4 Risk Assessment

44 U.S. Code of Federal Regulations Requirement §201.6 Local Mitigation Plans (c)(2): [The plan shall include] A risk assessment that provides the factual basis for activities proposed in the strategy to reduce losses from identified hazards. Local risk assessments must provide sufficient information to enable the jurisdiction to identify and prioritize appropriate mitigation actions to reduce losses from identified hazards.

As defined by the Federal Emergency Management Agency (FEMA), risk is a combination of hazard, vulnerability, and exposure. "It is the impact that a hazard would have on people, services, facilities, and structures in a community and refers to the likelihood of a hazard event resulting in an adverse condition that causes injury or damage."

The risk assessment process identifies and profiles relevant hazards and assesses the exposure of lives, property, and infrastructure to these hazards, as well as the vulnerabilities of a community. The process allows for a better understanding of a jurisdiction's potential risk to hazards and provides a framework for developing and prioritizing mitigation actions to reduce risk from future hazard events.

This risk assessment followed the methodology described in the FEMA publication "Understanding Your Risks—Identifying Hazards and Estimating Losses" (FEMA 386-2, 2002), which breaks the assessment into a four-step process:

1. Identify hazards
2. Profile hazard events
3. Inventory assets
4. Estimate losses

In other words, this risk assessment evaluates potential loss from hazards by assessing the vulnerability of the City's population; services; critical facilities; and buildings and infrastructure. Data collected through this process has been incorporated into the following sections of this chapter:

- **Section 4.1 Hazard Identification** profiles the natural hazards that threaten the City of Petaluma Planning Area (Planning Area) and describes why some hazards have been omitted from further consideration.
- **Section 4.2 Asset Summary** describes the methodology for determining vulnerability of the Planning Area to the identified hazards.
- **Section 4.3 Hazard Profiles and Risk Assessment** discusses the threat to the Planning Area and describes previous occurrences of hazard events and the likelihood of future occurrences. All the hazards identified in Section 4.1 are profiled and assessed individually in this section. Research and information from the City of Petaluma Hazard Mitigation Planning Committee (HMPC) is integrated into this section. This section also includes the identified vulnerability to each of the priority hazards, describing the impact that each hazard would have on the City. The vulnerability assessment quantifies (to the extent possible) using best available information, assets at risk to hazards and estimates potential losses.
- **Section 4.4 Human-Caused Hazards** identifies the hazards that threaten the Planning Area resulting from human actions.

- **Section 4.5 Hazards Summary** summarizes the results of the hazard identification and hazard profiles for the Planning Area based on the hazard identification data and input from the HMPC.

This risk assessment covers the entire geographical extent of the City of Petaluma, Urban Growth Boundary (UGB), and in some cases critical facilities within the City's water and wastewater service areas. This area is referred herein as the City's Planning Area. The HMPC agreed that the City's Planning Area for the Local Hazard Mitigation Plan (LHMP) should include the UGB.

This assessment qualitatively discusses critical facilities within the City's water and wastewater service areas to ensure that all the City's facilities are infrastructure are addressed in the risk assessment because some of these facilities were located outside the Planning Area. Given the location information of the City's water supply infrastructure is considered sensitive, this information was excluded from this assessment. Sensitive information included the City's water supply and distribution system (e.g. water pipelines, etc.). Instead the vulnerability of the potable water supply facilities is addressed more broadly and qualitatively compared to the level of detail considered for other facilities.

Additional information on the City's Planning Area as it pertains to this plan is provided in Chapter 2, Community Profile.

4.1 Hazard Identification: Natural and Human-Caused Hazards

44 U.S. Code of Federal Regulations Requirement §201.6(c)(2)(i): [The risk assessment shall include a] description of the type…of all natural hazards that can affect the jurisdiction.

The first step in developing a risk assessment is identifying the natural hazards. The HMPC conducted a hazard identification study to determine the hazards that threaten the Planning Area. The identification of human-caused hazards is summarized in Section 4.4.

4.1.1 Methodology and Results

Using existing natural hazards data and input gained through planning meetings, the HMPC agreed upon a list of natural and human-caused hazards that could affect the City of Petaluma. Hazards data was examined to identify and assess the significance of these hazards to the Planning Area. The sources of data included information from the California Office of Emergency Services (Cal OES), FEMA, the National Oceanic and Atmospheric Administration (NOAA), Sonoma County Office of Emergency Management, and other sources as referenced in this assessment. The assessment also relied on the City's 2010 LHMP "Taming Natural Disasters" plan prepared by the Association of Bay Area Governments (ABAG) (referred to as the City's 2010 LHMP Annex), relevant City planning documents, such as the City's General Plan 2025 Health and Safety Element and 2015 Floodplain Management Plan (FMP), and adopted hazard mitigation plans in the region.

Table 4-1 below provides a crosswalk of the hazards identified in the General Plan 2025, 2010 ABAG LHMP Annex, 2016 Sonoma County Operational Area Hazard Mitigation Plan, 2018 Sonoma County Water Agency LHMP, and 2018 California State Hazard Mitigation Plan (SHMP). Numerous hazards were identified in the state and county plan, including five natural hazards identified in the City's General Plan 2025 Community Facilities, Services, and Education Element; Water Resources Element, and Health and Safety Element. Natural hazards discussed in these elements included flooding, groundwater supply and drought, earthquake and other seismic-related hazards (e.g. surface rupture, ground shaking, ground failure, slope instability), wildfire, and noise issues. Human-caused hazards discussed in these elements included the use, storage, and transport of hazardous materials. The crosswalk was used to develop a list of preliminary hazards for the HMPC to evaluate which were most relevant to the City's Planning Area.

The significance of each hazard was measured in general terms and focused on key criteria such as frequency and resulting damage, which includes deaths, injuries, and property and economic damage. The natural and human-caused hazards evaluated as part of this plan include those that occurred in the past or have the potential to cause significant human and/or monetary losses in the future.

Table 4-1: Crosswalk with Other Hazard Mitigation Plans

Hazard	City of Petaluma General Plan 2025 (2011)	ABAG LHMP City of Petaluma Annex Plan (2010)	Sonoma County Operational Area HMP (2016)	Sonoma County Water Agency LHMP (2018)	California SHMP (2018)
Natural, Human-Health, and Climate and Weather-Influenced Hazards					
Agricultural and Silvicultural Pests and Diseases					√
Air Pollution	√				√
Aquatic Invasive Species					√
Avalanches					√
Dam Incidents		√		√	
Drought and Water Shortage	√			√	√
Climate Change			√	√	√
Earthquake and Geologic Hazards (liquefaction, subsidence, landslides)	√	√	√	√	√
Energy Shortage and Energy Resiliency					√
Epidemic/Pandemic/Vector-Borne Disease					√
Flood: 100-, 200-, 500-Year Events	√	√	√	√	√
Sea Level Rise				√	√
Severe Weather: Extreme Heat		√		√	√
Severe Weather: Heavy Rain/Thunderstorm/Lightning/Hail/Fog		√		√	√
Severe Weather: Wind		√		√	√
Tree Mortality					√
Tsunami				√	
Volcano					√
Wildfire	√	√	√		√
Technological Hazards					
Hazardous Materials Release	√				√
Oil Spills	√				√
Natural Gas Pipeline Hazards					√

Radiological Accidents					√
Transportation Accidents					√
Threat and Disturbance Hazards					
Terrorism				√	√
Cyber Threats				√	√
Civil Disorder					√

1. Hazards listed is based on the natural, technological, and human-caused hazards in the California SHMP.

In alphabetical order, the natural hazards identified and investigated for the City of Petaluma 2019 LHMP include:

- Dam Incidents
- Drought and Water Shortage
- Earthquake
    - Surface Rupture
    - Ground Shaking
    - Liquefaction
    - Subsidence
    - Landslides/Mudslides
- Flood: 100/500-Year Flood
- Sea Level Rise
- Severe Weather: Heavy Rain/Thunderstorm/Hail/Lightning
- Severe Weather: Extreme Heat
- Severe Weather: Wind
- Wildfire

The human-caused hazards identified and investigated for the City of Petaluma 2019 LHMP include:

- Hazardous Materials: Hazard Material Releases, Chemical Facilities, Gas Pipelines
- Cyber Threats: Malware, Ransomware

Based on discussions at the early planning meetings and preliminary analyses, the following natural and human-health hazards were eliminated from further consideration in this risk assessment because of a lack of past occurrences in the City of Petaluma or based on minimal potential impacts. Certain hazards were also eliminated based on separate regulatory programs and planning documentation that thoroughly addresses the hazard profile.

- Agricultural Hazards
- Air Pollution
- Aquatic Invasive Species
- Avalanches
- Energy Shortage and Energy Resiliency (integrated in the Extreme Weather: Winds vulnerability assessment)

- Epidemic/Pandemic/Vector-Borne Disease
- Tree Mortality
- Tsunami
- Volcano

Petaluma is an urban city surrounded largely by rural land uses in the unincorporated portion of Sonoma County that consist of both agriculture and open space. According to the General Plan 2025 and Petaluma General Plan Update Draft Environmental Impact Report (EIR), as of 2005 there were approximately 77 acres of designated agricultural land within the UGB (City of Petaluma 2005). Most of the designated agricultural land outside the City's UGB is within the Sonoma County Agricultural Preservation and Open Space District (SCAPOSD). Land within the SCAPOSD is designated as greenbelt agriculture, priority greenbelt, priority riparian corridors, wetland priority areas, and priority recreation areas. While land uses include farms, dairies, livestock ranches, and vineyards, the greenbelt land uses function as a separation between urban areas and active farming areas, thereby minimizing agricultural hazards and nuisances in the City.

Air quality and emissions within the Bay Area are generated by a variety of sources, including stationary sources, such as fireplaces and heating systems to mobile sources, such as vehicles and truck traffic. The Bay Area Air Quality Management District (BAAQMD) is the regional agency with the authority to develop and enforce regulations for the control of air pollution throughout the Bay Area. The Clean Air Plan is the BAAQMD's triennial plan for reducing air pollutant emissions in the Bay Area. The Bay Area is considered in "attainment" for all of the national standards of carbon monoxide, nitrogen dioxide, sulfur dioxide, lead, and particulate matter, with the exception of ozone. Given there are federal, state, and local laws and regulations in place for controlling air pollution, in addition to air quality management plans administered by the California Air Resources Board and BAAQMD, air pollution hazards and programs are not addressed in this plan.

Aquatic invasive species are non-indigenous species transported to new environments through human activities. The introduction of non-indigenous species into Petaluma's marine, estuarine, and freshwater environment can cause economic, human health, and ecological impacts. Invasive aquatic plants, such as water hyacinth has clogged the waterways in the California Delta, and the Petaluma River has a high percentage of introduced aquatic species (CDFG 2009). Known past occurrences related to aquatic invasive species in the City were mostly identified at Port Sonoma along the Petaluma River, but outside the Planning Area (CDFG 2009). Algae, also known as cyanobacteria can be normally found in water environments such as Petaluma River. When high temperatures and increased nutrient levels in the water occur, algae and other invasive species can grow, and some algal blooms can produce toxins that can be harmful to humans and animals. This hazard is currently addressed by the Sonoma County Department of Health Services (DHS), Environmental Health and Safety Public Health Division. The Division regularly tests water bodies in the County for aquatic invasive species, and specifically algae blooms at various beach and river park locations throughout the County. Given County monitoring programs are in place, this hazard was not addressed in this plan.

Avalanches and volcano hazards were not addressed in this plan. The City does not receive snowfall to have avalanche hazards. According to the 2018 California SHMP, only ten volcanic eruptions have occurred in California in the last 1,000 years and the likelihood of another eruption in the state is low (Cal OES 2018). Of the 20 volcanoes in the state, only a few are active and pose a threat (Cal OES 2018). Of these, the Clear Lake Volcano is the closest volcano to the City, and while it has been known for substantial geothermal activity, there are no past occurrences associated with the volcano. Given this volcanic field is approximately 80 miles to the north, volcano hazards were not addressed in this plan.

Energy shortage hazards can include energy disruptions related to electricity, renewable energy, natural gas, and gasoline and diesel fuels. Based on the energy types, electrical power outages, both planned and unscheduled disruptions can result in cascading hazards related to traffic, economic losses, other utility disruptions, and extreme heat and public health hazards. Climate change is also expected to bring more frequent and intense natural disasters, which could result in planned or unscheduled power outages or energy shortages. Given the PG&E's recent Public Safety Power Shutoff (PSPS) that began on October 9, 2019, energy shortage hazards are a major concern for the region and the City (City of Petaluma 2019c). Energy shortages are discussed as a secondary hazard impact and in the vulnerability assessment in the Severe Weather: Wind section of this chapter.

The City and the HMPC considered human-health hazards, such as epidemics, pandemics, and vector-borne disease hazards. These hazards are currently addressed by the Sonoma County Public Health Division Disease Control Unit, and the Safety Unit, Risk Management Division and therefore not addressed in this plan.

Drought conditions can cause increased tree mortality associated with lack of moisture, pest infestations, and other drought-related issues. Tree mortality is discussed in more detail as a subsection of wildfire hazards and as a secondary hazard.

The City of Petaluma is situated approximately 15 miles upstream of the San Pablo Bay. Based on the U.S. Geological Survey (USGS) Tsunami Inundation Map for Emergency Planning (Cal EMSA, CGS, and USC 2009) the City Planning Area lies approximately three miles upstream from the northern extent of the tsunami inundation area along Twin House Ranch Road and the Petaluma River. Based on this information, tsunami and coastal erosion hazards were not further analyzed in this plan. Sea level rise is addressed in this chapter.

The City acknowledged natural gas pipeline hazards, oil spills, radiological incidents, as well as transportation accidents associated with these hazards. Gas pipeline hazards are addressed as a secondary hazard associated with earthquakes in the vulnerability assessment. Oil spill and radiological accidents were not further evaluated in this plan, as there are few oil pipelines or oil wells in the City, and few areas at risk to radiological accidents according to the HMPC. Other human-caused hazards, such as terrorism, and civil unrest or disturbances were considered and discussed during HMPC meetings, but because they are addressed in the Emergency Operations Plan (EOP), they were not discussed in detail in this plan.

The following technological and human-caused hazards were eliminated from further analysis in the City of Petaluma LHMP because they are either addressed as secondary impacts associated with other hazards (e.g. earthquakes) or because they are addressed in other City plan documents (e.g. General Plan 2025 Transportation Element):

- Natural Gas Pipeline Hazards
- Oil Spills
- Radiological Accidents
- Transportation Accidents
- Terrorism
- Civil Disorder

4.1.2 Overall Hazard Significance Summary

Overall hazard significance was based on a combination of geographic extent, probability of future occurrences, and potential magnitude/severity. The individual ratings shown in Table 4- 2 are based on or interpolated from the analysis of the hazards in the sections that follow.

Table 4- 2: City of Petaluma Hazard Significance Summary

Hazard	Geographic Extent	Probability of Future Occurrences	Magnitude/Severity	Overall Significance
Dam Incident	Limited	Unlikely	Limited	Low
Drought	Extensive	Likely	Limited	Medium
Earthquake	Extensive	Likely	Catastrophic	High
Flood	Limited	Likely	Limited	Medium
Sea Level Rise	Limited	Occasional	Negligible	Low
Severe Weather: Extreme Heat	Extensive	Likely	Limited	Low
Severe Weather: Heavy Rain/Thunderstorms/Hail/Lighting	Extensive	Likely	Limited	Medium
Severe Weather: High Winds	Extensive	Likely	Limited	Medium
Wildfire	Significant	Occasional	Critical	Medium
Hazardous Material Releases	Significant	Likely	Limited	Medium
Cyber Threat	Extensive	Occasional	Critical	Low

Geographic Extent Limited: Less than 10% of planning area Significant: 10-50% of planning area Extensive: 50-100% of planning area **Probability of Future Occurrences** Highly Likely: Near 100% chance of occurrence in next year or happens every year. Likely: Between 10 and 100% chance of occurrence in next year, or a recurrence interval of 10 years or less. Occasional: Between 1 and 10% chance of occurrence in the next year or has a recurrence interval of 11 to 100 years. Unlikely: Less than 1% chance of occurrence in next 100 years or has a recurrence interval of greater than every 100 years.	**Magnitude/Severity** Catastrophic—More than 50 percent of property severely damaged; shutdown of facilities for more than 30 days; and/or multiple deaths Critical—25-50 percent of property severely damaged; shutdown of facilities for at least two weeks; and/or injuries and/or illnesses result in permanent disability Limited—10-25 percent of property severely damaged; shutdown of facilities for more than a week; and/or injuries/illnesses treatable do not result in permanent disability Negligible—Less than 10 percent of property severely damaged, shutdown of facilities and services for less than 24 hours; and/or injuries/illnesses treatable with first aid **Overall Significance** Low: minimal potential impact Medium: moderate potential impact High: widespread potential impact

FEMA's Hazus 4.0 Loss Estimation Tool

Hazus Multi-Hazard Loss Estimation tool (Hazus-MH) is FEMA's standardized method for modeling and estimating potential losses from earthquakes, floods, strong wind-caused events, and hurricanes. For the purposes of this plan, Hazus Version 4.0 was used with Geographic Information System (GIS) software to estimate economic and social impacts from the occurrence (or potential occurrence) of natural hazards (FEMA 2018a).

Hazus-MH provides tabular outputs as well as graphic and illustrative results of identified high-risk areas due to the profiled hazards of interest, with reports summarizing losses or damages from structures and critical facilities, populations affected or at risk, and debris generated from an event. Hazus 4.0 is a key component of the pre-disaster planning process and is used for mitigation and recovery, given its ability to estimate potential losses and damages on a city, county, and multi-regional context. For this LHMP, Hazus-MH was used to estimate effects from a probabilistic 2,500-year earthquake scenario as well as a USGS ShakeMap-based deterministic scenario, and the software is referenced in the dam incidents and flooding sections to point out methodologies applied to the vulnerability assessments as indicated in Hazus-MH loss calculation procedures (e.g. the FEMA flood depth damage functions per the Benefit Cost Analysis application) (FEMA 2018b). For more information on the earthquake scenarios processed with Hazus 4.0, refer to the Section 4.3.3 Earthquakes.

4.1.3 Disaster Declaration History

One method the HMPC used to identify hazards was researching past events that triggered federal and state emergency or disaster declarations in the Planning Area. Federal and state disaster declarations may be granted when the severity and magnitude of an event surpasses the ability of the local government to respond and recover. Disaster assistance is supplemental and sequential. When the local government's capacity has been surpassed, a state disaster declaration may be issued, allowing for the provision of state assistance. Should the disaster be so severe that both the local and state governments' capacities are exceeded, a federal presidential emergency or disaster declaration may be issued allowing for the provision of federal assistance to help disaster victims, business, and public agencies.

The federal government may issue a disaster declaration through FEMA, the U.S. Department of Agriculture (USDA), or the Small Business Administration (SBA). FEMA also issues emergency declarations which are more limited in scope and without the long-term federal recovery programs of major disaster declarations (Farm Service Agency 2018). The quantity and types of damage are the determining factors in the type of declaration issued. This section focuses on state and federal disaster and emergency declarations.

The City of Petaluma is among many communities in California that are susceptible to disaster. Details on federal and state disaster declarations were obtained by the HMPC, FEMA, and Cal OES and compiled in chronological order in Table 4-3.

Table 4-3: City of Petaluma and Sonoma County State and Federal Disaster Declarations, 1950-2018

Event/ Hazard	Year	Disaster #	Declaration Type
Heavy Rains and Flooding	1964	183	Major Disaster Declaration
Severe Storms and Flooding	1969	253	Major Disaster Declaration
Drought	1977	3023	Emergency Declaration
Flood	1982	651	Major Disaster Declaration
Coastal Storm	1983	677	Major Disaster Declaration
Flood	1986	758	Major Disaster Declaration
Freeze	1991	894	Major Disaster Declaration
Flood	1993	979	Major Disaster Declaration
El Niño - Fishing Losses	1994	1038	Major Disaster Declaration
Severe Storm(s)	1995	1044	Major Disaster Declaration
Severe Storm(s)	1995	1046	Major Disaster Declaration
Cavedale Fire	1996	--	Local Emergency
Severe Storm(s)	1997	1155	Major Disaster Declaration

Event/ Hazard	Year	Disaster #	Declaration Type
Severe Storm(s)	1998	1203	Major Disaster Declaration
Severe Storm(s)	1999	--	Local Emergency
Severe Storm(s)	2002	--	Local Emergency
Geysers Fire	2004	2554	Fire Management
Flood	2005	--	State and Federal Disaster Declaration
Severe Storm(s)	2006	1646	Major Disaster Declaration
SF Oil Spill	2007	--	Gubernatorial Declaration
H1N1 Influenza Pandemic	2009	--	Local Emergency
Great Tohoku Tsunami	2011	--	Gubernatorial Declaration
Drought	2014-2016	--	Gubernatorial Declaration
South Napa Earthquake	2014	4193	Major Disaster Declaration
Severe Storm(s)	2014	--	Local Emergency
Valley Fire	2015	4240	Major Disaster Declaration
Severe Storm(s)	2017	4301	Major Disaster Declaration
Flood	2017	4308	Major Disaster Declaration
Wildfires	2017	4344	Major Disaster Declaration

Source: 2018 California State Hazard Mitigation Plan, FEMA, 2016 Sonoma County Hazard Mitigation Plan

Most disaster declarations are issued on a county-wide basis. In some limited instances a city or area within a county is specifically designated. Sonoma County has received 29 declarations between 1964 and 2017, 18 of which received federal disaster declarations, 4 received a Gubernatorial Declaration, 6 were local emergency declarations and 1 for fire management assistance. Of the 29 disaster declarations, 12 were associated with severe storms and heavy rain (also includes the 1 coastal storm event), 5 associated with flooding, and 4 declarations related to wildfires; freeze, earthquake and pandemic all received 1 declaration. The County also received 1 declaration related to fishing losses, 1 related to the Cosco Busan oil spill in San Francisco Bay, and 1 related to the 2011 Japan Tsunami.

Since 2012, there have been 13 drought declarations issued by the Secretary of Agriculture for Sonoma County, 8 of which were “Fast Track Secretarial Disaster” designations; refer to Section 4.3.2 on drought hazards for more details on previous occurrences of drought events. According to the Secretary of Agriculture, a Fast Track designation is for a severe drought and provides an automatic designation when any portion of the county meets the severe drought intensity value for eight consecutive weeks during the growing season.

This combined federal and state disaster history suggests that Sonoma County (and the City of Petaluma) experiences a major event worthy of a disaster declaration every 1.8 years. The County has a 55 percent chance of receiving a disaster declaration in any given year. Further, a review of these events helps the City identify risk reduction targets and ways to improve their capabilities to avoid large-scale hazard events in the future.

4.1.4 Climate Change Considerations Summary

The City of Petaluma and Sonoma County acknowledge that climate change is occurring and began to plan for it when the City Council declared a climate emergency in May 2019. The City’s focus on addressing climate policy was further underscored by the establishment of a Climate Action Commission in October 2019. The Commission is an appointed six-member body designated to address the City’s impact on climate change, develop climate policies, and make recommendations to the Council.

Sonoma County initiated climate change efforts in 2009 by the establishment of a Regional Climate Protection Authority (RCPA). The RCPA was formed through locally sponsored state legislation to coordinate countywide climate protection efforts among Sonoma County's nine cities and multiple county agencies. The RCPA focuses on efficient buildings, clean energy, alternative transportation, and conservation and adaptation. In 2014, the RCPA prepared a climate hazard and vulnerability assessment, known as *Climate Ready Sonoma County: Climate Hazards and Vulnerabilities*. In 2016, the RCPA prepared Sonoma County's *Regional Climate Action Plan: Climate Action 2020 and Beyond* (referred to as the County's CAP). Although not formally adopted by the County, climate change projections summarized in the CAP are based on the Basin Characterization Model (BCM) prepared by scientists from the USGS and the University of California, Davis Center for Environment. The projections were developed by applying scaled-down models that identify watershed-level climate change impacts specific to Sonoma County; the projections represent the best available climate data for the County (RCPA 2016). The BCM projections and recent studies indicate that climate change could affect Sonoma County (and the City of Petaluma) in the following ways:

- **Higher Average Temperature and More Extreme Heat Events:** For scenarios with mitigated emissions, summer high temperatures are expected to rise by 1 to 2°F; scenarios with unmitigated emissions project average summer high temperatures will increase by up to 9 to 11°F by 2100.
- **More Frequent and Intense Droughts:** Three of the four climate scenarios examined indicate a rising climate water deficit (CWD), a numeric measure of drought stress, over this century, producing 10 to 20 percent drier soil conditions in the summer months. The greatest increases in soil dryness are projected to occur in the south and southeastern portions of the County (including Petaluma).
- **More Frequent and Intense Wildfire:** Wildfire risk will continue to rise due to increased dryness of vegetation compounded by the productivity of plants in the spring. By the end of the century, the chances of one or more fires during a 30-year period are projected to increase from 15 to 20 percent to 25 to 33 percent in the mountainous areas of the County.
- **Fewer Winter Nights that Freeze.** Projected winter low temperatures are expected to rise in the future. For scenarios with mitigated emissions, winter low temperatures are expected to rise by 1 to 2°F. In the two scenarios with unmitigated emissions, average winter low temperatures are projected to increase by up to 7 to 9°F by 2100.
- **Increased Risk of Extreme Floods:** Climate scenarios project increased seasonal variability of precipitation, runoff, and stream flows for Sonoma County, along with increased likelihood of "extreme" precipitation and drought events. There may be more years with more frequent storm events and occasional events that are much stronger than historical ones and the length of season over which storm events occur is predicted to increase.
- **More Frequent Coastal Flooding, Increased Erosion, and Saltwater Intrusion:** Sea levels are projected to rise between 16.5 and 65.8 inches by 2100. Rising sea levels combined with increased storm surge will lead to more frequent inundation of the low-lying areas, and flooding of homes, infrastructure, agricultural land, and natural areas on the shores of San Pablo Bay. The greatest impacts are anticipated during winter storms.

The important consideration for hazard mitigation is that climate change is exacerbating the hazards which are already identified and profiled. For example, it can be expected that coastal storm and wave surge along the Petaluma River will become more of a threat as sea level rises. Additional specifics associated with the hazards are discussed in the Climate Change Considerations subsection of each hazard profile.

4.2 Asset Summary

As a starting point for analyzing the Planning Area's vulnerability to identified hazards, the HMPC used a variety of data, including data provided by Sonoma County (e.g. structure values, assessor data) to define a baseline against which all disaster impacts could be compared. If a catastrophic disaster was to occur in the Planning Area, this section describes significant assets exposed or at risk in the Planning Area. Data used in this baseline assessment included:

- Total assets at risk;
- Critical facility inventory;
- Cultural, historical, and natural resources; and
- Population statistics, land use, and growth/development trends.

Total Assets at Risk

A spatial parcel dataset containing attributes such as structure values and year of property construction was provided by the City of Petaluma GIS Department, alongside a building outline layer useful in counting buildings per parcel. Property type, valuation details, and other information contained in this plan are based on data from the Sonoma County Assessor's Office. This data provided the baseline for an inventory of the total exposure of developed properties within the City of Petaluma. This data helps to ensure that the LHMP can be updated over time to reflect changes in development. It is important to note that depending on the nature and type of hazard event or disaster, it is generally the value of the infrastructure or improvements to the parcels that are of concern or at risk. Generally, the land itself is not a total loss, but may result in a reduction in value. Thus, the parcel analysis excludes land value.

Once the dataset was reviewed and organized, the parcel layer was clipped to the boundaries of the City of Petaluma UGB. For the purpose of parcel analysis and exposure calculations only parcels with improved values were used, except for exempt or government properties (which may not include an improvement value per its categorization and is one limitation that results in the total improvement values underestimating the actual value). "Improved" parcels have an improvement value greater than zero. Contents values were also estimated, as a percentage of building value based on their property type, using FEMA/Hazus guidelines. Content value estimates are based on 100 percent of the structure value for commercial and agriculture structures, 150 percent of the structure value for industrial structures, and finally 50 percent for residential structures. Improvement values were added to contents values to calculate the total structure values for all properties in the parcel layer. The parcel layer, originally in the form of polygons, was then converted into points based on the center (or centroid) of a parcel to then used in overlay analysis with those hazards profiled in this plan that are available in spatial format (i.e. flood and fire). These outputs summarize the count and value of improved properties, contents, and total values for the property inventory, and the exposure values by property type for the City of Petaluma.

Table **4-4** summarizes the total improved parcel exposure by parcel type for the City of Petaluma.

Table 4-4: City of Petaluma Total Improved Parcel Exposure by Parcel Type

Parcel Type	Total Parcels	Improved Value	Content Value	Total Value
Agricultural	2	$12,473	$12,473	$24,946
Commercial	1,029	$1,268,444,699	$1,268,444,699	$2,536,889,398
Multi-Family	295	$525,362,102	$262,681,051	$788,043,153
Residential	17,569	$4,368,066,096	$2,184,033,048	$6,552,099,144
TOTAL	18,895	$6,161,885,370	$3,715,171,271	$9,877,056,641

Source: Wood analysis based on City of Petaluma and Sonoma County Assessor's Office Data 2019

Critical and City Facility Inventory

A critical facility is defined (within the context of this plan) as a facility that is essential in providing utilities or support either during the response to an emergency or during a recovery operation. The following four categories were used to differentiate critical assets and facilities in Petaluma based on FEMA's Hazus-MH program and other FEMA guidelines:

- **Emergency Services –** Facilities or centers aimed at providing for the health and welfare of the whole population (e.g., hospitals, police, fire stations, emergency operations centers, evacuation shelters, schools).
- **Lifeline Utility Systems –** Facilities and structures such as potable water, wastewater, oil, natural gas, electric power and communications systems.
- **Transportation Systems –** These may include railways, highways, waterways, airways and city streets to enable effective movement of services, goods and people. Particular examples for Petaluma include airports, historic drawbridges, and train or other transportation stations.
- **High Potential Loss Facilities –** These include nuclear power plants, dams, and levees.

The City of Petaluma also provided key facilities that it deems essential. Table 4-5 lists both critical facilities obtained from the Homeland Infrastructure Foundation-Level Data (HIFLD 2018), a federal dataset, as well as the City-provided structure data. **Error! Reference source not found.** shows the City's critical facilities.

Table 4-5: Critical and City Facility Summary by Category and Type

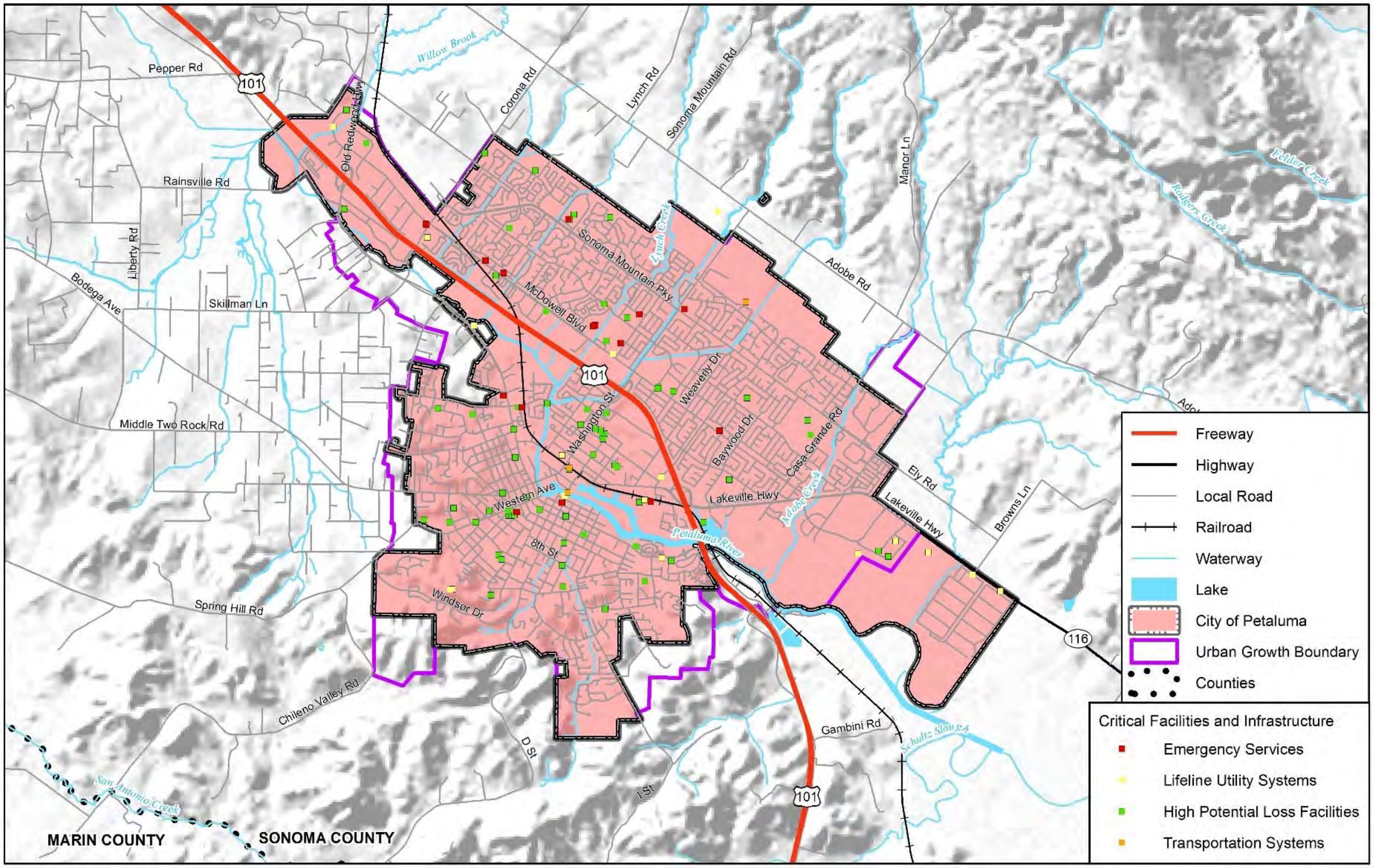
<table>
<tr><th>Overall Category</th><th>Critical Facility Type</th><th>Total Critical Facilities</th></tr>
<tr><td rowspan="7">Emergency Services</td><td>Emergency Medical Service Station</td><td>2</td></tr>
<tr><td>Fire Station</td><td>3</td></tr>
<tr><td>Hospitals</td><td>1</td></tr>
<tr><td>Law Enforcement</td><td>4</td></tr>
<tr><td>Nursing Homes</td><td>4</td></tr>
<tr><td>Senior Center</td><td>2</td></tr>
<tr><td>Shelter Home</td><td>1</td></tr>
<tr><td colspan="2">TOTAL</td><td>17</td></tr>
<tr><td rowspan="8">High Potential Loss Facilities</td><td>Community/Recreation Center</td><td>8</td></tr>
<tr><td>Day Care Facilities</td><td>13</td></tr>
<tr><td>Government/Admin</td><td>16</td></tr>
<tr><td>Private School and Day Care</td><td>2</td></tr>
<tr><td>Private Schools</td><td>4</td></tr>
<tr><td>Public School and Day Care</td><td>4</td></tr>
<tr><td>Public Schools</td><td>19</td></tr>
<tr><td>Supplemental Colleges</td><td>2</td></tr>
</table>

Overall Category	Critical Facility Type	Total Critical Facilities
TOTAL		**68**
Lifeline Utility Systems	AM Transmission Towers	1
	Electric Substations	3
	Microwave Service Towers	3
	Water Facility	8
	Wastewater Treatment Plant	2
TOTAL		**17**
Transportation Systems	Airport	1
	Historic Drawbridge	1
	Train Station	1
TOTAL		**3**
GRAND TOTAL		**105**

Sources: City of Petaluma, Homeland Infrastructure Foundation-Level Dataset

NOTE: The SMART Rail at Haystack Bridge in the City of Petaluma was not included as a critical facility because it is not owned by the City. This facility is owned and operated by Sonoma-Marin Area Rail Transit District.

