonoma County. As development and human activity in Sonoma County increased over the decades, the incidence of human-caused fires increased. Some of the largest or costliest fires since 1964 are listed in Table 15-1.

County residents today are greatly aware of the dangers that wildfire poses. From 2017 through 2020, a series of large, damaging wildfires directly affected Sonoma County. These fires burned over 300,000 acres in Sonoma County, destroyed nearly 7,000 structures, and killed 24 people. Wildfire has become an overwhelming and constant presence throughout the summer and fall, bringing long periods of toxic smoke, multiple red-flag warnings, planned power shutdowns, large-scale evacuations, and fear and trauma on the part of urban and rural residents alike.

Table 15-1. Sonoma County Fires Since 1964

	Name	Acres Burned	Structures Burned
1964	Hanley	52,700	108
1964	Nuns Canyon	10,400	27
1965	Knight's Valley	6,000	0
1965	Pocket Ranch	4,000	0
1965	Austin Creek	7,000	0
1972	Bradford	1,760	4
1978	Creighton Ridge	11,405	64
1988	Cloverdale	1,833	100
1988	Geysers	9,000	7
1996	Porter Creek	300	0
1996	Cavedale	2,100	0
1999	Geyser Road	1,300	0
2000	Berryessa	5,731	15
2004	Geysers	12,000	6
2008	85	322	0
2008	Pine	989	0
2013	McCabe	3,505	—
2015	Valley	76,067 (5,000 in Sonoma County)	1,955
2017	Sonoma Complex Fires (Tubbs, Nuns, Pocket, Presley, Young)	86,039	5,636
2017	Tubbs	36,807	5,643
2019	Kincade	77,753	371
2020	LNU Lightning Complex (Walbridge and Meyers)	57,563	303
2020	Glass	67,484	661

Wildfire Chronology

When humans moved into the landscape some 14,000 years ago, fire became a common feature on the landscape, as native people used fire to increase food production, keep more open landscapes, and promote other ecological values. It is estimated that grasslands and oak woodlands were burned about every 5 years, with forested areas burning about every 12 to 20 years.

Fire frequency decreased during post-statehood years, as European settlers did not perceive the ecological value of burning as it had been practiced by Native Americans. However, wildfires continued to ignite and burn, especially in historical wildfire corridors, These were primarily in the Mayacamas Mountains on the county's eastern boundary in the Coast Ridges on the west. Large destructive fires have occurred in both areas, most significantly in 1923, 1954, 1964, 1978, and 2017, 2019, and 2020.

In 1964, the Hanley and Nuns Canyon fires simultaneously burned 63,100 acres and 135 structures near the cities of Santa Rosa and Sonoma. Since then, there has been significant growth in rural WUI areas in the county, vastly increasing risks to life and property. The conversion of properties from agriculture, timber production, and grazing uses to residential use has left much of the county's wildland vegetation to grow unchecked by human activity or fire, significantly increasing potential for destructive wildfire.

In 2017, the Sonoma Complex fires (the Tubbs, Nuns, Adobe, and Pocket and Young fires) killed 24 residents and burned 110,716 acres. The 2017 Tubbs and Nuns Fires burned in nearly identical footprints to 1964's Hanley and Nuns Canyon fires, but because of development in the area nearly 6,000 structures were lost, compared with 135 in the earlier fire. Impacts like those from the 2017 fires will continue to impact the County and its residents for decades.

Sonoma County's recent wildfires reflect increasing fire size and intensity across California and the west. Table 15-2, derived from CAL FIRE data, shows the increasing frequency of destructive fires over the past 80 years. The 20 most destructive fires in state history all occurred in the previous 30 years. Of those 20 most destructive fires, the last 5 years represent:

- 75 percent of the number of events
- 85 percent of acres burned
- 82 percent of structures lost
- 76 percent of lives lost.

Table 15-2. CAL FIRE Destructive Wildfire Statistics, 1939-2020

Years	Number of fires	Acres Burned	Structures Burned	Lives Lost
20 Most Destructive Fires				
2015-2020	15	255,080	42,418	158
1991-2014	5	30,201	9,327	49
Total	***20***	***285,281***	***51,745***	***207***
Other Major Fires in Previous 50 Years				
1939 -1990	90	209,999	Not Available	Not Available
Total	**110**	**495,280**	**51,745**	**207**

Source: CAL FIRE, Created by Permit Sonoma GIS. Data subject to change as better data and analysis become available

Twelve of the 15 destructive wildfires in the past five years took place in Northern California, and seven of them burned within Sonoma County and/or in a bordering county. These data indicate a future characterized by increasing fire frequency, size, and destruction. With climate change, the potential for drought, hotter temperatures year-round, and increasing lightning events as experienced in 2020 is cause for significant concern.

Recent fires also indicate that wildfire does not impact only rural residents or forested areas. More than half (2,575) of the structures lost in the 2017 Tubbs Fire were in urban areas rated as "moderate" Fire Hazard Severity Zone or "urban/unzoned." Only 1,205 structures were lost in areas ranked as "very high" or "high" Fire Hazard Severity Zones

1964 Nuns Canyon Fire

The Nuns Canyon fire in the Sonoma Valley started on the same day as the Hanley fire and burned for six days. By the third and fourth days, the fire had burned 9,500 acres and reached Highway 12 and Boyes Hot Springs. By the sixth day, when the fire was brought under control, it had destroyed 27 homes and more than 10,000 acres.

1964 Hanley Fire

The Hanley fire started on September 19, 1964, on the Hanley property off Highway 29 on the slopes of Mt. St. Helena in Napa County. By the end of the next day, firefighters had contained the fire, but late in the night, winds drove the flames down the slopes to encircle Calistoga on two sides. Several homes on the perimeter of town were burned. On the third day, an ember ignited a spot fire on the ridge west of Highway 128 between Calistoga and Kellogg, in Sonoma County. The fire then raced into Knights Valley and turned southward into Franz Valley. By nightfall, the fire, driven by 70 mph winds, headed down Mark West Canyon toward Santa Rosa. The Sonoma County Hospital was threatened, with embers falling on the rooftop, and 40-foot high flames in nearby trees. To the east, the fire burned over the hills and down into the Rincon Valley area, where it was again stopped. The fire was not brought under control until the morning of September 26. The fire consumed 105 million board feet of timber valued at $1.5 million and destroyed 84 homes and 24 summer cabins. More than 52,000 acres were blackened. No human lives were lost.

2004 Geysers Fire

A number of fires have ignited in the area known as the Geysers. A fire on Labor Day weekend 2004 burned 12,500 acres in the Mayacamas Mountains in Sonoma and Lake counties over a five-day period, cost over $14 million to suppress, and caused over $10 million in property damage. The fire consumed six cabins and destroyed equipment and vehicles belonging to several companies operating in the area, including Calpine Corp., PG&E and AT&T. Firefighters were able to save pumping stations and geothermal power plants worth hundreds of millions of dollars. The 2004 *Sonoma Lake Napa Fire Management Plan* indicated that vegetation management was one of the primary reasons the geothermal facilities were not destroyed.

2015 Valley Fire

The Valley Fire was located mainly in southern Lake County but moved into Sonoma County, where it burned 5,000 acres near the Geysers and destroyed four steam cooling towers at the CalPine geothermal facility. Starting on September 12, 2015, the fire burned 76,067 acres and destroyed 1,958 structures including 1,280 homes, 27 multi-family structures, 66 commercial properties, and 585 minor structures such as outbuildings and sheds. An additional 93 structures were damaged, including 41 homes, 7 commercial properties and 45 other minor structures. Four firefighters were injured and there were 4 civilian fatalities.

2017 Sonoma Complex Fires—Tubbs, Nuns, and Pocket

On October 8, 2017, an historic wind event led to the worst firestorms in Sonoma County history, followed by almost three weeks of fire. In total, the Nuns, Tubbs, Pocket and Young fires (together comprising the 2017 Sonoma Complex Fire) claimed 24 lives, burned over 110,700 acres in Sonoma, Napa, and Lake counties, and destroyed 6,997 structures with total direct losses exceeding $7.8 billion. The following sections describe the three main fires in the complex that affected Sonoma County.

Tubbs Fire

The Tubbs Fire was the most destructive wildfire in California history when it occurred, burning parts of Napa, Sonoma, and Lake counties. The greatest losses were in the city of Santa Rosa. The Tubbs Fire was one of more than a dozen large fires that broke out in early October 2017 and simultaneously burned eight northern California counties. By the time of its containment on October 31, the fire was estimated to have burned 36,810 acres. At least 24 people in Sonoma County were believed to have been killed by the fire. The fire destroyed more than

5,643 structures, half of which were homes in Santa Rosa. Santa Rosa's economic loss from the Tubbs Fire was estimated at $1.2 billion, with 5 percent of the city's housing stock destroyed. The fire incurred $100 million in fire suppression costs.

Nuns Fire

The Nuns Fire broke out in a field in the community of Glen Ellen when strong winds knocked an alder tree into a powerline conductor. It merged with five other fires that together burned an area larger than the city of Oakland. It burned 56,556 acres and destroyed about 1,527 structures before being contained on October 31, 2017.

Pocket Fire

The Pocket Fire started on October 9, 2017 and was contained on October 31, 2017. The fire burned 17,357 acres within Sonoma County (Wildfire Today, 2018). This was a vegetation fire that started near Pocket Ranch Road east of the community of Geyserville. It began during a red flag warning issued by the National Weather Service. The fire was reported to have destroyed six structures and damaged two others (CalFire Investigation Report, 107CALNU010057, 10/9/2017).

2019 Kincade Fire

The Kincade Fire started northeast of Geyserville in the Mayacamas Mountains on October 23, 2019, and burned 77,753 acres and 371 structures before it was fully contained on November 6, 2019. The fire threatened over 90,000 structures and caused widespread evacuations (198,785 residents) throughout Sonoma County, including the communities of Geyserville, Healdsburg, and Windsor. The majority of Sonoma County and parts of Lake County were under evacuation warnings. The fire was the largest of the 2019 California wildfire season, and the largest ever in Sonoma County.

2020: LNU Lightning Complex Fire

Early on August 16, 2020, following a series of very hot days, thunderstorms hit California. Within the next 72 to 96 hours, over 12,000 lightning strikes were recorded over Northern California. These lightning strikes sparked up to 585 wildfires, many of which grew to be very large at a rapid pace due to parched brush (Wikipedia, 2021).

The Sonoma Lightning Complex, consisting of the Walbridge Fire (55,209 acres), and Meyers Fire (2,616 acres) burned 61,875 acres and 303 structures within Sonoma County. At the same time, in the Sonoma-Lake-Napa CAL FIRE Unit (LNU), the Hennessey Fire consumed 305,651 acres and caused six fatalities.

Firefighting resources were so stretched by the more than 500 wildfires burning across the state during the 2020 lightning siege that each engine company assigned to the fires in Sonoma County was responsible for more than 700 acres (Nicholls, 2020).

2020 Glass Fire

The 2020 Glass fire burned 67,484 acres and 611 structures in Sonoma County, threatening urban neighborhoods in eastern Santa Rosa, and prompting large-scale evacuations from Santa Rosa to Glen Ellen. The Glass Fire sparked in Napa Valley early on Sunday, September 27, 2020, growing at a rate of around 1 acre every five seconds between Sunday night and Monday morning, according to satellite images from the National Oceanic and

Atmospheric Administration. An estimated 70,000 people were under evacuation orders in the region surrounding the Glass Fire.

15.2.3 Location

CAL FIRE has identified several “historic wildland fire corridors” in Sonoma County, including the steep ridges of the coastal ridges in the northwest county, which experienced fires in 1923, 1951, and 1978; and the Geysers area in the northeast Mayacamas range, which has experienced fires in 2004, 2013 and 2019. The 1964 Hanley and Nunn’s fire footprints were nearly identical to the 2017 Tubbs and Nuns fires. The Mayacamas mountains south of Santa Rosa above the Sonoma Valley also have a history of repetitive fire loss, where the Cavedale fires of 1925 and 1996 and the 1964 Nunns fire, and 2017 Sonoma Complex fires caused significant damage.

Figure 15-1 shows the Sonoma County Wildfire Hazard Index, a model that predicts relative wildfire hazard on the landscape. The hazard index has the following categories: Very Low Relative Hazard, Low Relative Hazard, Moderate Relative Hazard, High Relative Hazard, and Very High Relative Hazard. The index is based on inputs that inform potential fire behavior, inputs that represent fire probability occurrence at any location, and a model of wildfire suppression difficulty. The hazard index reflects landscape conditions through the 2018 fire season. The wildfire hazard data was developed for the 2021 update of the County’s Community Wildfire Protection Plan Update. The data is preliminary, pending further peer review.

In general, the mapping shows higher-hazard areas on the hills and mountains of the Coast and Mayacamas ranges. Lower-hazard areas line the Pacific coast, San Pablo Bay, and the Sonoma valley.

15.2.4 Frequency

The overall probability of some wildfire event impacting the planning area is high. Table 15-1 shows 23 fires of 300 acres or more in Sonoma County between 1964 and 2020, an average of one large fire every 2.6 years.

Wildfire probability varies with time of year and size of fire. Wildland fire season in Sonoma County spans the months after the last spring rains have fallen and until the first significant fall or winter rains occur. August, September, and October have the greatest potential for wildland fires as vegetation dries out, humidity levels fall, and offshore winds blow. Changing climate conditions are beginning to extend the local fire season. Drought conditions are of special concern, as is the potential for changing weather patterns, including the potential for more dry lightning storms during fire season.

15.2.5 Severity

As seen in Figure 15-2, the frequency and severity of wildfires in Sonoma County has changed over the past 60 years, especially over the last five years (2015 to 2020). As the size of fire has increased, so has the number of structures burned. This correlates to an increase in fire severity. The more structures that burn, the higher the probability for fatalities, which is the ultimate measure for severity in a mitigation planning context. Except for the Hanley fire in 1964, no fires prior to 2015 had burned more than 12,000 acres, but the burn areas for fires from 2015 to 2020 range from 37,000 to 78,000 acres. Similarly, no fire before 2015 burned more than 108 structures, but fires from 2015 to 2020 burned from 370 to 5,600 structures.

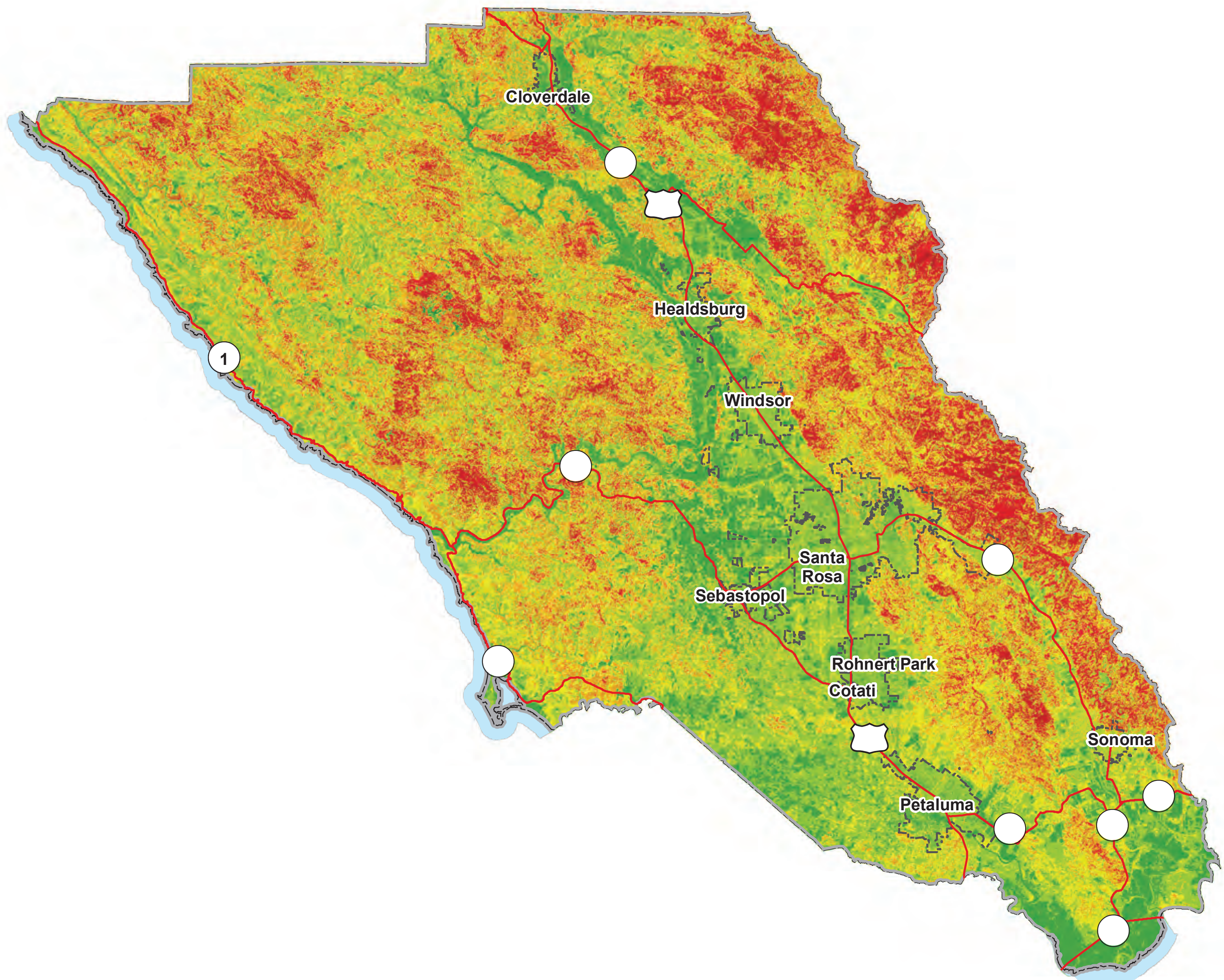
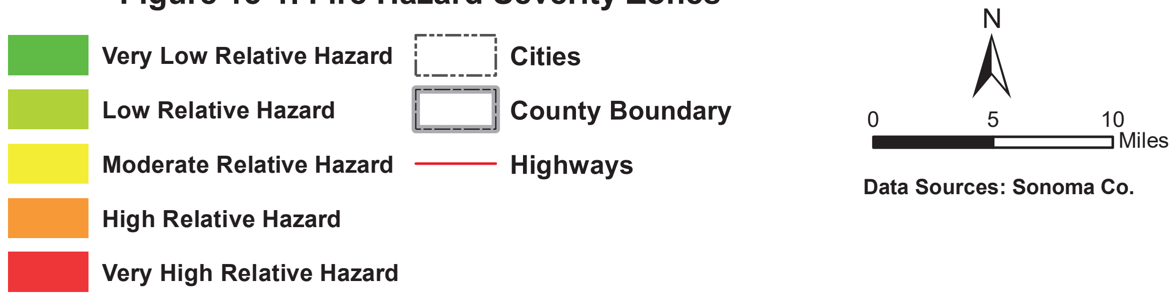


Figure 15-1. Fire Hazard Severity Zones



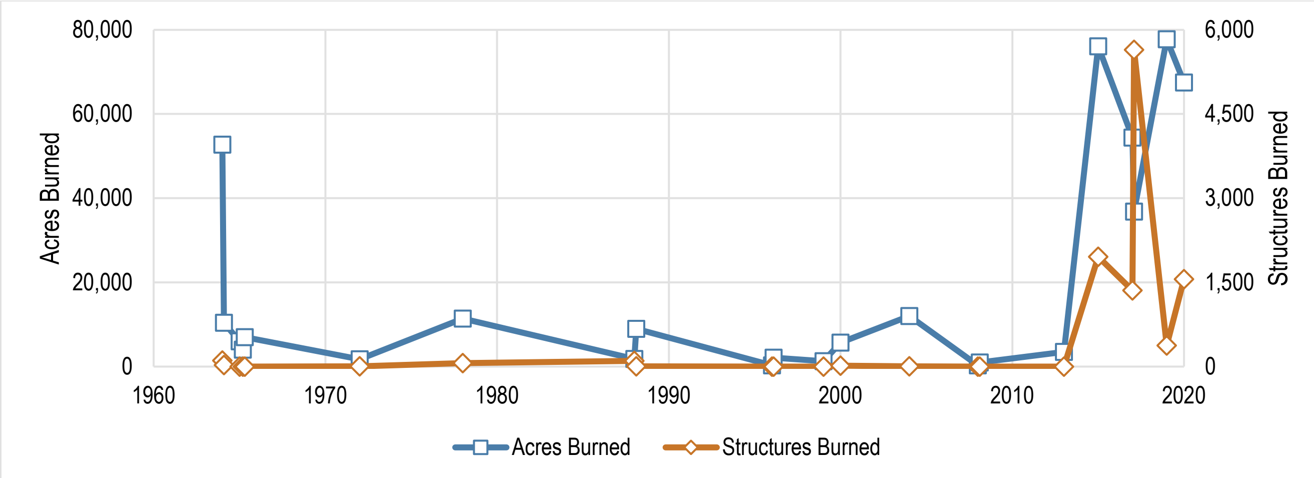


Figure 15-2. Acres and Structures burned, 1964 - 2020

Potential losses from wildfire include human life, structures and other improvements, natural resources, and natural systems such as water and watersheds. Damage to local economy can include loss of jobs due to direct fire losses or disruption from power safety shutoffs, or loss of crops from fire or smoke damage.

In 2017, at least 24 Sonoma County residents lost their lives due to wildfires. Reducing potential for loss of life should remain a top focus for planning and project implementation. Likewise, efforts should continue to help county residents create homes and communities that can better withstand exposure to the heat and embers of wildfires such as defensible space, structure hardening, and near-community “wildfire calming zones.”

Fire hazards present a significant risk to vegetation and wildlife habitats. Short-term loss caused by a wildfire can include the destruction of watersheds, timber, wildlife habitat, and scenic vistas. Long-term effects include smaller timber harvests, reduced access to affected recreational areas, and destruction of cultural and economic resources and community infrastructure. In addition, wildfire can lead to ancillary impacts such as landslides and flooding due to the impacts of silt in local watersheds.

Economic impacts due to wildfires include costs and losses due to burned or smoke-damaged crops, damaged public infrastructure and private property, interrupted transportation corridors, and disrupted communication lines. They also include diminished real property values and thus tax revenues, loss of retail sales, and relocation expenses of temporarily or permanently displaced residents. Power safety shutoffs also have significant impacts on local businesses and residents. Likewise, large-scale evacuations can have enormous impacts on local businesses.

Smoke and air pollution from wildfires can be a health hazard, especially for sensitive populations. Smoke generated by wildfire contains particulate matter (soot, tar, water vapor, and minerals), gases (carbon monoxide, carbon dioxide, nitrogen oxides) and toxics (formaldehyde, benzene). There has been a significant increase in scientific research regarding the impacts of wildfire smoke on public health. Impacts associated with wildfire include difficulty in breathing and increases in incidence of asthma, heart attacks and strokes. People who are over 65 years of age have a higher chance of heart attacks and strokes after two to three days of bad air quality due to wildfire smoke. Smoke worsens health conditions that are already more prevalent in lower-income locations, including some communities of color. One 2016 study in northern California found that people in lower-income zip code areas were disproportionately likely on wildfire smoke days to visit emergency rooms for asthma complications (Climate Connections, 2021).

Wildfire may also threaten the health and safety of those fighting the fires. First responders are exposed to the dangers from the initial incident and after-effects from smoke inhalation and heat stroke.

15.2.6 Warning Time

If a fire breaks out and spread rapidly, residents may need to evacuate within hours or minutes. Wildfires are mostly caused by human activities and systems, intentionally or accidentally. There is no way to predict when one might break out. Dry conditions, wind and droughts greatly increase fire likelihood. Dry lightning, whose incidence may increase due to changing climate, triggered devastating wildfires across Sonoma County and the state in 2020. Reliable National Weather Service lightning warnings are available on average 24 to 48 hours prior to a significant electrical storm, so special attention can be paid during weather events that may include lightning.

Typically, fires burn with the greatest severity between 1 p.m. and 6 p.m. Once a fire has started, fire alerting is reasonably rapid in most cases. However, when fires start under red flag conditions late at night, as was the case with the Sonoma Complex fires of 2017, alerting and evacuation can pose greater challenges for agencies and the public. Sonoma County has augmented systems and methodologies for alerting and evacuations since 2017 by developing and publicizing evacuation zones, and increasing the means for delivery of evacuation notification. Many Sonoma County communities, through programs such as Citizens Organized to Prepare for Emergencies (COPE) have organized to help notify their neighborhoods of emergencies.

Following a series of natural disasters, including Hurricane Katrina, that revealed shortcomings in the nation's ability to effectively alert populations at risk, Congress passed the Warning, Alert, and Response Network (WARN) Act in 2006. Today, new technologies such as smart phones and social media platforms offer new ways to communicate with the public, and the information ecosystem is much broader, including additional official channels, such as government social media accounts, opt-in short message service (SMS)-based alerting systems, and reverse 911 systems. Less official channels include mainstream media outlets and weather applications on connected devices. Unofficial channels include first-person reports via social media (National Academies of Sciences, Engineering, and Medicine, 2018).

15.3 EXPOSURE

A quantitative assessment of exposure to the wildfire hazard was conducted using the wildfire hazard mapping and the asset inventory developed for this plan, with an emphasis on the zones with the highest degree of susceptibility (moderate, high and very high fire risk). Summary results for the complete planning area are presented below. Detailed results by jurisdiction are provided in Appendix D.

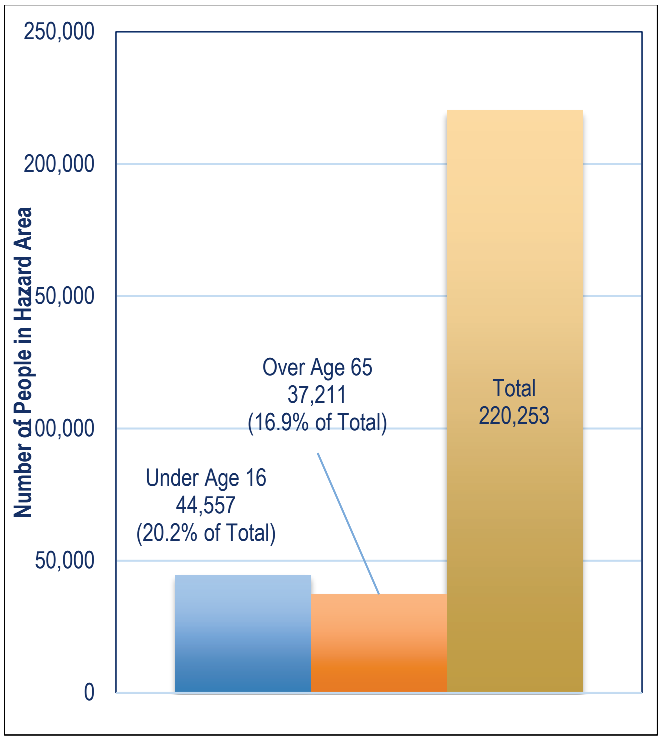
15.3.1 Population

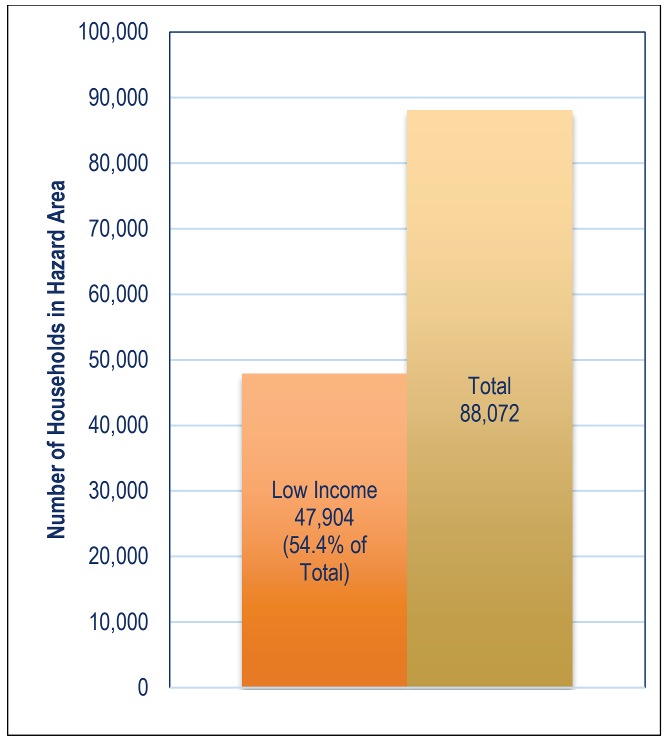
Population exposure was estimated by calculating the number of buildings in each hazard area as a percent of total planning area buildings and applying this percentage to the planning area population. Table 15-3 summarizes the estimated countywide population living in the mapped risk areas. In addition to populations who reside in risk areas where fires may occur, visitors, hikers and campers may be exposed to wildfires. The entire population of the planning area has the potential to be exposed to smoke from nearby wildfires.