Figure 4-1: Critical and City Facilities in Petaluma by Overall Category



Cultural, Historical, and Natural Resources

Assessing the City of Petaluma's vulnerability to disaster also involves inventorying the natural, historical, and cultural assets of the area. This step is important for the following reasons:

- The community may decide that these types of resources warrant a greater degree of protection due to their unique and irreplaceable nature and contribution to the overall economy.
- In the event of a disaster, an accurate inventory of natural, historical and cultural resources allows for more prudent care in the disaster's immediate aftermath when the potential for additional impacts is higher.
- The rules for reconstruction, restoration, rehabilitation, and/or replacement are often different for these types of designated resources.
- Natural resources can have beneficial functions that reduce the impacts of natural hazards, for example, wetlands and riparian habitat which help absorb and attenuate floodwaters and thus support overall mitigation objectives.

Cultural Resources

Historical resources are buildings, structures, objects, places, and areas that are eligible for listing in the National Register of Historic Places (NRHP), the California Register of Historic Resources (CRHR), or the City's List of Historic Resources, have an association with important persons, events in history, or cultural heritage, or have distinctive design or construction method.

For purpose of federal actions, a qualified historic resource is defined as a property listed in or formally determined eligible for listing in the NRHP before a disaster occurs. The NRHP is part of a national program to coordinate and support public and private efforts to identify, evaluate, and protect historic and archeological resources. Properties listed include districts (i.e. Petaluma Historic Commercial District), sites, buildings, structures, and objects that are significant in American history, architecture, archeology, engineering, and culture. The National Register is administered by the U.S. Department of the Interior National Park Service. Local and state agencies may consider a broader definition of qualified historic properties in the review, evaluation, and treatment of properties damaged during a disaster.

The State of California Office of Historic Preservation can provide technical rehabilitation and preservation services for historic properties affected by a natural disaster. Depending on the hazard, protection could range from emergency preparedness, developing a fire safe zone around sites susceptible to wildfires, or seismically strengthening or structurally reinforcing structures.

State and local registers of historic resources provide designated Historical Landmarks, Points of Historical Interest, and Historic Buildings. These resources include, but are not limited to:

- The California Register of Historical Resources (CRHR)
- The California Historical Landmarks
- The California Inventory of Historical Resources
- The California Points of Historical Interest

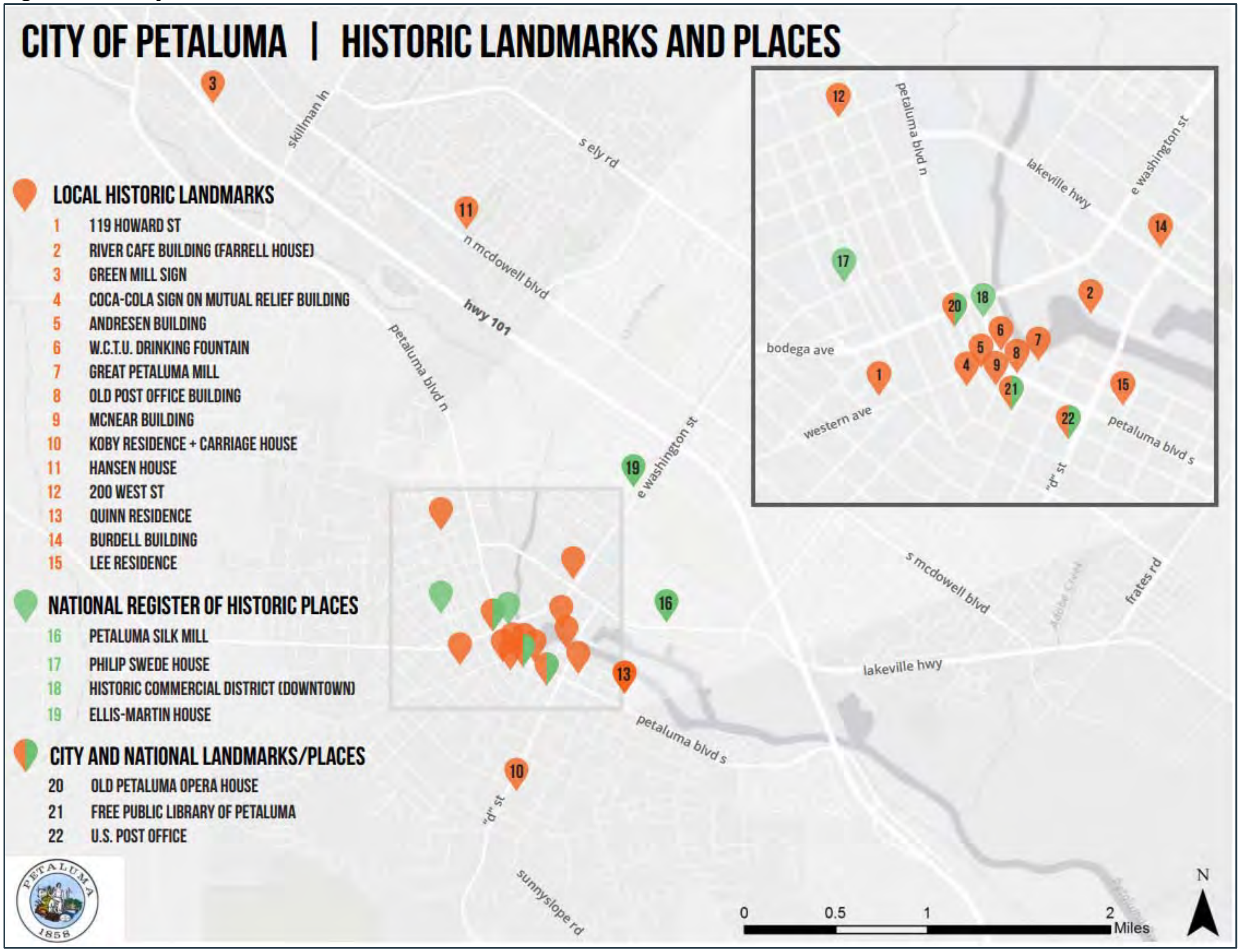
Historical resources designated by the City of Petaluma's Planning Division and Historic and Cultural Preservation group/chapter are provided in Figure 4-2. Table 4-6 summarizes the historic and cultural resources found in the National Register of Historic Places for the Petaluma area. Some of these historic and cultural places are duplicative in both the City and National databases and hence table and map.

Table 4-6: City of Petaluma Historical Resources from the National Register of Historic Places

Historical Resource Name	Listed Date	Location	Other Names or Description
Petaluma Adobe	4/15/1970	4 miles East of Petaluma on Casa Grande Rd.	Rancho Petaluma Adobe
Old Petaluma Opera House	12/22/1978	147--149 Kentucky St.	The Maclay Building
US Post Office--Petaluma	1/11/1985	120 4th St.	Petaluma USPS Post Office; US Post Office in California 1900-1941 TR
Petaluma Silk Mill	3/6/1986	420 Jefferson St.	Carlson-Currier Silk Mfg. Co.; Belding-Heminway-Corticelli
Free Public Library of Petaluma	6/23/1988	20 Fourth St.	Old Carnegie Library; Petaluma Historical Library and Museum
Swede, Philip, House	6/18/1992	301 Keokuk St.	--
Petaluma Historic Commercial District	3/31/1995	Along Petaluma Blvd., between B and Prospect Streets	Old Petaluma Opera House
Ellis--Martin House	10/4/2006	1197 E. Washington St.	Martin House; Ellis, John D., House

Source: National Register of Historic Places, 2019

Figure 4-2: City of Petaluma Historic Landmarks and Places



Source: City of Petaluma Planning Division – Historical and Cultural Preservation Division 2019

Lists of designated historical resources change periodically, and they may not include those currently in the nomination process and not yet listed. Additionally, as defined by the National Environmental Policy Act (NEPA), any property over 50 years of age is considered a historic resource and is potentially eligible for listing on the National Register. Thus, in the event that the property is to be altered, or has been altered, as the result of a major federal action, the property must be evaluated under the guidelines set forth by NEPA. Structural mitigation projects are considered alterations for the purpose of this regulation.

Cultural resources defined in California Environmental Quality Act (CEQA) Section 15064.5 include prehistoric and historic archaeological resources; historic-period resources (buildings, structures, area, place, or objects). Archaeological resources reflect past human activity extending from Native American prehistoric cultures throughout the early 20th century. The artifacts left by previous occupants may be encountered in small to large residential sites, or special use areas.

Many cultural and historical resources in the City are vulnerable to several hazards due to location and the nature of their construction. Some of these risks include earthquakes, wildfires, coastal storms, or adverse weather.

Tribal Cultural Resources

Tribal cultural resources are defined in Public Resources Code (PRC) Section 21074.1 as a site, feature, place, cultural landscape that is geographically defined in terms of the size and scope of the landscape, sacred place, or object with cultural value to a California Native American tribe. A Native American tribe is defined as "a federally recognized California Native American tribe or a non-federally recognized California Native American tribe that is on the contact list maintained by the Native American Heritage Commission". Traditional tribal cultural places are defined in PRC Sections 5097.9 and 5097.993 to include sanctified cemeteries, places of worship, religious or ceremonial sites, or sacred shrines, or any historic, cultural, or sacred site that is listed on or eligible for the CRHR including any historic or prehistoric ruins, burial grounds, or archaeological site. Cultural and tribal resources are governed primarily by federal, state, and local laws that regulate potential impacts to such resources. State regulations that were established to encourage the preservation and protection of traditional tribal cultural resources include:

- **Assembly Bill 52** (PRC Section 21080.3.1) mandates early tribal consultation prior to and during CEQA review to consider tribal cultural values in determination of project impacts and mitigation.
- **Senate Bill 18** (Government Code 655352.3) requires cities and counties to consult with Native American tribes early during broad land use planning efforts on both public and private lands, prior to site- and project-specific land use decisions. Consultation is intended to encourage preservation and protection of traditional tribal cultural places by developing treatment and management plans that might include incorporating the cultural places into designated open spaces.
- **State Executive Order B-10-11 (2011)** established the Governor's Tribal Advisor position and established Administration Policy to encourage State Agencies to communicate and consult with Californian tribes regarding tribal cultural resources.

Natural Resources

The City of Petaluma contains diverse in natural resources, exemplified by the creeks and rivers and salt marshes within its watershed that drain inland mountains to the confluence of the Petaluma River and San Pablo Bay.

Natural resources are important to include in benefit/cost analyses for future projects and may be used to leverage additional funding for mitigation projects that also contribute to community goals for protecting sensitive natural resources. Inventory and awareness of natural resource assets is vital to meeting conservation objectives. For example, protecting wetland areas provides sensitive habitat protection as well as floodwater conveyance and storage, which further enhances public safety.

Natural resources also exhibit varied levels of resiliency to anthropogenic impacts, climate change, and natural hazards such as flooding, drought, coastal storms or wildfire. Climate change is one of the most substantial threats to conserving the biodiversity and ecological habitat of the County (OPR 2019). Habitat resiliency is exemplified in coastal habitat migration to inland areas as a result to sea level rise, and recovery of burn areas following a wildfire.

Special Status Species

To further understand natural resources that may be particularly vulnerable to a hazard event, as well as those that need consideration when implementing mitigation activities, it is important to identify at-risk species (endangered and threatened species) potentially located in the City of Petaluma and its Planning Area. The US Fish and Wildlife Service (USFWS) maintains a list of federally-listed threatened and endangered species for the country, which can be queried at the state and county levels. The California Department of Fish and Wildlife (CDFW) also maintains species lists and accounts for threatened and endangered species. State and federal laws protect the habitat of these species through the environmental review process. Species of special concern may additionally include species that meets the State definition of threatened or endangered but has not been formally listed, experiences seriously population declines or habitat decline, or has naturally small populations exhibiting high susceptibility to population decline (CDFW 2019). Table 4-7 summarizes those special status animal species as indicated in the USFWS database that are located in Sonoma County and likely the areas surrounding the City of Petaluma Planning Area.

Table 4-7: Threatened and Endangered Species in Sonoma County and the City of Petaluma Area

Common Name	Scientific Name	Group	Status
California tiger Salamander	Ambystoma californiense	Amphibians	Endangered
California red-legged frog	Rana draytonii	Amphibians	Threatened
Short-tailed albatross	Phoebastria (=Diomedea) albatrus	Birds	Endangered
California least tern	Sterna antillarum browni	Birds	Endangered
California clapper rail	Rallus longirostris obsoletus	Birds	Endangered
Yellow-billed Cuckoo	Coccyzus americanus	Birds	Threatened
Western snowy plover	Charadrius nivosus	Birds	Threatened
Northern spotted owl	Strix occidentalis caurina	Birds	Threatened
Marbled murrelet	Brachyramphus marmoratus	Birds	Threatened
California freshwater shrimp	Syncaris pacifica	Crustaceans	Endangered
Conservancy fairy shrimp	Branchinecta conservatio	Crustaceans	Endangered
Vernal pool fairy shrimp	Branchinecta lynchi	Crustaceans	Threatened
longfin smelt	Spirinchus thaleichthys	Fishes	Candidate
Sonoma alopecurus	Alopecurus aequalis var. sonomensis	Flowering Plants	Endangered
Clara Hunt's milk-vetch	Astragalus clarianus	Flowering Plants	Endangered
White sedge	Carex albida	Flowering Plants	Endangered
Vine Hill clarkia	Clarkia imbricata	Flowering Plants	Endangered
Baker's larkspur	Delphinium bakeri	Flowering Plants	Endangered
Yellow larkspur	Delphinium luteum	Flowering Plants	Endangered
Contra Costa goldfields	Lasthenia conjugens	Flowering Plants	Endangered
Pitkin Marsh lily	Lilium pardalinum ssp. pitkinense	Flowering Plants	Endangered
Few-flowered navarretia	Navarretia leucocephala ssp. pauciflora (=N. pauciflora)	Flowering Plants	Endangered
Many-flowered navarretia	Navarretia leucocephala ssp. plieantha	Flowering Plants	Endangered
Slender Orcutt grass	Orcuttia tenuis	Flowering Plants	Threatened

Common Name	Scientific Name	Group	Status
Lake County stonecrop	Parvisedum leiocarpum	Flowering Plants	Endangered
Calistoga allocarya	Plagiobothrys strictus	Flowering Plants	Endangered
Napa bluegrass	Poa napensis	Flowering Plants	Endangered
Kenwood Marsh checker-mallow	Sidalcea oregana ssp. valida	Flowering Plants	Endangered
Sonoma sunshine	Blennosperma bakeri	Flowering Plants	Endangered
Sonoma spineflower	Chorizanthe valida	Flowering Plants	Endangered
Marin dwarf-flax	Hesperolinon congestum	Flowering Plants	Threatened
Burke's goldfields	Lasthenia burkei	Flowering Plants	Endangered
Sebastopol meadowfoam	Limnanthes vinculans	Flowering Plants	Endangered
Showy Indian clover	Trifolium amoenum	Flowering Plants	Endangered
Loch Lomond coyote thistle	Eryngium constancei	Flowering Plants	Endangered
Clover lupine	Lupinus tidestromii	Flowering Plants	Endangered
Pennell's bird's-beak	Cordylanthus tenuis ssp. capillaris	Flowering Plants	Endangered
Myrtle's silverspot butterfly	Speyeria zerene myrtleae	Insects	Endangered
San Bruno elfin butterfly	Callophrys mossii bayensis	Insects	Endangered
Callippe silverspot butterfly	Speyeria callippe	Insects	Endangered
Behren's silverspot butterfly	Speyeria zerene behrensii	Insects	Endangered
Salt marsh harvest mouse	Reithrodontomys raviventris	Mammals	Endangered
Point Arena mountain beaver	Aplodontia rufa nigra	Mammals	Endangered
Leatherback sea turtle	Dermochelys coriacea	Reptiles	Endangered
Leatherback sea turtle	Dermochelys coriacea	Reptiles	Endangered
Olive ridley sea turtle	Lepidochelys olivacea	Reptiles	Threatened
Short-tailed albatross	Phoebastria (=Diomedea) albatrus	Birds	Endangered
California least tern	Sterna antillarum browni	Birds	Endangered
California clapper rail	Rallus longirostris obsoletus	Birds	Endangered
Yellow-billed Cuckoo	Coccyzus americanus	Birds	Threatened

Source: USFWS – Environmental Conservation Online System, 2019

Population, Growth, and Development Trends

Between 2010 and 2018 the population of Petaluma increased by 4,310 persons (DOF 2019). The Sonoma County Economic Development Board is projecting the City of Petaluma will grow by 3.2 percent by 2022, outpacing the state and nation in five-year growth projections. The City's General Plan buildout plan also estimates an additional 15,500 residents in the City by 2025 and much of the growth is projected to occur within the UGB.

With the City's two growth management programs in place, the Regional Growth Management System and the UGB, development in the City has been managed or constrained to some degree. Development on the western side of the City is constrained by the hilly topography and the UGB, while the east side is constrained by the UGB until 2025. As discussed in Chapter 2, as of August 16, 2019, the City has forty-six major development projects going through the planning process with the Planning Division. A majority of the projects are residential projects with commercial projects the next most common. These major development projects are located throughout the City and most are located near downtown Petaluma. Additional information on population and growth and development trends are in Section 2.4 and Section 2.8 in Chapter 2.

4.3 Hazard Profiles and Risk Assessment

Requirement §201.6(c)(2)(i): [The risk assessment shall include a] description of the location and extent of all natural hazards that can affect the jurisdiction. The plan shall include information on previous occurrences of hazard events and on the probability of future hazard events.

Requirement §201.6(c)(2)(ii): [The risk assessment shall include a] description of the jurisdiction's vulnerability to the hazards described in paragraph (c)(2)(i) of this section. This description shall include an overall summary of each hazard and its impact on the community.

Requirement §201.6(c)(2)(ii)(A): The plan should describe vulnerability in terms of the types and numbers of existing and future buildings, infrastructure, and critical facilities located in the identified hazard areas.

Requirement §201.6(c)(2)(ii)(B): [The plan should describe vulnerability in terms of an] estimate of the potential dollar losses to vulnerable structures identified in paragraph (c)(2)(i)(A) of this section and a description of the methodology used to prepare the estimate.

Requirement §201.6(c)(2)(ii)(C): [The plan should describe vulnerability in terms of] providing a general description of land uses and development trends within the community so that mitigation options can be considered in future land use decisions.

The hazards identified in Section 4.1 Hazard Identification: Natural Hazards are profiled individually in this section. In general, information provided by HMPC is integrated into this section with information from other data sources. These profiles set the stage for the vulnerability assessment for each natural hazard that follow the detailed hazard profiles.

Each hazard is profiled in the following format:

- **Hazard Description** - This section gives a description of the hazard and associated issues followed by details on the hazard specific to the City of Petaluma Planning Area.
- **Location** – This section provides a spatial description of the potential locations or geographic areas in the City of Petaluma of where the hazard is expected to impact.
- **Extent (Magnitude/Severity)** - This section gives a description of the potential strength or magnitude of the hazard as it pertains to the City of Petaluma. Different hazards may have different measures of extent.
- **Previous Occurrences** - This section contains information on historical incidents, including impacts where known. The extent or location of the hazard within or near the Planning Area is also included in this subsection. Historical incident worksheets and other data sources were used to capture information on past occurrences.
- **Probability of Future Occurrence** - The frequency of past events is used in this section to gauge the likelihood of future occurrences. Where possible, frequency was calculated based on existing data. Frequency was determined by dividing the number of events observed by the number of years on record and multiplying by 100. This gives the percent chance of an event happening in any given year (e.g., three droughts over a 30-year period equates to a 10 percent chance of a drought in any given year). The likelihood of future occurrences is categorized into one of the following classifications:
  - **Highly Likely** - Nearly 100 percent chance of occurrence in next year or happens every year.
  - **Likely** - Between 10 and 99 percent chance of occurrence in next year or has a recurrence interval of 10 years or less.

- **Occasional** - Between 1 and 10 percent chance of occurrence in the next year or has a recurrence interval of 11 to 100 years.
- **Unlikely** - Less than 1 percent chance of occurrence in next 100 years or has a recurrence interval of every 100 years or greater.

- **Climate Change Considerations** – Climate change refers to a long-term change in the earth's temperature, precipitation, humidity, and seasons. This section addresses the probable effects of climate change qualitatively and as a secondary impact for each identified hazard. In other words, it describes the potential for climate change to affect the frequency and severity of natural hazards. Impacts can include water supply shortages, changes in the frequency, intensity, and extent of drought and extreme heat events, more precipitation and flooding risks, and increasing temperatures.

The discussion relies on information from the Fifth Assessment Report from the Intergovernmental Panel on Climate Change (IPCC) *Climate Change 2013: The Physical Science Basis Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (IPCC 2018). It also relies on numerous California publications including:

- *California's Fourth Climate Assessment* (California Natural Resources Agency 2018a);
- *Safeguarding California Plan: 2018 Update – California's Climate Adaptation Strategy* (Cal-Adapt 2018);
- *2014 Safeguarding California: Reducing Climate Risk* (California Natural Resources Agency 2014); and
- *2009 California Climate Adaptation Strategy* (CAS) (California Natural Resources Agency 2009).

The discussion integrates climate information from Cal-Adapt, a website that gathers data on how climate change might affect California at the local level based on the state's scientific and research community (CEC 2018). The climate change considerations subsections also summarizes climate change modelling and findings from the following two RCPA-prepared documents: *Climate Ready Sonoma County: Climate Hazards and Vulnerabilities* (2014) and *Sonoma County's Regional Climate Action Plan: Climate Action 2020 and Beyond* (2016). Climate change projections summarized in Sonoma County's CAP are based on BCM projections, which as previously mentioned were developed by applying scaled-down models that identify watershed-level climate change impacts specific to Sonoma County (RCPA 2016). Climate change is addressed in the plan as a secondary impact for each hazard.

Vulnerability Assessment – The vulnerability of the Planning Area to a specific natural hazard is assessed through the study of potential impacts to specific sectors:

- Property
- People
- Economy
- Critical Facilities and Infrastructure
- Historic, Cultural, and Natural Resources
- Future Development

Risk Summary – This is a summary of key findings and risk based on threat, vulnerability and consequences to the Planning Area from the specific hazard.

The significance of each hazard was determined based on the hazard profile, focusing on key criteria such as frequency and resulting damage, including deaths/injuries, and property and economic damage. This assessment was used by the HMPC to prioritize those hazards of greatest significance to the Planning

Area thereby allowing the City to focus resources where they are most needed. The following sections provide profiles of the natural hazards, listed alphabetically that the HMPC identified in Section 4.1 Identifying Hazards. Human-caused hazards are addressed in Section 4.4.

4.3.1 Dam Incidents

Hazard Description

Dams are manmade structures built for a variety of uses, including flood protection, power generation, agriculture, water supply, and recreation. When dams are constructed for flood protection, they usually are engineered to withstand a flood with a computed risk of occurrence. For example, a dam may be designed to contain a flood at a location on a stream that has a certain probability of occurring in any one year. If prolonged periods of rainfall and flooding occur that exceed the design requirements, that structure may be overtopped and fail. Overtopping is the primary cause of earthen dam incidents and failure in the United States. Dam incidents can also result from any one or a combination of the following causes:

- Earthquake
- Inadequate spillway capacity resulting in excess overtopping flows
- Internal erosion caused by embankment or foundation leakage or piping or rodent activity
- Improper design
- Improper maintenance
- Negligent operation
- Failure of upstream dams on the same waterway

Water released by a failed dam generates tremendous energy and can cause a flood that is catastrophic to life and property. A catastrophic dam incident or failure could challenge local response capabilities and require evacuations to save lives. Impacts to life safety will depend on the warning time and the resources available to notify and evacuate the public. Major loss of life could result as well as potentially catastrophic effects to roads, bridges, and homes. Associated water quality and health concerns could also be issues. Factors that influence the potential severity of a full or partial dam failure or dam incident are the amount of water impounded; the density, type, and value of development and infrastructure located downstream; and the speed of failure.

Controlled release or spillway flooding: inadequate spillway capacity often results in excess overtopping flows, though the potential for flooding as a result of discharge from dam outlet structures or spillways could be expected during excessive rain events. However, controlled releases of water from dams is a measure that can prevent or minimize spillway flooding or structure failure, by regulating capacity in a managed way. Even controlled releases can lead to unwanted or unpredicted flooding, depending on environmental and weather conditions, or even human error.

In general, there are three types of dams: concrete arch or hydraulic fill, earth-rockfill, and concrete gravity. Each type of dam has different failure characteristics. A concrete arch or hydraulic fill dam can fail almost instantaneously: the flood wave builds up rapidly to a peak then gradually declines. An earth-rockfill dam fails gradually due to erosion of the breach: a flood wave will build gradually to a peak and then decline until the reservoir is empty. And, a concrete gravity dam can fail instantaneously or gradually with a corresponding buildup and decline of the flood wave.

Location

According to the U.S. Army Corps of Engineers' National Inventory of Dams database, last updated in 2018, there are three potential dams of concern upstream of the City of Petaluma. These and other nearby dams may have been constructed for flood control, irrigation storage, recreation, and stock watering purposes. Of these dams of concern, one is considered to pose a high hazard, one is of significant hazard, and the last is rated as posing a low hazard.

The La Crema Winery Dam is an earth-material structure located just east of the City of Petaluma, about a half mile away and north of the City's wastewater treatment facility. The dam storage capacity is 103 acre-feet. This is a high hazard dam owned by the Jackson Family Wines entity, with no active EOP, or Emergency Action Plan (EAP) in place. The Pinheiro Dam is in the significant hazard category and was built in 1967. It is owned by a private entity and is located just over two miles east of the City, along a tributary to the Petaluma River. The dam storage capacity is 83 acre-feet. Finally, the Lawler Dam is located close to North Creek, about three miles northeast of Petaluma. This is a low hazard dam owned by the City, built in 1910 on the north part of the Petaluma Reservoir and with a primary use of providing water supply. It has a storage capacity of 227 acre-feet.

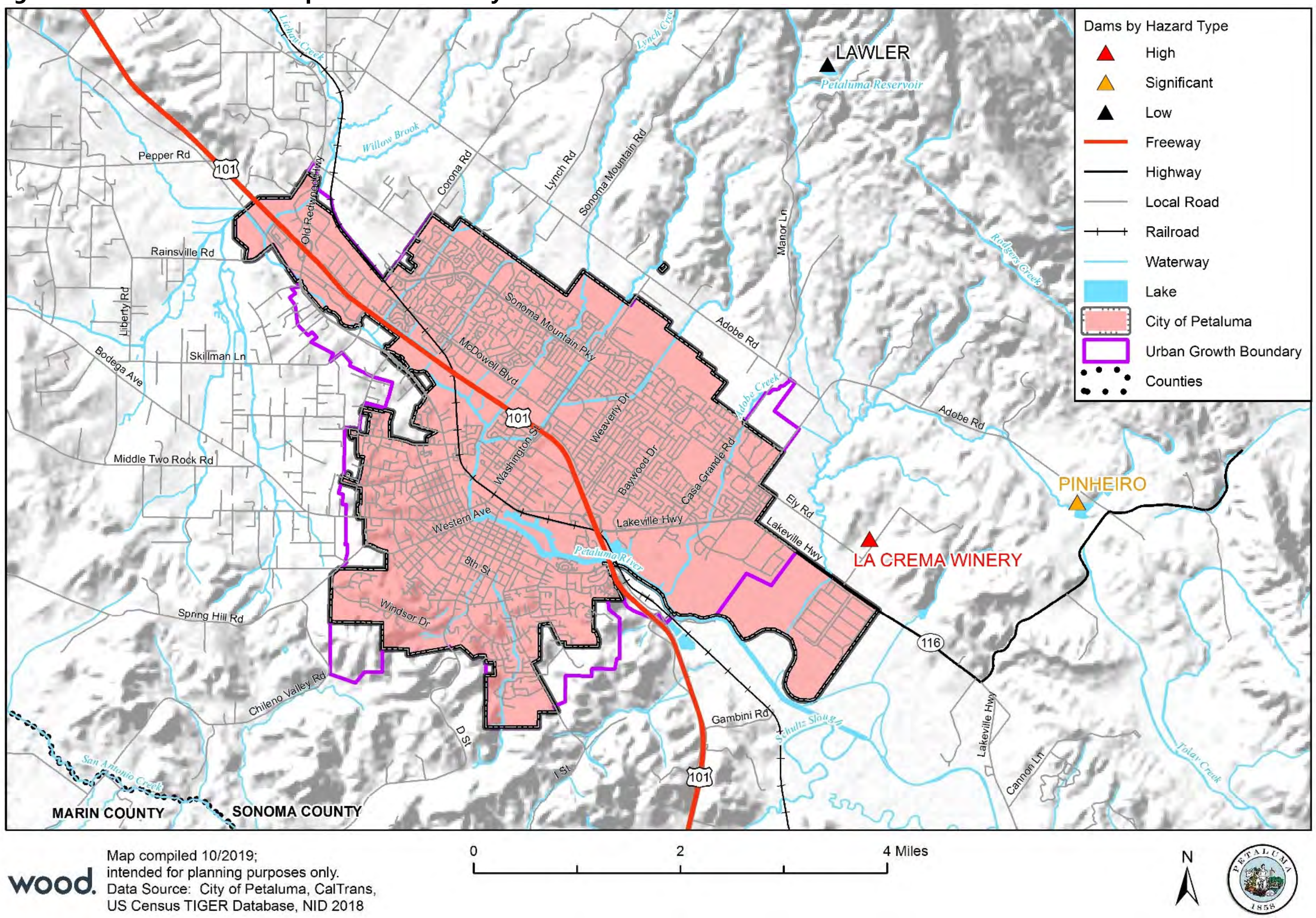
Table 4-8 below details these dams that could potentially affect the City of Petaluma given their close proximity and potential to inundate if either were to fail. **Figure 4-3** illustrates the locations of the two identified dams of concern near the City.

Table 4-8: Characteristics of the Dams of Concern Upstream of the City of Petaluma

Hazard Rating	Dam Name	River Drainage	Downstream Community	Dam Type	Dam Height (in Feet)	Storage Capacity (Acre-Feet)	Emergency Operations Plan	Dam Owner
Significant	Pinheiro	Tr Petaluma River	Petaluma	Earth	26	83	No	Private Entity
High	La Crema Winery	--	Petaluma	Earth	32	103	No	Jackson Family Wines
Low	Lawler	North Creek	Petaluma	Earth	40	227	No	City of Petaluma

Source: U.S. Army Corps of Engineers' National Inventory of Dams, 2018
Note: 1 acre-foot = 325,851 gallons

Figure 4-3: Dams of Interest Upstream of the City of Petaluma



Extent (Magnitude/Severity)

Limited – Standard practice among federal and state dam safety offices is to classify a dam according to the potential impact a dam failure (breach) or mis-operation (unscheduled release) would have on downstream areas. The hazard potential classification system categorizes dams based on the probable loss of human life and the impacts on economic, environmental, and lifeline facilities. Dams are classified into the following three categories which identify their potential hazard to life and property:

- High hazard indicates that a failure would most probably result in the loss of life;
- Significant hazard indicates that a failure could result in appreciable property damage;
- Low hazard indicates that failure would result in only minimal property damage and loss of life is unlikely; and
- Undetermined hazard dams have not been rated or their hazard rating is not known.

Since there are two potentially hazardous dams upstream of the City (one significant- and one high-rated hazard dam), there is some, though limited, potential for loss of life and/or property damage. Adjacent unincorporated portions of Sonoma or Marin Counties could also be affected by a dam failure upstream of the City, although the specific extent of impacts would depend on the nature of the failure, local emergency response capabilities, people and property found in the path of the dam inundation areas, and other such factors. However, based on the dam capacities of these the dams upstream of the Planning Area, it is unlikely that much risk would be imposed on those areas near Petaluma. Because the dam inundation maps are not currently available for the La Crema Winery and Pinheiro dams, it is difficult to determine the particular populations or properties at risk of a potential dam failure event on the City of Petaluma.

Previous Occurrences

There is no history of dam incidents or failures affecting the City.

Probability of Future Occurrences

Unlikely – The City remains at risk to upstream dam failures or incidents, particularly from the two that are classified as high or significant hazard structures. However, based on the lack of previous dam inundation events, HMPC input, and the fact that the dams posing risk to the City have relatively low storage capacities, dam failure and dam incidents are unlikely in the area. Nevertheless, the potential exists for future dam incidents in the City or portions of it, but the likelihood of this is low. Uncontrolled or controlled release flooding as well as spillway flooding below dams due to excessive rain or runoff are more likely to occur than failures.

Climate Change Considerations

The potential for climate change to affect the likelihood of dam failure is not fully understood at this point in time. With a potential for more extreme precipitation events a result of climate change, this could result in large inflows to reservoirs. However, this could be offset by generally lower reservoir levels if storage water resources become more limited or stretched in the future due to climate change, drought and/or population growth.

Vulnerability Assessment

A dam incident can range from a small, uncontrolled release to a catastrophic failure. Vulnerability to dam failures is confined to the areas and populations subject to inundation downstream of the facility. Secondary losses would include loss of the multi-use functions of the dam itself and associated revenues that accompany those functions, including potential potable water uses or critical irrigation for crops.

Property

In general, communities located below a high or significant hazard dam and along a waterway are potentially exposed to the impacts of a dam failure. For reference, high hazard dams threaten lives and property, significant hazard dams threaten property only. Inundation maps that identify anticipated flooded areas (which may not coincide with known floodplains) are often produced for all high hazard dams and are contained in the EAP required for each dam. The potential magnitude of a dam incident depends on the time of year and the base flow of the river when the incident or failure occurs. During the winter months, when the river flows are higher, the impact to the area would be much greater and evacuation times even shorter.

Due to the lack of dam inundation mapping for the dams upstream of the City, as well as the lack of EAPs, it is not well known how a potential dam failure could affect the City's property and infrastructure. Based on the location of the one high hazard dam and one significant hazard dam on the outskirts of the City in a sparsely populated area it appears the potential impacts to buildings and infrastructure downstream are minimal.

People

Persons located underneath or downstream of a dam are at risk of a dam failure, though the level of risk can be tempered by topography (specifically where populations are located within the inundation path of a dam but at higher elevations), amount of water in the reservoir/damming structure, and time of day of the breach. Injuries and fatalities can occur from debris, bodily injury, and drowning. Once a dam has breached, standing water presents all the same hazards to people as floodwater from other sources. People in the inundation area may need to be evacuated, cared for, and possibly permanently relocated. Impacts could include hundreds or thousands of evacuations and likely casualties, depending on the dam involved.

Due to the lack of dam inundation mapping for the three dams upstream of the City, as well as the lack of EAPs, it is not well known to what extent a potential dam failure could affect the City's population, nor the specific impacts on socially vulnerable or sensitive populations in the City's Planning Area.

Economy

Extensive and long-lasting economic impacts could result from a major dam failure including the long-term loss of water in a reservoir after a failure event. A major dam failure or incident and loss of water from the associate reservoir could include direct business and industry damages and indirect disruption of the local economy, including the disruption of irrigation water for crops or even water for livestock which may be key components of the local economy and its sectors.