Table 15-3. Exposed Population in Mapped Relative Fire Hazard Zones

	Moderate Relative Hazard	High Relative Hazard	Very High Relative Hazard
Population Exposed	68,365	8,368	1,158
% of Total Planning Area Population	14.1%	1.7%	0.2%

Socially vulnerable populations exposed to the wildfire hazard were estimated based on data for the Census-defined blocks that lie at least partially within the mapped high and very high relative fire hazard zones. Because many of those Census blocks extend outside the mapped hazard zones, the estimates are greater than the actual exposed populations, but they provide reasonable relative data for use in mitigation planning. Figure 15-3 summarizes the estimated exposure of socially vulnerable populations.





See Section 4.8.1 for the definition of "low income" used in this analysis

Figure 15-3. Socially Vulnerable Populations in High and Very High Fire Hazard Zones Census Blocks

15.3.2 Property

Table 15-4 summarizes the estimated countywide property exposure in the mapped landslide risk areas. Figure 15-4 shows the occupancy class for all buildings in the mapped fire hazard areas. These occupancy classes provide an indication of land use within the mapped hazard area. Some land uses are more vulnerable to fire, such as single-family homes, while others are less vulnerable, such as agricultural land or parks.

15.3.3 Critical Facilities

The breakdown of critical facilities exposure in the high and very high severity zones by facility type is shown in Figure 15-5.

Table 15-4. Exposed Property in Mapped Relative Fire Hazard Zones

	Moderate Relative Hazard	High Relative Hazard	Very High Relative Hazard
Number of Buildings Exposed	26,245	4,798	1,175
Value of Exposed Structures	$20,143,725,511	$9,058,841,363	$3,802,457,456
Value of Exposed Contents	$16,645,566,386	$8,613,600,440	$3,746,872,248
Total Exposed Property Value	**$36,789,291,897**	**$17,672,441,803**	**$7,549,329,704**
Total Exposed Value as % of Planning Area Total	***16.8%***	***8.1%***	***3.5%***

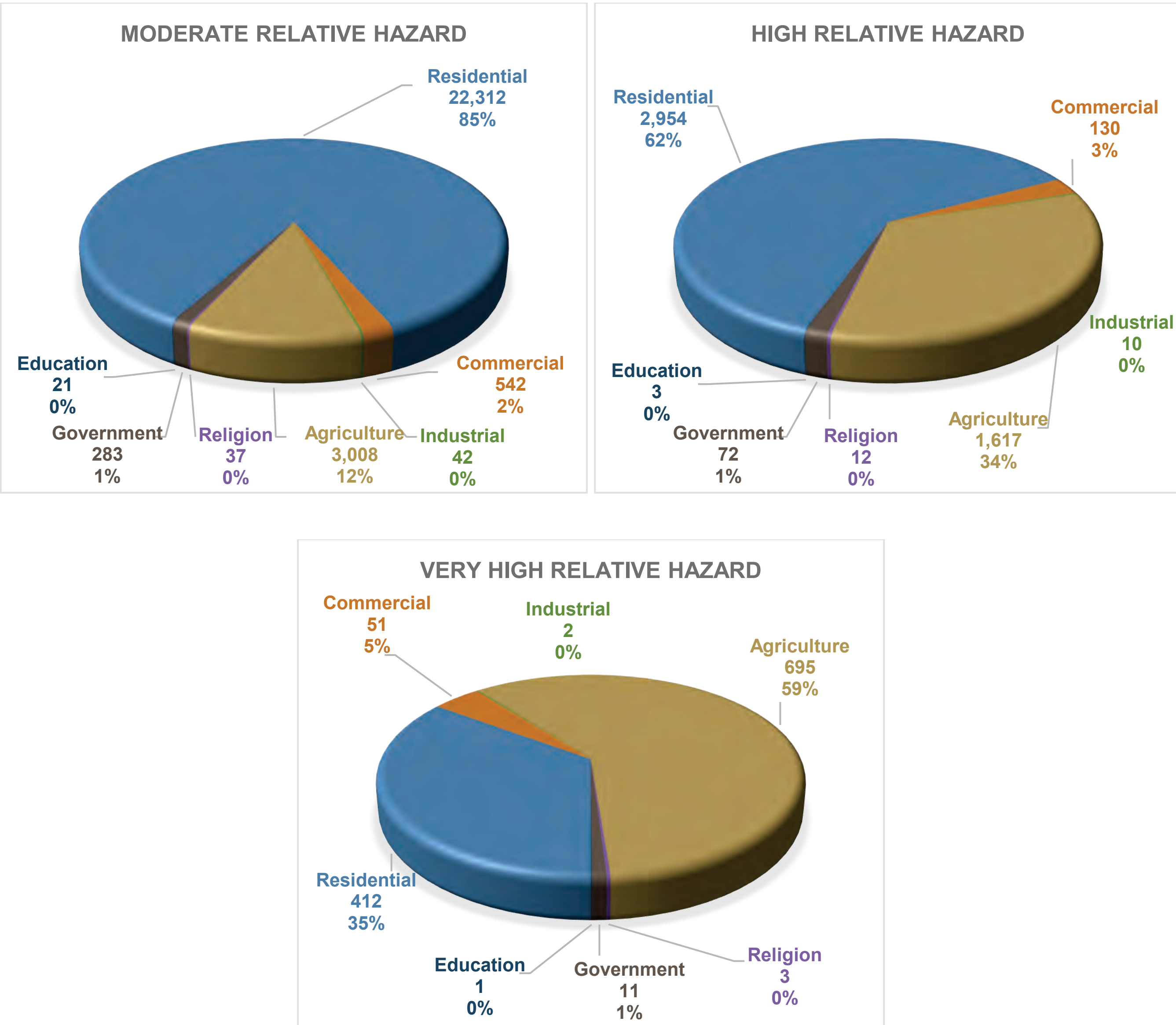


Figure 15-4. Structures in the High or Very High Relative Fire Hazard Zones, by Land Use Type

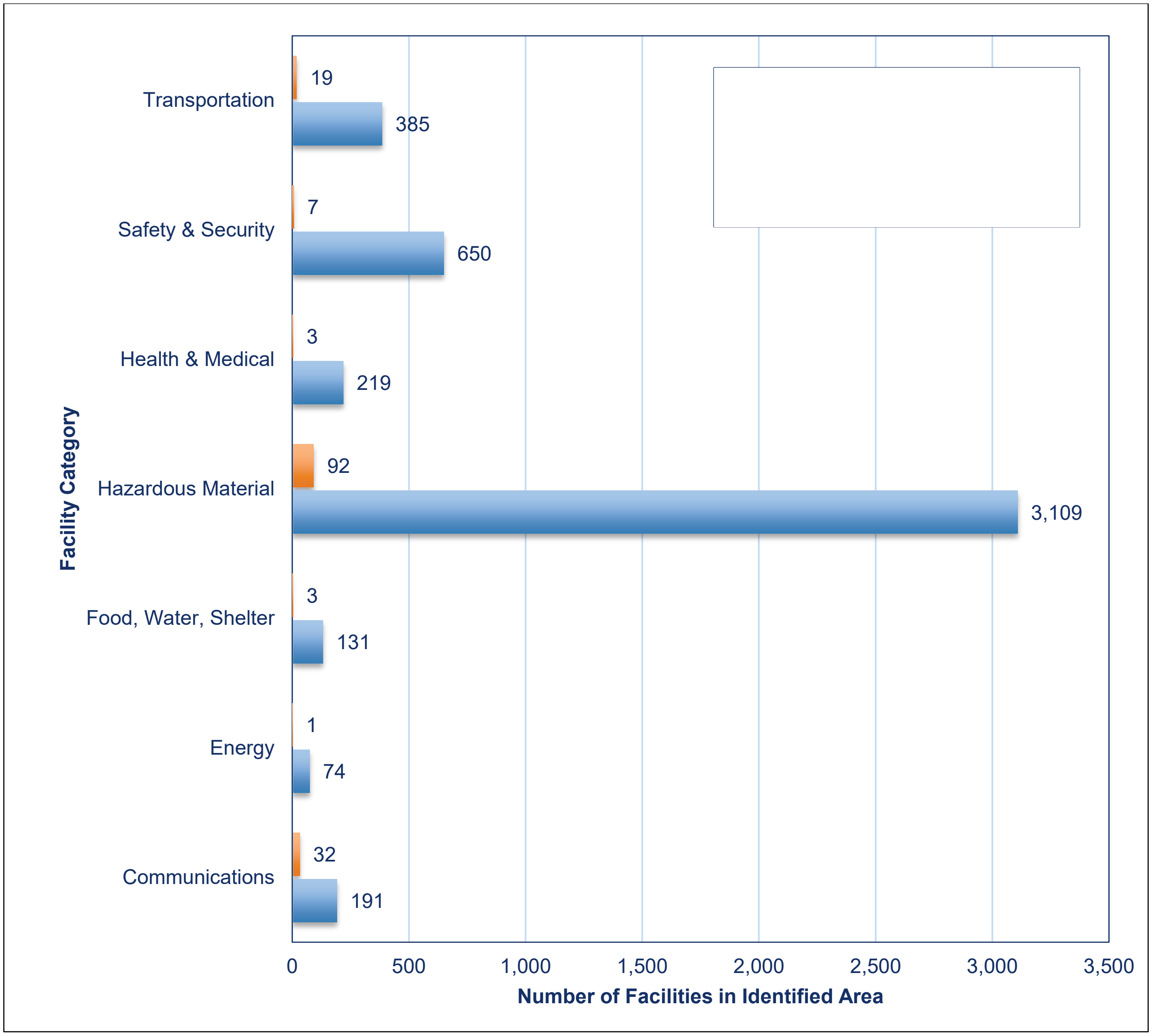


Figure 15-5. Critical Facilities in Mapped Relative Fire Hazard Zones and Countywide

15.3.4 Environment

All natural resources and habitats in mapped relative fire hazard zones are exposed to the risk of wildfire.

15.4 VULNERABILITY

15.4.1 Population

All people exposed to the wildfire hazard are potentially vulnerable to wildfire impacts. Persons with access and functional needs, the elderly and very young may be especially vulnerable to a wildfire if there is not adequate warning time for them to evacuate. People outside the mapped risk areas are susceptible to health hazards associated with smoke and air pollution from wildfires, especially sensitive populations including children, the elderly, and those with respiratory and cardiovascular diseases. Wildfires also threaten the health and safety of those fighting the fires.

15.4.2 Property

All property exposed to the wildfire hazard is vulnerable. Structures that were not constructed to standards designed to protect a building from a wildfire may be especially vulnerable. As of 2008, California State Building code requires minimum standards be met for new buildings in relative fire hazard zones. Less than 10 percent of housing in the planning area was built since this code requirement (U.S. Census Bureau n.d.).

Estimates were developed to indicate the loss that would occur if wildfire damage were equal to 1, 10, 30 or 50 percent of the exposed property value, as summarized in Table 15-5. Damage in excess of 50 percent is considered to be substantial by most building codes and typically requires total reconstruction of the structure.

Table 15-5. Loss Estimates for Wildfire Hazard

	Exposed Value	Loss Value	Loss as % of Total Planning Area Replacement Value
Moderate Relative Hazard			
Loss = 1% of Exposed Value	$36.79 billion	$370 million	less than 1%
Loss = 10% of Exposed Value		$3.68 billion	1.7%
Loss = 30% of Exposed Value		$11.04 billion	5.0%
Loss = 50% of Exposed Value		$18.40 billion	8.4%
High Relative Hazard			
Loss = 1% of Exposed Value	$17.67 billion	$180 million	less than 1%
Loss = 10% of Exposed Value		$1.77 billion	less than 1%
Loss = 30% of Exposed Value		$5.30 billion	2.4%
Loss = 50% of Exposed Value		$8.84 billion	4.0%
Very Relative Hazard			
Loss = 1% of Exposed Value	$7.55 billion	$80 million	less than 1%
Loss = 10% of Exposed Value		$760 million	less than 1%
Loss = 30% of Exposed Value		$2.26 billion	1.0%
Loss = 50% of Exposed Value		$3.78 billion	1.8%

15.4.3 Critical Facilities

Critical facilities not built to fire protection standards, utility poles and lines, and facilities containing hazardous materials are most vulnerable to the wildfire hazard. Most roads would not be damaged except in the worst scenarios, although roads and bridges can be blocked by debris or other wildfire-related conditions and become impassable. Additionally, heavy vehicle traffic during incidents and in post-fire recovery and rebuild can have significant impact on road surfaces. The following critical facilities are located in very high and high severity zones and their vulnerability could complicate response and recovery efforts during and following an event:

- **Hazardous Materials and Fuel Storage**—During a wildfire event, these materials could rupture due to excessive heat and act as fuel for the fire, causing rapid spreading and escalating the fire to unmanageable levels. In addition, they could leak into surrounding areas, saturating soils and seeping into surface waters, and have a disastrous effect on the environment.
- **Communication Facilities**—If these facilities are damaged and become inoperable, it would exacerbate already difficult communication in the planning area.

15.4.4 Environment

Sonoma County's ecosystems are fire adapted. Native plant species have evolved with fire in the landscape, and occurrence of fire is an integral component of forest health. Over millennia, nature has selected for species that survive the passage of wildfire, and for the healthiest, best-placed trees to survive. Some species require fire in order to propagate or germinate seeds. However, severe wildfire behavior, can also cause severe 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.
- **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.
- **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.
- **Damaged Fisheries**—Critical fisheries can suffer from increased water temperatures, sedimentation, and changes in water quality.
- **Destroyed Endangered Species Habitat—**Wildfire can have negative consequences for endangered species by degrading their habitat.
- **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.
- **Reduced Timber Harvesting**—Timber can be destroyed and lead to smaller available timber harvests.
- **Reduced Agricultural Resources**—Wildfire can have disastrous consequences on agricultural resources, removing them from production and necessitating lengthy restoration programs. In addition to fire directly impacting winery facilities and vineyards, smoke can impact grapes on the vine, tainting the grapes so that they become unusable for wine production.
- **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.