Critical Facilities and Infrastructure

A total dam failure can cause catastrophic impacts to areas downstream of the water body, including critical infrastructure and essential facilities. Dam incidents may result is less severe downstream impacts, depending on the severity of the incident. Any critical asset located under the dam in an inundation area would be susceptible to the impacts of a dam incident. Of particular risk would be roads and bridges that could be vulnerable to washouts, further complicating response and recovery by cutting off impacted areas. Risk to specific facilities could be considered sensitive information, especially those such as water treatment facilities or water delivery systems which may provide potable water for the local population. Due to the lack of dam inundation mapping for the dams upstream of the City, as well as the lack of EAPs, it is not well known the extent to which a potential dam failure could affect the City's property and infrastructure. Based on location alone it does appear that the failure or a major incident at the La Crema Winery Dam, a high hazard dam could potentially impact the City's wastewater treatment infrastructure located downstream and near the drainage areas, but the actual risk is unknown due to data limitations.

Historic, Cultural, and Natural Resources

Dam failure effects on the environment would be similar to those caused by flooding from other causes. Water could erode stream channels and topsoil and cover the environment with debris. For the most part the environment is resilient and would be able to rebound from whatever damages occur, though this process could take years. Historic and cultural resources could be affected just as housing or critical infrastructures would, were a dam to fail and cause downstream inundation that could further erode surfaces or cause scouring of structural foundations. Given the high hazard dam outside the City lacks inundation mapping or an EAP, risks to historical and cultural resources is unknown.

Future Development

Areas slated for future development should take into consideration potential impacts from dam failure risk upstream and should attempt to overlay the existing dam inundation maps (if available) with proposed future development. In the case of a dam failure, inundation would likely follow some existing FEMA mapped floodplains, which contains development restrictions for areas in the one percent annual chance floodplain, but it could exceed those floodplains and affect areas that are not regulated for flood hazards. Also, development below a low or undetermined hazard dam such as the Lawler dam could increase its hazard rating. Finally, added development could compromise dams and reservoir resources if populations depend on them for critical needs such as potable water during or after a dam failure event.

Risk Summary

- The overall significance of dam inundation in the City of Petaluma is Low.
- There are three dams of concern that fall upstream of the City: La Crema Winery Dam, Pinheiro Dam, and Lawler Dam.
- La Crema Winery Dam is considered a high hazard dam and owned by the Jackson Family Wines entity. It is located about half a mile east of the City and its storage capacity of 103 acre-feet.
- The second dam of concern is the Pinheiro Dam and considered significant hazard dam and located just over 2 miles east of the City. It is owned by a private entity and located along a tributary of the Petaluma River. This significant hazard dam has a storage capacity of 83 acre-feet.
- The last potential dam of interest is the Lawler Dam, a low significance structure with a capacity of 227 acre-feet.
- All three of these dams are of earthen-constructed structures, and none have a current EAP on file
- Due to the lack of historic occurrence data on dam inundation, no dam inundation mapping available, and lack of EAPs, it is not well known how a potential failure of any of these dams could affect the City's populations, property, and critical infrastructure.

4.3.2 Drought

Hazard Description

Drought is a gradual phenomenon. Although droughts are sometimes characterized as emergencies, they differ from typical emergency events. Most natural disasters, such as floods or forest fires, occur relatively rapidly and afford little time for preparing for disaster response. Droughts occur slowly, many times over a multi-year period, and it is often not obvious or easy to quantify when a drought begins and ends.

Drought is a complex issue involving many factors; it occurs when a normal amount of moisture is not available to satisfy an area's usual water-consuming activities. Drought can often be defined regionally based on its causes or effects:

- **Meteorological** drought is usually defined by a period of below average water supply.
- **Agricultural** drought occurs when there is an inadequate water supply to meet the needs of the state's crops and other agricultural operations such as livestock.
- **Hydrological** drought is defined as deficiencies in surface and subsurface water supplies. It is generally measured as streamflow, snowpack, and as lake, reservoir, and groundwater levels.
- **Socioeconomic** drought occurs when a drought impacts health, well-being, and quality of life, or when a drought starts to have an adverse economic impact on a region.

The California Department of Water Resources (DWR) says the following about drought:

> "One dry year does not normally constitute a drought in California. California's extensive system of water supply infrastructure—its reservoirs, groundwater basins, and inter-regional conveyance facilities—mitigates the effect of short-term dry periods for most water users. Defining when a drought begins is a function of drought impacts to water users. Hydrologic conditions constituting a drought for water users in one location may not constitute a drought for water users elsewhere, or for water users having a different water supply. Individual water suppliers may use criteria such as rainfall/runoff, amount of water in storage, or expected supply from a water wholesaler to define their water supply conditions."

The drought issue in California is further compounded by water rights. Water is a commodity possessed under a variety of legal doctrines. The prioritization of water rights between farming and federally protected fish habitats in California is part of this issue.

Drought impacts are wide-reaching and may be economic, environmental, or societal. Also, during a drought, allocations go down, which results in reduced water availability. Voluntary water conservation measures are typically implemented during extended droughts. A reduction of electric power generation and water quality deterioration are also potential problems. Drought conditions can also cause soil to compact and not absorb water well, potentially making an area more susceptible to flooding.

Location

Drought is a regional hazard, and during severe drought conditions, it can affect the entire state of California with varying levels of dryness. In other words, drought affects all aspects of the economy and environment and the community simultaneously. The most significant impacts associated with drought in the City's Planning Area are those related to water intensive activities such as municipal usage and general water supply (e.g. irrigation for parks and open spaces), wildfire protection (including relief and response activities), commerce, agriculture, and tourism.

According to City of Petaluma's General Plan and the City's Water and Sewer Rate Study (City of Petaluma 2017), the City obtains its water from a mix of sources including water from the Russian River purchased from the Sonoma County Water Authority (SCWA) (also known as Sonoma Water), recycled water, and groundwater. The City also conserves water supplies through a standard management program and practices. These water supply sources and projected acre-feet (AF) available by 2025 are displayed in Table 4-9.

Table 4-9: Petaluma's Current Water Supply Sources and Projected Availability for 2025

Water Supply	2005 Usage	2025 Projected Availability
SCWA	11,799 AF	13,397 AF
Recycled Water	0	1,425 AF
Water Conservation	0	767 AF
Groundwater	0	186 AF
TOTAL	**11,799 AF**	**15,775 AF**

Sources: City of Petaluma General Plan 2008.

Notes:

2. One Acre-Foot = 43,560 cubic feet.
3. SCWA: Sonoma County Water Authority

The City purchases over 95 percent of its water supply on a wholesale basis from Sonoma Water and less than 5 percent is supplied by groundwater production from City wells. To aid in the overall conservation of water and reduction of use in the City for the coming years, the City built its first recycled water system in 1984 for irrigation of agricultural properties outside the City limits. The Ellis Creek Water Recycling Facility, built in 2009, takes wastewater subjected to additional high-level treatment and distributes the treated water for agricultural or landscape irrigation uses. The Ellis Creek recycled water facility treated 581 million gallons in 2019, but this amount varies year to year. The City is preparing to expand the recycled water treatment capacity in 2020, while increasing the distribution of recycled water incrementally through 2025. This City also applies a four-stage rationing plan during declared water shortages. This plan applies to catastrophic losses of water (City of Petaluma 2015). The rationing plan determines a consumption reduction of over 35 percent of the normal consumption depending on the cause, severity, and anticipated duration of the water supply shortage. Stage 1 involves minimal reductions of up to 15 percent of water supply conditions, stage 2 involves moderate reductions of 15 to 25 percent, stage 3 involves severe reductions of 25 to 35 percent, and stage 4 involves critical reductions greater than 35 percent (City of Petaluma 2015).

Sustainable Groundwater Management Act of 2014

Groundwater resources plays a significant role in the development, growth, and sustainability of the Petaluma Valley. Groundwater is the primary source for domestic and agricultural use by rural property owners in the Petaluma Valley Basin, while urban water supply to the City is primarily imported from Russian River surface water. The residents of Petaluma and all of California have been experiencing significant drought and water shortages since 2011 and only recently did the City and the majority of the state come out of drought. In January 2014 the Governor declared an emergency proclamation due to multiple years of drought. The proclamation called on citizens to reduce water use by 20 percent; with a subsequent executive order that directed urban water agencies to reduce water use by 25 percent. In September 2014, the Governor signed a three-bill package (California Senate Bills 1168 and 1319, and Assembly Bill 1739), known as the Sustainable Groundwater Management Act of 2014 (SGMA). The SGMA establishes local Groundwater Sustainability Agencies (GSAs) to manage groundwater sustainability within the groundwater sub-basins defined by DWR.

There are three GSAs in Sonoma County: Santa Rosa Plain, Sonoma Valley, and the Petaluma Valley. The Petaluma Valley groundwater basins spans 46,000 acres within the larger 93,440-acre Petaluma Valley watershed. Groundwater flows generally move from recharge areas in the mountains surrounding Petaluma Valley toward the City and then south towards San Pablo Bay. While groundwater data is currently being studied in the Petaluma Valley Basin, current groundwater elevation data suggests that elevations are relatively stable in the southern to central areas of Petaluma Valley, but exhibiting long-term declines in the northwest portion of the basin (Petaluma Valley GSA 2019). Historical occurrences of nitrate concentrations have been documented in the western portion of the Basin (DWR 1982). There have been other areas with poor water quality in the southern portion of the basin and saltwater intrusion from the tidally influenced portion of the Petaluma River (Petaluma Valley GSA 2019).

Extent (Magnitude/Severity)

Limited – Extent can be measured according to a scale developed by the United States Drought Monitor, which measures drought in five categories: “abnormally dry,” “moderately dry,” “severely dry,” “extremely dry,” and “exceptionally dry”. The City of Petaluma is vulnerable to all levels of drought, which are further subject to the effects of climate change, precipitation trends, and wet and dry periods. Drought can have a widespread impact on the environment and economy in the Planning Area, but it typically does not result in loss of life or damage to property. Rather drought may have an impact on agriculture, business, and the movement of goods and services related to agricultural, commodities, tourism and recreation, and water supply sectors.

Given that the City of Petaluma’s water users fall within the categories of residential (68 percent of water users) and commercial/office, industrial, and institutional (non-residential represents 32 percent of water users), it can be assumed that three main factors have an effect on water demands: climatic, demographic, and economic. These are described below and are expected to influence water demands in the future, as they have in the past.

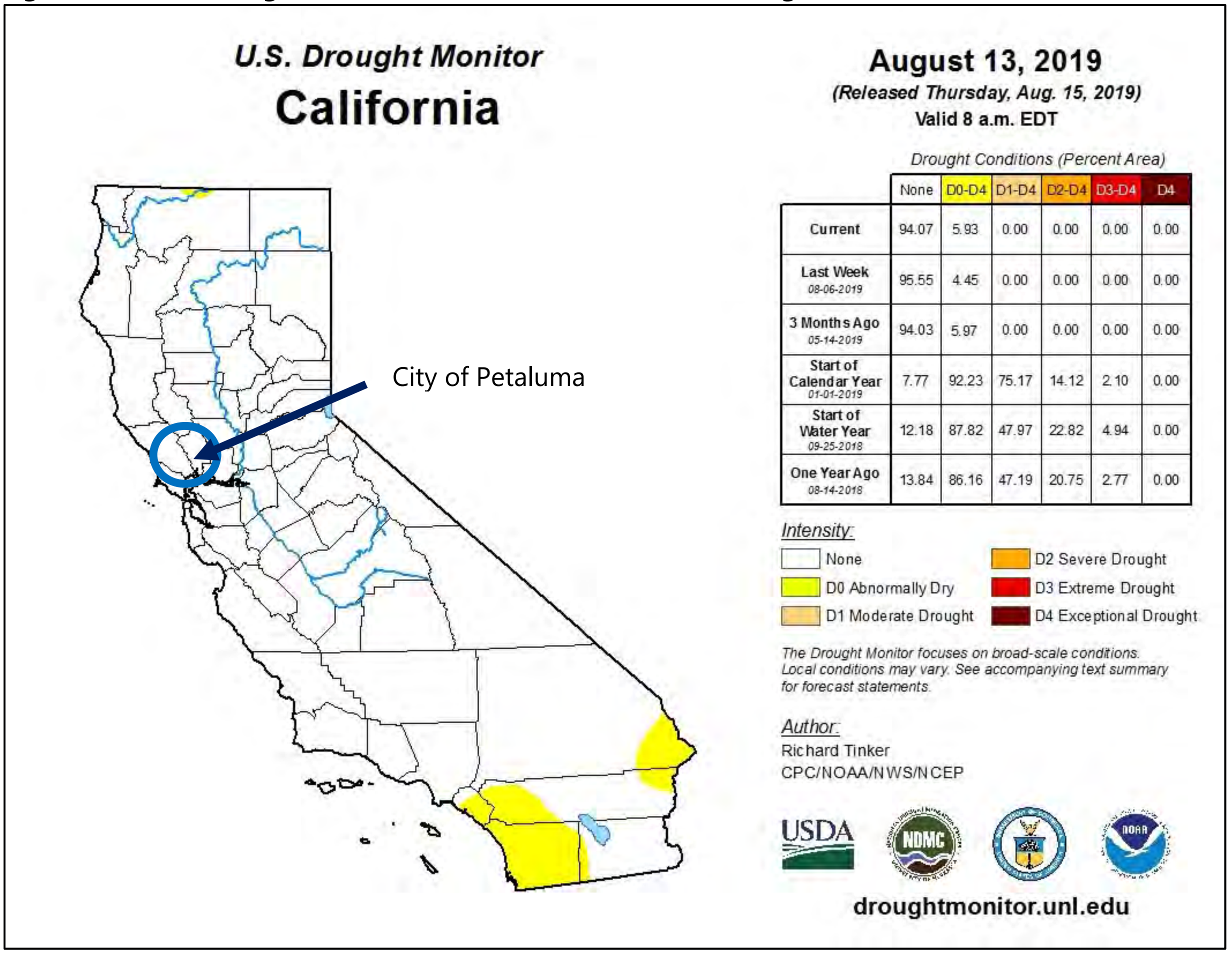
- **Climatic**. The weather in Petaluma is mild with a mean annual temperature of 70 degrees Fahrenheit. Average annual precipitation is about 25 inches. Climate has the most dramatic annual effect on water demands, and severe deviations from normal temperatures and average rainfall can increase or decrease annual water demands. Although Petaluma’s municipal supply doesn’t fully rely on surface water sources, precipitation shortages can have negative effects on what the City receives and can process for potable and other key uses.
- **Demographic**. Since water use is related to demographics and population change, an accurate description of population and housing stock in the service area serves as a basis for water planning activities described in the City’s 2015 Urban Water Management Plan (UWMP) or other planning mechanisms. According the American Community Survey, the City’s population was 60,210 in 2017. Population projections for the City indicate an increase from to 73,350 by 2040, or an increase of about 13,140 people per year (City of Petaluma 2015).
- **Economic**. Commercial water users have the second highest water demand after residential users (both single family and multi-family). According to the City’s 2015 UWMP, commercial water users demand for potable and raw water is projected to increase from a volume of 930 to 1,048 by 2040.

Industrial users are expected to increase their demand for water by 64 percent by 2040. Although agricultural areas are outside of Petaluma, the City does supply recycled water to these areas with plans to expand services in the future.

The magnitude or severity of a drought across the City could vary and is difficult to predict. However, understanding the total population affected as well as economy and resources vulnerable provides insight on how to estimate potential losses and damages to the City's assets; drought related information can be obtained and measured from the National Drought Mitigation Center's Impact Reporter and Drought Monitor tools (United States Drought Monitor 2018; United States Drought Impact Reporter 2018).

Figure 4-4, Figure 4-5, and Figure 4-6 provide "snapshots in time" of the drought conditions in California as of August 2019, November 2018, and August 2015 (during the period of the last multi-year drought in the state, from 2012- 2017). The snapshots selected are instrumental in depicting both the historic and potential change in drought's geographic range and severity in Sonoma County (circled in blue). These maps were extracted from the National Drought Mitigation Center and consider several factors including the Palmer Drought Index, Soil Moisture Models, U.S. Geological Survey (USGS) Weekly Streamflows, Standardized Precipitation Index, and Satellite Vegetation Health Index (United States Drought Monitor 2018).

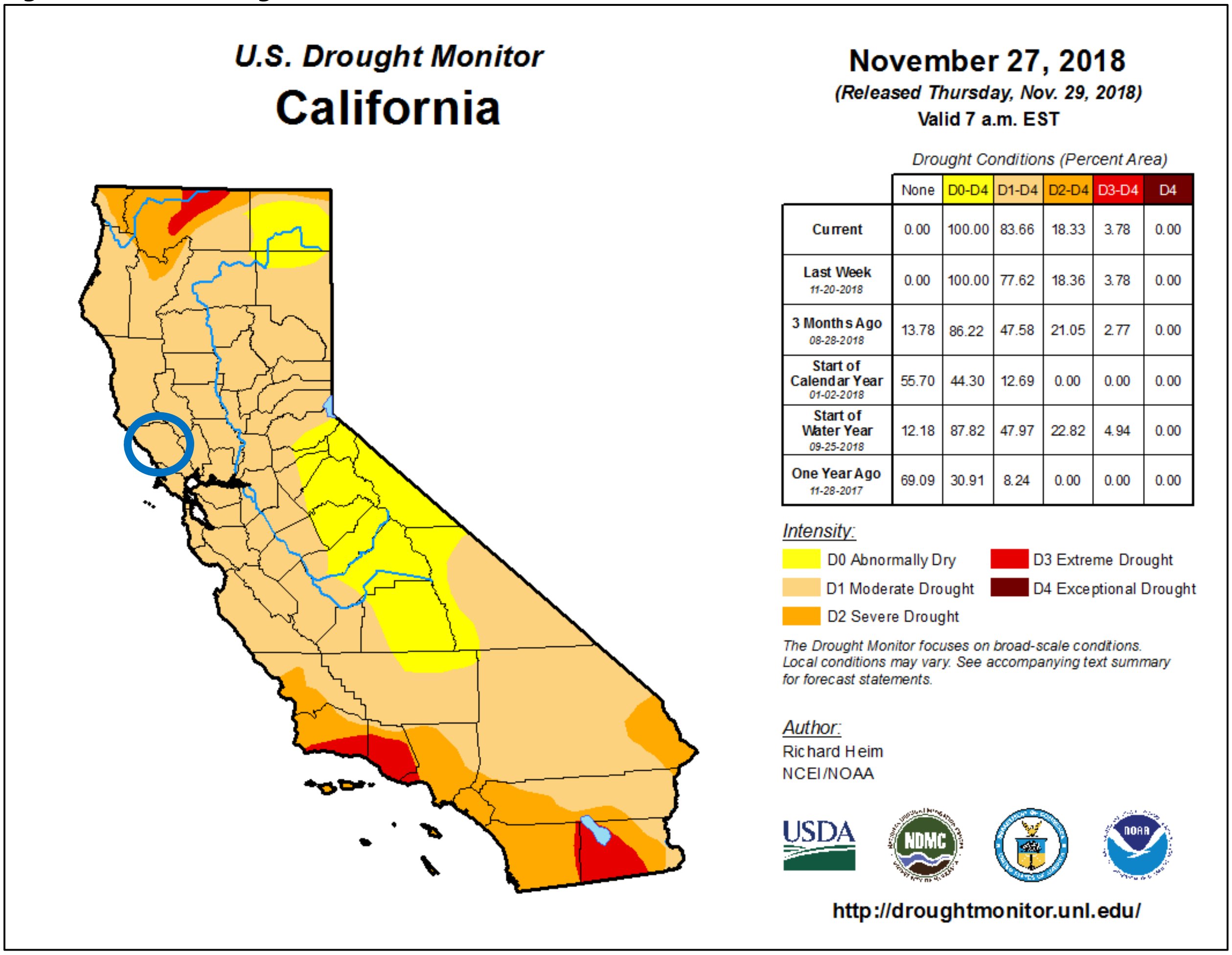
Figure 4-4: U.S. Drought Monitor Conditions for California, August 13, 2019



	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current	94.07	5.93	0.00	0.00	0.00	0.00
Last Week 08-06-2019	95.55	4.45	0.00	0.00	0.00	0.00
3 Months Ago 05-14-2019	94.03	5.97	0.00	0.00	0.00	0.00
Start of Calendar Year 01-01-2019	7.77	92.23	75.17	14.12	2.10	0.00
Start of Water Year 09-25-2018	12.18	87.82	47.97	22.82	4.94	0.00
One Year Ago 08-14-2018	13.84	86.16	47.19	20.75	2.77	0.00

Source: National Drought Mitigation Center, 2018

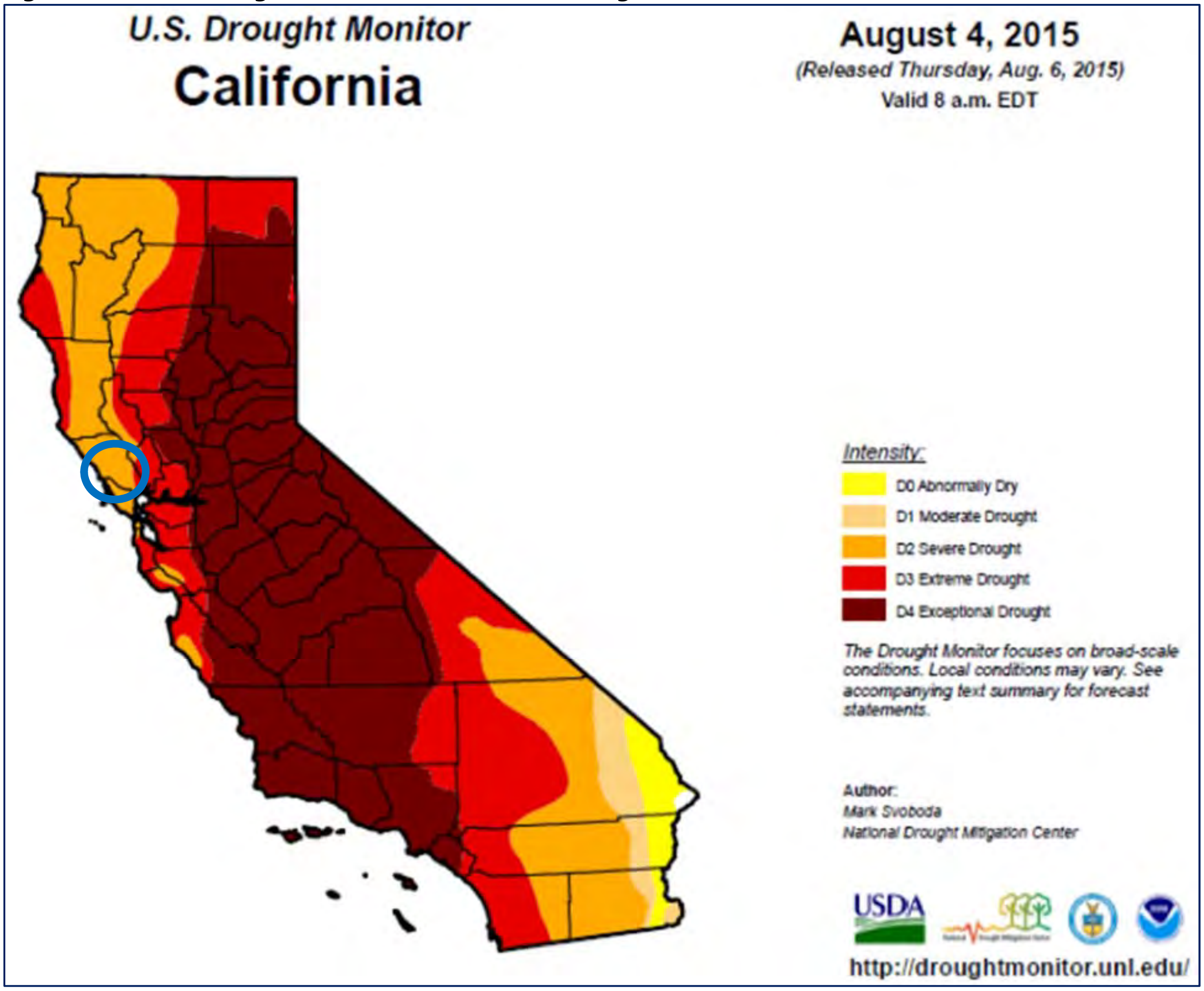
Figure 4-5: U.S. Drought Monitor Conditions for California, November 29, 2018



	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current	0.00	100.00	83.66	18.33	3.78	0.00
Last Week 11-20-2018	0.00	100.00	77.62	18.36	3.78	0.00
3 Months Ago 08-28-2018	13.78	86.22	47.58	21.05	2.77	0.00
Start of Calendar Year 01-02-2018	55.70	44.30	12.69	0.00	0.00	0.00
Start of Water Year 09-25-2018	12.18	87.82	47.97	22.82	4.94	0.00
One Year Ago 11-28-2017	69.09	30.91	8.24	0.00	0.00	0.00

Source: National Drought Mitigation Center, 2018

Figure 4-6: U.S. Drought Monitor for California: August 4, 2015

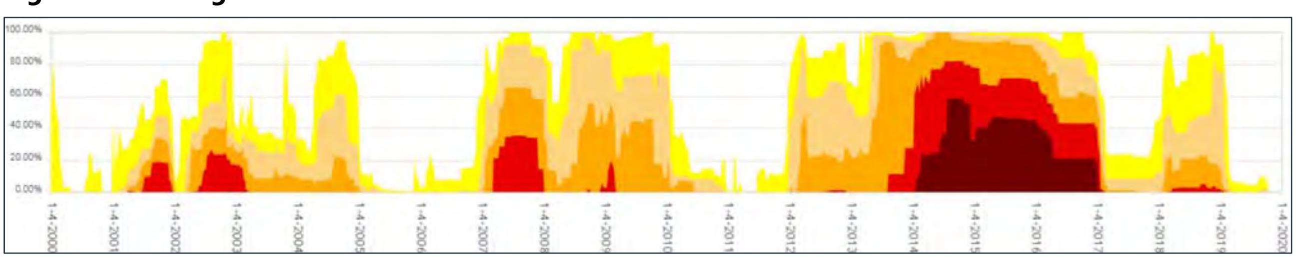


Source: National Drought Mitigation Center, 2018

Previous Occurrences

Historically, California has experienced multiple severe droughts. According to California's DWR, droughts exceeding three years are relatively rare in Northern California, the source of much of the state's developed water supply. The 1929-34 drought established the criteria commonly used in designing storage capacity and yield of large Northern California reservoirs. Figure 4-7 depicts California's multi-year historical dry periods from 2000-2019.

Figure 4-7: Drought Conditions in California – 2000 – 2019



Source: U.S. Drought Monitor https://droughtmonitor.unl.edu/Data/Timeseries.aspx

Since the year 2000 there have been several cases of multi-year droughts across California; these are described below:

2007-2009 – Water years 2007-2009 were the seventh driest three-year period in the measured record for state-wide precipitation and the fifteenth driest three-year period for DWR 8-station precipitation index (a rough indicator of potential water supply available to the State Water Project and Central Valley Project).

2012-2017 – The water years of 2012-14 stand out as California's driest three consecutive years in terms of statewide precipitation. The drought occurred at a time of record warmth in California, with new climate records set in 2014 for statewide average temperatures. On January 17, 2014, California declared a drought state of emergency and during this time the state assisted farmers and communities that were most impacted by the drought conditions and helped with drinking water shortages. The state also directed all state agencies to use less water and expand their water conservation campaigns. During this time, these factors have led to excessively dry conditions in the City of Petaluma and the surrounding areas than in past years, often requiring disaster declarations to be enacted to combat drought conditions. Sonoma County declared a Proclamation of Local Emergency Due to Drought Conditions from February 2015 to the end of 2015. On June 1, 2015 the Petaluma City Council imposed Stage 2 (mandatory) restrictions . From June 2015 to February 2016, the City as a whole was required to reduce its overall water use by 16 percent compared to 2013 consumption.

This drought period now marks the second time a statewide proclamation of emergency has been issued for this hazard. On April 17, 2017 Executive Order B-40-17 was issued, which officially ended the drought state of emergency in California, except for Fresno, Kings, Tulare, and Tuolumne counties. Table 4-10 summarizes the drought-related disaster declarations proclaimed for Sonoma County from 1976 through 2019. These declarations include those from FEMA, the USDA's Secretary of Agriculture, and events noted in the State of California's 2018 State Hazard Mitigation Plan.

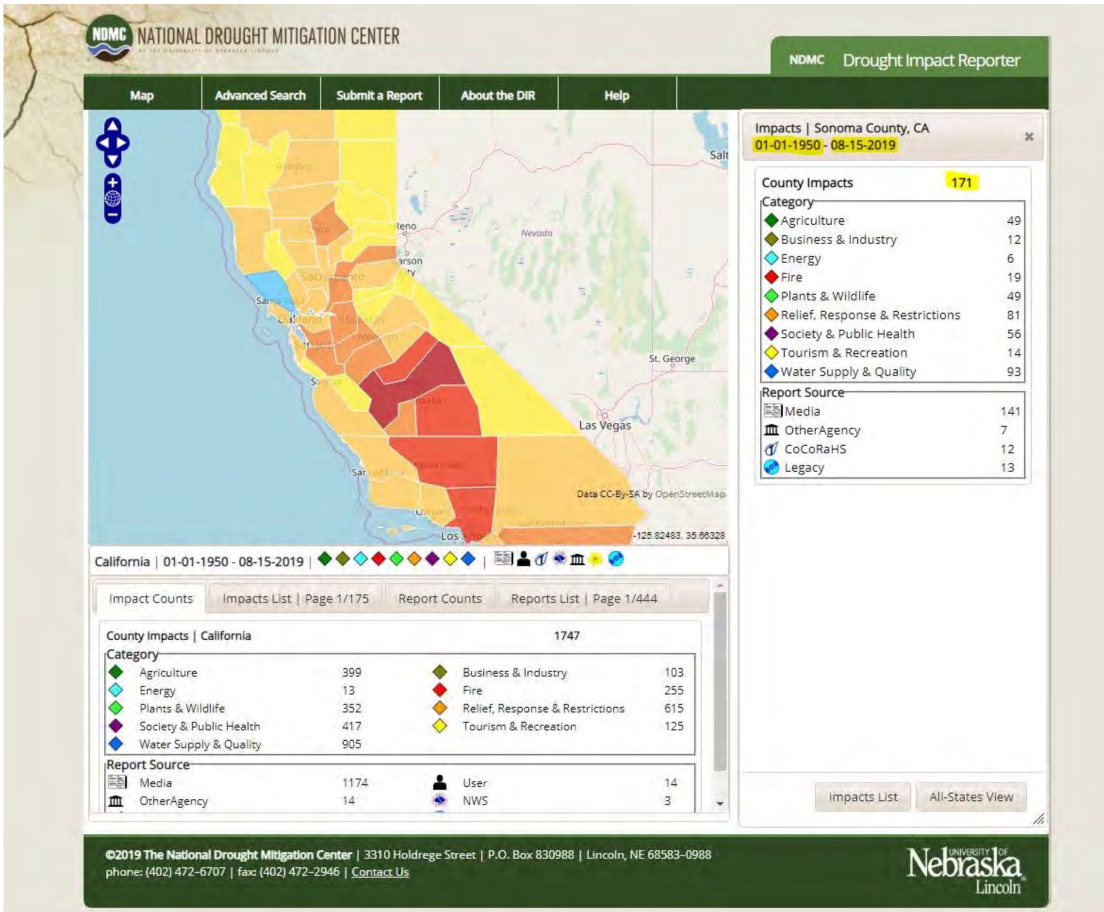
Table 4-10: Disaster Declarations and Proclamations Related to Drought in Sonoma County

Declaration or Order	Date
1976 Drought (State)	1976
EM-3023 (FEMA)	1/20/1977
S3248 (Secretary of Agriculture)	2012
S3452 (Secretary of Agriculture)	2012
S3565 (Secretary of Agriculture)	2013
S3569 (Secretary of Agriculture)	2013
S3637(Secretary of Agriculture)	2014
S3743 (Secretary of Agriculture)	2014
S3797 (Secretary of Agriculture)	2014
S3784 (Secretary of Agriculture)	2015
S3943 (Secretary of Agriculture)	2015
S3952 (Secretary of Agriculture)	2016
S3964 (Secretary of Agriculture)	2016
S4163 (Secretary of Agriculture)	2016-2017
S4144 (Secretary of Agriculture)	2017

Source: USDA Disaster Designations 2019; California SHMP 2018; FEMA

Figure 4-8 graphically displays the amount of drought-related reported impacts to Sonoma County (United States Drought Impact Reporter 2019). While it is difficult to extract the impacts specifically affecting Petaluma, a total of 171 reports were made within Sonoma County between January 1, 1950 and August 15, 2019. It is assumed that these drought-related impacts for areas across Sonoma County are likely to have also affected Petaluma at some point or to some extent. Based on the summary of negative effects to Sonoma County since 1950, the categories of water supply/quality have had the most reports, followed by relief, response, and restrictions operations and society and public health. Agriculture and plants and wildlife have also suffered the effects of drought, but to a lesser extent.

Figure 4-8: Drought Impact Reporter Summarizing Impacts at the County Level in Sonoma County, 1950-2019



Source: National Drought Mitigation Center Drought Impact Reporter, 2019

Probability of Future Occurrences

Likely – Historical drought data for California and more particularly the Sonoma County municipalities indicate there have been significant droughts and negative effects from water shortages in the past and the present. Based on this data, droughts are likely to affect the City's Planning Area and surrounding parts approximately every ten years; some of these droughts may persist for multiple years.

Climate Change Considerations

Scientific studies prepared for various California climate assessments and adaptations strategies show that drought conditions in California are likely to become more frequent and persistent over the next century due to climate change. Temperatures are warming, heat waves are more frequent, and precipitation has become increasingly variable (Natural Resources Agency 2018a). Water resources are also already experiencing the following stresses: population growth, poor water quality, groundwater overdraft, and aging water infrastructure.

The recent drought conditions over the past decade underscore the need to examine water supply and distribution management, conservation, and use policies. California and Sonoma County have experienced a succession of dry spells, and with warmer temperatures the impacts of drought conditions have increased (OEHHA 2018). In an average year, approximately 40 percent of the state's total water supply comes from groundwater, and during a dry year this increases to more than half of the state's water supply, with groundwater acting as a critical buffer against the impacts of drought and climate change (Natural Resources Agency 2018a). The City of Petaluma only uses groundwater in emergencies, but the Petaluma Valley Groundwater Basin has shown to have a reduction in groundwater levels due to the 2012-2015 drought period (City of Petaluma 2015).

According to California's Climate Adaptation Strategy, also referred to as "Safeguarding California Plan: 2018 Update," climate change is likely to significantly diminish California's future water supply. As a result, the state must change its water management, as climate change will create greater competition for limited water supplies (California Natural Resources Agency 2018b). Similarly, as summarized in the Sonoma County CAP, climate change could result in hotter and drier weather, and more frequent and intense droughts. The CWA (numeric measure of drought stress that quantifies the extent to which plants need for water exceeds moisture available in soil) for the region is projected to increase over this century, producing 10 to 20 percent drier soil conditions in the summer months, leaving less water available for groundwater recharge or runoff into rivers and creeks (RCAP 2016). The greatest increases in soil dryness are projected in the south and southeastern portions of the County, near Petaluma (RCAP 2016). These water management concerns will also impact Sonoma Water, the City's main water supplier.

Vulnerability Assessment

Property

Drought impacts are wide-reaching and may be economic, environmental, and societal. The most significant impacts associated with drought in the City's Planning Area are those related to water intensive activities, such as agriculture, municipal water use, commerce, tourism, and recreation. The vulnerability of a water intensive activity to the effects of drought usually depends on its water demand, whether the demand is met, and what water supplies are available to meet the demand. For the City of Petaluma, water allocations go down during a drought, and the City's contractual surface water entitlements may be reduced. According to the 2015 UWMP, because the City relies more on surface water supplies from the Russian River they can also use available groundwater supplies as a buffer during drought conditions. Water restrictions and other conservation measures are typically implemented during extended droughts, and these can result in economic impacts on water utilities managed by the City of Petaluma. Drought conditions can also cause soil to compact and not absorb water efficiently, potentially making areas more susceptible to flooding.

According to the Drought Impact Reporter the Sonoma County recorded a total of 171 impacts to drought in the survey period between 1/1/1950 and 8/15/2019 (69-year period). Of these, the majority of the impacts were associated with Water Supply and Quality; and Relief, Response, and Restrictions. These statistics are shown in Figure 4-8 (above). While the Drought Impact Reporter data reflects impacts at the county-level, the data should be used to develop an ongoing record of drought impacts that can be more specifically tied to events that occur within the City's Planning Area to better understand city-specific vulnerable sectors and impacts.

People

According to the California Department of Finance (DOF) as of 2017 the City population was around 60,210. The City supplies a majority of its water (95 percent) to residential users. The population is expected to continue to increase in the future. This projected population growth would add additional strain to the surface water supplies. There are also several initiatives in the UWMP (and water contingency plan and groundwater management policies) that emphasize water conservation, and its planned expansion of the City's recycled water system is expected to reduce the water demand for irrigation water in the summer months. Water conservation will also ensure that the existing groundwater remains operational during severe drought conditions and readily available during emergencies.

Drought can also cause public health problems related to poor water quality, and health problems can become exacerbated due to dust. Generally, drought may require conservation of water resources, which means that water use is restricted to essential uses, which may reduce watering for landscaping. The community may also exhibit a range of abilities to prepare for, respond to, and recover from drought hazards, as these conditions impact populations with health-related issues related to heat-related illness, respiratory problems, and people who work outdoors. These conditions can also impact lower-income populations, as food and water prices increase. There are sensitive and socially vulnerable populations residing near the downtown area of the Planning Area that may be the most susceptible to water restrictions, and health-related illnesses. Socially vulnerable populations may also be sensitive to increases in water rates and in turn, food prices.

Economy

Drought impacts to the local and regional economy can be difficult to quantify but can be extensive and long-lasting depending on the circumstances during and after a severe drought event. If water resources are limited, effects would be more severe for industries that rely on large amounts of water, and any prolonged drought would intensify these impacts. Sectors critical to the economy such as commerce, distribution, agriculture, tourism, related environmental resources, municipal and industrial water supply, key city assets, energy generation, and even socioeconomic aspects can be affected due to lack of or reduced quality of water resources.

While there are few water intensive agricultural uses within the City's Planning Area, the City does supply agricultural areas outside the City with recycled water and plans to expand services in the future. Long lasting droughts can be indirectly detrimental to the City's water supply but may be mitigated through the expansion of the recycled water facility.

Critical Facilities and Infrastructure

The most direct impact of drought will be on the City's water supply. Drought can also directly affect the water storage, treatment, and distribution and conveyance systems. Landscaping around city facilities may no longer be maintained during water restrictions, but the risk within the Planning Area will be largely aesthetic.

Historic, Cultural, and Natural Resources

Severe, prolonged drought can impact the natural environment. Wildlife and natural habitats including the Petaluma River can be affected, including the shrinkage of habitat, habitat fragmentation, reduced food supply for wildlife, and possibly the migration of species in the nearby hillsides that define the City of Petaluma. Prolonged drought can also cause poor soil quality, loss of wetlands, tree mortality (along the periphery of the City's Planning Area), and increased soil erosion.

Tree mortality is identified as a cascading impact that can affect (or worsen) other hazards, such as wildfire and wind conditions. For example, drought-impacted trees can become susceptible to diseases and insect infestations that further exacerbate the risk of tree mortality. One of the most prevailing impacts of drought to the natural environment is the increased risk of wildfires, as seen during the 2017-2018 wildfire seasons. Wildfires now burn larger and more intensely during dry conditions and are happening outside the typical fire season. Lastly, drought conditions can cause soil to compact and not absorb water well, potentially making an area more susceptible to flooding.

Impacts to the City's historic and cultural building inventory may be negligible. The City's open spaces and park and public lands can suffer during droughts, though the ability of the City to use recycled water for irrigation purposes can offset this vulnerability.

Future Development

Future development and water conservation are the focus of each update to the City of Petaluma's UWMP and this planning process specifically address drought conditions and water contingencies. In 2015, the City of Petaluma provided water to more than 61,798 customers, and the UWMP describes how current and future water resources and demands within the City's service area will be managed to provide adequate and reliable water supply.

As the population grows over time the City will have to revise their reliability and supply projections from the Sonoma Water. Sonoma Water may reduce water deliveries as water levels in major reservoirs decrease. Therefore, as new development occurs in the City's Planning Area it will be important to assess the availability and reliability of multiple water sources, such as groundwater and recycled water. The City currently supplies a majority of water supply to single family residents and is expecting demand for potable and raw water to increase by 70 percent by 2040. Consistent with Senate Bill 610, any proposed developments in the City are mandated to estimate future water uses and identify water supplies that may be used to meet their uses. This water supply assessment process is intended to ensure that adequate water supplies exist to support new growth.

Risk Summary

- There have been six multi-year droughts since 1950, three of which have occurred since 2000. The most recent drought lasted from 2012 to 2017 and resulted in a declared state of emergency.
- 171 drought impact reports were made within Sonoma County between 1950 and 2019.
- As of 2015, the City of Petaluma was supplying 6,744 acre-feet of water, the majority of which is supplied to single family residential properties. The City's 2015 UWMP projects that demand for potable and raw water will increase to 9,623 acre-feet, or by 70 percent by the year 2040.
- Population is expected to increase to 73,350 by 2040, or an increase of about 13,140 people per year; this projected growth would add additional strain to the water supply, particularly during future severe drought events.
- Climate change projections indicate the region will experience more frequent and intense droughts due to drier soil conditions in the summer months, leaving less water available for groundwater recharge.
- The enforcement of water conservation policies, regular updates to the UWMP, and the expansion of the City's recycled water facility will help ensure the City of Petaluma is more resilient to drought events in the future.

4.3.3 Earthquakes

Hazard Description

An earthquake is caused by a sudden slip on a fault. Stresses in the earth's outer layer push the sides of the fault together. Stress builds up, and the rocks slip suddenly, releasing energy in waves that travel through the earth's crust and cause the shaking that is felt during an earthquake. The amount of energy released during an earthquake is usually expressed as a magnitude and is measured directly from the earthquake as recorded on seismographs. Another measure of earthquake severity is intensity. Intensity is an expression of the amount of shaking at any given location on the ground surface (see discussion in the Extent section). Seismic shaking is typically the greatest cause of losses to structures during earthquakes.

Seismic Hazards

Earthquakes can cause structural losses, injury, and possibly death, as well as damage to infrastructure such as water, power, gas, communication, and transportation networks and systems. The degree of damage depends on many interrelated factors. Among these are the magnitude, focal depth, distance from the causative fault, source mechanism, duration of shaking, high rock accelerations, type of surface deposits or bedrock, degree of consolidation of surface deposits, presence of high groundwater, topography, and the design, type, and quality of building construction.

Primary hazards associated with seismic activity include surface rupture along faults, ground shaking, and associated building failure. Secondary hazards result from the interaction of ground shaking with existing ground instabilities or facilities and include liquefaction, settlement, debris flows, landslides, tsunamis and seiches, and perhaps flooding or wildfires from broken pipelines, gas, or electrical infrastructure.

Ground Shaking

When movement occurs along a fault, the energy generated is released as waves, which cause ground shaking. Ground shaking intensity varies with the magnitude of the earthquake, the distance from the epicenter, and the type of rock or sediment through which the seismic waves move. The geological characteristics of an area can be a greater hazard than the area's distance to the earthquake epicenter.

The City of Petaluma is situated within an area of high potential seismic activity (the San Francisco Bay Region), and so the fault systems within and around the City have the potential to produce earthquakes that could impact the City of Petaluma significantly (e.g. the San Andreas Fault System which is currently active). A high-magnitude earthquake on one of these faults could cause moderate to high ground shaking in the City. Figure 4-9 below is an earthquake shaking map for the City of Petaluma that is based on the two percent probability of occurrence in 50 years, per the USGS analyses of nearby faults. The probability of occurrence map represents a worst-case shaking scenario and shows that the City of Petaluma will experience strong ground shaking, which has the potential to be damaging.

Liquefaction Susceptibility

Liquefaction can be defined as the loss of soil strength or stiffness due to a buildup of pore-water pressure during a seismic event, and is associated primarily with relatively loose, saturated fine to medium-grained unconsolidated soils. Seismic ground shaking of relatively loose, granular soils that are saturated or submerged can cause the soils to liquefy and temporarily behave as a dense fluid. If this layer is at the surface, its effect is much like that of quicksand for any structure located on it. If the liquefied layer is in the subsurface, the material above it may slide laterally depending on the confinement of the unstable mass. Liquefaction is caused by a sudden temporary increase in pore-water pressure due to seismic densification or other displacement of submerged granular soils. Liquefiable soil conditions are not uncommon in alluvial deposits in moderate to large canyons and could also be present in other areas of alluvial soils where the groundwater level is shallow (i.e. 50 feet below the surface). Bedrock units, due to their dense nature, are unlikely to present a liquefaction hazard.

According to the USGS Earthquake Hazards Program data for liquefaction susceptibility, there are several areas of liquefaction susceptibility in the City of Petaluma and its Planning Area (see Figure 4-10 below). The majority of the city is in the moderate liquefaction susceptibility zone, while parts of it in the center and close to Highway 101 (near Washington Street and Western Avenue) are within more severe liquefaction susceptibility zones. Approximately 1,851 acres fall in the high liquefaction susceptibility areas within Petaluma and 559 acres in the very high liquefaction susceptibility areas. Most of these highly susceptible categories follow the Northwestern Pacific railroad, which is similar to the Petaluma River's general location as it flows from the northwest of the City, though the center and downtown area, then out through the center-east.

Earthquakes can also lead to secondary hazards including flooding, building structure failure, debris flows, and fire (among others). The City is at risk of flooding from dam or levee failure as well as risk of broken pipelines and critical structures such as the water treatment facility on the east of the City.

Figure 4-9: Potential Ground Shaking Probability in the City of Petaluma

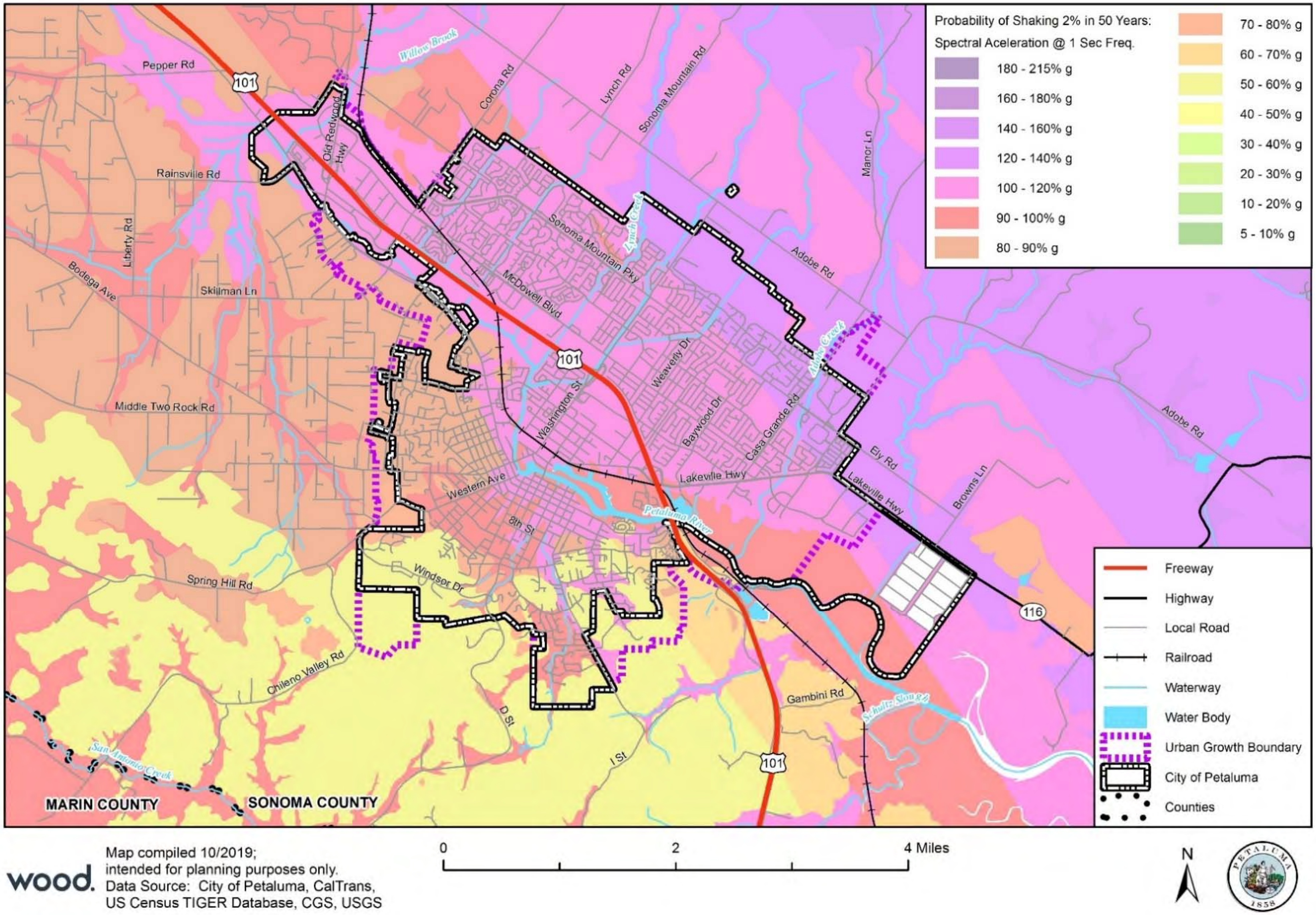
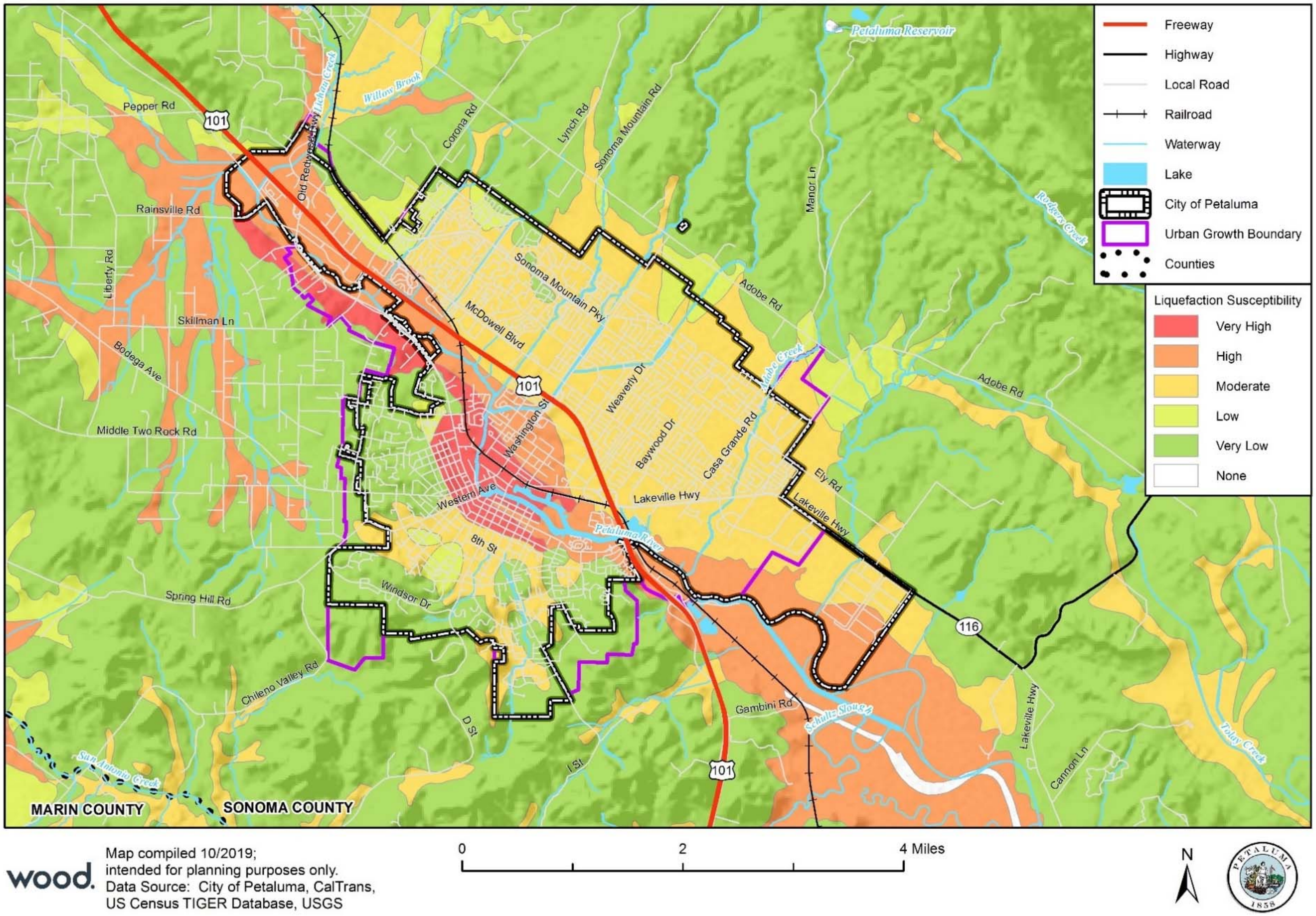


Figure 4-10: Liquefaction Susceptibility in the City of Petaluma



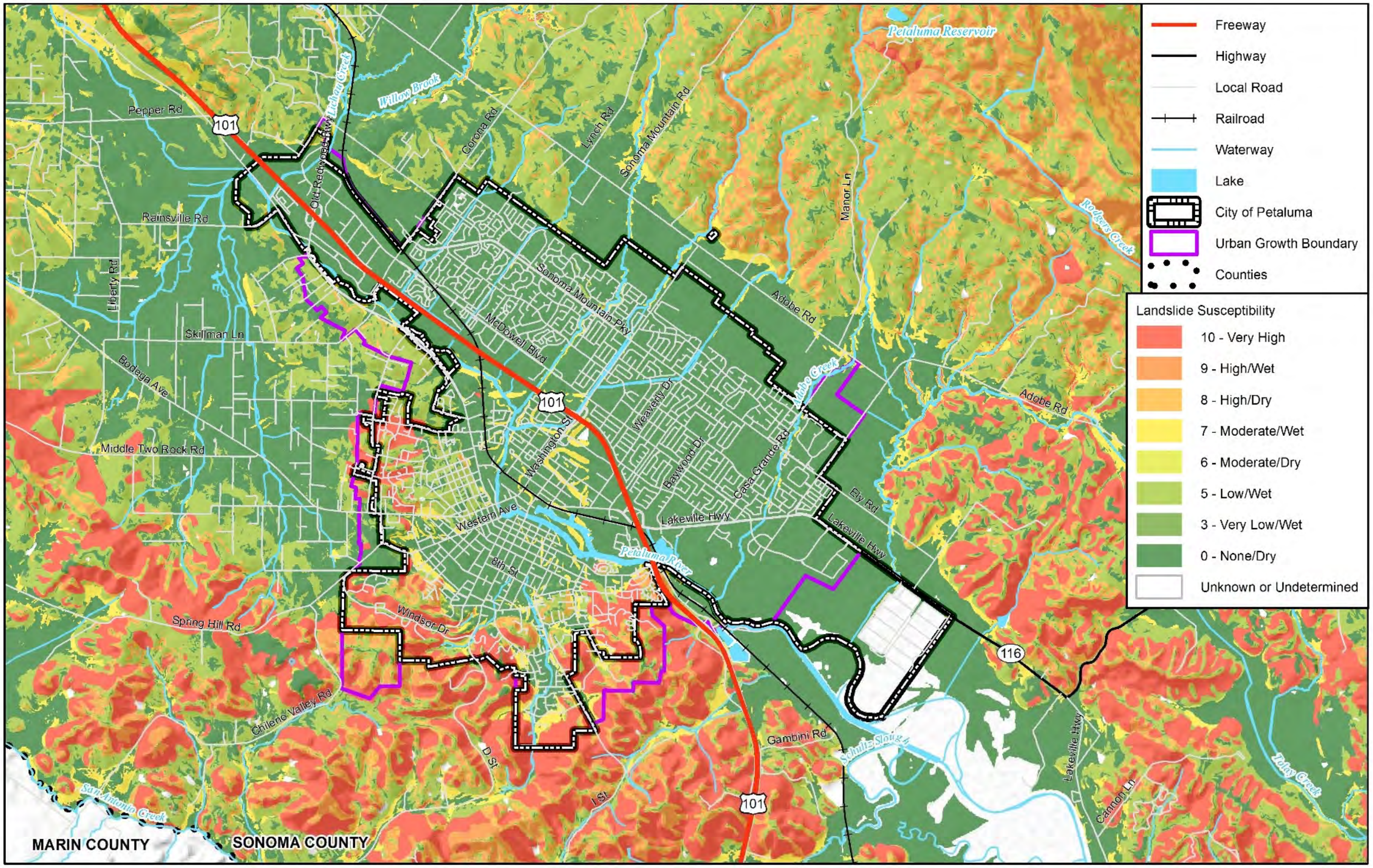
Landslide Potential and Susceptibility

A landslide is a geologic hazard where the force of gravity combines with other factors to cause earth material to move or slide down an incline. Some landslides move slowly and cause damage gradually, whereas others move so rapidly that they can destroy property and take lives suddenly and unexpectedly. Slopes with the greatest potential for sliding are between 34 degrees and 37 degrees. Although steep slopes are commonly present where landslides occur, it is not necessary for the slopes to be long.

There are predictable relationships between local geology and landslides. The down-slope movement of earth material as a landslide is part of the continuous, natural process of erosion. This process, however, can be influenced by a variety of causes that change the stability of the slope. Slope instability may result from natural processes, such as the erosion of the toe of a slope by a stream, or by ground shaking caused by an earthquake. Slopes can also be modified artificially by grading, or by the addition of water or structures to a slope. Landslide problems can be caused by land mismanagement, particularly in mountain, canyon, and coastal regions. In areas burned by forest and brush fires, a lower threshold of precipitation may initiate landslides and debris flows. As human populations expand over more of the land surface, these processes become an increasing concern. As such, development that occurs on a slope can substantially increase the frequency and extent of potential slope stability hazards. Knowledge of these relationships can improve planning and reduce vulnerability. Slope stability is dependent on many factors and their interrelationships, including rock type, moisture content, slope steepness, and natural or man-made undercutting.

The California Geological Survey (CGS) along with the California Department of Conservation have generated a landslide dataset that classifies susceptibility in California to various degrees, from Very High (the most potentially dangerous) to a none or dry category (the least risk). Unknown or undetermined areas exist as well, as displayed in Figure 4-11 below. In Petaluma the majority of the Planning Area is in the lower risk categories of landslide susceptibility, meaning that the local soils and geology are not very likely to lead to landslide activity. However, some higher landslide susceptibility areas fall inside the Planning Area’s boundary, such as in the west and south of the City where there is hilly terrain.

Figure 4-11: Landslide Susceptibility in the City of Petaluma and Its Planning Area



Map compiled 10/2019;
intended for planning purposes only.
Data Source: City of Petaluma, CalTrans, US Census TIGER Database, CGS/CA Dept. of Conservation

0 2 4 Miles

N

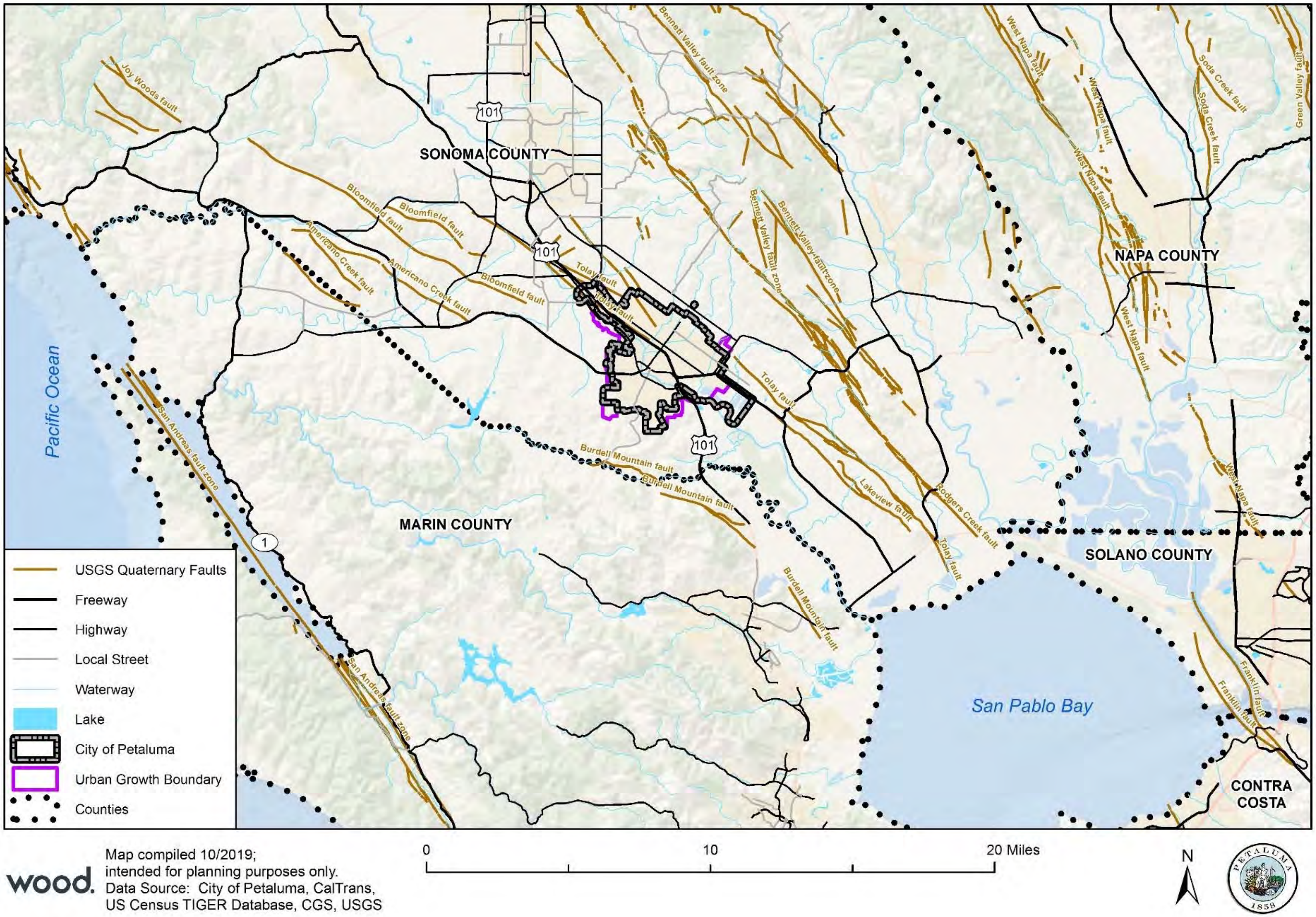
Faults

California is a seismically active area with numerous faults throughout the region. An active fault is defined by CGS as a fault that has had surface rupture or displacement within the last 11,000 years (Holocene times). This does not mean, however, that faults having no evidence of surface displacement within the last 11,000 years are necessarily inactive. Potentially active faults are those that have shown displacement within the last 1.8 million years (Quaternary period) but have not moved within the Holocene times. Any fault older than Pleistocene (>1.8 million years) is considered inactive and dormant. Although based on the history of fault movement and seismic activity in the area, it is known that the main faults posing risk to the City are the San Andreas Fault system and the Healdsburg-Rodgers Creek Fault (see the Location section of this chapter for additional details).

As shown in Figure 4-12, there are several earthquake faults classified as Quaternary (those which are recognized at the surface and which have shown activity in the past 1.6 million years, or during the geologic Quaternary epoch) in the Planning Area. Additional faults are present which are located farther from the City of Petaluma than is shown in the map (and could cause seismic activity in the future). The faults illustrated in Figure 4-12 are summarized below:

- Lakeview fault on the southeast of the City;
- Part of Tolay fault on the southeast of the City boundary, as well as reaching on the northwest portion of the City;
- Bennett Valley fault zone, to the northeast of the City but outside of its limits; and
- The Rodgers Creek fault, along Rodgers Creek to the northeast of the City but outside of the limits.

Figure 4-12: Earthquake Faults near the Planning Area



Location

There are two notable faults adjacent to the City of Petaluma, which are discussed in more detail below. Addition faults nearby the Planning Area are illustrated in Figure 4-12. There is one active fault (the San Andreas Fault) and potentially active fault (such as the Healdsburg-Rodgers Creek Fault) that fall outside the Planning Area but have historically been the source of earthquakes felt in Petaluma. These local and regional faults are described in more detail below based on information summarized in the Sonoma County Hazard Mitigation Plan from 2016 as well as the City of Petaluma General Plan.

San Andreas Fault. The San Andreas Fault is located approximately 20 miles west of the Planning Area. It is a shallow fault and is considered the most active fault in California. Historically, the San Andreas Fault system is the main fault responsible for earthquakes felt in the City and is also expected to continue being the source of future earthquake activity.

Healdsburg-Rodgers Creek Fault. The Healdsburg-Rodgers Creek Fault is an active fault associated with the Santa Rosa Plain, in Sonoma County. It is a strike slip fault, measuring around 117 kilometers in length. The most notable earthquake activity along this fault took place in 1969 during the Santa Rosa Earthquakes. These were a magnitude 5.6 and 5.7 strikes early October of that year, in Santa Rosa County to the north of the City of Petaluma.

Extent (Magnitude/Severity)

Catastrophic – Extent (meaning the severity of an earthquake) refers to the amount of energy released during an earthquake and is usually expressed in terms of intensity or magnitude. These metrics are measured directly from the earthquake as recorded on seismographs.

Intensity represents the observed effects of ground-shaking at any specified location, and earthquake shaking decreases with distance from the earthquake epicenter. Intensity is an expression of the amount of shaking at any given location on the ground surface based on felt or observed effects. Seismic shaking is typically the greatest cause of losses to structures during earthquakes. Intensity is measured with the Modified Mercalli Intensity (MMI) scale (see

Table 4-11).

Magnitude represents the amount of seismic energy released at the hypocenter of an earthquake and is based on the amplitude of the earthquake waves recorded. Seismologists have developed several magnitude scales; one of the first was the Richter Scale, developed in 1932 by Dr. Charles F. Richter of the California Institute of Technology. The Moment Magnitude Scale is the current scale used to quantify the magnitude or strength of the seismic energy released by an earthquake.

Table 4-11 below compares magnitude and the felt effects associated with the MMI scale. Damage typically occurs in MMI of VII or above and based on Figure 4-9. The majority of the City is found in areas where spectral acceleration is expected to surpass the 70 percent g (or gravitational velocity); this means that there is a high probability of the City experiencing strong seismic movements in the next few decades.

Table 4-11: Magnitude and Mercalli Intensity Scale Measurements and Associated Characteristics

Magnitude	Mercalli Intensity	Effects	Frequency
Less than 2.0	I	Micro-earthquakes, not felt or rarely felt; recorded by seismographs.	Continual
2.0-2.9	I to II	Felt slightly by some people; damages to buildings.	Over 1M per year
3.0-3.9	II to IV	Often felt by people; rarely causes damage; shaking of indoor objects noticeable.	Over 100,000 per year
4.0-4.9	IV to VI	Noticeable shaking of indoor objects and rattling noises; felt by most people in the affected area; slightly felt outside; generally, no to minimal damage.	10K to 15K per year
5.0-5.9	VI to VIII	Can cause damage of varying severity to poorly constructed buildings; at most, none to slight damage to all other buildings. Felt by everyone.	1K to 1,500 per year
6.0-6.9	VII to X	Damage to a moderate number of well-built structures in populated areas; earthquake-resistant structures survive with slight to moderate damage; poorly designed structures receive moderate to severe damage; felt in wider areas; up to hundreds of miles/kilometers from the epicenter; strong to violent shaking in epicentral area.	100 to 150 per year
7.0-7.9	VIII<	Causes damage to most buildings, some to partially or completely collapse or receive severe damage; well-designed structures are likely to receive damage; felt across great distances with major damage mostly limited to 250 km from epicenter.	10 to 20 per year
8.0-8.9	VIII<	Major damage to buildings, structures likely to be destroyed; will cause moderate to heavy damage to sturdy or earthquake-resistant buildings; damaging in large areas; felt in extremely large regions.	One per year
9.0 and Greater	VIII<	At or near total destruction - severe damage or collapse to all buildings; heavy damage and shaking extends to distant locations; permanent changes in ground topography.	One per 10-50 years

Source: USGS

Previous Occurrences

In 2014 a 6.0 magnitude earthquake occurred in the southern portion of the City of Napa on the West Napa Fault. The event was the largest earthquake in the San Francisco Bay Area since the 1989 Loma Prieta earthquake. Total damage in the southern Napa and Vallejo areas ranged from $362 million to $1 billion. *Photo Credit: LA Times 2014*

Earthquakes have occurred nearby the Planning Area in the past (within Sonoma County and adjacent areas). According to the USGS, a recent earthquake event of a magnitude of 6.0 took place near South Napa, about 23 miles to the east of the City of Petaluma Planning Area. This event occurred the morning of August 24, 2014 and had a reported intensity of VII in the Mercalli scale. The earthquake was on the West Napa Fault, which was not mapped under the Alquist-Priolo earthquake fault hazard zone and was the largest event of this kind in the San Francisco Bay area since the 1989 Loma Prieta earthquake. The seismic activity of this event had an estimated 11.1 kilometers of depth. Thousands of structures across Sonoma County were damaged, and hundreds of people were injured during the quake across the affected areas in the County. One person was reported as being killed during the earthquake. Because of the extensive damages, the California Governor issued an emergency proclamation on August 24, 2014, and the U.S. President declared the incident a major disaster on September 11, 2014. Total economic losses were around $400 million, and state and federal assistance surpassed the $30 million mark. The Small Business Administration granted over $21 million in low-interest disaster loans to local businesses and other agencies affected by the event.

Other recent earthquake events in the area include smaller magnitude earthquakes such as:

- A magnitude 2.8 earthquake with reported intensity of III, on December 24, 2017. This event's epicenter was about 6 kilometers west of Temelec, near Sonoma. The depth of the event was of 1 kilometer.
- A magnitude 2.7 earthquake with reported intensity of II, on November 17, 2013. The epicenter of this incident was about 5 kilometers east-southeast of Penngrove, north of Petaluma. The depth of the event was of 4.4 kilometers.
- A magnitude 3.3 earthquake took place on July 25, 2011 and had a reported intensity of IV. Its depth was of 6.7 kilometers and the epicenter was located a few kilometers north-northwest of Petaluma.