15.5 FUTURE TRENDS IN DEVELOPMENT

Urbanization tends to alter the natural fire regime and can lead to expansion of urbanized areas into wildland areas. Placement of additional housing in the wildland/urban interface areas located in high or very high relative fire hazard zones can increase the fire threat, particularly in the historical fire corridors north and east of Santa Rosa and in the Sonoma Valley. Development in these areas can burden existing fire protection services, particularly in areas dependent on volunteer firefighters.

Most of the homes in Sonoma County's WUI areas were constructed before 2008, when California's WUI Building Code (California Code Chapter 7A) went into effect. This code requires ignition-resistant building materials in WUI areas. Structures built before it took effect and those without adequate vegetation management are at higher risk to wildland fire ignition. In Sonoma County, there are 27,286 structures in the WUI. Approximately 12,600 of those (all structures with a footprint greater than 1,500 square feet) are in areas with high and very high risk of wildland fires.

Patterns of land use and development have placed extensive residential infrastructure into places that recent, large fires have placed at severe risk. These fires have resulted in the loss of over 6,000 homes in Sonoma County, as well as thousands of other structures. This risk is expected to increase in coming decades. Fire will likely recur within similar footprints and place the same infrastructure at risk into the foreseeable future, as well as occurring in previously unburned areas.

The expansion of development toward wildfire hazard areas can be managed with strong land use and building codes. State and local policies and regulations require landowners to carry out activities such as maintaining defensible space and reducing vulnerability to damage or loss from wildfire. In Sonoma County, defensible space is regulated in Local Responsibility Areas through Sonoma County Code Chapter 13A. In the State Responsibility areas, the California Building Code includes minimum standards related to the design and construction of buildings in fire hazard zones. Any newly permitted buildings must conform to standards that manage flammable materials from around the building (defensible space laws) and construct buildings from fire-resistant material. New residential construction in high hazard areas in the State Responsibility Areas must be built according to the standards of the 2007 WUI Building Code. Defensible SPACE in the SRA is regulated through Public Resource Code 4290 and 4291, Title 14 of the California Code of Regulations, and Government Code Sections 51175 through 51189.

The State of California has enacted significant legislation that attempts to manage and mitigate wildfire risk. Appendix B provides a summary of this legislation, much of which will have an impact on future development that interfaces a wildfire hazard severity zone. In addition, the planning partners' general plans include policies that address managing development in relative fire hazard zones. The planning area is well equipped with these tools, and this planning process has asked each planning partner to assess its capabilities with regards to the tools. As the planning area experiences future growth, it is anticipated that the exposure to this hazard will remain as assessed or even decrease over time due to these capabilities.

15.6 SCENARIO

A major wildfire in the planning area might begin with a wet spring, which could encourage growth of light flashy fuels, such as grasses and brush. The summer could see the onset of insect infestation or plant pathogens that increase tree mortality. A dry summer could follow the wet spring, exacerbated by dry hot winds. Carelessness with combustible materials, equipment use, a vehicle fire, a tossed lit cigarette, or a lightning storm could trigger a multitude of small isolated fires.

The embers from these smaller fires could be carried miles by hot, dry winds. The deposition zone for these embers could be deep in forested areas or in urban areas. Fires that start in flat areas move slower, but wind still pushes them. It is not unusual for a wildfire pushed by wind to burn the ground fuel and later climb into the crown and reverse its track. This is one of many ways that fires can escape containment, typically during periods when response capabilities are overwhelmed. These new small fires would most likely merge. Suppression resources would be redirected from protecting the natural resources to saving lives, homes, and communities. In 2017, the Tubbs fire became an urban conflagration fire, as embers from wildland areas carried across multiple lane Highway 101 to ignite businesses and the community of Coffey Park, where approximately 1,300 homes were lost along with commercial buildings.

The worst-case scenario would include an active fire season throughout the American west, spreading resources thin. Firefighting teams would be exhausted or unavailable. Many federal assets would be responding to other fires that started earlier in the season.

To further complicate the problem, heavy rains could follow, causing flooding and landslides and releasing tons of sediment into rivers, permanently changing floodplains and damaging sensitive habitat and riparian areas. Such a fire followed by rain could release millions of cubic yards of sediment into streams for years, creating new floodplains and changing existing ones. With the forests removed from the watershed, stream flows could easily double. Floods that could be expected every 50 years may occur every couple of years. With the streambeds unable to carry the increased discharge because of increased sediment, the floodplains and floodplain elevations would increase.

15.7 ISSUES

Wildfire is an inevitable and normal ecological process in the fire-adapted landscape of Sonoma County. Nearly 100 years of aggressive fire suppression has contributed to the high wildfire risk of today. Absent fire for many years, wildland areas became overstocked with highly flammable vegetation. At the same time, expansion of homes into rural WUI areas increased the number of homes in high-risk areas. Typically, residential property owners do not maintain forested lands, exacerbating wildfire potential. On public lands, available budget for large-scale wildland fuels maintenance is an ongoing issue. Overcrowded conditions degrade overall forest health and degrade the environmental values provided by forest ecosystems.

While in a few areas, recent wildfires burned hot enough to damage wildland ecosystems, in general wildland ecosystems have not sustained irrevocable damage. In many cases fires were beneficial. Large, uncontrolled wildfires can cause significant damage to ecosystem services, however life, home and economic losses to residents and communities must be considered along with environmental consequences.

Research shows that home loss in wildland fires is primarily driven by two equally important factors:

- The vulnerabilities of buildings that make them prone to ignition—Embers cause 80 percent of wildland fire home ignitions. The following elements are most vulnerable to embers but can be retrofitted on existing homes to reduce risk of ignition:
  - Non-Class A roofs
  - Roof edges and soffits
  - Combustible plants and materials within 5 feet of house walls
  - Non-WUI approved venting products that allow for ember entry into structures
  - Wooden attachments, such as fences and decks
  - Non-WUI rated windows
  - Siding

- The vegetative fuels within 100 feet of structures (the area referred to as defensible space)—Good defensible space, wherein vegetation has been reduced to reduce fire intensity and spread, is critical to reduce ignition.

Most of the homes in Sonoma County's WUI areas were constructed before 2008, when the WUI Building Code went into effect. This code requires ignition-resistant building materials in WUI areas. Structures built before it took effect and those without adequate vegetation management are at higher risk to wildland fire ignition.

Outside of the home and the 100-foot defensible space zone, surrounding wildland fuels can play a role in home destruction, as fire and embers can spread from nearby wildland areas into communities. It is in this area that vegetation management can come into play. This refers to actions taken to alter natural vegetation or plant communities that abut communities, usually on the scale of 10s to 1,000s of acres. Vegetation management can include prescribed fire, prescribed grazing, timber harvest techniques, invasive plant removal, or mechanical treatment to remove fine fuels, dense stands of fire-prone species, shrubs, and dead and dying vegetation. Fuels are reduced in order to create "community calming zones" or restore ecosystems to less flammable conditions. Strategically placed calming zones can reduce near-community fire intensity and spread, provide safe anchors that firefighters can use to stop forward progress of the fire, and supplement and support near-home mitigation strategies. Roadside fuels treatment can support emergency ingress and egress, increasing community and firefighter safety.

Although the patterns of land use, natural plant communities, topography, weather, soils, and geology vary across the landscapes of Sonoma County, notable patterns are discernible. An approach is needed for deploying existing techniques at the scale of whole communities. Such an approach would be informed by the principles of landscape ecology. It would view the natural lands where fires tend to originate and the built infrastructure of human communities that abut the natural landscapes as a coupled system. Mitigating large-scale loss of life and property can be achieved using relatively well-established techniques of home hardening, defensible space and vegetation management at the scale of whole communities and the natural landscapes that surround them.

16. CLIMATE CHANGE

16.1 GENERAL BACKGROUND

16.1.1 What is Climate Change?

Climate is the result of long-term weather patterns—including temperature, precipitation, humidity, wind and seasons—and plays a fundamental role in shaping natural ecosystems and the human economies and cultures that depend on them. "Climate change" refers to changes over a long period of time, with units of climate change measurements often conducted in 30-year increments.

The well-established worldwide warming trend of recent decades and its related impacts are caused by increasing concentrations of carbon dioxide and other greenhouse gases in the earth's atmosphere. Greenhouse gases are gases that trap heat in the atmosphere, resulting in a warming effect. Carbon dioxide is the most commonly known greenhouse gas; however, methane, nitrous oxide and fluorinated gases also contribute to warming. Emissions of these gases come from a variety of sources, such as the combustion of fossil fuels, agricultural production and changes in land use. According to the National Aeronautics and Space Administration (NASA), carbon dioxide concentrations measured about 280 parts per million (ppm) before the industrial era began in the late 1700s and have risen dramatically since then, surpassing 400 ppm in 2013 for the first time in recorded history (see Figure 16-1).

16.1.2 How Climate Change Affects Hazard Mitigation

Climate change will affect the people, property, economy, and ecosystems of the planning area in a variety of ways. Consequences of climate change include increased flood vulnerability, and increased heat-related illnesses. The most important effect for the development of this plan is that climate change will have a measurable impact on the occurrence and severity of natural hazards.

An essential aspect of hazard mitigation is predicting the likelihood of hazard events in a planning area. Typically, predictions are based on statistical projections from records of past events. This approach assumes that the likelihood of hazard events remains essentially unchanged over time. Thus, averages based on the past frequencies of, for example, floods are used to estimate future frequencies: if a river has flooded an average of once every 5 years for the past 100 years, then it can be expected to continue to flood an average of once every 5 years.

Source: NASA, 2020

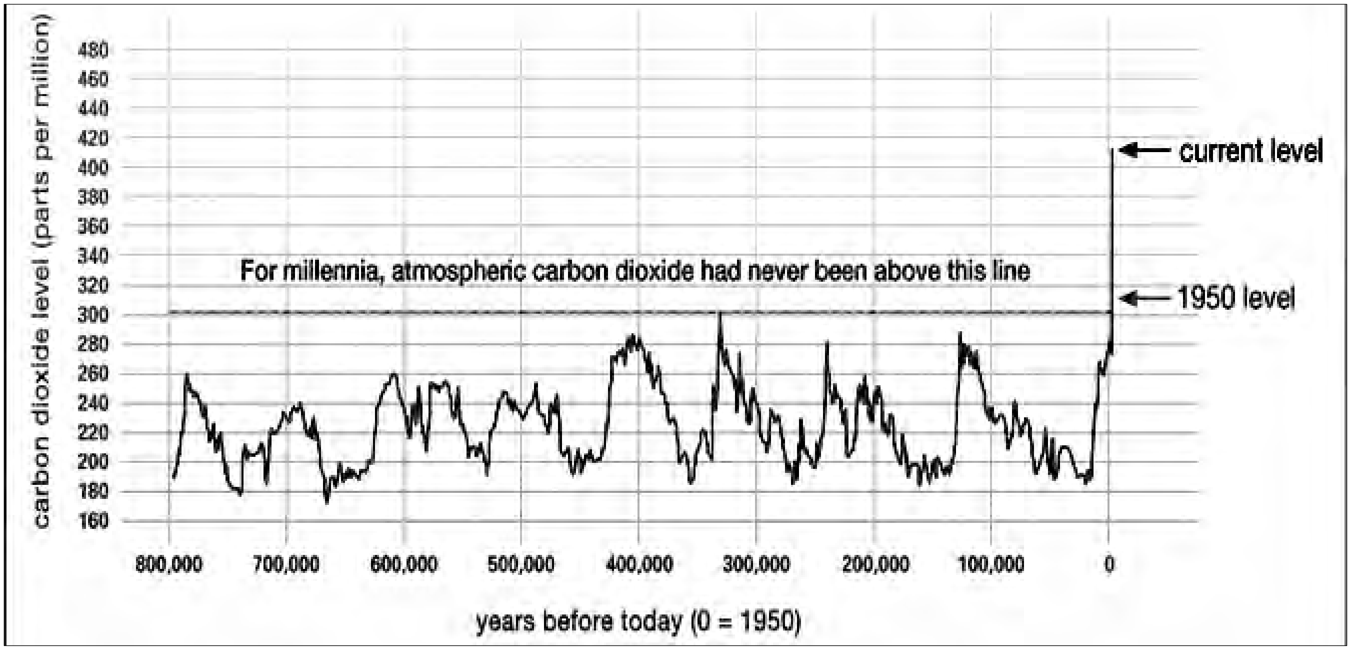


Figure 16-1. Global Carbon Dioxide Concentrations Over Time

For hazards that are affected by climate conditions, the assumption that future behavior will be equivalent to past behavior is not valid if climate conditions are changing. As flooding is generally associated with precipitation frequency and quantity, for example, the frequency of flooding will not remain constant if broad precipitation patterns change over time. Specifically, as hydrology changes, storms currently considered to be the 100-year flood might strike more often, leaving many communities at greater risk.

The risks of landslide, severe storms, and wildfire are all affected by climate patterns as well. For this reason, an understanding of climate change is pertinent to efforts to mitigate natural hazards. Information about how climate patterns are changing provides insight on the reliability of future hazard projections used in mitigation analysis.

16.1.3 Current Indicators of Climate Change

Global Indicators

The major scientific agencies of the United States—including NASA and the National Oceanic and Atmospheric Administration (NOAA)—have presented evidence that climate change is occurring. NASA summarizes key evidence as follows (NASA, 2020a):

- **Global Temperature Rise**—The planet’s average surface temperature has risen about 1.62 ºF since the late 19th century, a change driven largely by increased carbon dioxide and other human-made emissions into the atmosphere. Most of the warming occurred in the past 35 years, with the five warmest years on record taking place since 2010.
- **Warming Oceans**—The oceans have absorbed much of this increased heat, with the top 2,300 feet of ocean showing warming of more than 0.4 ºF since 1969.

- **Shrinking Ice Sheets**—The Greenland and Antarctic ice sheets have decreased in mass. Greenland lost an average of 286 billion tons of ice per year between 1993 and 2016, and Antarctica lost about 127 billion tons of ice per year during the same time period. The rate of Antarctica ice mass loss has tripled in the last decade.
- **Glacial Retreat**—Glaciers are retreating almost everywhere around the world—including in the Alps, Himalayas, Andes, Rockies, Alaska and Africa.
- **Decreased Snow Cover**—Satellite observations reveal that the amount of spring snow cover in the Northern Hemisphere has decreased over the past five decades and that the snow is melting earlier
- **Sea Level Rise**—Global sea level rose about 8 inches in the last century. The rate in the last two decades is nearly double that of the last century and is accelerating slightly every year.
- **Declining Arctic Sea Ice**—Both the extent and thickness of Arctic sea ice has declined rapidly over the last several decades
- **Extreme Events**—The number of record high temperature events in the United States has been increasing since 1950, while the number of record low temperature events has been decreasing. The U.S. has also witnessed increasing numbers of intense rainfall events.
- **Ocean Acidification**—Since the beginning of the Industrial Revolution, the acidity of surface ocean waters has increased by about 30 percent. The amount of carbon dioxide absorbed by the upper layer of the oceans is increasing by about 2 billion tons per year.

California Indicators

Climate change poses an immediate and growing threat to California's environment, public health, and economic vitality. Monitoring and research efforts across the state generate observational data that describe changes that are already underway. These data can serve as the basis for indicators that track trends over time. Climate change indicators help to track, evaluate, and report on the climate change issues the state is working to address. They facilitate the communication of climate-related information to a broad audience by synthesizing large volumes of complex data into a concise, easily understood format. The *California Fourth Climate Assessment* identifies temperature, precipitation, drought, snowpack, fog, wildfire, and sea level rise as the most dynamic and indicative elements of a changing climate in the greater Bay Area (Ackerly et al. 2018).

Impact on Physical Systems

California's Office of Environmental Health Hazard Assessment has identified the following physical impacts as indicators of climate change in the state (California Office of Environmental Health Hazard Assessment 2018):

- **Dissolved Oxygen in Coastal Waters**—Throughout the south coast survey region, dissolved oxygen levels to at least 500-meter depths have declined.
- **Lake Water Temperature**—Average water temperatures in Lake Tahoe—derived from measurements from the bottom to the surface of the lake—have gone up by nearly a full degree Fahrenheit since 1970, at an average rate of 0.02 ºF each year. In the last four years, Lake Tahoe's waters warmed at a rate about 10 times faster than the long-term rate. This rapid warming is of special concern, because Lake Tahoe's enormous volume should make it less vulnerable to change.
- **Snow-Water Content**—Snow-water content has ranged from over 200 percent of average in 1952, 1969 and 1983 to a record-low 5 percent of average in 2015 during the extreme drought. Regional differences in snow-water content have been noted in the Sierra Nevada. Cooler air temperatures at higher elevations

generally allow for more snow to accumulate. Since 1950, the northern Sierra Nevada showed an overall decline of 7.4 inches. Less of a decline (1.2 inches) has occurred in the southern region, where elevations are higher. These declines are part of a broader pattern of decreasing snowpack in the western United States. This pattern correlates with warming spring temperatures and earlier snowmelt in recent years.

- **Coastal Ocean Temperature—**Sea surface temperature increased at the rate of 0.2 °F per decade at Pacific Grove (between 1920 and 2014) and at La Jolla (between 1917 and 2016). Since 1973, however, warming at La Jolla occurred at a faster rate of 0.6 °F per decade. At Trinidad Bay, sea surface temperatures increased at the rate of 0.4 °F per decade over the same shorter time period (1973 - 2016). Unusually warm waters occurred in the Pacific Ocean in 2014-2015, leading to widespread impacts on marine life, including shifts in species distribution, mass stranding of sea lions and sea birds, and fishery closures (further discussed below). This marine heat wave first appeared as a large area of exceptionally high sea surface temperatures in the Gulf of Alaska in November 2013 (nicknamed “the warm blob”). It later extended along the entire west coast of North America.
- **Glacier Change—**The surface area of seven Sierra Nevada glaciers has decreased dramatically since the beginning of the twentieth century. The graph on the right shows the fraction of the area of these glaciers relative to the year 1903. These glaciers are among the largest at higher elevations for which data are available. In 2014, the size of these glaciers ranged from 14 to 52 percent of their 1903 area—a reduction of 48 to 86 percent.
- **Sea Level Rise—**Sea level has risen by about 7 inches at San Francisco since 1900 and by about 6 inches at La Jolla since 1924. Sea levels show year-to-year variability but are rising overall at almost all tide gauge locations in California.
- **Snowmelt Runoff**—Since 1906, the fraction of annual snowmelt runoff that flows into the Sacramento River between April and July has decreased by about 9 percent. The 2015 water year had the third lowest percentage of spring runoff on record. Compared to the 50-year period between 1906 and 1955, peak monthly runoff (when runoff volume is at its maximum) occurred nearly a month earlier in 1956 – 2007. This shift indicates an earlier onset of springtime temperatures.

Impact on Biological Systems

California’s Office of Environmental Health Hazard Assessment has identified the following biological impacts as indicators of climate change in the state (California Office of Environmental Health Hazard Assessment 2018):

- **Changes in Forests and Woodlands**—Compared to the 1930s, forests across much of California today have lower densities of large trees (over 24 inches in diameter), and higher densities of small trees (4 to 12 inches in diameter). Pines have declined in all regions, while oaks have increased in two Sierra Nevada regions but decreased in the South and Central Coast ranges. Water stress, which increases in a warming climate, poses a greater risk to large trees and pines than to small trees and oaks. Other factors that influence forest structure and composition and are exacerbated by climate change include fire suppression, logging practices and wildfires.
- **Forest Tree Mortality**—Annual tree mortality in California forests increased in 2014, two years into the 2012 – 2016 drought. Steep increases in mortality followed in subsequent years; the highest number, 62 million tree deaths, was recorded in 2016. The drought may foreshadow an increasingly common condition known as a “hotter drought,” where warm temperatures coincide with periodic dry years. When temperatures are high, plant water demand increases while soil moisture decreases, creating a stress on trees. This stress in combination with bark beetle infestation led to the dramatic number of tree deaths.

- **Heat-Related Mortality and Morbidity**—Heat-related deaths and illnesses in California increased dramatically in 2006 following a record-breaking heatwave. That year, at least 140 deaths occurred between July 15 and August 1. About 16,000 more emergency room visits, and about 1,100 more hospitalizations than usual occurred during this period (compared to a similar time period in the summer of 2006 when there was not a heat wave). Multiple locations in California broke records for the highest number of uninterrupted days over 100 °F ever recorded: 11 in Sacramento; 12 in Modesto; and 21 in Woodland Hills near Los Angeles. Deaths related to this heat wave were largely attributed to elevated nighttime temperatures.
- **Wildfires—**The number of acres burned by wildfires statewide has increased since 1950. Although fires are fewer in number, large fires—affecting 1,000 acres or more—account for most of the area burned. On average, there are about half as many large fires each year as fires affecting less than 1,000 acres.

16.1.4 Projected Future Impacts

Climate change projections contain inherent uncertainty, for example, dependence upon future greenhouse gas emission scenarios. Generally, the uncertainty in greenhouse gas emissions is addressed by the presentation of differing scenarios: low-emissions or high-emissions scenarios. In low-emissions scenarios, greenhouse gas emissions are reduced substantially from current levels. In high-emissions scenarios, greenhouse gas emissions generally increase or continue at current levels. Uncertainty in outcomes is generally addressed by averaging a variety of model outcomes. Despite this uncertainty, climate change projections present valuable information to help guide decision-making for possible future conditions.

Global Projections

The Intergovernmental Panel on Climate Change (IPCC), which includes more than 1,300 scientists from the United States and other countries, projects that Earth's average temperatures will rise between 2.5 and 10 ºF over the next 100 years (NASA, 2020). Some research has concluded that every increase of 2 ºF in average global average temperature can have the following impacts (National Research Council, 2011):

- 3 to 10 percent increases in the amount of rain falling during the heaviest precipitation events, which can increase flooding risks
- 200 to 400 percent increases in the area burned by wildfire in parts of the western United States
- 5 to 10 percent decreases in stream flow in some river basins
- 5 to 15 percent reductions in the yields of crops as currently grown.

Sea level is rising at increasing rates due to global warming of the atmosphere and oceans and melting of the glaciers and ice sheets. Rising sea level and projections of stronger and more frequent El Niño events indicate a growing vulnerability to coastal flooding and erosion. While the IPCC's "business as usual" scenario, in which greenhouse gas emissions continue at the current rate of increase, predicts up to 3.61 feet of global sea level rise by 2100 (Intergovernmental Panel on Climate Change (IPCC) n.d.), other observations and projections suggest that these ranges do not capture the full range of physically plausible global average sea level rise over the 21st century (National Oceanic and Atmospheric Administration 2017). The National Climate Assessment completed by NOAA suggested that sea levels could rise as much as 8.2 feet by the end of the century if rapid loss of Antarctic ice occurred (U.S. Global Change Research Program (USGCRP) 2018).

Projections for California

The following sections summarize information developed for the planning area by Cal-Adapt, a resource for public information on how climate change might impact local communities, based on the most current data available. The projections are averaged across the county-wide planning area and include information from two emissions scenarios developed by the IPCC (low emissions and high emissions).

Modeled Climate Changes

Table 16-1 summarizes projected impacts for three potential climate change scenarios. By the end of the century under a high-emissions scenario, the following changes are projected, depending on the scenario:

- Average maximum temperatures would rise by up to 11.7 °F.
- Average minimum temperatures would rise by up to 8.4 °F.
- Average precipitation could increase by 35 percent or decrease by 21 percent
- The water deficit would increase by up to 22 percent

Table 16-1. Historical and Future Projections for Climate Information in Sonoma County

	Change from Current (1981 2010) Average					
	Moderate Warming, High Rainfall		Moderate Warming, Moderate Rainfall		Hot, Low Rainfall	
Variable	2040 2069	2070 2099	2040 2069	2070 2099	2040 2069	2070 2099
Precipitation	25%	35%	-2%	6%	-19%	-21%
Minimum Winter Temperature	3.4 ºF	6.2 ºF	2.7 ºF	5.5 ºF	4.8 ºF	8. 4ºF
Maximum Summer Temperature	4.8 ºF	8.6 ºF	3.9 ºF	7.6 ºF	6.6 ºF	11.7 ºF
Water Deficit	5%	10%	6%	10%	12%	22%
Groundwater Recharge	25%	29%	4%	6%	-20%	-17%
Runoff	61%	90%	-1%	22%	-32%	-34%

Source: California Landscape Conservation Partnership. 2021

Sea Level Rise

Sea levels have been rising over the past several decades and are expected to continue to rise. Sea level rise is mostly attributed to two factors: the expansion of water as it warms (thermal expansion) and the melting of ice sheets and glaciers. As average ocean temperatures continue to increase, thermal expansion will continue and can be projected with some degree of certainty. Less certain is how quickly ice sheets will melt, accounting for most of the uncertainty in projections.

Sea level rise will cause currently dry areas to be permanently or chronically inundated. Temporary inundation from extreme tide events and storm surge also will change. Unlike many other impacts resulting from climate change, sea level rise will have a defined extent and location. This allows for a more-detailed risk assessment to be conducted for this climate change impact (see Chapter 12). Although the extent and timing of sea level rise is still uncertain, assessing potential areas at risk provides information appropriate for planning purposes.

16.1.5 Responses to Climate Change

Communities and governments worldwide are working to address, evaluate and prepare for climate changes that are likely to impact communities in coming decades. Generally, climate change discussions encompass two separate but inter-related considerations: mitigation and adaptation. The term "mitigation" can be confusing, because it's meaning changes across disciplines:

- Mitigation in emergency management—as generally addressed in this hazard mitigation plan—is typically defined as the effort to reduce loss of life and property by lessening the impact of disasters.
- Mitigation in climate change discussions is defined as a human intervention to reduce impacts on the climate system. It includes strategies to reduce greenhouse gas sources and emissions and enhance greenhouse gas sinks.

In this chapter, mitigation is used as defined by the climate change community. In the other chapters of this plan, mitigation is primarily used in an emergency management context.

Adaptation refers to adjustments in natural or human systems in response to the actual or anticipated effects of climate change and associated impacts. These adjustments may moderate harm or exploit beneficial opportunities. Mitigation and adaptation are related, as the world's ability to reduce greenhouse gas emissions will affect the degree of adaptation that will be necessary. Some initiatives and actions can both reduce greenhouse gas emissions and support adaptation to likely future conditions.

Societies across the world are facing the need to adapt to changing conditions associated with natural disasters and climate change. Farmers are altering crops and agricultural methods to deal with changing rainfall and rising temperature; architects and engineers are redesigning buildings; planners are looking at managing water supplies to deal with droughts or flooding.

Adaptive capacity goes beyond human systems, as some ecosystems are able to adapt to change and to buffer surrounding areas from the impacts of change. Forests can bind soils and hold large volumes of water during times of plenty, releasing it through the year; floodplains can absorb vast volumes of water during peak flows; coastal ecosystems can hold out against storms, attenuating waves and reducing erosion. Other ecosystem services—such as food provision, timber, materials, medicines and recreation—can provide a buffer to societies in the face of changing conditions. Ecosystem-based adaptation is the use of biodiversity and ecosystem services as part of an overall strategy to help people adapt to the adverse effects of climate change. This includes the sustainable management, conservation and restoration of specific ecosystems that provide key services.

Assessment of the current efforts and adaptive capacity of the planning partners participating in this hazard mitigation plan are included in the jurisdiction-specific annexes in Volume 2.

16.2 SONOMA COUNTY EFFORTS TO ADDRESS CLIMATE CHANGE

16.2.1 A Roadmap for Climate Resilience in Sonoma County

In April 2016, the North Bay Climate Adaptation Initiative released *A Roadmap for Climate Resilience in Sonoma County*. The roadmap provides a framework and recommendations for how Sonoma County should approach climate resilience. It defines nine climate resilience goals to address extreme heat, drought, wildfires, fewer freezing nights, extreme floods, higher sea level, and high storm surges. Each goal has a set of priority actions to address the climate hazards related to the goal.

Since the roadmap was published, Sonoma County has experienced more frequent and severe climate hazards, including devastating Russian River floods in 2019 and extreme wildfires in 2017, 2019, and 2020. Given current and forecasted climate conditions, each of these hazards will continue to be a significant risk for Sonoma County.

16.2.2 Sonoma County Regional Climate Protection Authority

The Sonoma County Regional Climate Protection Authority (RCPA) leads a local government coalition to mobilize regional climate action in Sonoma County. RCPA is a special district governed by a Board of Directors comprising representatives from the Sonoma County Board of Supervisors and council members from each of the county's cities. The RCPA provides a forum for local elected officials to engage in dialogue on a wide range of topics related to decarbonization, carbon sequestration, and community resilience.