Probability of Future Occurrences

Likely – Given the information presented herein as well as recent quake activity history, earthquake hazards are expected to be a likely occurrence in the City of Petaluma as well as in Sonoma County. It is estimated that similar seismic activity events may occur every 20 to 30 years in the Planning Area and the overall San Francisco Bay region (State of California Seismic Safety Commission).

The USGS noted in 2008 that there was a 63 percent probability of a strong earthquake (of magnitude 6.7 or greater) striking the San Francisco Bay Region (of which Petaluma is part) by 2032. The probability of having a strong earthquake (of this magnitude 6.7 or greater) generated from the Healdsburg-Rodgers Creek Fault was then estimated at about 27 percent while the San Andreas Fault had an estimated 21 percent chance of causing a strong earthquake by 2032 (USGS 2003). However, more recent information released in 2015 by the USGS new Uniform California Earthquake Rupture Forecast 3, or UCERF3, considers additional parameters and data. This new criteria and advanced technology, the updated results estimate that the actual chance of a strong earthquake of magnitude 6.7 or above is around 72 percent in the San Francisco Bay Region. The San Andreas fault now has a 33 percent chance of rupturing and causing earthquake activity, though the Rodgers Creek fault system's probability has decreased to about 15 percent chance of rupture (Uniform Earthquake Rupture Forecast Version 3 2014).

Climate Change Considerations

While climate change is not expected to directly affect earthquake frequency or intensity it could exacerbate indirect or secondary impacts of earthquakes. For example, climate change could increase the frequency and intensity of extreme precipitation events, in turn increasing the probability of landslides and liquefaction events during an earthquake if the earthquake coincided with a wet cycle.

Vulnerability Assessment

Ground shaking is the primary hazard related to earthquake activity. Many factors affect the survivability of structures and systems from earthquake-caused ground motions. These factors include proximity to the fault, direction of rupture, epicentral location and depth, magnitude, local geologic and soils conditions, types and quality of construction, building configurations and heights, and comparable factors that relate to utility, transportation, and other network systems. Ground motions become structurally damaging when average peak accelerations reach 10 to 15 percent of gravity, average peak velocities reach 8 to 12 centimeters per second, and when the MMI Scale is about VII, which is considered to be very strong (general alarm; walls crack; plaster falls).

Fault rupture itself contributes very little to damage unless the structure or system element crosses the active fault. In general, newer construction is more earthquake resistant than older construction because of improved building codes and enforcement. Manufactured housing is very susceptible to damage because rarely are the foundation systems braced for earthquake motions. Locally generated earthquake motions, even from very moderate events, tend to be more damaging to smaller buildings, especially those constructed of unreinforced masonry.

The HMPC noted that the City of Petaluma's unreinforced masonry building (URM) inventory was initiated in 1992 based on a resolution to strengthen and upgrade the City's URM buildings as required by local and state regulations (with more details available in the Petaluma Ordinance No. 1882, Section 17.34.110). The URM reinforcement resolution (No. 92-48 N.C.S. of the City of Petaluma), required the URM buildings to be retrofitted by the year 2017 (for Group IV, which was the last priority group), though the time limits varied by group types. Group I URM structures were at highest risk of failure, with Groups II, III, and IV to follow in terms of risk category so that Group IV was at lowest risk of failure. Based on the resolution, it was noted that 22 buildings in the City were categorized under Group I; 17 buildings were categorized under Group II; 27 buildings were categorized under Group III; and, 32 buildings were categorized under Group IV, for a total of 98 URM inventoried structures. Given this URM retrofit process, it is unlikely that the City of Petaluma continues to have URM structures susceptible to seismic movement events, which in turn reduces the City's overall structure exposure and risk.

Other common impacts from earthquakes include damage to infrastructure and buildings (e.g., crumbling of unreinforced masonry, failure of architectural facades, rupturing of underground utilities, and road closures). Earthquakes also frequently trigger secondary hazards, such as dam and levee failures, flooding, and fires that can become disasters themselves.

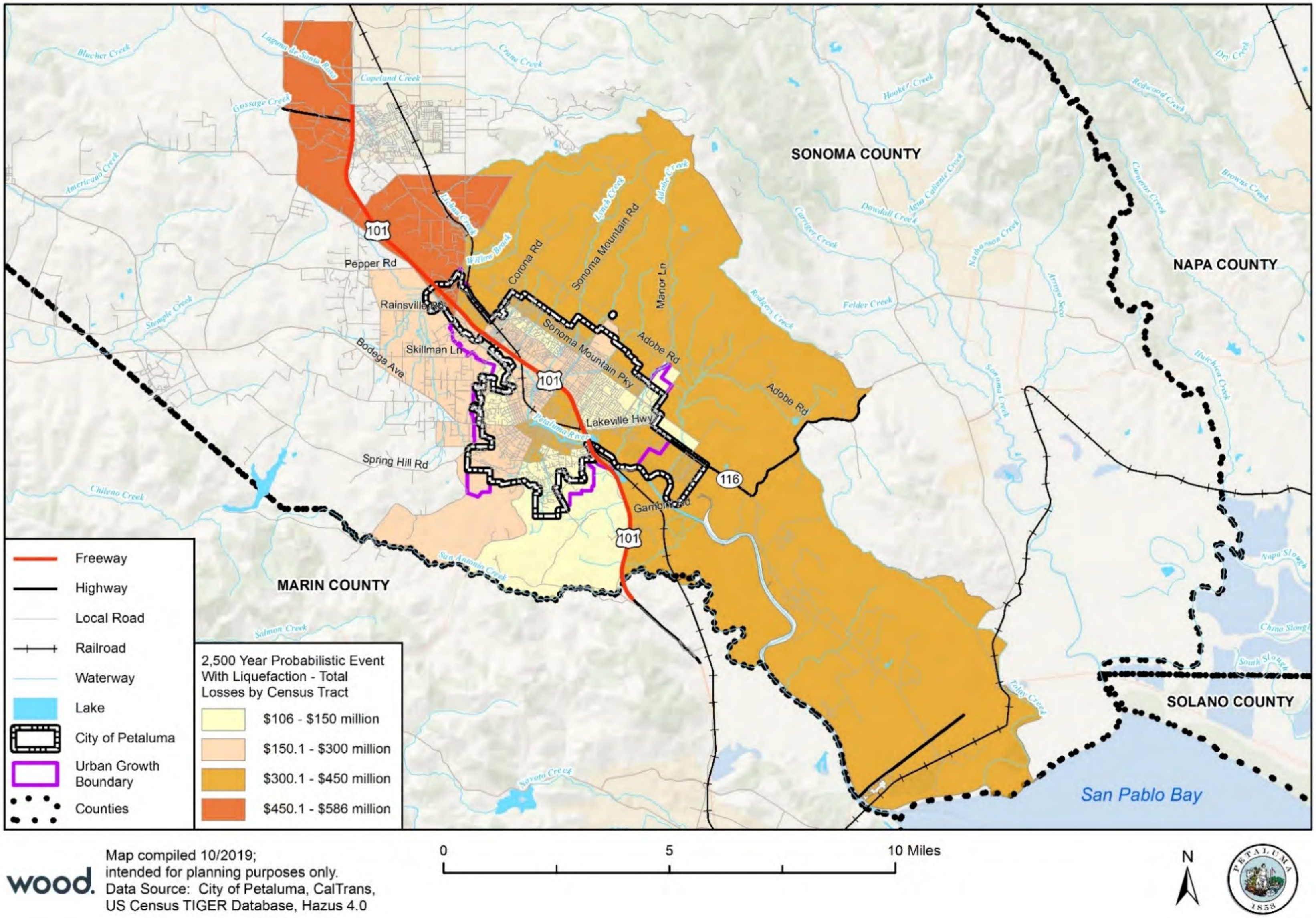
FEMA's loss estimation software, Hazus-MH (which originally stood for 'Hazards U.S.'), was used to analyze the City's vulnerability to earthquakes, at the census tract level (for 15 tract units that cover the City of Petaluma, displayed in Figure 4-13 below). Note that these census tract boundaries do not neatly line up with the City's boundary, and as such a slightly larger area than that covered in this planning context was necessary to include Petaluma. Because of these boundary differences, the damage and loss estimates may be slightly exaggerated (given the larger coverage of structures and population).

2,500-Year Probabilistic Earthquake Scenario

The 2,500-year probabilistic Hazus-based earthquake scenario results include liquefaction susceptibility. Loss estimates and vulnerability assessment discussions are based on the following subsections: property; people; the local economy; critical facilities and infrastructure; historic, cultural, natural resources; and future development in the Planning Area.

The total losses by census tract are shown in Figure 4-13. Refer to Section 4.1.1 and FEMA's Hazus 4.0 Loss Estimation Tool for more information on the Hazus tool and its analysis functions. This methodology was selected to support the vulnerability assessment, as it is a national standard for modelling earthquake loss. To evaluate potential losses associated with earthquake activity in the Planning Area, a Hazus 2,500-year probabilistic scenario including liquefaction susceptibility was run for the City's 15 census tracts, using a Magnitude of 7.0 as the parameter that would simulate a strong earthquake. Due to these inputs, this 2,500-year scenario with liquefaction susceptibility represents a worst-case level of shaking that considers multiple faults in the region. Hazus estimates the number of people displaced, the number of buildings damaged and their type (e.g. construction material, occupancy class), the number of causalities, and the damage to transportation systems and utilities (e.g. critical facilities).

Figure 4-13: Hazus 2,500 Year Probabilistic Earthquake Scenario with Liquefaction Susceptibility – Total Losses by Census Tract



A summary of the key losses based on the Hazus earthquake analysis results included the following:

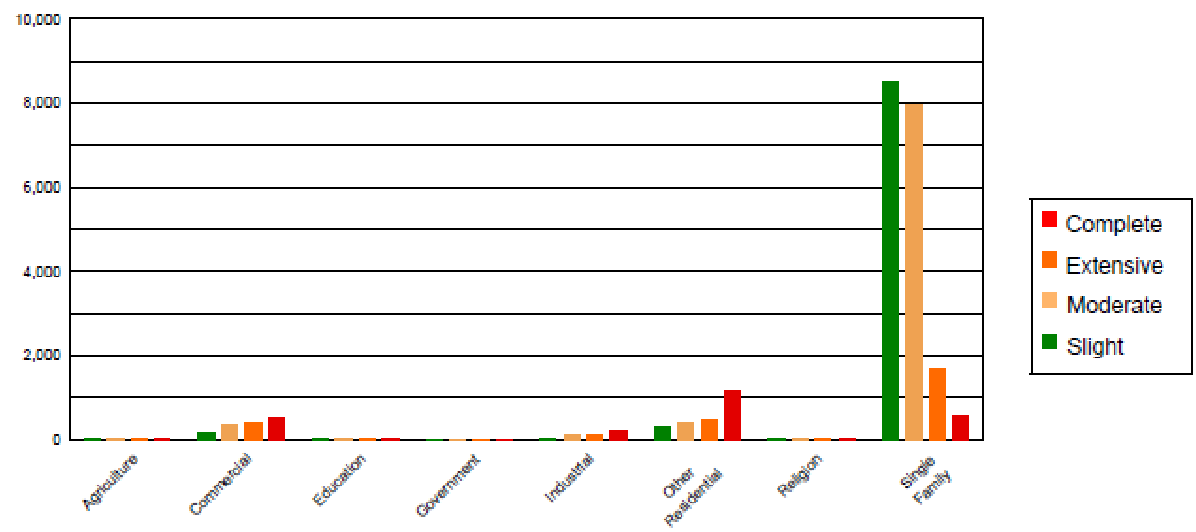
- Total economic loss estimated for the earthquake was $3.63 billion, which includes building losses and lifeline related losses based on the Hazus inventory for the Planning Area.
- Building-related losses, including direct building damages and business interruption losses, totaled $3.47 billion.
- $484.9 million in losses came from income related losses from wage-related, capital-related, rental properties, and relocation costs, while almost $3 billion came from capital stock losses related to structural, contents-based, and inventory property categories.
- 14 percent of the estimated losses were related to business interruptions.
- 14,179 buildings (53 percent of total in the region) would be at least moderately damaged; 2,545 of those buildings would be damaged beyond repair.
- Residential structures made up 47 percent of the total earthquake-induced losses.
- $78.8 million in losses are associated with transportation system economic damages and losses (e.g. highways, buses, airport facilities and related infrastructure).
- $89.4 million in losses are associated with utility and lifeline system economic damages and losses (e.g. potable water, wastewater, natural gas, oil systems, communications, and related infrastructure).
- The mid-day earthquake (2 p.m.) caused the most injuries and casualties: 2,131 injuries and 162 casualties.
- The model estimates that a total of 740,000 tons of debris will be generated. Brick and Wood structures comprise 31 percent of the total, with the rest being Reinforced Concrete and Steel materials.
- Around 25,875 households are expected to suffer from potable water or electric power losses, or both, in the first day of the earthquake event.
- Of the total 41 essential facilities considered by the Hazus earthquake scenario for the planning area (hospitals, schools, emergency operations centers, police stations, and fire stations), 7 will be at least moderately damaged.
- Before the earthquake, the region had 82 hospital beds available for use. On the day of the earthquake, the model estimates that only 23 hospital beds (28 percent) would be available for use by patients already in the hospital and those injured by the earthquake.

Property

Significant earthquakes can cause damages to buildings, private and public property, and other infrastructure. The number of properties at risk is also based on when the majority of development was constructed in the City's Planning Area and whether that development was developed after the City adopted the latest state seismic code. The California State Building Code (CBC) was modified several times since 1960, which resulted in code requirements that directly affected the structural integrity of development in California. According to the HMPC, the City of Petaluma adopted the 2016 CBC, which included the building and seismic code improvements, and most redevelopment in the City's Planning Area occurred during the past 40 years when the City enforced these new code requirements. The Hazus earthquake results also accounted for the improved seismic codes in the model.

Hazus estimates that 14,179 buildings (53 percent of the total buildings in the region) would be at least moderately damaged, while 2,545 of those buildings would be damaged beyond repair by the earthquake scenario. A majority of the buildings experiencing damage are residential structures, and wood frame construction makes up the majority of building/structure material in the planning area's inventory. Figure 4-14 summarizes the specific estimated damages to buildings based on occupancy and damage category.

Figure 4-14: Estimated Building Damage by General Occupancy Type and Damage Category



	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Agriculture	8	0.24	22	0.24	32	0.36	23	0.83	30	1.17
Commercial	59	1.77	155	1.71	340	3.83	402	14.53	519	20.38
Education	5	0.16	12	0.14	18	0.20	12	0.45	12	0.49
Government	2	0.05	3	0.04	5	0.05	5	0.17	7	0.27
Industrial	14	0.43	42	0.47	111	1.25	141	5.10	197	7.72
Other Residential	116	3.49	304	3.36	398	4.49	493	17.82	1,172	46.05
Religion	5	0.16	13	0.15	21	0.24	19	0.70	25	0.99
Single Family	3,116	93.70	8,488	93.90	7,944	89.58	1,671	60.40	584	22.94
Total	3,326		9,040		8,868		2,766		2,545	

Source: Hazus 4.0

With a majority of the buildings in the Planning Area being residential, the Hazus model estimates that over 47 percent of the total losses incurred by this earthquake scenario are single family homes and other residential categories. The building inventory in the region varies in terms of construction types. A large number of buildings are also constructed of wood materials, though the building inventory includes URM buildings and manufactured housing. These types of wood, masonry, and manufactured housing structures are particularly vulnerable to ground shaking in an earthquake event. Table 4-12 describes the Hazus results of expected building damage by building type. Most buildings/structures found are expected to sustain slight to moderate damages.

Table 4-12: Expected Building Damage by Building Type (All Building Design Levels)

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Wood	3,246	97.61	8850	97.90	8,283	93.40	1,742	62.97	623	24.47
Steel	8	0.23	23	0.25	91	1.03	158	5.69	212	8.33
Concrete	19	0.58	54	0.60	94	1.06	100	3.60	139	5.47
Precast	10	0.30	33	0.36	100	1.12	126	4.57	170	6.69
RM	41	1.25	68	0.75	171	1.93	214	7.73	233	9.14
URM	1	0.03	4	0.04	18	0.20	30	1.08	74	2.92
MH	1	0.02	8	0.09	111	1.25	397	14.35	1,094	42.98
Total	3,326		9,040		8,868		2,766		2,545	

*Note:
RM Reinforced Masonry
URM Unreinforced Masonry
MH Manufactured Housing

Source: Hazus 4.0

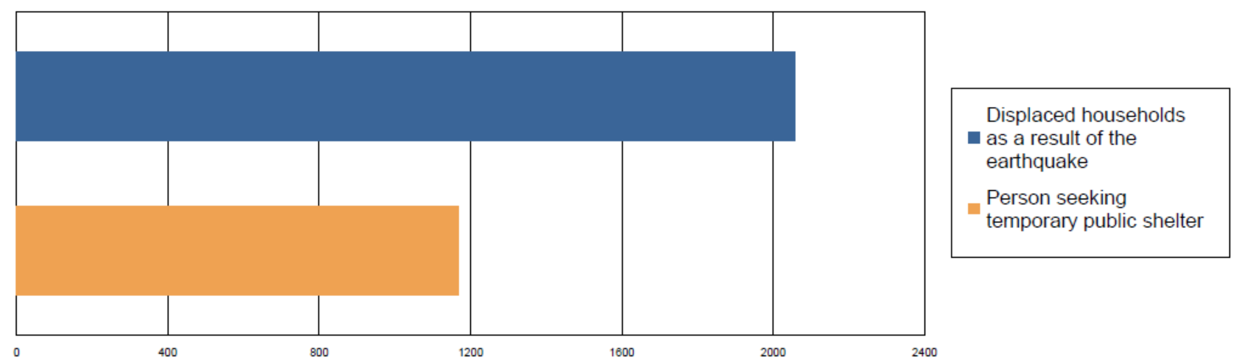
People

Hazus estimates the number of people that would be injured or killed by the 2,500-probabilistic earthquake scenario, which includes liquefaction susceptibility. The causalities are broken down into four severity levels. Level 1 means that injuries occur but do not need hospitalization (i.e. the lowest level, causing the least damages or injuries), through to Level 4, where victims are killed by the earthquake (i.e. the highest, or worst, of the levels). The estimates are also provided for three times of the day which represent the periods of a standard working day when different sectors of the community are likely at their peak occupancy loads (e.g. in business/office settings versus residing at home). As shown in Table 4-13 below, the highest number of injuries and casualties are estimated to occur in the early afternoon (2 p.m.) with the greatest impacts on the commercial and educational sectors when those sector loads are considered to be at their maximum. The 2 p.m. time has the greatest potential for fatalities, with an estimate of 162, followed by the 5 p.m. scenario which estimates 108 fatalities (more information below).

Some populations in the Planning Area may be more vulnerable to an earthquake event than others. For example, those with mobility issues as well as the elderly may have challenges with evacuating or traveling to a shelter without assistance if they cannot stay in their homes. Other vulnerable populations may be individuals whom English is not their native language. Of these socially vulnerable populations and according to the census tracts and block groups in the City, several of these populations are anticipated to reside within central Petaluma and within older housing that may have been constructed prior to the seismic code improvements.

According to 2013-2017 American Community Survey estimates, 24.3 percent of individuals in the City of Petaluma speak a language other than English in their home. These individuals may not receive or understand evacuation information including where shelters are located or where to receive resources to aid in the recovery process. These same individuals and households are designated as socially vulnerable populations, many which reside in the downtown Petaluma area. Figure 4-15 shows the Hazus report estimates for the total number of households expected to be displaced as result of the earthquake. The report estimates 2,058 households to be displaced, and of those, 1,169 individuals will be seeking temporary shelter. This does not take into account future population growth or other variables, such as populations increases due to tourism.

Figure 4-15: Displaced Households and Persons Seeking Shelter Estimates



Displaced households as a result of the earthquake	Persons seeking temporary public shelter
2,058	1,169

Source: Hazus 4.0

Table 4-13 shows the Hazus estimates for total casualties and injuries.

Table 4-13: Casualty and Injury Estimates from Hazus Results

		Level 1	Level 2	Level 3	Level 4
2 AM	Commercial	18	6	1	2
	Commuting	0	0	0	0
	Educational	0	0	0	0
	Hotels	0	0	0	0
	Industrial	25	8	1	3
	Other-Residential	205	56	6	11
	Single Family	208	39	3	5
	Total	**456**	**108**	**11**	**20**
2 PM	Commercial	994	317	54	107
	Commuting	2	2	4	1
	Educational	297	96	17	33
	Hotels	0	0	0	0
	Industrial	184	57	9	18
	Other-Residential	39	11	1	2
	Single Family	40	7	1	1
	Total	**1,555**	**490**	**86**	**162**
5 PM	Commercial	694	220	38	74
	Commuting	32	43	72	14
	Educational	29	9	2	3
	Hotels	0	0	0	0
	Industrial	115	36	6	11
	Other-Residential	76	21	2	4
	Single Family	82	15	1	2
	Total	**1,027**	**345**	**120**	**108**

Source: Hazus 4.0

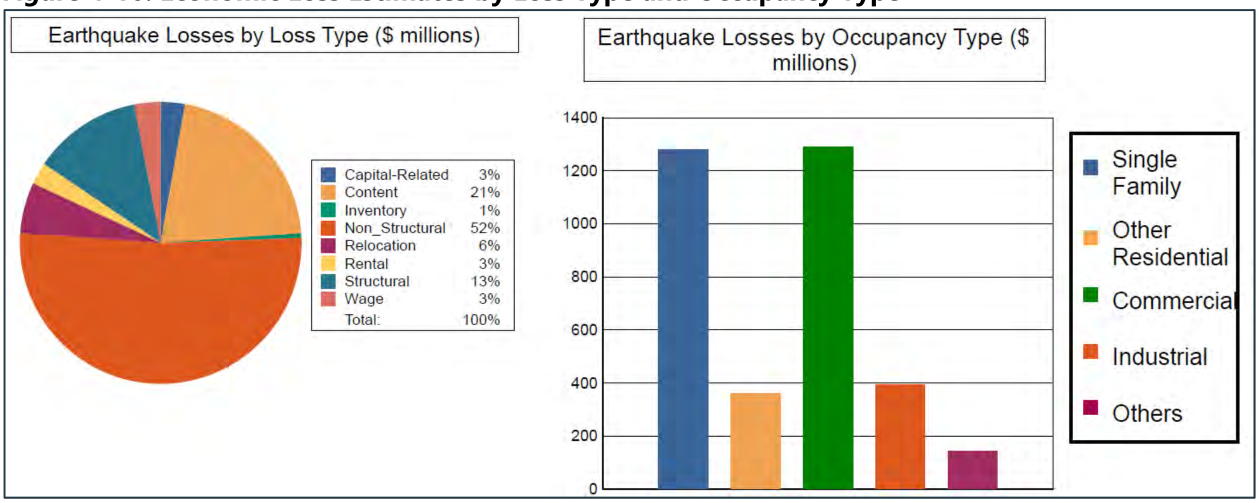
Economy

Earthquakes can have a severe impact on local and regional economies. Impacts can be both direct, such as damages to commercial and residential structures, as well as indirect such as cascading effects involving business interruptions due to employees being displaced from their homes. Another secondary or cascading impact an earthquake could have is causing damages to transportation infrastructure that is critical to employees and business activity. Based on the Hazus results, a magnitude 7.0 earthquake could potentially cause a total of $3.63 billion in economic losses. This amount includes both income losses (estimated to be $484.9 million) as well as capital stock losses ($3 billion).

Another secondary impact of an earthquake is business disruption and the resulting economic loss as a result of that disruption. Hazus describes business interruption losses as those losses associated with the inability to operate a business because of the damage sustained by the earthquake and includes the temporary living expenses for individuals displaced from their homes.

Hazus also estimates the total building-related losses. This includes business interruption losses and direct building losses (the estimated costs to repair or replace the damage caused to buildings and its contents) at $3.47 billion, 14 percent of which are related to business interruption in the region. As shown in Figure 4-16 and Table 4-14 below, the largest loss in this scenario was sustained by residential occupancies, making up 47 percent of total loss. The following figures and tables report the estimate of losses by loss type, occupancy type, and building-related loss.

Figure 4-16: Economic Loss Estimates by Loss Type and Occupancy Type



Source: Hazus 4.0

Table 4-14: Building-Related Economic Loss Estimates (Millions of dollars)

Category	Area	Single Family	Other Residential	Commercial	Industrial	Others	Total
Income Losses							
	Wage	0.00	6.87	89.86	4.87	3.06	104.65
	Capital-Related	0.00	2.93	87.85	2.88	0.87	94.53
	Rental	27.10	16.57	43.85	1.82	1.26	90.60
	Relocation	96.75	14.22	63.65	8.40	12.12	195.14
	Subtotal	**123.85**	**40.58**	**285.21**	**17.97**	**17.31**	**484.92**
Capital Stock Losses							
	Structural	152.54	42.73	171.91	44.77	22.41	434.36
	Non_Structural	750.88	223.21	559.75	189.94	66.80	1,790.58
	Content	252.10	55.19	266.41	123.72	34.14	731.56
	Inventory	0.00	0.00	6.68	16.22	0.78	23.69
	Subtotal	**1,155.52**	**321.13**	**1,004.75**	**374.65**	**124.13**	**2,980.19**
	Total	**1,279.37**	**361.71**	**1,289.96**	**392.62**	**141.44**	**3,465.10**

Source: Hazus 4.0

In addition to economic losses experienced by building-related losses, Hazus estimates the economic losses as a result of transportation and utility lifeline losses and the direct repair cost for each component. As shown in Table 4-15 and Table 4-16 below it is estimated that $78.8 million will be lost as a result of damages to transportation components and $89.4 million are expected to be lost as result of utility system damages. The information in this table does not take into account an appraisal for the Ellis Creek Water Recycling Facility, which was recently appraised at $173 million (Walker 2020).

Table 4-15: Transportation System Economic Losses (Millions of Dollars)

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Highway	Segments	761.20	$42.98	5.65
	Bridges	69.16	$22.13	32.01
	Tunnels	0.00	$0.00	0.00
	Subtotal	**830**	**65.10**	
Railways	Segments	50.25	$2.98	5.93
	Bridges	0.00	$0.00	0.00
	Tunnels	0.00	$0.00	0.00
	Facilities	0.00	$0.00	0.00
	Subtotal	**50**	**3.00**	
Light Rail	Segments	0.00	$0.00	0.00
	Bridges	0.00	$0.00	0.00
	Tunnels	0.00	$0.00	0.00
	Facilities	0.00	$0.00	0.00
	Subtotal	**0**	**0.00**	
Bus	Facilities	2.57	$1.85	72.09
	Subtotal	**3**	**1.90**	
Ferry	Facilities	0.00	$0.00	0.00
	Subtotal	**0**	**0.00**	
Port	Facilities	0.00	$0.00	0.00
	Subtotal	**0**	**0.00**	
Airport	Facilities	10.65	$7.75	72.80
	Runways	37.96	$1.11	2.92
	Subtotal	**49**	**8.90**	
	Total	**931.80**	**78.80**	

Source: Hazus 4.0

Table 4-16: Utility System Economic Losses (Millions of Dollars)

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Potable Water	Pipelines	0.00	$0.00	0.00
	Facilities	0.00	$0.00	0.00
	Distribution Line	54.10	$20.56	38.01
	Subtotal	**54.08**	**$20.56**	
Waste Water	Pipelines	0.00	$0.00	0.00
	Facilities	78.60	$49.77	63.33
	Distribution Line	32.40	$14.73	45.40
	Subtotal	**111.03**	**$64.51**	
Natural Gas	Pipelines	0.00	$0.00	0.00
	Facilities	0.00	$0.00	0.00
	Distribution Line	21.60	$4.23	19.53
	Subtotal	**21.63**	**$4.23**	
Oil Systems	Pipelines	0.00	$0.00	0.00
	Facilities	0.00	$0.00	0.00
	Subtotal	**0.00**	**$0.00**	
Electrical Power	Facilities	0.00	$0.00	0.00
	Subtotal	**0.00**	**$0.00**	
Communication	Facilities	0.10	$0.08	68.64
	Subtotal	**0.12**	**$0.08**	
	Total	**186.86**	**$89.37**	

Source: Hazus 4.0

Critical Facilities and Infrastructure

Large seismic events could have catastrophic effects on the City and surrounding areas, possibly damaging transportation and utility lifelines, bridges, railroads, and other critical facilities and infrastructure. Hazus estimates impacts to essential facilities including hospitals, schools, Emergency Operations Centers (EOCs), police stations, and fire stations. The Hazus analysis also takes into account four hazardous material sites, though zero nuclear power plants and zero military installations fall within the study area.

According to the earthquake analysis, there is one hospital with a total capacity of 82 beds, 32 schools, zero emergency operations facility, one police station, and seven fire stations in the study area. Hazus estimates that seven of these essential facilities are expected to suffer moderate damage. With regards to transportation systems, 65 will suffer at least moderate damage, and 5 will suffer complete damage. However, only two of the utility system facilities will suffer at least moderate damage, but zero of these types of facilities will suffer complete damage.

Table 4-17, Table 4-18, and Table 4-19 summarize the expected damages generated by the Hazus scenario for each type of transportation system and utility system, including pipelines in the area. Based on personal communication with the HMPC, the Ellis Creek Water Recycling Facility is expected to be able to resume operation within one week after an earthquake event (Walker 2020).

Table 4-17: Expected Damage to the Transportation Systems

System	Component	Number of Locations				
		Locations/ Segments	With at Least Mod. Damage	With Complete Damage	With Functionality > 50 %	
					After Day 1	After Day 7
Highway	Segments	63	0	0	62	62
	Bridges	64	62	5	2	7
	Tunnels	0	0	0	0	0
Railways	Segments	16	0	0	16	16
	Bridges	0	0	0	0	0
	Tunnels	0	0	0	0	0
	Facilities	0	0	0	0	0
Light Rail	Segments	0	0	0	0	0
	Bridges	0	0	0	0	0
	Tunnels	0	0	0	0	0
	Facilities	0	0	0	0	0
Bus	Facilities	2	2	0	0	0
Ferry	Facilities	0	0	0	0	0
Port	Facilities	0	0	0	0	0
Airport	Facilities	1	1	0	0	0
	Runways	1	0	0	1	1

Source: Hazus 4.0

Table 4-18: Expected Utility System Facility Damage

System	# of Locations				
	Total #	With at Least Moderate Damage	With Complete Damage	with Functionality > 50 %	
				After Day 1	After Day 7
Potable Water	0	0	0	0	0
Waste Water	1	1	0	0	0
Natural Gas	0	0	0	0	0
Oil Systems	0	0	0	0	0
Electrical Power	0	0	0	0	0
Communication	1	1	0	0	0

Source: Hazus 4.0

Table 4-19: Expected Utility System Pipeline Damage (Site Specific)

System	Total Pipelines Length (kms)	Number of Leaks	Number of Breaks
Potable Water	2,704	3867	1282
Waste Water	1,622	2771	919
Natural Gas	1,082	795	264
Oil	0	0	0

Source: Hazus 4.0

Historic, Cultural, and Natural Resources

An earthquake in the City's Planning Area or in the surrounding region could cause cascading (secondary) effects, including dam or pipeline failure that would impact the natural environment in different ways, depending on the extent of the cascading hazard. For example, earthquake-induced landslides or debris flows could significantly damage habitat and re-route streams and waterways, causing water quality impacts. Other types of ground deformation could also result.

Future Development

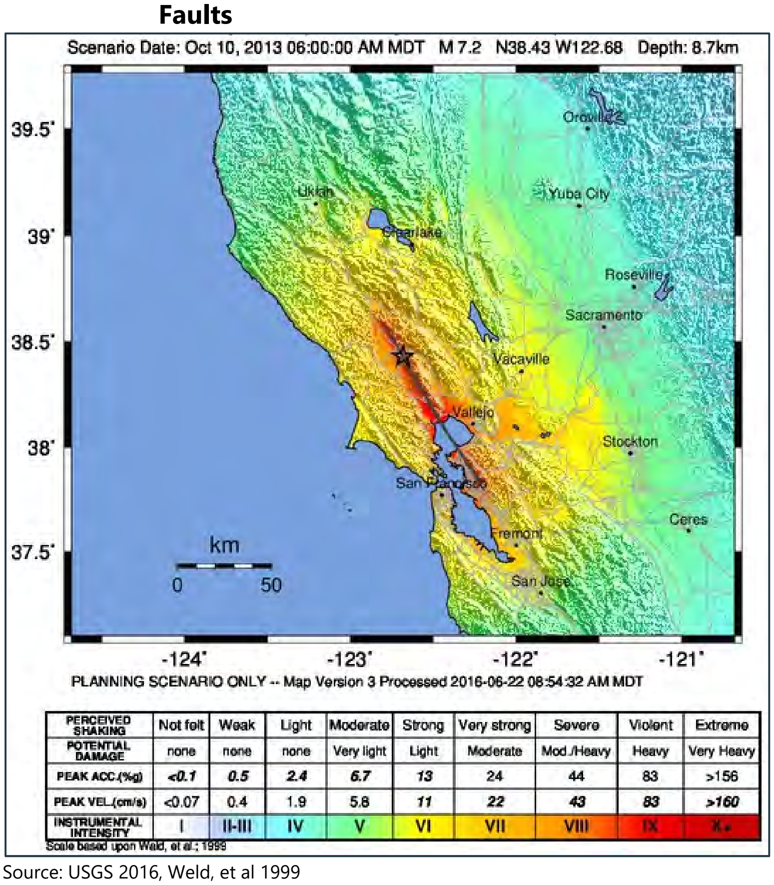
The Hazus scenario only estimates damage and causalities for existing building inventory and populations and does not take into account future development plans. The City of Petaluma has experienced growth in the past eight years (2010-2018) that is not expected to slow (Refer to Chapter 2 Community Profile for further discussion on demographics and population changes). The latest U.S. Census estimates show that 6.9 percent is the average percent change of population in the City, which went from having a little over 57,000 people in 2010 to almost 62,000 in 2018.

As more portions of the City and its vicinity are developed and infill areas in the City are redeveloped, it will be important for the City of Petaluma to meet its stated goal and objectives and ensure that risk reduction in the community is taken into account, particularly when dealing with earthquakes and other geologic hazards. The City of Petaluma General Plan of 2025 (adopted in 2008 and revised in 2012) and its Health and Safety Element establish standards and requirements for the protection from geologic and seismic hazards. Building and development will also be regulated through building standards.

Magnitude 7.2 Deterministic ShakeMap Earthquake Scenario

A second Hazus-based earthquake scenario was run for the Petaluma Planning Area using census tract units that was based on a deterministic model. A deterministic scenario relies on seismic data to predict the outcome of a specific earthquake event. This deterministic scenario used USGS provided ShakeMap datasets to model what a Magnitude 7.2 earthquake of the Hayward Rodgers Creek Faults would generate in terms of damages and losses for the chosen area of interest (i.e. the Petaluma Planning Area). These faults were selected because they are known to have caused seismic activity and pose a risk to the Petaluma and nearby communities. The M7.2 ShakeMap scenario datasets used to import into Hazus 4.0 include four USGS-provided key data layers in spatial format: peak ground velocity, peak ground acceleration, peak spectral acceleration for 0.3 seconds (0.3 % g, or gravitational velocity), and peak ground acceleration for 1.0 seconds (1.0 % g).The epicenter of this USGS modeled scenario is located at latitude 38.43 North and 122.68 West and had a depth of 8.7 kilometers. A fifth layer of liquefaction susceptibility was also included in the Hazus model, which is the same utilized in the previous 2,500-year probabilistic scenario to enhance the model with more accurate ground and soil conditions. Figure 4-17 includes the general location of the scenario's epicenter (marked with a start northeast of the San Francisco Bay area) as well as intensity information and reference to the USGS ShakeMap data.

Figure 4-17: USGS Generated ShakeMap Earthquake Scenario for the Hayward-Rodgers Creek Faults



Source: USGS 2016, Weld, et al 1999

For more information on the USGS generated ShakeMap scenarios, modeling criteria, manual information, and overall catalog of available data refer to the USGS Earthquake Hazards Program ShakeMap information page.

This deterministic M7.2 scenario results included liquefaction susceptibility. Loss estimates and vulnerability assessment were completed based on the following subsections, similar to the previous scenario: property; people; the local economy; critical facilities and infrastructure; historic, cultural, natural resources; and future development of the Planning Area. The total losses by census tract from this M7.2 scenario are shown in Figure 4-18 and summarized in Table 4-20 below. Refer to Section 4.1.1 and FEMA's Hazus 4.0 Loss Estimation Tool for more information on the Hazus tool and its analysis functions. As stated in the previous section, Hazus is a loss estimation tool which derives totals on the number of people displaced, the number of buildings damaged and their type (e.g. construction material, occupancy class), the number of causalities, and the damage to transportation systems and utilities (e.g. critical facilities) given the input parameters, scenario type, and region/area of interest.

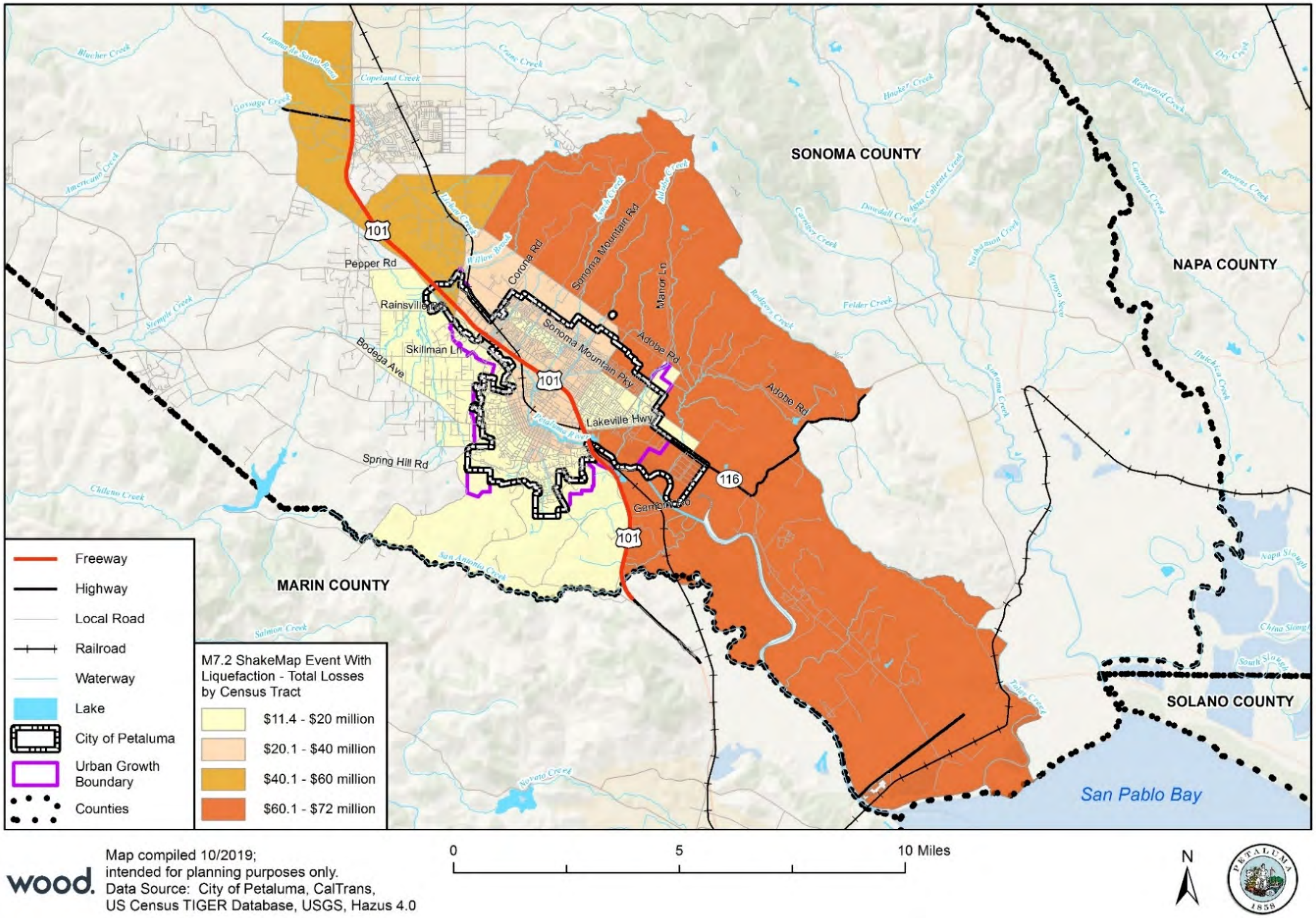
Table 4-20: Hazus 4.0 Deterministic M7.2 Earthquake Scenario Loss Estimations for Petaluma's Census Tracts

Type of Impact	Impacts to Planning Area
Total Buildings Damaged	Slight: 9,144 Moderate: 1,772 Extensive: 286 Complete: 25
Building and Income Related Losses	$ 395.2 million 54 % of damage related to residential structures 12 % of loss due to business interruption
Total Economic Losses (Includes building, income, and lifeline/critical facility losses)	$ 449.9 million
Casualties (Based on a 2 a.m. time of occurrence)	Without requiring hospitalization: 29 Requiring hospitalization: 2 Life threatening: 0 Fatalities: 0
Casualties (Based on a 2 p.m. time of occurrence)	Without requiring hospitalization: 58 Requiring hospitalization: 9 Life threatening: 2 Fatalities: 2
Casualties (Based on a 5 p.m. time of occurrence)	Without requiring hospitalization: 48 Requiring hospitalization: 17 Life threatening: 20 Fatalities: 5
Damage to Transportation Systems	0 damages to highway or bridges 0 damages to airport facilities or runways 0 damages to bus facilities 0 damages to light rail 0 damages to ferry and port facilities
Damage to Essential Facilities	0 damages to schools, police stations, fire stations, emergency operations centers, or hospitals
Damage to Utility Systems	0 of the following facilities will suffer damages: potable water; wastewater; natural gas; oil systems; electrical power; and communications. Potable water breaks: 277 Wastewater breaks: 198 Natural gas breaks: 57 Oil pipeline breaks: 0
Households without Power/Water Service (Based on 26,824 total households)	Power loss, Day 1: 1,028 Power loss, Day 3: 557

Type of Impact	Impacts to Planning Area
	Power loss, Day 7: 187 Power loss, Day 30: 30 Power loss, Day 90: 2 Water loss, Day 1: 12,510 Water loss, Day 3: 9,792 Water loss, Day 7: 3,352 Water loss, Day 30: 0 Water loss, Day 90: 0
Displaced Households	72
Persons Seeking Temporary Shelter	42
Debris Generation	60,000 tons

Source: Hazus 4.0, USGS ShakeMap M7.2 Scenario for Hayward-Rodgers Creek

Figure 4-18: Hazus M7.2 ShakeMap Deterministic Earthquake Scenario (Hayward-Rodgers Creek Faults) in Petaluma with Liquefaction Susceptibility – Total Losses by Census Tract



Property

The Hazus results for this M7.2 scenario indicate 2,082 buildings will be at least moderately damaged. This is over 8 percent of the total buildings in the region. However, approximately 25 buildings will be completely destroyed. The majority of these at least moderately damaged buildings are residential in nature, followed by commercial buildings and lastly industrial buildings. With a majority of the buildings in the Planning Area being residential, the Hazus model estimates that over 54 percent of the total losses incurred by this earthquake scenario are single family homes and other residential categories. Table 4-21 provides a detailed breakdown of these expected building damages based on the occupancy types.

Table 4-21: Expected M7.2 Earthquake Scenario Building Damages by Occupancy Type

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Agriculture	56	0.37	36	0.40	17	0.98	4	1.49	1	2.34
Commercial	700	4.57	455	4.98	267	15.08	48	16.97	3	13.54
Education	34	0.22	18	0.19	7	0.40	1	0.46	0	0.33
Government	11	0.07	5	0.06	4	0.21	1	0.36	0	0.39
Industrial	209	1.36	157	1.72	112	6.30	25	8.77	2	9.39
Other Residential	688	4.49	794	8.68	817	46.11	173	60.42	11	45.82
Religion	44	0.29	25	0.28	12	0.69	3	0.90	0	0.89
Single Family	13,577	88.63	7,653	83.69	536	30.23	30	10.62	7	27.30
Total	**15,318**		**9,144**		**1,772**		**286**		**25**	

Source: Hazus 4.0, USGS ShakeMap M7.2 Scenario for Hayward-Rodgers Creek

The building inventory in the region varies in terms of construction types. A large number of buildings are also of wood materials, though the building inventory also includes unreinforced masonry buildings and manufactured housing. These types of wood, masonry, and manufactured housing structures are particularly vulnerable to ground shaking in an earthquake event. Most buildings/structures found are expected to sustain slight to moderate damages, with the Wood and Manufactured Housing materials making up the largest percentages of the damaged building materials category.

People

Hazus estimates the number of people that would be injured or killed by the M7.2 ShakeMap earthquake scenario which includes liquefaction susceptibility. The causalities are broken down into four severity levels as described in the previous Hazus model summary (2,500-year probabilistic scenario). The estimates are provided for three times of the day which represent the periods of a standard working day when different sectors of the community are likely at their peak occupancy loads. The highest number of injuries and casualties are estimated to occur in the late afternoon (5 p.m.) with the greatest impacts on commercial sectors followed by commuting activities and residential areas as these sector loads are considered to be at their maximum in the late afternoon/early evening times. This 5 p.m. time has the greatest potential for fatalities, with an estimate of 5, followed by the 2 p.m. scenario which estimates 2 fatalities.

Some populations in the Planning Area may be more vulnerable to an earthquake event than others. Most vulnerable individuals who may not receive or understand evacuation information including where shelters are located or where to receive resources to aid in the recovery process would be at high risk of earthquakes. The Hazus report estimates 72 households to be displaced, and of those, 42 individuals will be seeking temporary shelter. It should be noted that this does not take into account future population growth or any other variables such as seasonal or weekend tourism to the region. An earthquake would have a disproportionate impact on socially vulnerable populations residing in the downtown area of Petaluma.

Economy

Earthquakes can have a severe impact on local and regional economies as previously discussed in the 2,500-year probabilistic Hazus analysis sub-section. Based on this Hazus M7.2 scenario, the modeled earthquake could potentially cause a total of $449.9 million in economic losses. This amount includes both income losses (estimated to be $46 million) as well as capital stock losses ($395.2 million).

Another secondary impact of an earthquake is business disruption and the resulting economic loss as a result of that disruption. Hazus describes business interruption losses as those losses associated with the inability to operate a business because of the damage sustained by the earthquake and includes the temporary living expenses for individuals displaced from their homes. Of the total $395.2 million in building-related losses, 12 percent are related to business interruptions in the region.

In addition to economic losses experienced by building-related losses, Hazus estimates the economic losses as a result of transportation and utility lifeline losses and the direct repair cost for each component. It is estimated that $30.7 million will be lost as a result of damages to transportation components while almost $24 million are expected to be lost as result of utility system damages from the M7.2 modeled ShakeMap scenario.

Critical Facilities and Infrastructure

Large seismic events could have catastrophic effects on the City and surrounding areas, possibly damaging transportation and utility lifelines, bridges, railroads, and other critical facilities and infrastructure. Hazus estimates impacts to essential facilities including hospitals, schools, EOCs, police stations, and fire stations. The Hazus analysis also takes into account four hazardous material sites. No nuclear power plants or military installations fall within the study area.

According to the earthquake analysis, there is one (1) hospital with a total capacity of 82 beds, thirty-two (32) schools, zero (0) emergency operations facility, one (1) police stations, and seven (7) fire stations in the study area. This M7.2 Hazus earthquake scenario estimates that none of these essential facilities are expected to suffer moderate or complete damage. With regards to transportation systems, no major roadways or other transportation infrastructure will suffer moderate or complete damage.

The only utility systems or structures that are expected to suffer site specific damages are shown in Table 4-22 and Table 4-23. These damage estimates are also summarized in the overall scenario summary table at the beginning of the section (Table 4-20).

Table 4-22: Expected Utility System Pipeline Damage (Site Specific)

System	Total Pipelines Length (kms)	Number of Leaks	Number of Breaks
Potable Water	2,704	671	277
Waste Water	1,622	481	198
Natural Gas	1,082	138	57
Oil	0	0	0

Source: Hazus 4.0, USGS ShakeMap M7.2 Scenario for Hayward-Rodgers Creek

Table 4-23: Expected Potable Water and Electric Power System Performance

	Total # of Households	Number of Households without Service				
		At Day 1	At Day 3	At Day 7	At Day 30	At Day 90
Potable Water	26,824	12,510	9,792	3,352	0	0
Electric Power		1,028	557	187	30	2

Source: Hazus 4.0, USGS ShakeMap M7.2 Scenario for Hayward-Rodgers Creek

Historic, Cultural, and Natural Resources

The same general impacts, potential risk, and cascading or secondary issues discussed for the 2,500-year probabilistic scenario's would apply to the Planning Area's historic, cultural, and natural resources based on this M7.2 modeled ShakeMap scenario which uses the Hayward-Rodgers Creek faults.

Future Development

The same general impacts, potential risk, and cascading or secondary issues discussed in the 2,500-year probabilistic scenario's would apply to the Planning Area's future development based on this M7.2 modeled ShakeMap scenario which focuses on the Hayward-Rodgers Creek faults as causing the seismic movements.

Risk Summary

- The overall risk significance of earthquake hazards to the City of Petaluma is **High**.
- Earthquakes and seismic activity are expected to have a probability of occasional occurrence in the future, given the local seismic conditions, past history, and input from the City.
- Two earthquake faults of concern can affect the City: the San Andreas Fault and the Healdsburg-Rodgers Creek Fault, although only the first is considered to be currently active and the fault that may lead to more damages or losses in the future.
- The majority of the Planning Area is found in moderate, high, or very high liquefaction susceptibility zones, with the downtown area being in high and very high liquefaction zones (and hence at high risk of potential seismic activity).
- Based on the first Hazus earthquake analysis, it is expected that a 2,500-year probabilistic earthquake with a magnitude of 7.0 and liquefaction susceptibility taken into account would cause $ 3.63 billion in total economic losses, and mostly affect residential buildings (since an estimated 14,179 buildings would be at least moderately damaged, with 2,545 completely destroyed).
- The Hazus scenario resulted in $78.8 million of losses to the transportation systems, while $89.4 million would be incurred in damages and losses to the utility and lifeline systems. Around 25,875 households would be affected by potable water or electric power losses from this earthquake scenario.
- The Hazus scenario also estimates that around 740,000 tons of debris would be generated, with brick and wood structures suffering the most.
- The potential for casualties during the worst-case scenario for which time of day of the earthquake might hit (the 2 p.m. scenario) would lead to 162 casualties and 2,131 injuries.
- Based on the second Hazus earthquake analysis, it is expected that a Magnitude 7.2 deterministic earthquake using the Hayward-Rodgers Creek faults and liquefaction susceptibility taken into account

would cause $ 449.9 million in total economic losses, and mostly affect residential buildings (since an estimated 2,082 buildings would be at least moderately damaged, with 25 completely destroyed).

- The Hazus scenario resulted in $ 30.7 million of losses to the transportation systems, while $24 million would be incurred in damages and losses to the utility and lifeline systems. Around 12,510 households would be affected by potable water or electric power losses from this earthquake scenario.
- The Hazus scenario estimates that around 60,000 tons of debris would be generated, with brick and wood structures suffering the most.
- The potential for casualties during the worst-case scenario for which time of day of the earthquake might hit (the 5 p.m. scenario) would lead to 5 casualties and 85 injuries.

4.3.4 Wildfire

Hazard Description

Wildfires are any uncontrolled fires that occur most often on undeveloped land and require fire suppression. They are caused by lightning or by human-activities such as smoking, arson, equipment misuse, and from electrical infrastructure. Wildfires are a significant concern throughout California. In recent years wildfires have occurred in vegetated areas in the vicinity of the City of Petaluma. Wildfires in surrounding areas, even a few counties away, can create significant impacts to the City such as those stemming from intense smoke, which can then lead to poor air quality, traffic visibility issues, and public health concerns. Generally, the fire season extends from June through October of each year during the hot, dry months. Fire conditions arise from a combination of high temperatures, intense sunlight, low rainfall, an accumulation of vegetation, and high winds.

Throughout California, communities are increasingly concerned about wildfire safety as increased development in the foothills and mountain areas and subsequent fire control practices have affected the natural cycle of the ecosystem. While wildfire risk is predominantly associated with wildland-urban interface (WUI) areas, significant wildfires can also occur in heavily populated areas. The WUI is a general term that applies to development adjacent to landscapes that support wildfire.

Location

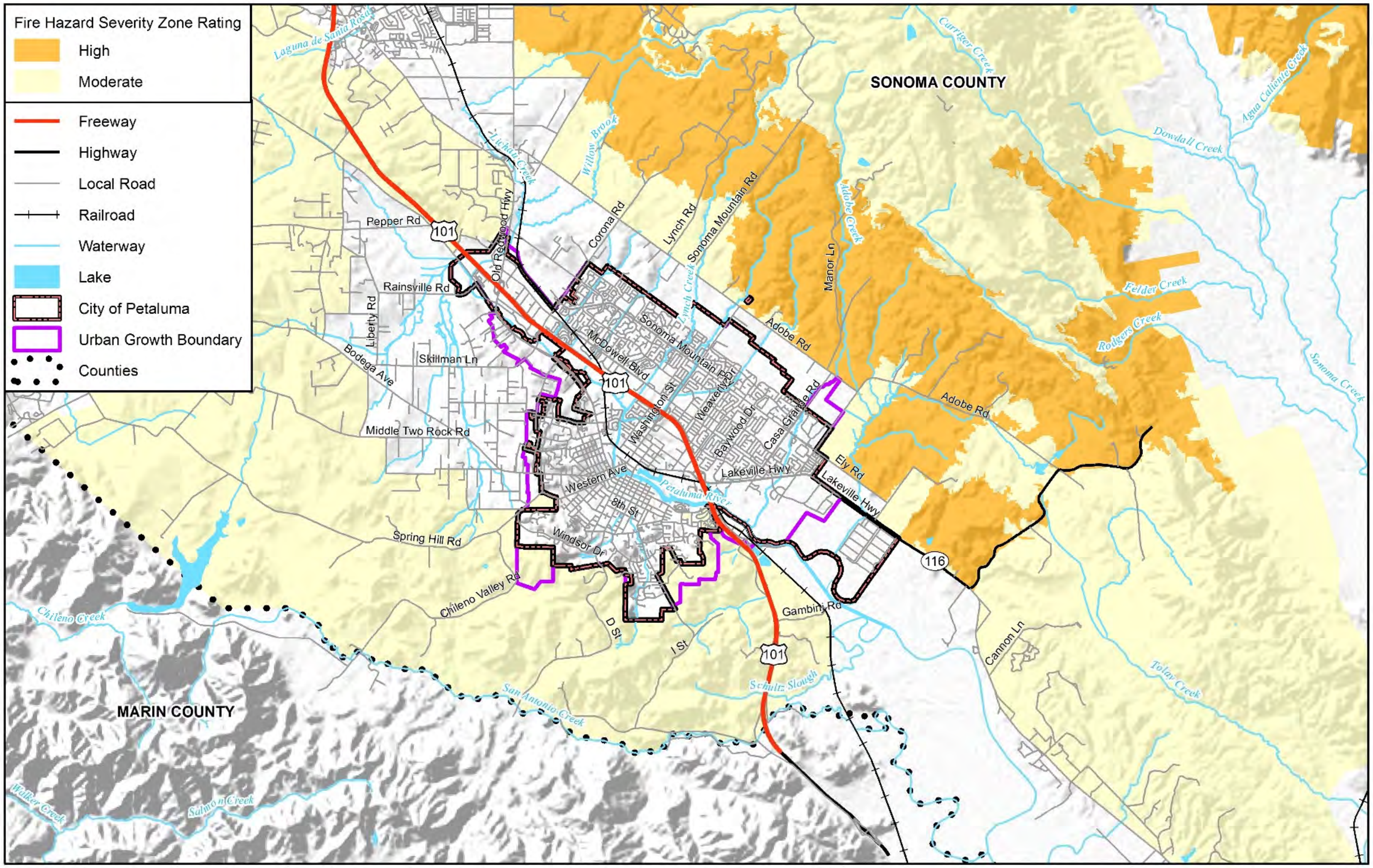
Wildfires affect grass, forest, and brushlands, as well as any structures populations located within or surrounding them. Where there is human access to wildland areas the risk of fire increases due to a greater chance for human carelessness and historical fire management practices. In other areas, large concentrations of highly flammable brush and grasslands located in flat open spaces are also susceptible to wildfire.

The California Department of Forestry and Fire Protection's (CAL FIRE) Fire and Resource Assessment Program (FRAP) models map wildfire hazards using a science-based approach and computerized techniques to classify moderate, high, and very high fire severity zones in a Fire Hazard Severity Zone (FHSZ) dataset. The model uses existing CAL FIRE data and hazard information based on fuel, weather, and terrain, explained in more detail in the Extent (Magnitude/Severity) section below.

Figure 4-19 displays the fire hazard severity zones falling within State Responsibility Areas, or SRAs, around the City of Petaluma. Figure 4-20 shows these hazard severity zones but within Local Responsibility Areas, or LRAs, in and surrounding the City. Fire threat zones are displayed in Figure 4-21.

These three maps provide general indications of potential future fire behavior as well as where fire occurrence might take place. The south portions of the City, particularly south of the Petaluma River and near Windsor Drive show wildfire hazard areas based on fire threat data and the FHSZs mapped at both the SRA and LRA levels. Other potential areas of concern are along the edges of the City boundary, on the eastern and northern sides where moderate and high severity zones intermingle.

Figure 4-19: Fire Hazard Severity Zones in State Responsibility Areas (SRAs) Around the City of Petaluma



Map compiled 10/2019; intended for planning purposes only.
Data Source: City of Petaluma, CalTrans, US Census TIGER Database, CalFire FRAP

0 3 6 Miles

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Figure 4-20: Fire Hazard Severity Zones in Local Responsibility Areas (LRAs) in Petaluma

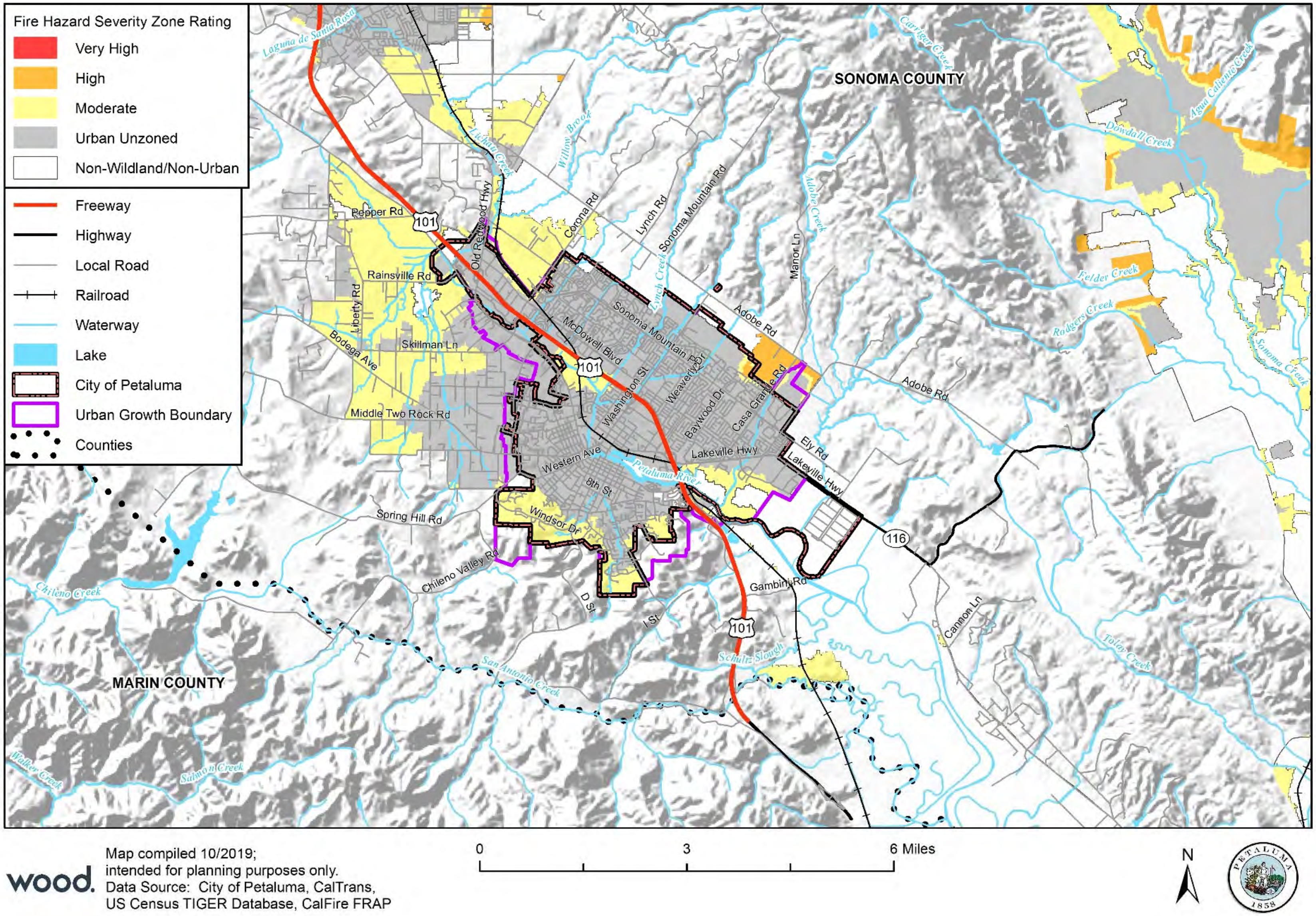
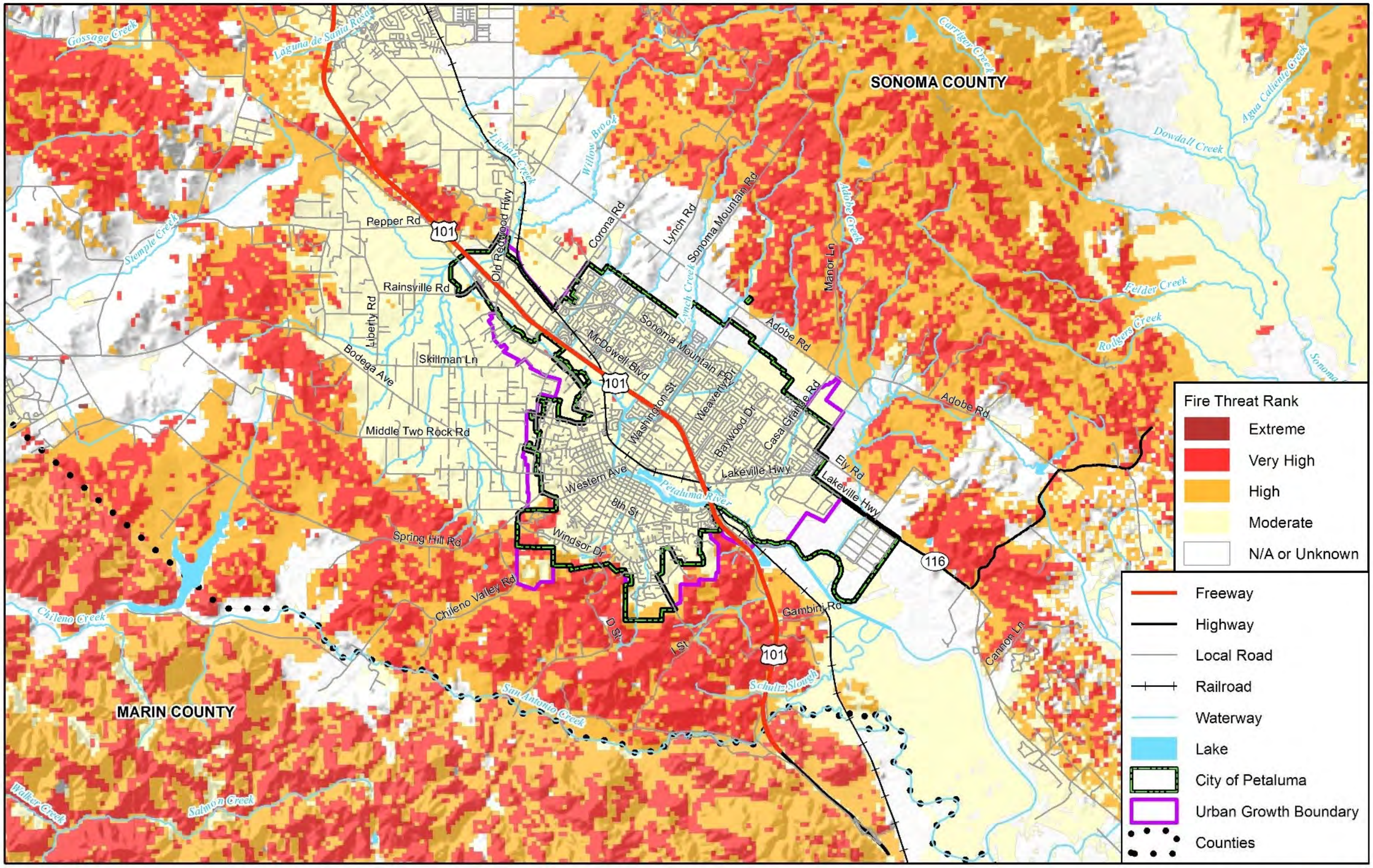


Figure 4-21: Fire Threat Zones in and Near the City of Petaluma



Map compiled 10/2019;
intended for planning purposes only.
Data Source: City of Petaluma, CalTrans,
US Census TIGER Database, CalFire FRAP

Extent (Magnitude/Severity)

Critical – Potential losses from wildfires include human life, structures and other improvements, natural and cultural resources, quality and quantity of water supplies, cropland, timber, recreational opportunities, and impacts to the community's way of life. Economic losses could also result from reduced tourism and visitation and generally impacted economic sectors. Smoke and air pollution from wildfires can be a severe health hazard. In addition, catastrophic wildfire can create favorable conditions for other secondary hazards such as flooding, landslides, and erosion during the rainy season. Typically, the potential for significant damage to life and property exists in areas designated as "wildland-urban interface" areas, or WUIs, where development is adjacent to densely vegetated area.

Generally, there are three major factors that sustain wildfires and predict a given area's potential to burn. These factors are fuel, topography, and weather, as described below.

- **Fuel** - Fuel is the material that feeds a fire and is a key factor in wildfire behavior. Fuel is generally classified by type and by volume. Fuel sources are diverse and include everything from dead tree leaves, twigs, and branches to dead standing trees, live trees, brush, and cured grasses. Manmade structures, such as homes and other associated combustibles are also fuel sources. The type of prevalent fuel directly influences the behavior of wildfire. Fuel is the only factor that is under human control. Fuel types within the City include seasonal grasses, and mature landscaping, such as deciduous and evergreen oaks, and conifers. Fuel types surrounding the City Planning Area include mainly seasonal grasslands and brush.
- **Topography** - An area's terrain and land slopes affect its susceptibility to wildfire spread. Both fire intensity and rate of spread increase as slope increases due to the tendency of heat from a fire to rise via convection. The arrangement of vegetation throughout a hillside can also contribute to increased fire activity on slopes.
- **Weather** - Weather components such as temperature, relative humidity, wind, and lightning also affect the potential for wildfire. High temperatures and low relative humidity dry out fuels that feed wildfires, creating a situation where fuel will more readily ignite and burn more intensely. Thus, during periods of drought, the threat of wildfire increases. Wind is the most treacherous weather factor. The greater a wind, the faster a fire will spread and the more intense it will be. Lightning can also ignite wildfires, often in difficult to reach areas for firefighters.

However, fires in the broader region (Sonoma County and bordering counties such as Mendocino or Napa) in recent years have resulted in the loss of property as well as human injuries or even deaths. The smoke and air pollution from wildfires are also severe health hazards particularly for sensitive populations including the elderly, children, and people with respiratory and cardiovascular diseases. Wildfires can also threaten the health and safety of those fighting the fires, so the overall magnitude or severity of fires can be wide-reaching and incur many types of impacts. Overall, wildfire severity can usually be quantified in terms of acres burned during an event, number and cost of properties/structures damaged (including critical facilities), money lost from disruption of services, and population affected by the fires (e.g. people displaced, injured or killed).

Previous Occurrences

Wildfires are a significant concern throughout California. According to CAL FIRE under the CAL FIRE system, vegetation fires occur across California on a regular basis; most can be controlled and contained early with limited damage. The foothills and mountain areas of California have experienced numerous devastating fires over the last 100 years, with the fire risk significantly increasing in recent years due to high fuel loads and expansion of development into the WUI areas. For those ignitions that are not readily contained and become wildfires, damage can be extensive. There are many causes of wildfire, from naturally caused lightning fires to human-caused fires linked to activities such as smoking, campfires, debris burning, equipment use, and arson. Recent studies conclude that the greater the population density in an area, the greater the chance of an ignition from human sources, as well as powerlines or other electrical or utility infrastructure.

Although not fully representative of annual fire activity, data from CAL FIRE supplemented with the Wildland Fire Occurrence databases from USGS (e.g. the Geospatial Multi-Agency Coordination, or GeoMAC) reported 26 fires affecting the vicinity of the City from 1941 to 2019. Table 4-24 below summarizes these fires that occurred around Petaluma, while Figure 4-22 displays the fires that have occurred close to the City. The fires have been organized in chronological order, with the oldest fire taking place in 1941 and the most recent of record in October 2019. In terms of larges fires, the Nuns Fire occurred in 2017 and burned 55,798 acres. The 37 Fire, which also took place in 201 burned 1,657 acres. Most recently, the Kincade Fire (not mapped) in Sonoma County north of Geyserville burned 77,758 acres.

The NOAA National Centers for Environmental Information (NCEI) database was also queried for past wildfire events in or near Petaluma. This NCEI query yielded a record of a “Dense Smoke” event related to the 2018 Camp Fire, dated November 9, 2018. This record specifically calls out Petaluma. As such, even events that take place elsewhere can affect the planning area as noted herein.