The RCPA developed *Climate Action 2020 Plan*: *A Regional Program for Sonoma County Communities*, but it was challenged in court and its environmental impact report was ruled to be inadequate. Unable to adopt the Climate Action 2020 Plan, the Sonoma County Board of Supervisors adopted the Climate Change Action Resolution to help create countywide consistency and clear guidance about coordinated implementation of greenhouse gas reduction measures. Under the resolution, Sonoma County agrees to work toward the RCPA's countywide target to reduce greenhouse gas emissions to 40 percent below 1990 levels by 2030 and 80 percent below 1990 levels by 2050. Sonoma County adopts the following goals to reduce greenhouse gas emissions, and will pursue local actions that support these goals:

- Increase building energy efficiency
- Increase renewable energy use
- Switch equipment from fossil fuel to electricity
- Reduce travel demand through focused growth
- Encourage a shift toward low-carbon transportation options
- Increase vehicle and equipment fuel efficiency
- Encourage a shift toward low-carbon fuels in vehicles and equipment
- Reduce idling
- Increase solid waste diversion
- Increase capture and use of methane from landfills
- Reduce water consumption
- Increase recycled water and graywater use
- Increase water and waste-water infrastructure efficiency
- Increase use of renewable energy in water and wastewater systems
- Reduce emissions from livestock operations
- Reduce emissions from fertilizer use
- Protect and enhance the value of open and working lands

- Promote sustainable agriculture
- Increase carbon sequestration
- Reduce emissions from the consumption of goods and services; and

The County will continue to work to increase the health and resilience of social, natural, and built resources to withstand the impacts of climate change by pursuing local actions that support the following goals:

- Promote healthy, safe communities
- Protect water resources
- Promote as sustainable, climate-resilient economy
- Mainstream the use of climate projections

Potential objectives would address the economic, social, and environmental impacts of future wildfires, floods, extreme heat, drought, sea level rise, and other climate change risks.

16.3 VULNERABILITY ASSESSMENT— HAZARDS OF CONCERN

The following sections provide information on how each identified hazard of concern for this planning process may be impacted by climate change and how these impacts may alter current exposure and vulnerability to these hazards for the people, property, critical facilities, and environment in the planning area.

16.3.1 Dam Failure

Climate Change Impacts on the Hazard

The *California Fourth Climate Change Assessment* identifies expected changes to rainfall and winter storm patterns. On average, changes in California's annual precipitation levels are not expected to be dramatic; however, the increase in frequency and intensity for the largest storms (sometimes referred to as atmospheric rivers) may pose increasing risks to the Sonoma County's critical infrastructure, including dams. Dams are designed partly based on assumptions about a river's flow behavior, expressed as hydrographs. Changes in weather patterns can have significant effects on the hydrograph used for the design of a dam. If the hygrograph changes, it is conceivable that the dam can lose some or all of its designed margin of safety, also known as freeboard.

If freeboard is reduced, dam operators may be forced to release increased volumes earlier in a storm cycle in order to maintain the required margins of safety. Such early releases of increased volumes can increase flood potential downstream. According to the California Department of Water Resources, flood flows on many California rivers have been record-setting since the 1950s. This means that water infrastructure, such as dams, have been forced to manage flows for which they were not designed. The California Division of Safety of Dams has indicated that climate change may result in the need for increased safety precautions to address higher winter runoff, frequent fluctuations of water levels, and increased potential for sedimentation and debris accumulation from changing erosion patterns and increases in wildfires. According to the Division, climate change also will impact the ability of dam operators to estimate extreme flood events (California Department of Water Resources, 2008).

Dams are constructed with safety features known as "spillways." Spillways are put in place on dams as a safety measure in the event of the reservoir filling too quickly. Spillway overflow events, often referred to as "design failures," result in increased discharges downstream and increased flooding potential. Although climate change will not increase the probability of catastrophic dam failure, it may increase the probability of design failures.

Exposure, Sensitivity and Vulnerability

The following summarizes changes in exposure and vulnerability to the dam failure hazard resulting from climate change:

- **Population**—Population exposure and vulnerability to the dam failure hazard could change as the demand on aging infrastructure increases due to a changing hydrograph.
- **Property**—Property exposure and vulnerability to the dam failure hazard could change as the demand on aging infrastructure increases due to a changing hydrograph.
- **Critical facilities**—The exposure and vulnerability of critical facilities could change as the demand on aging infrastructure increases due to a changing hydrograph. Dam owners and operators are sensitive to the risk and may need to alter maintenance and operations to account for changes in the hydrograph and increased sedimentation. Critical facility owners and operators in levee failure inundation areas should always be aware of residual risk from flood events that may overtop the levee system.
- **Environment**—The exposure and vulnerability of the environment to dam failure could change for the same reasons cited above. Ecosystem services may be used to mitigate some factors that could increase the risk of design failures, such as increasing the natural water storage capacity in watersheds above dams.
- **Economy**—Dams in California are highly regulated and monitored. While the threat of dam failure could increase due to the impacts from climate change, it is assumed that dam owner/operators will be aware of potential deficiencies due to state regulation and oversight. The largest economic impacts will be costs associated with retrofits to these facilities so that they have the strength and integrity to withstand increased demand associated with a changing hydrograph.

16.3.2 Drought

Climate Change Impacts on the Hazard

Global water resources are already experiencing the following stresses without climate change:

- Growing populations
- Increased competition for available water
- Poor water quality
- Environmental claims
- Uncertain reserved water rights
- Groundwater overdraft
- Aging urban water infrastructure.

With a warmer climate, droughts are projected to become more frequent, more severe, and longer lasting. According to California's *Fourth Climate Assessment*, future increases in temperature, regardless of whether total precipitation goes up or down, will likely cause longer and deeper California droughts, posing major problems for water supplies, natural ecosystems, and agriculture (Ackerly et al., 2018).

Because changes in precipitation patterns are still uncertain, the potential impacts and likelihood of drought are also uncertain, however climatic water deficits are projected to increase across most climate scenarios. The California Department of Water Resources (DWR) has noted impacts of climate change on statewide water resources by charting changes in snowpack, sea level, and river flow. As temperatures rise and more precipitation comes in the form of rain instead of snow, these changes will likely continue or grow even more significant. DWR estimates that the Sierra Nevada snowpack, which provides a large amount of the water supply for other parts of the state, will experience a 48- to 65-percent loss by the end of the century compared to historical averages. Projections for the planning area show a significant decline in projected snow water equivalent in April snowpack. Increasing temperatures may also increase net evaporation from reservoirs by 15 to 37 percent.

As a result of climate change, Sonoma County can expect to experience hotter, drier weather with longer summers causing more frequent and more severe droughts. *Climate Ready Sonoma County: Climate Hazards and Vulnerabilities by the North Bay Climate Adaptation Initiative* looks at the risks and uncertainties involved with climate readiness. Although models disagree about whether Sonoma County precipitation levels will decrease or increase as a result of climate change, projected warmer temperatures are expected to increase the rate of evaporation from bodies of water, further decreasing the amount of available water. However, all scenario models indicate more variable precipitation, with unusual amounts of rain at unusual times, contributing to increased drought. With longer periods when soils are drier and less runoff into reservoirs, drought conditions reduce local water supply, stress regional supplies, and limit the availability of statewide water sources (County of Sonoma 2017).

Exposure, Sensitivity and Vulnerability

The following summarizes changes in exposure and vulnerability to the drought hazard resulting from climate change:

- **Population**—Since droughts typically do not directly kill, injure or displace people, population exposure and vulnerability to drought are unlikely to increase as a result of climate change, in the context for hazard mitigation planning. However, greater numbers of people may need to engage in behavior change, such as water saving efforts to mitigate the economic impacts discussed below.
- **Property**—Property exposure and vulnerability may increase as a result of increased drought resulting from climate change, although this would most likely occur in non-structural property such as crops and landscaping. It is unlikely that structure exposure and vulnerability would increase as a direct result of drought, although secondary hazards associated with drought, such as wildfire, may increase and threaten structures (see wildfire section below).
- **Critical facilities**—Critical facility exposure and vulnerability are unlikely to increase as a result of increased drought resulting from climate change, with the exception of water and wastewater critical infrastructure. The demand for water storage is likely to increase as water tables are depleted from the extraction of groundwater.
- **Environment**—The vulnerability of the environment may increase as a result of increased drought resulting from climate change. Prolonged or more frequent drought resulting from climate change may stress ecosystems in the region, which include many special-status species.
- **Economy**—The largest measurable impacts of drought tend to be economic. Increased incidence of drought could increase the potential for impacts on the local economy.

16.3.3 Earthquake

Climate Change Impacts on the Hazard

The impacts of global climate change on earthquake probability are unknown. Some scientists say that melting glaciers could induce tectonic activity as ice melts and water runs off, shifting tremendous amounts of weight on the earth's crust. NASA and USGS scientists found that retreating glaciers in southern Alaska may be opening the way for future earthquakes there (NASA, 2004).

Secondary impacts of earthquakes could be magnified by climate change. Soils saturated by repetitive storms or heavy precipitation could experience liquefaction or an increased propensity for slides during seismic activity due to the increased saturation. Dams storing increased volumes of water due to changes in the hydrograph could fail during seismic events.

Exposure, Sensitivity and Vulnerability

Because impacts on the earthquake hazard are not well understood, increases in exposure and vulnerability of local resources are not able to be determined.

16.3.4 Flood

Climate Change Impacts on the Hazard

Use of historical hydrologic data has long been the standard of practice for designing and operating water supply and flood protection projects. For example, historical data are used for flood forecasting models and to forecast snowmelt runoff for water supply. This method of forecasting assumes that the climate of the future will be similar to that of the period of historical record. However, the hydrologic record cannot be used to predict changes in frequency and severity of extreme climate events such as floods. Scientists project greater storm intensity with climate change, resulting in more direct runoff and flooding. High frequency flood events in particular will likely increase with a changing climate. What is currently considered a 1-percent-annual-chance also may strike more often, leaving many communities at greater risk. Going forward, model calibration must happen more frequently, new forecast-based tools must be developed, and a standard of practice that explicitly considers climate change must be adopted.

Climate change is already impacting water resources, and resource managers have observed the following:

- Historical hydrologic patterns can no longer be solely relied upon to forecast the water future.
- Precipitation and runoff patterns are changing, increasing the uncertainty for water supply and quality, flood management and ecosystem functions.
- Extreme climatic events will become more frequent, necessitating improvement in flood protection, drought preparedness and emergency response.

The amount of snow is critical for water supply and environmental needs, but so is the timing of snowmelt runoff into rivers and streams. Rising snowlines caused by climate change will allow more mountain areas to contribute to peak storm runoff. Changes in watershed vegetation and soil moisture conditions will likewise change runoff and recharge patterns. As stream flows and velocities change, erosion patterns will also change, altering channel shapes and depths, possibly increasing sedimentation behind dams, and affecting habitat and water quality. With potential increases in the frequency and intensity of wildfires due to climate change, there is potential for more floods following fire, which increase sediment loads and water quality impacts.

Exposure, Sensitivity and Vulnerability

The following summarizes changes in exposure and vulnerability to the flood hazard resulting from climate change:

- **Population and Property**—Population and property exposure and vulnerability may increase as a result of climate change impacts on the flood hazard. Runoff patterns may change, resulting in flooding in areas where it has not previously occurred.
- **Critical facilities**—Critical facility exposure and vulnerability may increase as a result of climate change impacts on the flood hazard. Runoff patterns may change, resulting in risk to facilities that have not historically been at risk from flooding. Changes in the management and design of flood protection critical facilities may be needed as additional stress is placed on these systems. Planners will need to factor a new level of safety into the design, operation, and regulation of flood protection facilities such as dams, bypass channels and levees, as well as the design of local sewers and storm drains.
- **Environment**—The exposure and vulnerability of the environment may increase as a result of climate change impacts on the flood hazard. Changes in the timing and frequency of flood events may have broader ecosystem impacts that alter the ability of already stressed species to survive.
- **Economy**—If flooding becomes more frequent, there may be impacts on the local economy. More resources may need to be directed to response and recovery efforts, and businesses may need to close more frequently due to loss of service or access during flood events.

16.3.5 Landslide/Mass Movements

Climate Change Impacts on the Hazard

Climate change may impact the variability of storm patterns, potentially increasing the probability of more intense storms with varying duration. Increase in global temperature is likely to affect the snowpack and its ability to hold and store water. Warming temperatures also could increase the occurrence and duration of droughts, which would increase the probability of wildfire, reducing the vegetation that helps to support steep slopes. Each these factors would increase the probability of mass movements occurring.

Exposure, Sensitivity and Vulnerability

The following summarizes changes in exposure and vulnerability to the mass movement hazard resulting from climate change:

- **Population and Property**—Increased frequency and severity of rainfall and wildfire events are likely to increase the frequency and severity of landslide events in the planning area. Climate change is unlikely to impact slopes or soil types, but it could impact vegetation type and coverage, which would make some areas more vulnerable to soil saturation from increased rainfall. Steep slopes (10 percent grades or higher) in WUI (wildland urban interface) areas are likely to see increases in vulnerability.
- **Critical facilities**—Critical facility exposure and vulnerability would be unlikely to increase due to climate change impacts on the mass movement hazard, except for those in areas as noted above. However, critical facility owners and operators may experience more frequent disruption to service provision resulting from mass movement hazards. For example, transportation systems may experience

more frequent delays if movements blocking these systems occur more frequently. In addition, increased sedimentation resulting from mass movements may negatively impact flood control facilities, such as dams.

- **Environment**—Except for areas noted above, exposure and vulnerability of the environment would be unlikely to increase because of climate change. Landslide impacts on vegetation and wildlife are mostly negative, but are generally local, which allows species to recover with time. In the long term, landslides may even have positive effects on the habitats of flora and fauna (Schuster and Highland, 2003).
- **Economy**—Changes to the mass movement hazard resulting from climate change are unlikely to result in impacts on the local economy; but impacts may be felt if the limited major highways in the planning area are repeatedly impacted.

16.3.6 Sea Level Rise

The sea-level rise hazard is associated almost entirely with climate change. Therefore, the sea-level rise risk assessment presented in Chapter 12 addresses the impacts of climate change on this hazard.