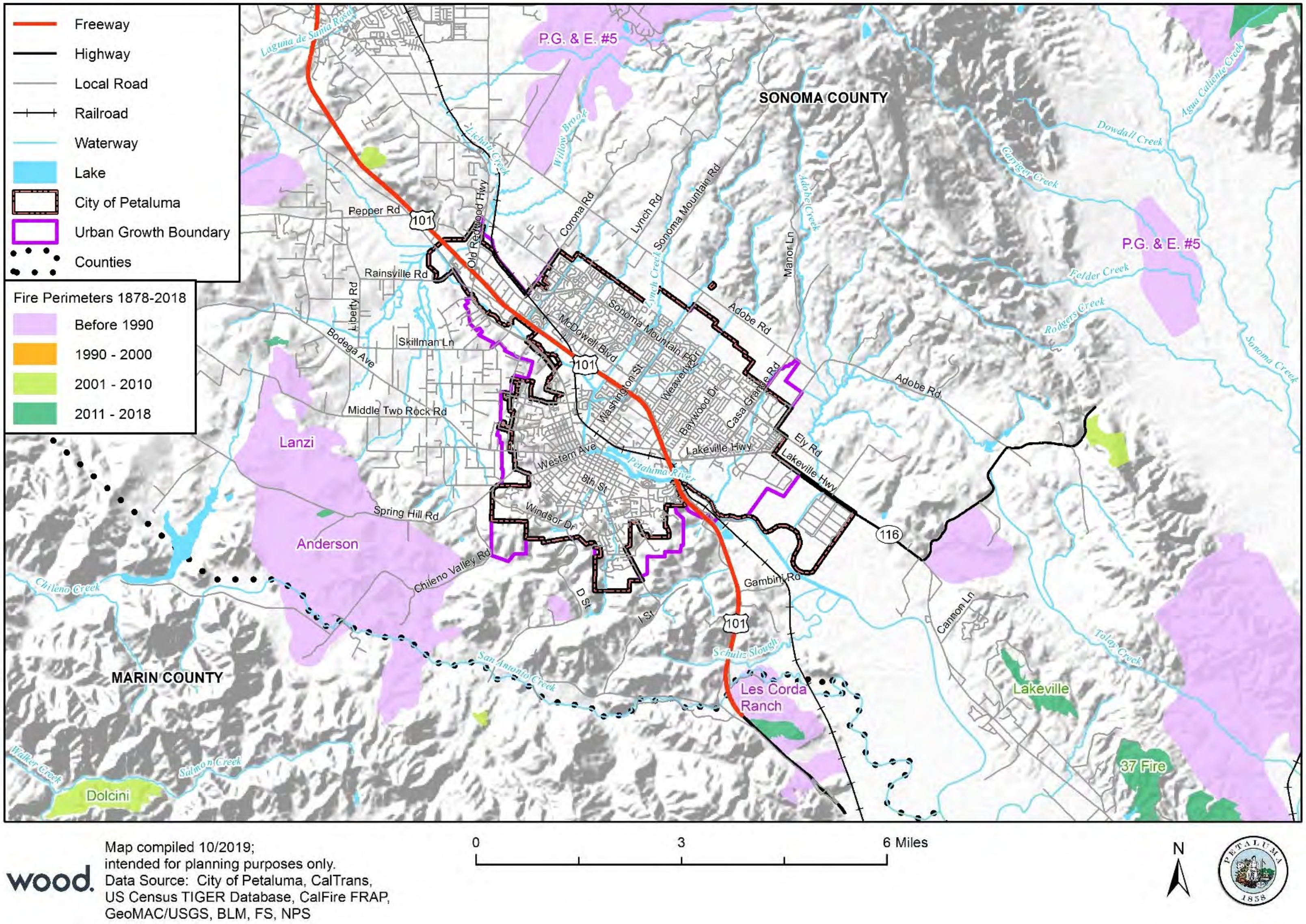
Table 4-24: Summary of Fire History Near the City of Petaluma

Fire Name	Year	Cause of Fire	Acres Burned	Details/Agency in Charge
Unknown	1941	Unknown / Unidentified	278	Contract County
--	1945	Unknown / Unidentified	602	California Department of Forestry and Fire Protection
--	1945	Unknown / Unidentified	526	California Department of Forestry and Fire Protection
--	1945	Unknown / Unidentified	500	California Department of Forestry and Fire Protection
P.G.&E. #5	1961	Unknown / Unidentified	825	California Department of Forestry and Fire Protection
Lanzi	1963	Unknown / Unidentified	377	California Department of Forestry and Fire Protection
Nuns Canyon	1964	Unknown / Unidentified	9,808	California Department of Forestry and Fire Protection
Anderson	1965	Unknown / Unidentified	4,954	California Department of Forestry and Fire Protection
P.G.& E.#5	1965	Unknown / Unidentified	3,250	California Department of Forestry and Fire Protection
Les Corda Ranch	1966	Unknown / Unidentified	588	Contract County

Fire Name	Year	Cause of Fire	Acres Burned	Details/Agency in Charge
--	1968	Unknown / Unidentified	4,554	California Department of Forestry and Fire Protection
D Street	1968	Unknown / Unidentified	63	Contract County
Olympali	1981	Unknown / Unidentified	212	Contract County
Les	1983	Unknown / Unidentified	57	Contract County
Dump	2001	Arson	144	California Department of Forestry and Fire Protection
Redhill	2001	Unknown / Unidentified	19	Contract County
Dolcini	2004	Unknown / Unidentified	365	California Department of Forestry and Fire Protection
Grade 2	2007	Unknown / Unidentified	60	California Department of Forestry and Fire Protection
Antonio	2012	Vehicle	95	Contract County
Lakeville	2013	Equipment Use	178	California Department of Forestry and Fire Protection
Nuns	2017	Unknown / Unidentified	55,798	California Department of Forestry and Fire Protection
37 Fire	2017	Unknown / Unidentified	1,657	California Department of Forestry and Fire Protection
Bodega	2017	Unknown / Unidentified	18	California Department of Forestry and Fire Protection
Spring	2017	Unknown / Unidentified	12	California Department of Forestry and Fire Protection
Unknown	--	Unknown / Unidentified	2,927	Contract County
Unknown	--	Unknown / Unidentified	303	Contract County
Kincade	2019	Unknown/Unidentified	77,758	California Department of Forestry and Fire Protection

Source, CalFire 2018, USGS/BLM/BIA/FS/NPS (from Federal Wildland Fire Occurrence database, 2019)

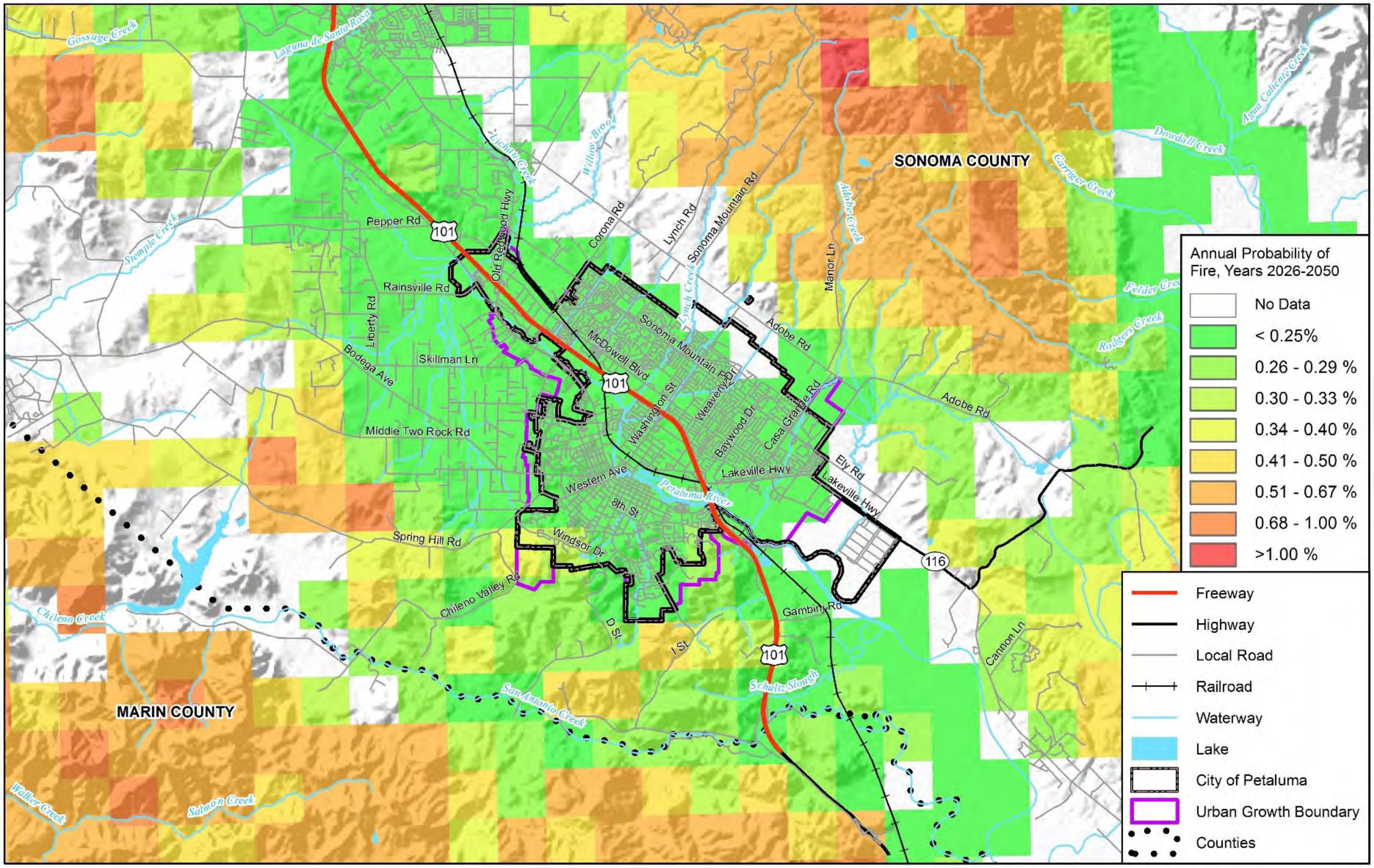
Figure 4-22: Fire History and Burn Perimeters near the City of Petaluma, 1878 to 2018



Probability of Future Occurrences

Occasional – Considering the local fuels, weather conditions, and the flat topography in the area combined with a lack of extensive WUI development means that fires may only occur occasionally in or immediately surrounding the City. A widely damaging wildland fire within the City is considered to be more unlikely, although changing issues and increasing record-high temperatures accompanied by low humidity, strong winds, and drought conditions could worsen the likelihood of fires in the Planning Area in the future. Based on the CAL FIRE Probability and Carbon Accounting mapping, which is based on Mann et al.'s projections for the years 2026-2050 (shown on Figure 4-23 below), the annual probability of fire occurrence is rather low for the most the City (CAL FIRE 2019). The south-southwest corner has a slightly higher probability, though based on the range of values shown in the figure even those 0.4-0.5 percent probabilities remain low compared to areas north and south of the City, within unincorporated portions of Sonoma and Marin Counties. For more information on this CAL FIRE probability mapping methodology and related resources, visit https://frap.fire.ca.gov/frap-projects/fire-probability-and-carbon-accounting/

Figure 4-23: Annual Fire Probability in the City of Petaluma for the Years 2026-2050



Map compiled 10/2019;
intended for planning purposes only.
Data Source: City of Petaluma, CalTrans, US Census TIGER Database, CalFire

Climate Change Considerations

Increases in greenhouse gases coupled with population growth and development are expected to continue impacting California's forests and natural resources. Likewise, the effects of climate change have the potential to impact wildfire behavior, the frequency of ignitions, fire management, and fuel loads. Increasing temperatures may intensify wildfire threat and susceptibility to more frequent wildfires in the grasslands that surround the Planning Area.

Uncertainty exists in how climate change will affect total precipitation, but models suggest that there is a tendency for wetter conditions in the northern part of the state and drier conditions in the south (California Natural Resources Agency 2018). Forests are also sensitive to variable precipitation events, and damaging droughts such as the multi-year event from 2012-2017 contributed to widespread tree mortality as warmer temperatures stressed trees and made them more susceptible to pests and pathogens (California Natural Resources Agency 2018). While the surrounding hillsides near the City's Planning Area consist of mostly grasslands, there are emerging studies that indicate that hot and dry winds can influence shrubland and grassland fires. Studies noted in California's Fourth Assessment report indicate climate change impacts on wind patterns may strongly affect forests, potentially serving as a trigger mechanism for conversion of forest to other types of vegetation (California Natural Resources Agency 2018).

According to the Sonoma County's 2016 Regional CAP, climate change is expected to result in more frequent and intense wildfires. These risks are expected to continue to rise due to increased dryness of vegetation compounded by the productivity of plants in the spring. Based on the Regional CAP data, by the end of the century, the chances of one or more fires during a 30-year period are projected to increase from 15 to 20 percent to 25 to 33 percent in the mountainous areas of the County.

While the CAL FIRE program actively collaborates with state, local, and national agencies to reduce climate change impacts, current scientific models expect California will be affected by increased numbers of forest fires with added intensity due to longer warmer seasons, reduced distribution of biodiversity, lack of moisture, changes in ecosystems, drought impacts (e.g. pest diseases and continued spread of invasive species), and other such impacts in coming years. Due to these increasingly worsening or recurring issues, wildfire hazards should be carefully studied with regards to future negative effects in or near the City Planning Area due to expected growth and development, even if it does not prove a prominent danger to Petaluma and its residents in present times.

Vulnerability Assessment

The City's wildfire risk and vulnerability is a medium concern. Wildfires can affect major transportation roads, such as U.S. Highway 101 and Highway 116 by impeding commuters to get to and from their destinations (e.g. to the Bay Area), as well as potentially block emergency responders. As previously mentioned, wildfire can also damage or destroy property and infrastructure, injure people or even cause death. During the May to October fire season, the dry vegetation and hot sometimes windy weather, combined with a growing population, results in an increase in the number of potential ignitions. Any fire, once ignited, has the potential to quickly become a large, out-of-control fire. Fires that prevent essential goods or services from entering or leaving the City could negatively affect local residents and businesses by impacting the local economy and the community's livelihood (e.g. limited access to jobs, daycare, schools, resources, and residences).

The CAL FIRE-produced FHSZs within LRAs displayed in Figure 4-24 were used to assess general wildfire risk in the Planning Area, using methodology detailed below. The results are summarized in the tables and maps that follow.

The City's parcel layer was used as the basis for the inventory of parcels, while the CAL FIRE FHSZs in LRAs, ranked by severity, was used to intersect the parcels and determine general risk based on the severity rank categorization, all in GIS. Centroids were generated for each parcel for simpler overlay analysis, so that a parcel was either "in" a fire threat layer of type "moderate severity," "high severity," or "very high severity," or "out" of any of these fire threat categories (e.g. in Urban Unzoned or Non-Wildland/Non-Urban areas). For purposes of this analysis, it was assumed that every parcel with an improved value greater than zero was developed in some way, even those stated as "vacant." This specification ensures parcels such as rights-of-way are discarded for the purposes of determining vulnerability to fire, and to be able to aggregate valuations based on each parcel type (e.g. residential, commercial, agricultural). The assessor's office data calculates improved values based on the "annual structure value" which relates to the improvements of the parcel; this was the field used to determine improved values for each parcel.

Once parcels in the form of centroids are categorized by property type, next the content values were calculated as follows: a) residential and multi-family properties received contents valued at 50 percent of the parcel improved value; b) commercial and agricultural properties' contents were valued at 100 percent of the parcel improved value; and, c) vacant parcels (if applicable) received 0 percent content values. These valuation assignments are based on FEMA's methodology for estimating contents within their loss estimation software, Hazus-MH.

Properties falling in the FHSZs are listed in Table 4-25, along with a summary of all improved structure values, contents values, total values (which are the aggregated improved structure values plus the content values), loss estimates (equal to 100 percent of the total parcel values) and population at risk. As Figure 4-25 illustrates, the areas with parcels exposed to the FHSZs within the LRAs are found along the south, east of the Urban Growth Boundary, and near the central-west portions of the City (along Highway 101, northwest of Washington St. and south of McDowell Blvd.)

Property

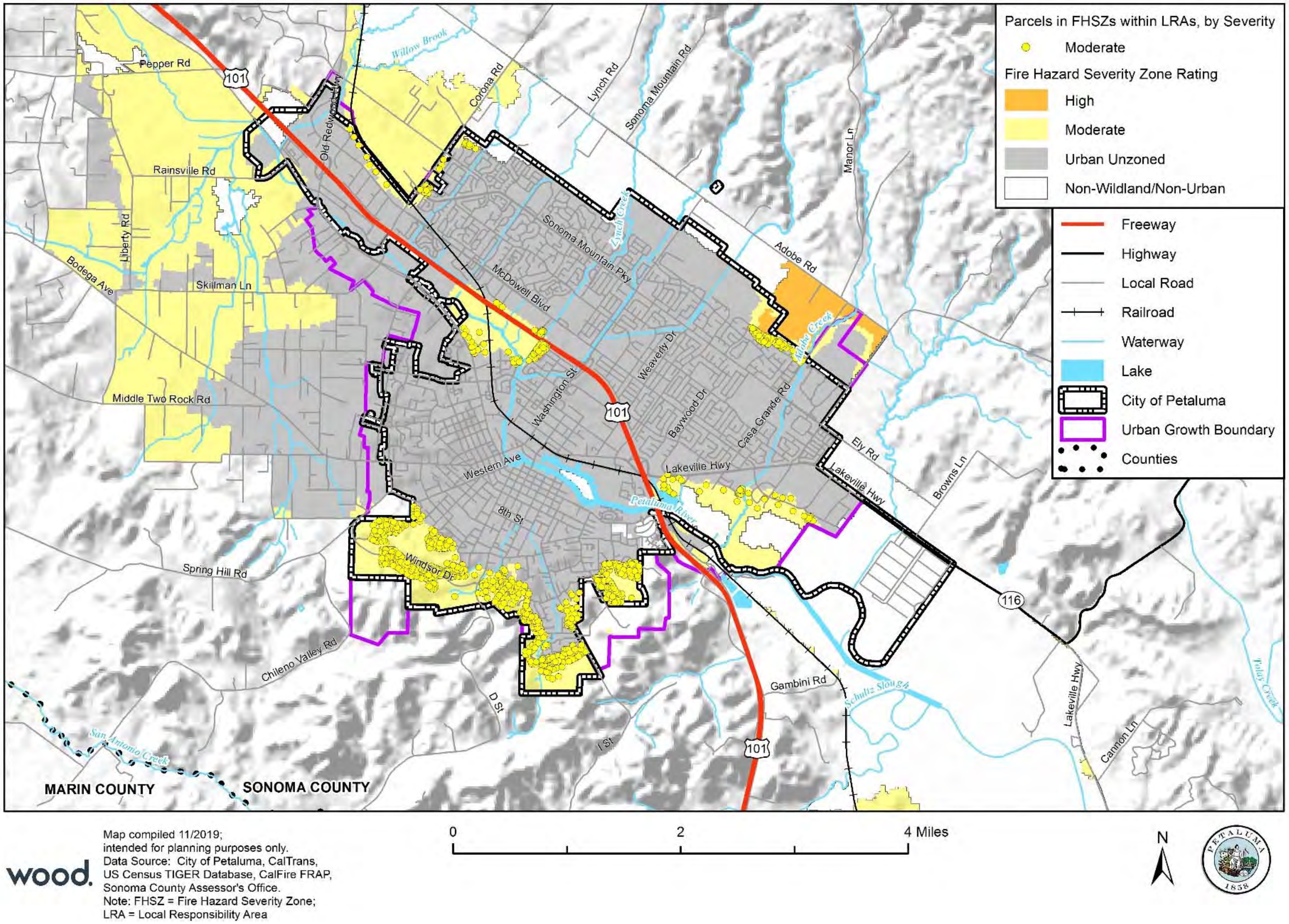
The fire severity zones and parcel overlay analysis yielded the following results below. The highest number of parcels at risk fall under the Residential category (with a total of 917 parcels), followed by the Commercial category (with 93 parcels), Multi-family (with 3 parcels), and finally Agricultural (with 2 parcels at risk). A total of $937.8 million in parcel value is at risk of being affected by potential fires, based on a $572.3 million improved structure value combined between all the parcel types, and $365.5 million in content values. The moderate fire hazard severity category contains all the parcels at risk, with 1,015. No parcels fall in the high or very high FHSZ areas. Figure 4-24 displays parcels located in the FHSZ areas.

Table 4-25: Parcels in Fire Hazard Severity Zones within Local Responsibility Areas in Petaluma

Fire Threat Ranking	Parcel Type	Total Parcels	Improved Structure Value	Contents Value	Total Value	Loss Estimate (100% of the Total Value)	Population at Risk
Moderate	Agricultural	2	$12,473	$12,473	$24,946	$24,946	--
	Commercial	93	$158,660,345	$158,660,345	$317,320,690	$317,320,690	--
	Multifamily	3	$49,818,964	$24,909,482	$74,728,446	$74,728,446	8
	Residential	917	$363,846,182	$181,923,091	$545,769,273	$545,769,273	2,458
TOTAL		**1,015**	**$572,337,964**	**$365,505,391**	**$937,843,355**	**$937,843,355**	**2,466**

Source: City of Petaluma GIS, Sonoma County Assessor's Office; CalFire; Wood Parcel Analysis; U.S. Census Bureau

Figure 4-24: Parcels in Fire Hazard Severity Zones in Local Responsibility Areas - City of Petaluma



People


The Kincade Fire in northern Sonoma County started on October 23, 2019 and was not fully contained until November 6, 2019. It started near Geyserville and spread smoke toward Petaluma Valley and the surrounding Bay Area. The City opened the Petaluma Community Shelter for fire evacuees. During the same time, part of the City was without electricity due to the planned power shutoffs.
Photo Credit: San Francisco Chronicle 2019

Wildfire risk is of greatest concern to populations residing in the moderate, high, and very high wildfire threat zones. The 2018 U.S. Census estimates were used to show the average persons per household in the City of Petaluma, so that total persons at risk of each fire threat category could be calculated, based on property type. For each residential property type (i.e., general residential, multifamily), an average household value of 2.68 people per parcel was applied to roughly estimate potential population at risk. Table 4-25 above summarized the estimated population residing in each fire threat zone along with the parcel analysis summary by fire threat type. The results were estimated by multiplying the average persons per household in Petaluma times the number of residential parcels in each fire threat zone. Based on the analysis, the moderate FHSZ has 2,466 potential people at risk.

Based on HMPC feedback, the Petaluma Fire Department has a program called Citizens Organized to be Prepared for Emergencies, or COPE, which holds quarterly seminars on preparedness. The COPE program stresses the importance of encouraging neighborhood organization through efforts such as the "Map Your Neighborhood." In future wildfire events this program could be useful in effectively engaging the local populations in avoiding damages to fires or evacuating before a fire, hence preventing injuries and losses. The City website also contains information and resources regarding these recent projects and efforts.

Economy

Wildfires can be incredibly destructive depending on the circumstances of the event, particularly the type of resources and populations they affect due to fire size, location, length of the burn, and ongoing or existing weather or hazard conditions. For example, damages to structures and properties are obvious impacts to the economy due to fire, though cascading negative effects on the economic sectors include road closures, lower revenue to the City based on reduced tourism and visitation, or excessive costs of firefighting and relocating people or natural and man-made resources (thus indirectly impacting city revenues). Transportation lifelines being closed and/or damaged could impede a majority of the population's ability to commute to nearby cities and the Bay Area. Additional direct or indirect impacts to the economy could be further exacerbated by existing hazard issues such as earthquakes, drought, or severe weather, if those make it difficult to control the fires or reestablish the economic drivers in the Planning Area.

Critical Facilities and Infrastructure

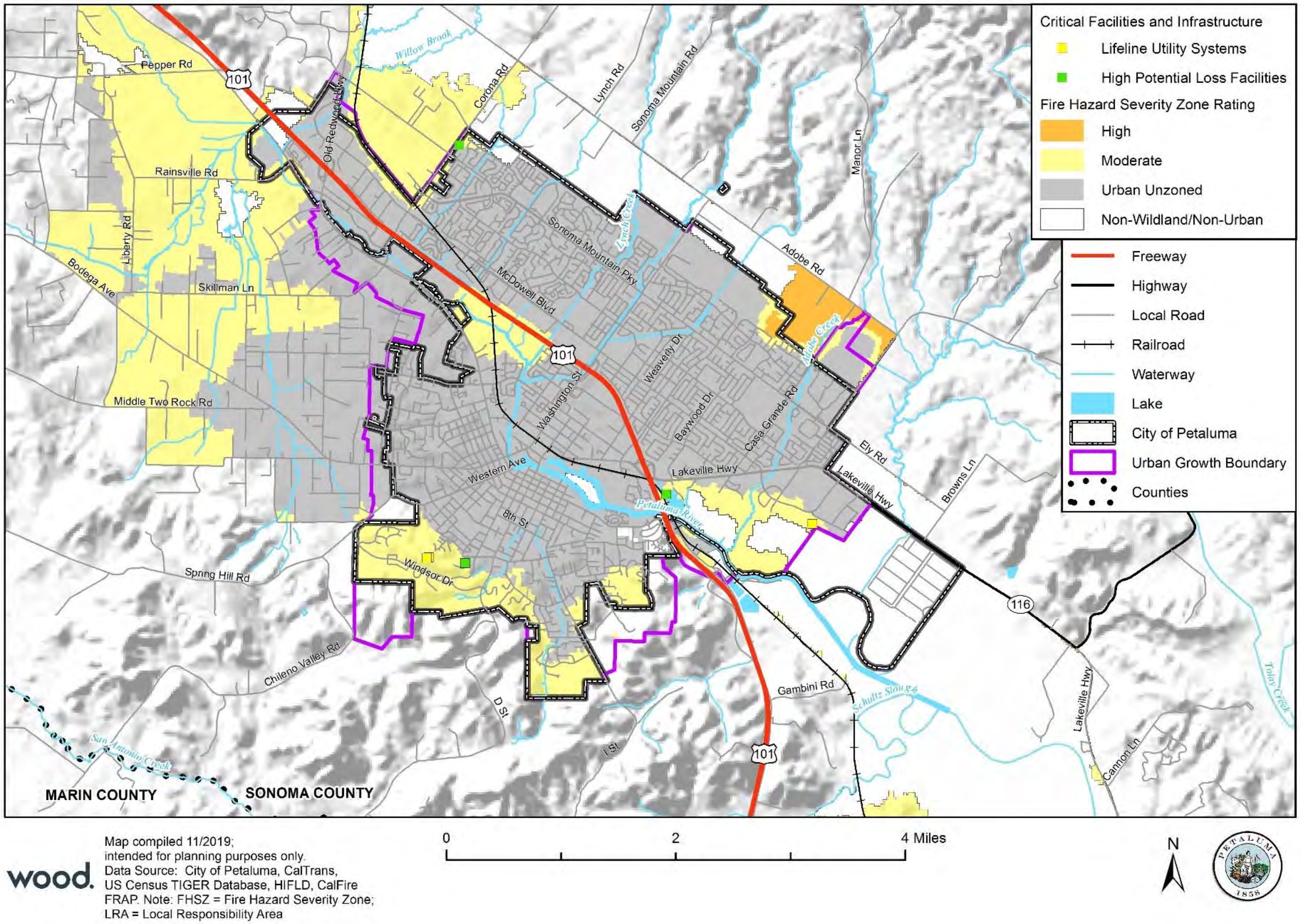
Critical facilities are those community components that are most needed to withstand the impacts of a disaster. An overlay analysis using GIS was performed to determine where critical facilities are located within FHSZs ranked moderate, high, or very high (within the LRAs as defined by CAL FIRE). Only those facilities located in these zones are noted as being at risk. Figure 4-25 shows those critical facilities located in the City that fall in the FHSZs, while Table 4-26 describes the facilities. Based on these results, a total of six critical facilities are found in zones of the type "moderate." No other fire threat zones contain critical facilities in the Planning Area. From these facilities, three are High Potential Loss Facilities, and the other three fall under the Lifeline Utility Systems category.

Table 4-26: The City of Petaluma's Critical Facilities at Risk to Wildfire based on FHSZs in LRAs

Fire Threat Zone	Critical Facility Category	Critical Facility Type	Critical Facility Total
Moderate	High Potential Loss Facilities	Community/Recreation Center	1
		Day Care Facilities	1
		Public Schools	1
	TOTAL		**3**
	Lifeline Utility Systems	Microwave Service Towers	1
		Water Facility	2
	TOTAL		**3**
	GRAND TOTAL		**6**

Source: City of Petaluma GIS; HIFLD; CalFire FRAP; Wood GIS Analysis

Figure 4-25: Critical Facilities and Infrastructure within Fire Threat Zones in the City of Petaluma



According to California's Fourth Climate Assessment, wildfire may be the biggest immediate threat to California's transportation system, as vegetation fuel accumulation continues to increase (California Natural Resources Agency 2018). Wildfires can also lead to mudslides and debris flows, later resulting in the temporary transportation system closures or other key impacts to the community. Studies cited in the most recent climate assessment also found that a considerable amount of infrastructure is exposed to wildfire risk, with the highest risk being roads and highways, such as U.S. Highway 101 and Highway 116. Railroads may also be at risk of warping during wildfires, and transportation or freight activity disrupted, while smoke and fire-fighting operations can lead to temporary service disruptions that can additionally affect movement of goods and services (California Natural Resources Agency 2018).

Historic, Cultural, and Natural Resources

The City has eight cultural and historic resource places, as summarized under Section 4.2 of this plan. Since these structures are sensitive in nature and may not have been built according to the latest building codes due to their age, it is expected that they might be at risk of wildfires (e.g. because of their potential inability to withstand significant heat). However, other areas such as parks or natural spaces could also be at risk of a wildfire, but these places would need to be further studied to determine vulnerability and risk more specifically.

Future Development

Population growth and development in the City of Petaluma is increasing, as noted on the Petaluma City Profile Report released in 2018.,Petaluma is expected to grow 3.2 percent by the year 2022, which results in an increase of 62,700 residents. The increasing urbanization of the Planning Area makes wildfire vulnerability a growing issue, as future development in the WUI should increase risk to this hazard citywide. WUI related risks can however be managed with strong land use regulations and building code requirements. For example, development in the WUI can require firebreaks between development and grasslands, as well as enforce that building construction be compliant with CBC Chapter 7A: Materials and Construction Methods for Exterior Wildfire Exposure.

Risk Summary

- The overall risk significance of wildfire hazards to the City of Petaluma is **Medium**.
- Wildfires are expected to have a probability of occasional occurrence in the future, given the local fuel, topography, and weather conditions and the extent of the WUI. Based on recent CAL FIRE future fire occurrence probability mapping, the City of Petaluma is mostly expected to have a low likelihood of fire from years 2026 to 2050.
- The areas of the City with high or very high fire threat, which in turn pose the highest risk to life and property, are located on the south- of the Planning Area, near Windsor Drive. However, all of the City's parcels falling fire hazard severity zones are in the "moderate" zone, with 1,015 parcels vulnerable to wildfire (within LRA as defined by CAL FIRE).
- Approximately 2,466 people may be at risk of the moderate FHSZs within the LRA.
- Six critical facilities are in moderate fire threat areas within the City of Petaluma (no other facilities fall in any additional fire threat zones).
- Eight historic and cultural properties and places are exposed to wildfire risks, based on the NRHP database.

- Population growth is expected to be at 3.2 percent by 2022 in the City of Petaluma, so WUI development may become a larger issue into the future. Building to the current code with regards to materials and structures is recommended based these development trends.

4.3.5 Flood

Hazard Description

Floods are among the most frequent and costly natural disasters in terms of human hardship and economic loss. Flooding is usually the result of, or often exacerbated by, weather events. Floods can cause substantial damage to structures, landscapes, and utilities as well as life safety issues. Certain health hazards are also common to flood events; standing water and wet materials in structures can become breeding grounds for microorganisms such as bacteria, mold, and viruses. Standing water or affected infrastructure can in turn cause disease, trigger allergic reactions, and damage materials long after the flood. When floodwaters contain sewage or decaying animal carcasses, infectious disease also becomes a concern. Direct impacts such as drowning can be limited with adequate warning and public education about what to do during floods. Where flooding occurs in populated areas, warning and evacuation will be of critical importance to reduce life and safety impacts.

Floodplains are defined as the areas immediately adjacent to a channel from a river, stream, or other waterway. Floodplains are illustrated on inundation maps, which show areas of potential flooding and water depths. In its common usage and based on FEMA guidelines, the floodplain most often refers to the area that is inundated by the 100-year flood, or the flood that has a one percent chance in any given year of being equaled or exceeded. The 100-year flood is the national minimum standard to which communities regulate their floodplains through the FEMA National Flood Insurance Program (NFIP). The 500-year flood is the flood that has a 0.2 percent chance of being equaled or exceeded in any given year. A 500-year flood event would be slightly deeper and cover a greater area than a 100-year flood event. The potential for flooding can change and increase through various land use changes and changes to land surface, which then may result in a change to the floodplain. A change in environment can create localized flooding problems inside and outside of natural floodplains by altering or confining natural drainage channels. These changes are most often created by human activity.

The City of Petaluma is susceptible to various types of flood events as described below.

- **Riverine Flooding** - Riverine flooding, defined as the condition when a watercourse (e.g. river or channel) exceeds its "bank-full" capacity, generally occurs as a result of prolonged rainfall, or rainfall that is combined with already saturated soils from previous rain events. This type of flood occurs in river systems whose tributaries may drain large geographic areas and include one or more independent river basins. The onset and duration of riverine floods may vary from a few hours to many days. Factors that directly affect the amount of flood runoff include precipitation amount, intensity and distribution, the amount of soil moisture, seasonal variation in vegetation, snow depth, and water-resistance of the surface due to urbanization. In the Planning Area, flooding is largely caused by heavy and continued rains, increased outflows from upstream dams, and heavy flow from tributary streams. Local intense storms can overwhelm nearby waterways as well as the integrity of flood control structures. The warning time associated with slow rise floods assists in life and property protection.

- **Localized Flooding** - Flash flooding describes localized floods of great volume and short duration. This type of flood usually results from a heavy rainfall on a relatively small drainage area. Precipitation of this sort usually occurs in the winter and spring. Flash floods often require immediate evacuation. Related to this type of flooding is also localized flooding, which is often caused by flash flooding, severe weather, or an unusual amount of rainfall. Flooding from these intense weather events occurs in areas experiencing an increase in runoff from impervious surfaces associated with development and urbanization as well as inadequate storm drainage systems.
- **Dam or Levee Failure Flooding** – Potential inundation caused by failure or mis-operation of one or more upstream dams or water control structures such as levees is also a concern to the City of Petaluma. A catastrophic flood control or water retention structural failure could easily overwhelm local response capabilities and require evacuations towards the east of the City, which is in closest proximity to the two dams identified in this plan. Impacts to life safety will depend on the warning time and the resources available to notify and evacuate the public, as well as the magnitude of the event. Loss of life could potentially result, however, and there could be associated health concerns as well as negative effects to local buildings and infrastructure. Dam failure is addressed in more detail under Section 4.3.1 Dam Incidents, while levee failures and other aspects related to localized flood problem areas are discussed throughout this chapter.

Location

Flooding of various types may occur anywhere within the City's Planning Area. Details on local water features, watersheds, and flood control structures and systems are provided below.

City of Petaluma Watersheds and Waterways

The City of Petaluma is primarily located within the San Pablo Bay and the Petaluma River-Frontal San Pablo Bay Estuaries watersheds (under Hydrologic Unit Codes 1805000208 and 1805000206, respectively), both of which are part of the greater San Pablo Bay Watershed (Hydrologic Unit Code 18050002).