16.3.7 Severe Weather

Climate Change Impacts on the Hazard

Climate change presents a challenge for risk management associated with severe weather. The frequency of weather-related disasters is increasing, leading to increased economic losses. The science for linking the severity of specific severe weather events to climate change is still evolving; however, a number or trends provide some indication of how climate change may be impacting these events. According to the *U.S. National Climate Change Assessment* (2014), there were more than twice as many high temperature records as low temperature records broken between 2001 and 2012, and heavy rainfall events are becoming more frequent and more severe.

The increase in average surface temperatures can also lead to more intense heat waves. Evidence suggests that heat waves are already increasing, especially in western states. Extreme heat days in the planning area are likely to increase.

Climate change impacts on other severe weather events such as thunderstorms and high winds are still not well understood.

Exposure, Sensitivity and Vulnerability

The following summarizes changes in exposure and vulnerability to the severe weather hazard resulting from climate change:

- **Population and Property**—Population and property exposure and vulnerability are likely to increase as a direct result of climate change impacts on the severe weather hazard in term of summer extreme heat events and potentially winter storm events. Secondary impacts, such as the risk of fire or extent of localized flooding, may increase, impacting greater numbers of people and structures.
- **Critical facilities**—Critical facility exposure and vulnerability may increase as a result of climate change impacts on the severe weather hazard. Critical facility owners and operators may experience more frequent disruption to service provision. For example, more frequent and intense heat waves or storms may cause more frequent disruptions in power service.

- **Environment**—More frequent storms and heat events and more intense rainfall may place additional stress on already stressed ecosystems.
- **Economy**—Climate change impacts on the severe weather hazard may impact the local economy through more frequent disruption to services, such as power outages.

16.3.8 Tsunami

Climate Change Impacts on the Hazard

The impacts of global climate change on tsunami probability are unknown. Some scientists say that melting glaciers could induce tectonic activity, inducing earthquakes. Other scientists have indicated that underwater avalanches (also caused by melting glaciers), may also result in tsunamis. Even if climate change does not increase the frequency with which tsunamis occur, it may result in more destructive waves. As sea levels continue to rise, tsunami inundation areas would likely reach further into communities than current mapping indicates.

Exposure, Sensitivity and Vulnerability

As land area likely to be inundated by tsunami waves increases, exposure and vulnerability to the tsunami hazard may increase for population, property, critical facilities, and the environment. Changes to the tsunami hazard from climate change may result in more direct economic impacts on a greater number of businesses and economic centers, as well as the infrastructure systems that support those businesses.

16.3.9 Wildfire

Climate Change Impacts on the Hazard

Climate change has the potential to affect multiple elements of the wildfire system: fire behavior, ignitions, fire management, and vegetation fuels. Hot dry spells create the highest fire risk. Increased temperatures may intensify wildfire danger by warming and drying out vegetation, which can increase flammability.

Changes in climate patterns may impact the distribution and perseverance of insect outbreaks that create dead trees (increase fuel). When climate alters fuel loads and fuel moisture, forest susceptibility to wildfires changes. Climate change also may increase winds that spread fires. Faster fires are harder to contain, and thus are more likely to expand into residential neighborhoods.

Exposure, Sensitivity and Vulnerability

The following summarizes changes in exposure and vulnerability to the wildfire hazard resulting from climate change:

- **Population—***California's Fourth Climate Change Assessment - Bay Regional Report* states that "wildfires will continue to be a major disturbance in the region. Future wildfire projections suggest a longer fire season, an increase in wildfire frequency, and an expansion of the area susceptible to fire."
- **Property and Critical facilities**—The exposure and vulnerability of property and infrastructure is anticipated to increase based on projections from California's *Fourth Climate Change Assessment*. The application and enforcement of codes and standards to mitigate the risk from wildfire hazards could help to decrease this risk as development moves into wildfire hazard areas.

- **Environment**— It is possible that the exposure and vulnerability of the environment will be impacted by changes in wildfire risk due to climate change. Natural fire regimes may change, resulting in more or less frequent or higher intensity burns. These impacts may alter the composition of the ecosystems in areas in and surrounding planning area. If more acres are burned every year, wildlife may be more stressed as the suitable habitat is lost.
- **Economy**— Recent wildfire activity in California has shown that economic impacts include the value of destroyed and damaged capital, the health costs related to air pollution exposure, and indirect losses due to broader economic disruption cascading along with regional and national supply chains. Indirect economic impacts can cascade outside of the impacted areas. These impacts can be expected to increase if the frequency and severity of wildfires increase as projected. Preventative power outages and direct loss of property due to wildfires also cause significant economic impacts.

16.4 ISSUES

Major gaps in current knowledge and understanding about how climate change will impact Sonoma County's hazards are as follows:

- Planning for climate change related impacts can be difficult due to inherent uncertainties in projection methodologies (although there are confirmed trends in terms of increasing temperatures, increasing water deficits, and increasing wildfire hazards).
- Average temperatures are expected to continue to increase in the planning area, which may lead to a host of primary and secondary impacts, such as an increased incidence of heat waves.
- Expected changes in precipitation patterns are still poorly understood and could have significant impacts on the water supply and flooding in the planning area since all future scenarios project greater rainfall variability from year to year..
- Some impacts of climate change are poorly understood such as potential impacts on the frequency and severity of earthquakes, thunderstorms, and tsunamis.
- Potentially heavy rain events may result in inland stormwater flooding after stormwater management systems are overwhelmed.
- Permanent and temporary inundation resulting from sea level rise has the potential to impact portions of the population and assets in the planning area.
- There are still many unknowns regarding relationships between wildfire and a changing climate. However, current models project increasing wildfire probability and risks of structure loss based on impacts of climate change and projected development. Continued research and modeling are necessary to better understand the impacts of climate change on the fire environment throughout the planning area and to inform adaptation strategies
- Climate change has the potential to impact the following:
    - The vulnerability of municipal and on-site water supplies
    - Forest structure, composition, and flammability
    - The severity of wildfires and acres burned
    - The adequacy of access and evacuation routes
    - Response times for limited fire suppression resources
    - Heat wave duration coupled with wildfire smoke, especially as they affect disadvantaged populations unlikely to have air conditioning.

17. HAZARDS OF INTEREST

The hazards of concern assessed in Chapters 7 through 15 and rated and rated in Chapter 18 are those that present significant risks in the planning area. Additional hazards, both natural and human-caused, were identified by the Steering Committee as having some potential to impact the planning area, but at a much lower risk level than the hazards of concern. These other hazards are identified as hazards of interest.

The sections below provide short profiles of each hazard of interest, including qualitative discussion of their potential to impact in Sonoma County. No formal risk assessment of these hazards was performed, and no mitigation initiatives have been developed to address them. However, all planning partners for this plan should be aware of these hazards and should take steps to reduce the risks they present whenever it is practical to do so.

17.1 PUBLIC HEALTH EMERGENCY

According to the World Health Organization, a pandemic involves the worldwide spread of a new disease. While an epidemic remains limited to one city, region, or country, a pandemic will spread beyond national borders and possibly worldwide. Authorities consider a disease to be an epidemic when the number of people with the infection is higher than the forecast number within a specific region. If an infection becomes widespread in several countries at the same time, it may turn into a pandemic. A new virus strain or subtype that easily transmits between humans can cause a pandemic. Bacteria that become resistant to antibiotic treatment may also be behind the rapid spread (Felman 2020).

Sometimes, pandemics occur when new diseases develop the ability to spread rapidly. Often, a new virus cannot spread between animals and people, but after it changes or mutates, it may start to spread easily, and a pandemic may result. Seasonal flu epidemics generally occur because of a viral subtype that is already circulating among people. Novel subtypes, on the other hand, generally cause pandemics. These subtypes will not previously have circulated among humans. A pandemic can lead to social disruption, economic loss, and general hardship on a wide scale (Felman 2020).

In March 2020, Sonoma County was included in the FEMA Major Disaster Declaration for the COVID-19 coronavirus pandemic. As of January 2021, about 23,000 people, or 4.57 percent of the Sonoma County population, had contracted the coronavirus and 234 people, 1.01 percent of the population, had died from it (Sonoma County Emergency 2021). As of January 2021, over 18,000 people in Sonoma County had received the COVID-19 vaccine (Sonoma County Emergency 2021).

17.2 TERRORISM

17.2.1 Defining Terrorism

Acts of terrorism are intentional, criminal, malicious acts with the following characteristics:

- They involve the use of illegal force.
- They are intended to intimidate or coerce.
- They are committed in support of political or social objectives.

The Federal Bureau of Investigation (FBI) categorizes two types of terrorism in the United States:

- **Domestic terrorism** involves groups or individuals whose terrorist activities are directed at elements of our government or population without foreign direction. The bombing of the Alfred P. Murrah federal building in Oklahoma City is an example of domestic terrorism. The FBI is the primary response agency for domestic terrorism. The FBI coordinates domestic preparedness programs and activities of the United States to limit acts posed by terrorists, including the use of weapons of mass destruction.
- **International terrorism** involves groups or individuals whose terrorist activities are foreign-based or directed by countries or groups outside the United States, or whose activities transcend national boundaries. Examples include the 1993 bombing of the World Trade Center and the attacks of September 11, 2001 at the World Trade Center and the Pentagon.

Three factors distinguish terrorism hazards from other types of hazards:

- In the case of chemical, biological, and radioactive agents, their presence may not be immediately obvious, making it difficult to determine when and where they may have been released, who has been exposed, and what danger is present for first responders and emergency medical technicians.
- There is limited scientific understanding of how these agents affect the population at large.
- Terrorism evokes strong emotional reactions, ranging from anxiety to fear to anger to despair to depression.

Most terrorist events in the United States have been bombing attacks, involving detonated or undetonated explosive devices, tear gas, pipe bombs, or firebombs. The effects of terrorism can vary from loss of life and injuries to property damage and disruptions in services such as electricity, water supplies, transportation, or communications. The event may have an immediate effect or a delayed effect. Terrorists often choose targets that offer limited danger to themselves and areas with relatively easy public access. Foreign terrorists look for visible targets where they can avoid detection before and after an attack such as international airports, large cities, major special events, and high-profile landmarks.

17.2.2 Cyberterrorism

Cyberterrorism is the use of computers and information, particularly over the Internet, to recruit others to a cause, cause physical or financial harm, or cause a severe disruption of service. It can be driven by religious, political, or other motives. Like traditional terrorism tactics, cyberterrorism seeks to evoke strong emotional reactions, but it does so through information technology rather than a physically violent or disruptive action.

Cyberterrorism has three main types of objectives (Kostadinov 2012):

- **Organizational**—Cyberterrorism with an organizational objective includes functions other than cyber-attacks. Terrorist groups today use the internet every day for recruitment, training, fundraising, communication, or planning. Organizational cyberterrorism can use platforms such as social media as a tool to spread a message beyond country borders and instigate physical forms of terrorism. Organizational efforts may include system attacks as a tool for training new members of a faction in cyber warfare.
- **Undermining**—Cyberterrorism with undermining as an objective seeks to hinder the normal functioning of computer systems, services, or websites. Such methods include defacing, denying, and exposing information. These attacks aim to undermine the victim's high dependence on online structures to support vital operational functions. They typically do not result in grave consequences unless undertaken as part of a larger attack. Undermining attacks on computers include the following:
  - Physical attack against computer equipment, a computer facility, or transmission lines to disrupt the reliability of equipment.
  - Using electromagnetic energy, usually in the form of an electromagnetic pulse, to attack computer equipment or data transmissions. By overheating circuitry or jamming communications, an electronic attack disrupts the reliability of equipment and the integrity of data.
  - Using malicious code directed against computer processing code, instruction logic, or data. The code can generate malicious network packets that disrupt data or logic. This type of cyber-attack can disrupt the reliability of equipment, the integrity of data, and the confidentiality of communications.
- **Destructive**—The destructive objective for cyberterrorism is what organizations fear most. Through the use of computer technology and the Internet, the terrorists seek to inflict destruction or damage on tangible property or assets, and even death or injury to individuals. There are no cases of pure cyberterrorism as of the date of this plan.

17.2.3 Addressing Terrorism

While education, heightened awareness, and early warning of unusual circumstances may deter crime and terrorism, intentional acts that harm people and property are possible at any time. Public safety entities react to the threat, locating, isolating and neutralizing further damage, and investigating potential scenes and suspects to bring criminals to justice. Those involved with terrorism response, including public health and public information staff, are trained to deal swiftly with the public's emotional reaction. The area of the event must be clearly identified in all emergency alert messages to prevent those not affected by the incident from overwhelming local emergency rooms and response resources, which would reduce service to those actually affected. The public must be informed clearly and frequently about what government agencies are doing to mitigate the impacts of the event. The public will also be given clear directions on how to protect the health of individuals and families.

In dealing with terrorism, the unpredictability of human beings must be considered. People with a desire to perform criminal acts may seek out targets of opportunity that may not fall into established lists of critical areas or facilities. First responders train not only to respond to organized terrorism events, but also to respond to random acts by individuals who, for a variety of reasons ranging from fear to emotional trauma to mental instability, may choose to harm others and destroy property.

The Sonoma County Department of Emergency Management is responsible for the mitigation, preparedness, planning, coordination of response, and recovery activities related to county emergencies and disasters, including terrorism. The department serves as the primary coordination point for emergency management's activities affecting more than one jurisdiction, and the unincorporated areas of the county. The Department of Emergency Management became an independent County department in July 2019.

In January 2019, the County adopted a resolution authorizing the County Administrator and the Director of Emergency Management to seek state and federal financial funding assistance through the State of California or the federal Department of Homeland Security related to homeland security, emergency management, hazard mitigation, preparedness and disaster response programs, which could include counterterrorism initiatives (County of Sonoma 2019).

17.3 CYBER-ATTACK

A cyber threat is an intentional and malicious crime that compromises the digital infrastructure of a person or organization, often for financial or terror-related reasons. Such attacks vary in nature and are perpetrated using digital mediums or sometimes social engineering to target human operators. Generally, attacks last minutes to days, but large-scale events and their impacts can last much longer. As information technology continues to grow in capability and interconnectivity, cyber threats become increasingly frequent and destructive. In 2014, internet security teams at Symantec and Verizon indicated that nearly 1 million new pieces of malware—malicious code designed to steal or destroy information—were created every day (Harrison and Pagliery 2015).

Cyber threats differ by motive, attack type and perpetrator profile. Motives range from the pursuit of financial gain to political or social aims. Cyber threats are difficult to identify and comprehend. Types of threats include using viruses to erase entire systems, breaking into systems and altering files, using someone's personal computer to attack others, or stealing confidential information. The spectrum of cyber risks is limitless, with threats having a wide-range of effects on the individual, community, organizational, or nation. The following sections describe cyber-attacks in general and, more specifically, cyberterrorism.

Public and private computer systems are subject to a variety of cyber-attacks, from blanket malware infection to targeted attacks on system capabilities. Cyber-attacks seek to breach IT security measures designed to protect an individual or organization. The initial attack is followed by more severe attacks for the purpose of causing harm, stealing data, or financial gain. Organizations are prone to attacks that can be either automated or targeted. Table 17-1 describes the most common cyber-attack mechanisms faced by organizations today.

Since 2013, a type of cyber-attack called cyber ransom has become increasingly common against individuals and small- and medium-sized organizations. Cyber ransom occurs when an individual downloads ransom malware, or ransomware, often through phishing or drive-by download, and the subsequent execution of code results in encryption of all data and personal files stored on the system. The victim then receives a message that demands a fee in the form of electronic currency or cryptocurrency, such as Bitcoin, for the decryption code. In October 2015, the FBI said that commonly used ransomware is so difficult to override, that victims should pay the ransom to retrieve their data (Danielson 2015).

With millions of threats created each day, the importance of protection against cyber-attacks becomes a necessary function of everyday operations for individuals, government facilities, and businesses. The increasing dependency on technology for vital information storage and the often automated method of infection means higher stakes for the success of measurable protection and education.

Table 17-1. Common Mechanisms for Cyber Attacks

Type	Description
Socially Engineered Trojans	Programs designed to mimic legitimate processes (e.g. updating software, running fake antivirus software) with the end goal of human-interaction caused infection. When the victim runs the fake process, the Trojan is installed on the system.
Unpatched Software	Nearly all software has weak points that may be exploited by malware. Most common software exploitations occur with Java, Adobe Reader, and Adobe Flash. These vulnerabilities are often exploited as small amounts of malicious code are often downloaded via drive-by download.
Phishing	Malicious email messages that ask users to click a link or download a program. Phishing attacks may appear as legitimate emails from trusted third parties.
Password Attacks	Third party attempts to crack a user's password and subsequently gain access to a system. Password attacks do not typically require malware, but rather stem from software applications on the attacker's system. These applications may use a variety of methods to gain access, including generating large numbers of generated guesses, or dictionary attacks, in which passwords are systematically tested against all of the words in a dictionary.
Drive-by Downloads	Malware is downloaded unknowingly by the victims when they visit an infected site.
Denial of Service Attacks	Attacks that focus on disrupting service to a network in which attackers send high volumes of data until the network becomes overloaded and can no longer function.
Man in the Middle	Man-in-the-Middle attacks mirror victims and endpoints for online information exchange. In this type of attack, the attacker communicates with the victims, who believe they are interacting with a legitimate endpoint website. The attacker is also communicating with the actual endpoint website by impersonating the victim. As the process goes through, the attacker obtains entered and received information from both the victim and endpoint.
Malvertising	Malware downloaded to a system when the victim clicks on an affected ad.
Advanced Persistent Threat	An attack in which the attacker gains access to a network and remains undetected. Advanced persistent threat attacks are designed to steal data instead of cause damage.

18. RISK RATING

FEMA requires all hazard mitigation planning partners to have jurisdiction-specific mitigation actions based on local risk, vulnerability, and community priorities. This plan included a risk rating protocol for each planning partner, in which "risk" was calculated by multiplying probability by impact on people, property and the economy. The risk estimates were generated using methodologies promoted by FEMA. The Steering Committee reviewed, discussed and approved the methodology and results. All planning partners rated risk for their own jurisdictions following the same methodology.

Numerical ratings of probability and impact were based on the hazard profiles and exposure and vulnerability evaluations presented in Chapters 7 through 16. Using that data, each planning partner rated the risk of all the natural hazards of concern described in this plan. When available, estimates of risk were generated with data from Hazus or GIS. For hazards of concern with less specific data available, qualitative assessments were used. As appropriate, results were adjusted based on local knowledge and other information not captured in the quantitative assessments. The hazards of interest described in Chapter 17 were not rated for the following reasons:

- A key component of risk as defined for the planning effort is probability of occurrence. While it is possible to assign a recurrence interval for natural hazards because of historical occurrence, it is not feasible to assign recurrence intervals for the other hazards of interest, which lack such historical precedent.
- Federal hazard mitigation planning regulations do not require the assessment of non-natural hazards (44 CFR, 201.6). It is FEMA's position that this is a local decision.

Risk rating results are used to help establish mitigation priorities. Each partner used its risk rating to inform the development of its action plan. Planning partners were directed to identify mitigation actions, at a minimum, to address each hazard with a "high" or "medium" risk rating. Actions that address hazards with a low or no hazard rating are optional.

Volume 2 presents the risk ratings for each planning partner. The following planning-area-wide risk rating was prepared by the planning team.

18.1 PROBABILITY OF OCCURRENCE

The probability of occurrence of a hazard is indicated by a probability factor based on likelihood of annual occurrence:

- High—Hazard event is likely to occur within 25 years (Probability Factor = 3)
- Medium—Hazard event is likely to occur within 100 years (Probability Factor =2)
- Low—Hazard event is not likely to occur within 100 years (Probability Factor =1)
- No exposure—There is no probability of occurrence (Probability Factor = 0)

The assessment of hazard frequency is based on past hazard events in the area and the potential for changes in the frequency of these events resulting from climate change. Table 18-1 summarizes the probability assessment for each natural hazard of concern for this plan.

Table 18-1. Probability of Hazards

Hazard Event	Probability (high, medium, low)	Probability Factor
Dam Failure	Medium	2
Drought	High	3
Earthquake (Hayward Scenario)	Medium	2
Flooding (1% annual chance)	High	3
Landslide/Mass Movement (very high/high risk areas)	High	3
Sea Level Rise (200-cm + 100-yr)	High	3
Severe Weather	High	3
Tsunami	Low	1
Wildfire (very high/high risk areas)	High	3

18.2 IMPACT

Hazard impacts were assessed in three categories: impacts on people, impacts on property and impacts on the local economy. Numerical impact factors were assigned as follows:

- **People**—Values were assigned based on the percentage of the total ***population exposed*** to the hazard event. The degree of impact on individuals will vary and is not measurable, so the calculation assumes for simplicity and consistency that all people exposed to a hazard because they live in a hazard zone will be equally impacted when a hazard event occurs. It should be noted that planners can use an element of subjectivity when assigning values for impacts on people. Impact factors were assigned as follows:
  - High—25 percent or more of the population is exposed to a hazard (Impact Factor = 3)
  - Medium—10 percent to 25 percent of the population is exposed to a hazard (Impact Factor = 2)
  - Low—10 percent or less of the population is exposed to the hazard (Impact Factor = 1)
  - No impact—None of the population is exposed to a hazard (Impact Factor = 0)
- **Property**—Values were assigned based on the percentage of the total ***property value exposed*** to the hazard event:
  - High—25 percent or more of the total assessed property value is exposed to a hazard (Impact Factor = 3)
  - Medium—10 percent to 25 percent of the total assessed property value is exposed to a hazard (Impact Factor = 2)
  - Low—10 percent or less of the total assessed property value is exposed to the hazard (Impact Factor = 1)
  - No impact—None of the total assessed property value is exposed to a hazard (Impact Factor = 0)
- **Economy**—Values were assigned based on the percentage of the total ***property value vulnerable*** to the hazard event. Values represent estimates of the loss from a major event of each hazard in comparison to the total replacement value of the property exposed to the hazard. Loss estimates separate from the exposure estimates were generated for the earthquake, flooding, and tsunami hazards using Hazus. For other hazards, such as dam failure, landslide/mass movement and wildfire, vulnerability was estimated as a percentage of exposure, due to the lack of loss estimation tools specific to those hazards.

- High—Estimated loss from the hazard is 10 percent or more of the total exposed property value (Impact Factor = 3)
- Medium—Estimated loss from the hazard is 5 percent to 10 percent of the total exposed property value (Impact Factor = 2)
- Low—Estimated loss from the hazard is 5 percent or less of the total exposed property value (Impact Factor = 1)
- No impact—No loss is estimated from the hazard (Impact Factor = 0)

The impacts of each risk category were assigned a weighting factor to reflect the significance of the impact. These weighting factors are consistent with those typically used for measuring the benefits of hazard mitigation actions: impact on people was given a weighting factor of 3; impact on property was given a weighting factor of 2; and impact on the economy was given a weighting factor of 1. Table 18-2 summarizes the impacts for each hazard.

Table 18-2. Impact on People, Property and the Economy from Hazards

	People (Weighting Factor 3)		Property (Weighting Factor 2)		Economy (Weighting Factor 1)	
Hazard Event	Impact / Score	Weighted Score	Impact / Score	Weighte d Score	Impact / Score	Weighted Score
Dam Failure	Medium / 2	6	Medium / 2	4	Medium / 2	2
Drought	None / 0	0	Low / 1	2	Medium / 2	2
Earthquake (Hayward Scenario)	High / 3	9	High / 3	6	High / 3	3
Flooding (1% annual chance)	Low / 1	3	Low / 1	2	Low / 1	1
Landslide/Mass Movement (very high/high risk areas)	Medium / 2	6	High / 3	6	Medium / 2	2
Sea Level Rise (200-cm + 100-yr)	Low / 1	3	Low / 1	2	Low / 1	1
Severe Weather	Medium / 2	6	Low / 1	2	Low / 1	1
Tsunami	Low / 1	3	Low / 1	2	None / 0	0
Wildfire (very high/high risk areas)	Low / 1	3	Medium / 2	4	Medium / 2	2

18.3 RISK RATING

The risk rating for each hazard was determined by multiplying the probability factor by the sum of the weighted impact factors, as summarized in Table 18-3. Based on these ratings, each hazard was identified as being in the highest, medium, or lowest risk category. Figure 18-1 shows the hazard risk rating for the planning area. Hazard risk rating for each participating planning partner can be found in Volume 2 of this plan.

Table 18-3. Hazard Risk Rating

Hazard Event	Probability Factor	Sum of Weighted Impact Factors	Total (Probability x Impact)
Dam Failure	2	6 + 4 + 2 = 12	24
Drought	3	0 + 2 + 2 = 4	12
Earthquake (Hayward Scenario)	2	9 + 6 + 3 = 18	36
Flooding (1% annual chance)	3	3 + 2 + 1 = 6	18
Landslide/Mass Movement (very high/high risk areas)	3	6 + 6 + 2 = 14	42
Sea Level Rise (200-cm + 100-yr)	3	3 + 2 + 1 = 6	18
Severe Weather	3	6 + 2 + 1 = 9	18
Tsunami	1	3 + 2 + 0 = 5	5
Wildfire (very high/high risk areas)	3	3 + 4 + 2 = 9	27/36[a]

a. The quantitative score for wildfire (27) was adjusted base on the judgment of County staff to a score equivalent to earthquake.

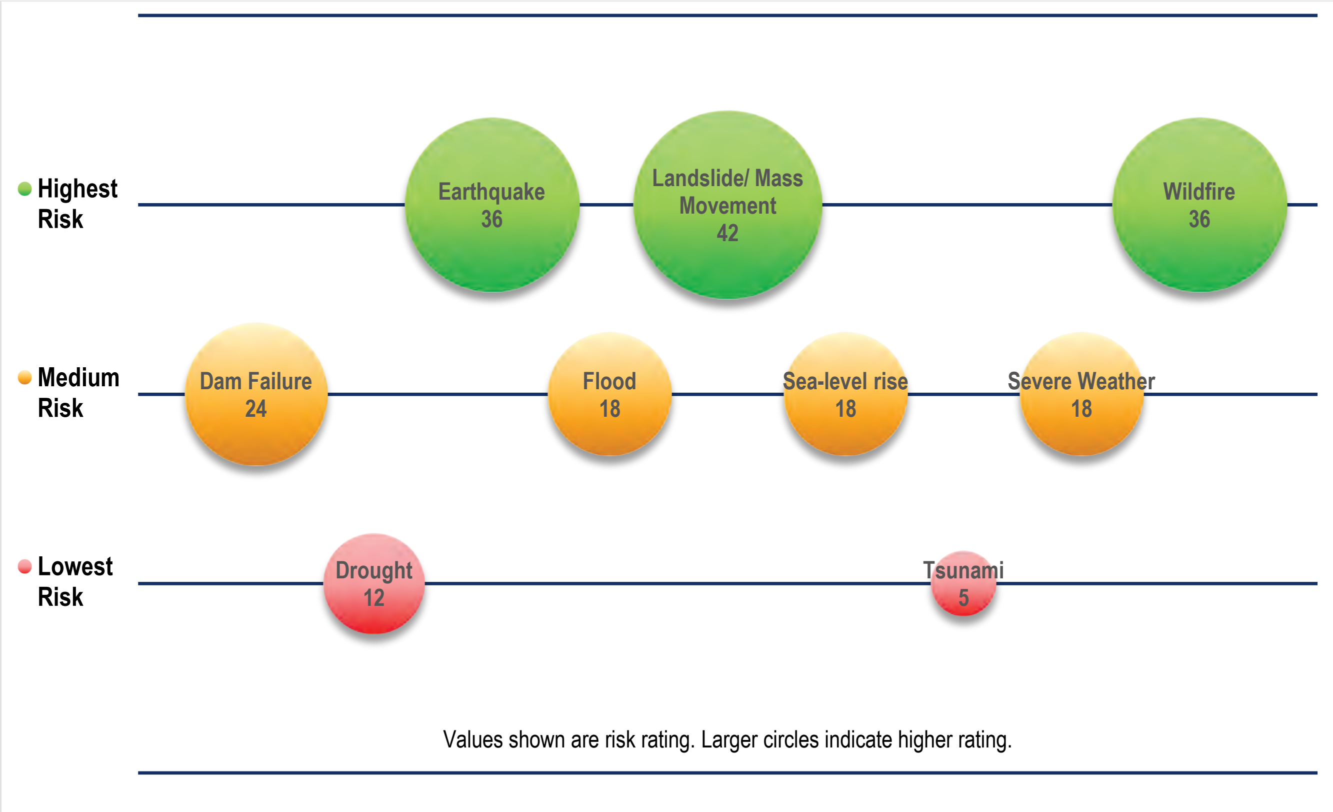


Figure 18-1. Hazard Risk Rating