The City is located in the Petaluma Valley, a fairly flat alluvial plain with elevation ranging from sea level along the Petaluma River, to over 400 feet in the nearby hills. This valley is characterized by a Mediterranean climate with long and dry summers, followed by cool and wet winters. The mean annual precipitation over the valley is approximately 26 inches (City of Petaluma 2015).

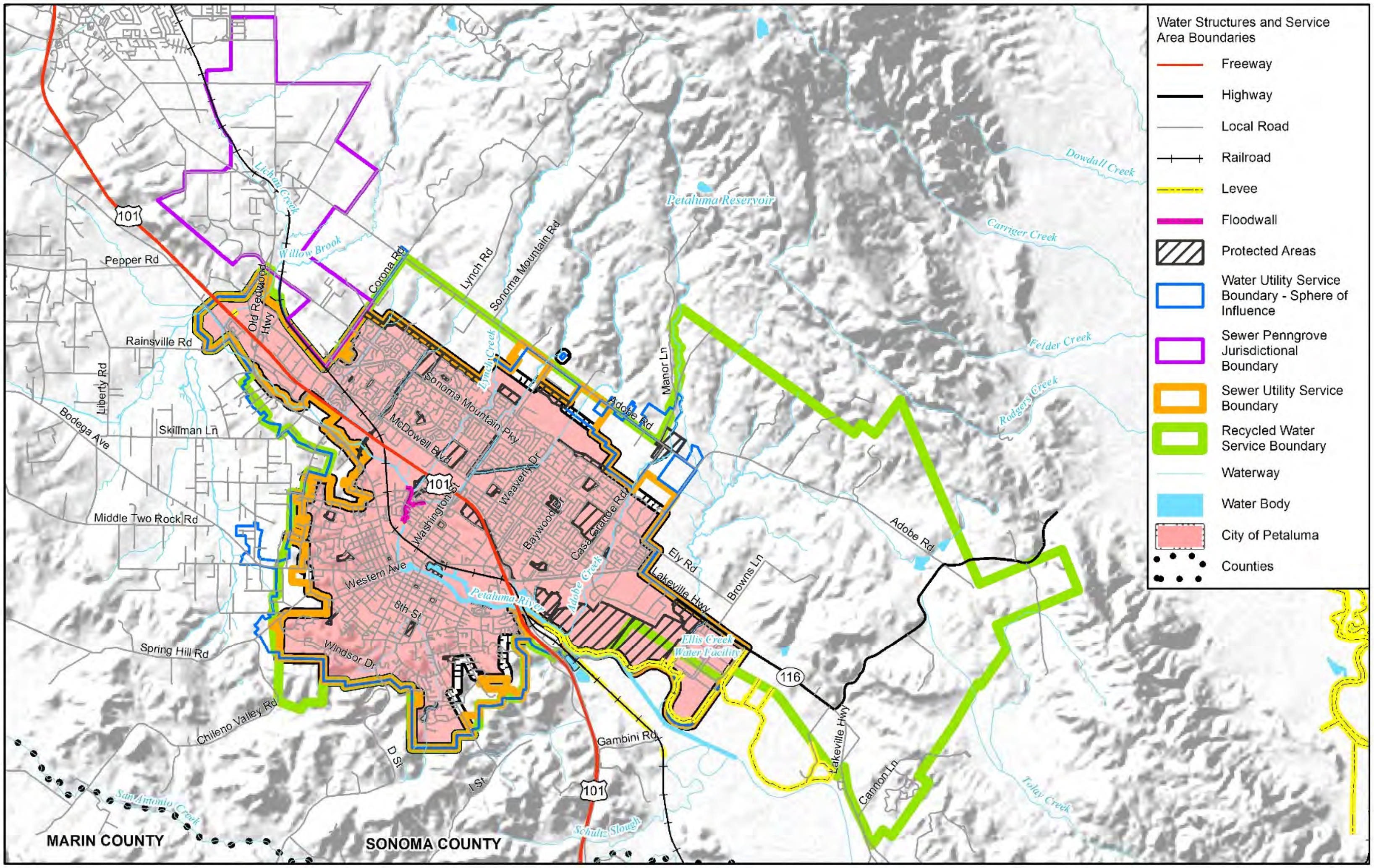
The main waterways in the City include the Petaluma River, Adobe Creek, Lynch Creek, Lichau Creek, and smaller branches or tributaries such as Willow Brook. The Petaluma River is historically important due to its key role in enabling exploration activities, settlement, and the development of the Petaluma and San Pablo Bay watersheds. Over the years, inundation and overtopping of the banks of the Petaluma River have caused siltation of the streambed, which in turn has had an effect on the water-carrying capacity and also navigability of the waterway (causing problems for many decades on the surrounding communities). The City's two watersheds are described below.

San Pablo Bay Watershed (HUC 18050002) - The larger San Pablo Bay Watershed covers approximately 1,227 square miles and spans the counties of Sonoma, Marin, Napa, Alameda, Contra Costa, San Francisco, and Solano, all within California. The San Pablo Bay watershed drains into the San Pablo and San Francisco Bays, and the main tributaries of this watershed are the Napa River, Petaluma River, and Sonoma Creek.

Figure 4-26 below illustrates general waterways and water features in the City, including FEMA NFHL levee centerlines and water service area boundaries (e.g. utilities, sewer, etc.). The main river present in the City is the Petaluma River, and the largest levee structure covers part of this river on the southern portion of the boundary, near the Ellis Creek Water Facility. Small portions of the Petaluma River and Lynch Creek are leveed, on the center and western portion of the City north of Washington Street. Some protected areas are also present on the south-southeast of the City, as portrayed in the Figure 4-26 with dark grey hash marks. The smaller San Pablo Bay Watershed, associated with HUC 1805000208, is displayed alongside the Petaluma River watershed (with HUC 1805000206) in Figure 4-27.

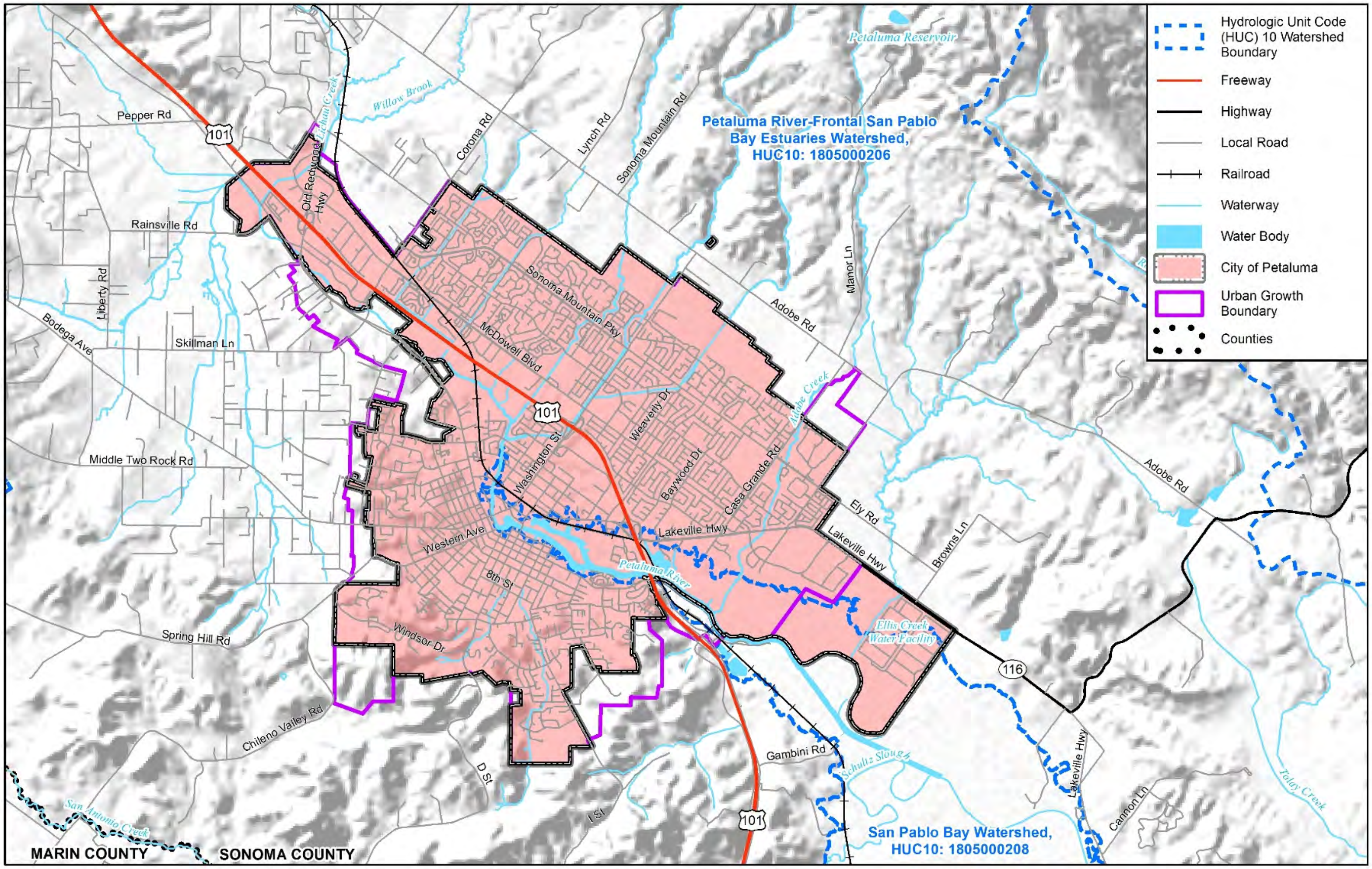
Petaluma River-Frontal San Pablo Bay Estuaries Watershed (HUC 1805000206) – This smaller watershed is located in the southern portion of Sonoma County, with some parts falling in Marin County. It is approximately 126,518 acres in size and it is the watershed which covers the majority of the City and its Planning Area. Tidal influences extend into the City and the watershed, with the confluence of Lynch Creek on the north-central portion of the City. The watershed contains salt marshes and wetlands.

Figure 4-26: City of Petaluma Water Service Areas and Flood Control Structures



Map compiled 9/2019; intended for planning purposes only.
Data Source: City of Petaluma, CalTrans, US Census TIGER Database, FEMA NFHL, USGS

Figure 4-27: Watersheds in the City of Petaluma and Its Planning Area



Map compiled 10/2019;
intended for planning purposes only.
Data Source: City of Petaluma, CalTrans, US Census TIGER Database, FEMA NFHL, USGS/NHD

Local and Regional Drainage Facilities

Major drainage features within the Planning Area or managed by the City of Petaluma include:

- Petaluma River
- Adobe Creek
- Lynch Creek
- Lichau Creek
- Willow Brook
- Small unnamed branches and tributaries in the San Pablo Bay and Petaluma River-Frontal San Pablo Bay Estuaries watersheds
- Petaluma Water Aqueduct
- The Lawler structure/dam
- City and County stormwater drainage facilities (e.g. as indicated in the Petaluma Storm Water Management Plan)
- City water weir
- City pumps, tanks, lift, ditches, and other water structures/stations

Floodplain Mapping and Studies

FEMA established standards for floodplain mapping studies as part of the NFIP (FEMA 2019). The NFIP makes flood insurance available to property owners in participating communities adopting FEMA-approved local floodplain studies, maps, and regulations. Floodplain studies that may be approved by FEMA include federally funded studies; studies developed by state, city, and regional public agencies; and technical studies generated by private interests as part of property annexation and land development efforts. Such studies may include entire stream reaches or limited stream sections depending on the nature and scope of a study. A general overview of floodplain mapping and related components is provided in the following paragraphs.

Flood Insurance Study (FIS) - The FIS develops flood-risk data for various areas of a community that are used to establish flood insurance rates and assist the community in its efforts to promote sound floodplain management. The latest FIS applicable to the City of Petaluma was included in a five-volume report along with other incorporated jurisdictions and unincorporated areas studied in Sonoma County; this recent report was last revised March 7, 2017.

Flood Insurance Rate Map (FIRM) - The FIRM is designed for flood insurance and floodplain management applications. For flood insurance, the FIRM designates flood insurance rate zones to assign premium rates for flood insurance policies. The designated flood zones are based on flood risk in the area. For floodplain management, the FIRM delineates 100- and 500-year floodplains, floodways, and the locations of selected cross sections used in the hydrology and hydraulic analyses and local floodplain regulations.

Land areas that are high risk within the 100-year floodplain (meaning they have a one percent annual chance of flooding), are called Special Flood Hazard Areas (SFHAs) and are mapped as A or AE zones. The difference between A and AE zones are the level of detail in analysis and mapping, so that A zones are more general while AE contain additional detail and also display Base Flood Elevations, or BFEs. In communities that participate in the NFIP, mandatory flood insurance purchase requirements apply to Zones A and AE (i.e., those areas subject to a 100-year flood event).

The City of Petaluma FIRMs, just as with most portions of California and larger developments across the U.S., have been replaced by new digital flood insurance rate maps (or DFIRMS) as part of FEMA's Risk Map and Map Modernization programs. DFIRMs and related datasets (e.g. cross sections used in floodplain studies and analyses, BFEs, etc.) are now delivered via National Flood Hazard Layer (NFHL) databases, accessible for free online at FEMA's Flood Map Service Center site.

These digital DFIRMs achieve the following purposes:

- Incorporate the latest flood study updates (LOMRs and LOMAs)
- Utilize community supplied data
- Verify the currency of the floodplains and refit them to community supplied base maps and base data
- Upgrade the FIRMs to a GIS database format to set the stage for future updates and to enable manipulation, storage, and support for GIS analyses and other digital applications
- Solicit community participation

The most current DFIRMs for the City of Petaluma and other jurisdictions or unincorporated areas within Sonoma County are included in the county's NFHL database. The latest effective date for studies in the County is March 7, 2017. The spatial features available in this NFHL database, such as floodplains and levees, were used for the analyses and mapping in this plan as they relate to flooding hazards.

Letter of Map Revision (LOMR) and Letter of Map Amendment (LOMA) - LOMRs and LOMAs represent separate floodplain studies dealing with individual properties or limited stream segments that update the FIS and FIRM data (as revisions or amendments) between periodic FEMA publications of the FIS and FIRM products.

Major Sources of Flooding

General rainfall floods, primarily associated with seasonal storms and thunderstorms, can occur in the City during winter and spring months. This type of flood results from prolonged heavy rainfall over tributary areas and is characterized by high peak flows of moderate duration. Flooding is more severe when antecedent rain has resulted in saturated ground conditions.

In the more urbanized areas of Petaluma, flood problems intensify because the immediate areas are developed and contain mostly impervious surfaces such as roads and paved structures. Because of this, the nearby open land available to absorb rainfall and runoff is often limited or difficult to access naturally. In other words, the decrease in the amount of open land that can absorb precipitation increases the volume of water that must be carried away by waterways and developed infrastructure, causing localized flash flooding and stormwater issues.

The latest FEMA NFHL data indicate that 100- and 500-year floodplains are predominantly located on the south-southeast and north-northwest of the City, along the Petaluma River (see Figure 4-28). Other smaller flooding areas are also expected to occur along Lakeville Highway and Casa Grande Road, on the confluence of Adobe Creek with the Petaluma River, as well as east of Washington Street and McDowell Boulevard, on the confluences of Lynch Creek and nearby tributaries associated with the Petaluma River. The more upstream portions of Lynch Creek, near the north-northeast of the City are also affected by flooding, towards Adobe Road north of Sonoma Mountain Parkway.

The Sonoma Water authority was enabled, in 1958, to create several geographic zones encompassing major watersheds in the county, in order to finance development and maintenance of flood protection projects as flood control zones. The City of Petaluma falls in Zone 2A, named the Petaluma River Watershed area. Zone advisory committees exist which are in charge of prioritizing, managing, and approving zone related capital improvement plans and projects such as flood protection and drainage facility works, natural waterway maintenance, plan development, erosion and sedimentation control activities, and others also pertaining to Sonoma Water's goals and objectives. Petaluma's Zone 2A flood control area is represented in Figure 4-28 below including the zone's stream maintenance program focus areas along major waterways (i.e. primary sources of flooding) in the City.

Figure 4-28: FEMA Special Flood Hazard Areas for the 1% and 0.2% Annual Chance Flood Events in the City of Petaluma

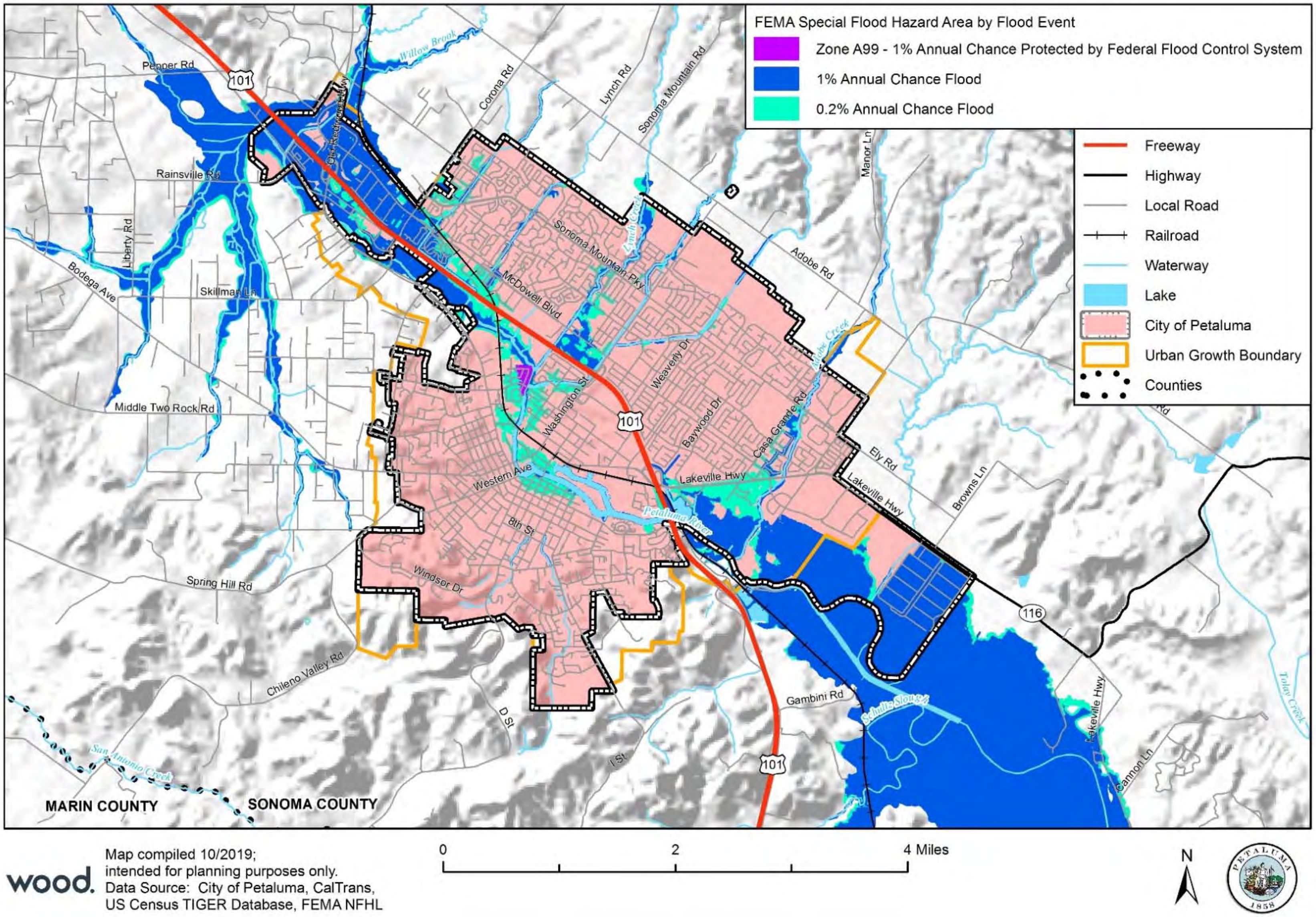


Figure 4-29: Petaluma Flood Control Zone 2A and Stream Maintenance Program Focus Areas

Localized Flooding Problem Areas

Based on historical occurrence data, the Payran neighborhood and nearby areas have been severely impacted by flooding from storms and flash floods compared to other communities in the City's Planning Area. This is the area where the two worst floods for Petaluma occurred and resulted in millions of dollars in damages and losses (i.e. the floods of 1982 and 2005). More information on heavily flood-affected areas is summarized in the Previous Occurrences subsection and the Vulnerability Assessment (including the Insurance Coverage and NFIP Claims and Losses subsection, information on repetitive loss properties and Community Information System records for Petaluma).

The Petaluma River Flood Control project is currently nearing completion, and the Payran levee project is part of this larger flood control project. Once constructed, this flood control project is expected to relieve flood risk and historic and repetitive flooding impacts to the Payran area. According to the City's FMP, the Petaluma has already been noticing a significant reduction in flooding related issues due to project implementation and construction (City of Petaluma 2015b).

Levees

In many locations in California, levees and flood control facilities have been built and are maintained by various public and private entities, including water, irrigation, and flood control districts; other state and local agencies; and private interests (National Levee Database 2018). Some of these facilities were constructed with flood control as secondary or incidental to their primary purpose. The City of Petaluma owns, operates, and maintains two floodwalls within the Planning Area, were both shown in Figure 4-29 as dark pink line features. The two flood control structures are located west of Washington Street along the Petaluma River, in the center-west portion of the Planning Area. However, other levees contained in the latest FEMA NFHL database cover the boundaries of the City and Planning Area; these are also located along the Petaluma River, but on the south-southeast portion of the Planning Area. Petaluma pledged to pursue certification of several of these existing levees in order to better protect the City's infrastructure, including the wastewater treatment plant and wetland areas.

A small portion of a Zone A99 is located in the Planning Area, as shown in Figure 4-28 by the purple polygon. This special flood designation is located in the Payran residential neighborhood, a few streets west of Washington Street and to the east of the railroad, in the central and western portion of the City. These A99 flood zones are 100-year floodplains that will be protected by federal flood control systems or structures, as their construction methods have reached specified legal requirements. The City of Petaluma submitted this A99 flood zone determination application in 2013, and on June 10, 2014 a LOMR using this flood zone classification became effective. It is expected that when construction has been fully completed the Payran levee project will be certified by the U.S. Army Corps of Engineers, and this zone will switch to a flood zone of type "X" (i.e. areas of minimal flood hazard) (City of Petaluma 2015b).

Extent (Magnitude/Severity)

Limited – Flood maps can be used as an indicator of flood extent. Flood depth and velocity also affect the extent of flood hazards and resulting damage. The deeper and faster flood flows become, the more damage they can cause in a community. However, shallow flooding with high velocities (e.g., such as a flash flood event caused by precipitation) can cause as much damage as deep flooding with a slow velocity (e.g., from a riverine flood event). This typically happens when a channel migrates over a floodplain and redirects flows and transports debris and sediment.

While cities can implement measures to prevent or reduce the severity and magnitude of flood hazards, some level of risk often remains. These types of threats include upstream dam failure, infrastructure failure, and severe flood events that exceed flood design standards or drainage capacity, leading to flash flooding. Flood severity can be determined by logging peak discharge flows. This information is tracked by both FEMA and the USGS. FEMA's BFE depth curve datasets can provide further insight as to how much gets flooded of a community and where exactly, enhancing the level of detail on the magnitude of flooding that can affect a particular community. Based on the most recent NFHL database from FEMA (which includes these BFEs), the City of Petaluma and its Planning Area is expected to experience the worst flooding conditions across the northeast and southeast, with pockets of deep inundation across the central portions of the Petaluma River near the downtown area, and north-northwest of Washington Street and north-northeast of Western Avenue (near the Payran neighborhood).

Based on a flood depth grid indicating the amount of feet that areas of the City could experience in terms of flooding amount, the City of Petaluma may experience one to two feet of flooding near Wickersham Park and the Theater District area, and two to four feet of flooding in small pockets of roads or lawn/field areas near the Norcal Paintball Park north of Payran Street. Other portions of the City may face deeper flooding (over 5 feet), such in the residential neighborhood's paved areas located between Caulfield Lane and S. McDowell Boulevard, east of U.S. Highway 101.

Other localized flooding from existing stormwater infrastructure, for example, is more difficult to estimate but could happen anywhere in the Planning Area and could be severe depending on the flood event itself and the conditions of the existing infrastructure. Table 4-27 below summarizes the general FEMA-available flood zones for context. Overall, while the historic extent of flooding hazards was likely critical, today, flooding hazards were rated by the City and HMPC as being limited in terms of magnitude or severity for the City of Petaluma.

Table 4-27: FEMA's Special Flood Hazard Area Zone Descriptions

Flood Zone	Definition
FEMA Special Flood Hazard Areas (SFHA) Subject to Inundation by the 100- or 500-Year Floods	
Zone A	100-year floodplain, or areas with a 1% annual chance of flooding. Because detailed analyses are not performed these areas, no depths or base flood elevations are shown in Zone A areas.
Zone AE	Detailed studies for the 100-year floodplain. The base floodplain where base flood elevations are provided. AE Zones are now used on new format FIRMs instead of A1-A30 zones.
Zone AH	Areas with a 1% chance of shallow flooding, usually in the form of a pong with an average depth ranging from 1 to 3 feet. These are flood elevations derived from detailed analyses.
Zone AO	River or stream flood hazard areas and areas with a 1% or greater chance of shallow flooding each year, usually in the form of sheet flow, with an average depth ranging from 1 to 3 feet. Average flood depths derived from detailed analyses.
Zone A99	100-year floodplain, areas with a 1% 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.
Other Flood Areas	
Floodway	A regulatory floodway is the channel of a river or other watercourse and the adjacent land areas that must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than a designated height.
Zone X (shaded)	Areas with a 0.2% annual chance flooding (1 in 500 chance), between the limits of the 100-year and 500-year floodplains. This zone is also used to designate base floodplains of lesser hazards, such as areas protected by levees from the 100-year flood, shallow flooding areas with average depths of less than one foot, or drainage areas less than 1 square mile.
Zone X (unshaded)	500-year floodplain (0.2% annual chance). Area of minimal flood hazard.

Source: FEMA Flood Map Service Center, 2018

Previous Occurrences

The City of Petaluma has historically been impacted by flooding from sources such as general riverine and flash flooding from winter storms. Historical records are described below, but may not represent all historical events. The records below are from several sources, including: the NCEI database, which is managed by NOAA; 2016 Sonoma County Operational Area HMP; the 2018 California SHMP, 2015 Petaluma FMP; the U.S. Department of Agriculture's Secretarial Disaster Designations; and, the OpenFEMA Disaster Declaration dataset.

January 3-5, 1982 – This is the largest flood of record in the City. It led to approximately $28 million in damages, and the storm that caused the flooding is documented in an Army Corps of Engineers post-flood event report, reading as follows: "During the January 1982 storm, flooding occurred over a 50+ block area on both sides of the river through the City of Petaluma. Most of the 500 homes and the 100 commercial-industrial establishments in this area incurred flood damage. In many cases, water depth reached two to three feet inside the structure. The most severely hit area appears to be along Jess Avenue where most homes had four to five feet inside. Payran Street was also an area of major damage in which flooding reached over three feet inside the structure." (City of Petaluma 2015b).

February 14-17, 1986 - $1 million in damages were caused in the Petaluma River urbanized sections between the Lynch Creek confluence with the Lakeville Street Bridge. An article in the San Francisco Chronicle headlined "Petaluma Takes to the Boats" published February 15, 1986, noted how 400 homes were evacuated due to this flood in the Linda Del Mar subdivision, and how flood waters reached a depth of about 5 feet (City of Petaluma 2015b).

March 9, 1995 – This flood event led to about $9,000 of damage to the Petaluma Wastewater Treatment Plant as flood control structures were severely impacted. Hopper Street also experienced damage. In addition, seven schools were closed, and over 300 homes had to be evacuated for safety reasons. Another article in the San Francisco Chronicle was published on March 10, 1995 on this event, titled "Soggy Anger on the Street That Always Floods." The article discussed how Payran Street was impacted during this event and how that particular street and area commonly get flooded over the years.

February 1998 – The winter of 1997-1998 felt the effects of the El Niño storms, which caused great storms in the west coast that lead to the major flooding in Petaluma among other California coastal areas. Approximately $6 million were incurred from damages in the City, from both the early February event (2nd-3rd of the month) as well as the February 29, 2019 storms. State and federal governments declared the events as disasters (under the FEMA DR 1203 declaration). The Payran neighborhood and businesses in the Industrial Ave/Auto Center Drive area saw the worst effects, and oxidation ponds the City's wastewater treatment facility also were badly damaged. The San Francisco Chronicle published an article on February 20, 1998 titled "More Rain, More Havoc" about this event. The article reported that the Payran community got hit for the third time in three weeks with storms and flooding, and almost 50 homes needed evacuation. Around 30 seniors required evacuation as well, from a mobile home park north of the City.

December 31, 2005 – The middle and northern areas of the City experienced significant flooding due to this New Year's Eve event, incurring $56 million in structural damages (affecting 53 structures). Flood waters also damaged streets and river channel banks, particularly within the Petaluma Factory Outlets, and at several commercial structures and mobile homes. This flood event led to a State and Federal Disaster Declaration.


The north end of the City of Petaluma experienced significant flooding on December 30, 2005 through December 31, 2005. Streets and buildings in the north end of the City had up to five feet of flooding and several houses and mobile homes were damaged on Petaluma Boulevard North and North McDowell Boulevard. The City also noted damage to business along Industrial Drive and Corona Road, near the Petaluma Outlets, and on Old Redwood Highway
Photo Credit: City of Petaluma Fire Department 2019

January 25-26, 2008 - Very heavy rain caused flash flooding around Petaluma late Friday night, January 26, 2008. The Petaluma River near Corona Road went over its flood stage of 25.5 feet reaching nearly 30 feet. At least a dozen homes were flooded as were several businesses. A nearly stationary frontal band hung over parts of the Bay Area bringing intense rainfall for several hours. It is estimated that $800,000 was incurred in overall damages across all the storm-affected areas in the Bay Area (particularly coastal sections of Marin, San Francisco, and San Mateo Counties).

December 2, 2012 – Minor flooding was observed around Petaluma Sky Ranch/airport area, as water levels on Willow Brook were overtopped. Penngrove Park was also affected.

December 11, 2014 – The northern and southern portions of the City were affected by flooding, and waters inundated Industrial Avenue and nearby areas. Road closures were necessary along that Avenue as well as Auto Center Drive. Evacuations of businesses ensued. Residential neighborhoods near Corona Creek and near Ellis Creek were also hit. There were no reported damaged structures.

December 15, 2016 - Northbound State Route 121 closed due to flooding near the Junctions of Route 116 and 121 in Petaluma, though overall the flood event was minor.

Probability of Future Occurrences

Likely - The 100-year flood is the flood that has a one percent chance in any given year of being equaled or exceeded, while the 500-year flood is expected to have a 0.2 percent chance of occurring (or being exceeded) in any year, respectively. As such, it is likely that riverine flooding will occur in the future, though localized stormwater flooding and general flash flooding is also expected to take place especially during the wet months and heavy rain or storm events.

Climate Change Considerations

Emerging findings from California's Fourth Climate Assessment show that costs associated with direct climate change impacts by 2050 will be dominated by human mortality, coastal damage, and the potential for droughts and mega-floods (California Natural Resources Agency 2018). Scientific studies outlined in the same assessment also indicated shifts in California's precipitation regime, which show more dry days, more dry years, a longer dry season, mixed with increases in occasional heavy precipitation events and floods (i.e. a shift towards potentially less frequent but more extreme precipitation events). Studies also project great storm intensity with climate change, resulting in more direct runoff and flooding due to the flash flooding or precipitation nature of these expected events. As a result of fewer but more violent precipitation events, high frequency flood events will increase with climate change. Also, with wildfires already being a problem in California, increasing periods of drought and lack of precipitation are expected to exacerbate conditions for fires to occur, and in turn worsen the potential for runoff and flooding associated with burned areas due to increased impermeability and damage terrain and soils.

This Fourth Climate Assessment indicates that climate change is expected to alter built water supply systems, so that current management practices for flood control and water supplies across the state of California may need to be revised. Future revisions should aim to account for subsidence-prone infrastructure (e.g. levees), which coupled with rising sea levels and worsening storm conditions can lead to overtopping or failure of these flood control structures (California Natural Resources Agency 2018).

Based on Sonoma County's 2016 CAP and GHG emission modelling, climate change is projected to result in an increased risk of extreme flood, and an increased seasonal variability of precipitation, runoff, and stream flows for Sonoma County, along with increased likelihood of "extreme" precipitation and drought events. There may be more years with more frequent storm events and occasional events that are much stronger than historical ones and the length of season over which storm events occur is predicted to increase (SCTA 2016). Also, according to the CAP, more frequent coastal flooding and increased erosion is anticipated. In addition to flooding, sea levels are projected to rise between 16.5 and 65.8 inches by 2100. Rising sea levels combined with increased storm surge is anticipated to lead to more frequent inundation of the low-lying areas, and flooding of homes, infrastructure, agricultural land, and natural areas on the shores of San Pablo Bay. The greatest impacts are anticipated during winter storms.

Vulnerability Assessment

Historically, the Planning Area has been at risk to flooding primarily on the north-northwest and south-southeast portion of the City. Normally, storm floodwaters are kept within defined limits by a variety of storm drainage and flood control measures (e.g. levees). But, occasionally, extended heavy rains result in floodwaters that exceed local drainage infrastructure capacity and cause damage.

Flooding has occurred in the past: within the 100-year floodplain and in other localized areas. In addition to damage to area infrastructure and City facilities, other problems associated with flooding include erosion, sedimentation, degradation of water quality, loss of environmental resources, certain health hazards, and the inconvenience or potential financial and accessibility issues that come with road closures and other such effects.

The City of Petaluma has mapped flood hazard areas as portrayed in the figures contained throughout this section. For the following vulnerability assessment, GIS was used to identify and quantify the possible impacts of flooding within the City's Planning Area. The following methodology was followed in creating these flood vulnerability maps and determining values at risk to the 100- and 500-year flood events.

Insurance Coverage and NFIP Claims and Losses for Repetitive Loss Properties

The City of Petaluma joined the NFIP (regular entry) on February 15, 1980. The current effective map date is from October 12, 2015. The City currently participates in the Community Rating System (CRS), holding a class rating of 6 as of May 1, 2019 (leading to a 20 percent discount rate for SFHAs). NFIP Community Information System (CIS) insurance data indicates that as of July 10, 2019 there were 415 policies in place in the City, resulting in $145,671,200 of insurance in effect. Since the City began participating in the NFIP there have been 373 total closed losses, amounting to $8,703,708 in payments. According to the 2018 California SHMP, in 2017, Sonoma County was the top-ranking county in state for Repetitive Losses, accounting for more than 48 percent of the total top 10 repetitive losses. The City of Petaluma's latest CIS report, released July 10, 2019, shows 30 Repetitive Loss buildings (13 of which are insured) as defined by

FEMA. Repetitive loss properties have incurred 89 total losses, 43 of which were insured cases, and these accrued to $3,179,133 in payments from both building- and contents-related losses. The majority of these repetitive loss properties fell within AE, A, A1-A30, AO, AH flood hazard areas (FEMA 2019c). Table 4-28 below summarizes the repetitive loss information detailed in the City's latest CIS report, while Figure 4-30 displays the locations of these repetitive loss properties.

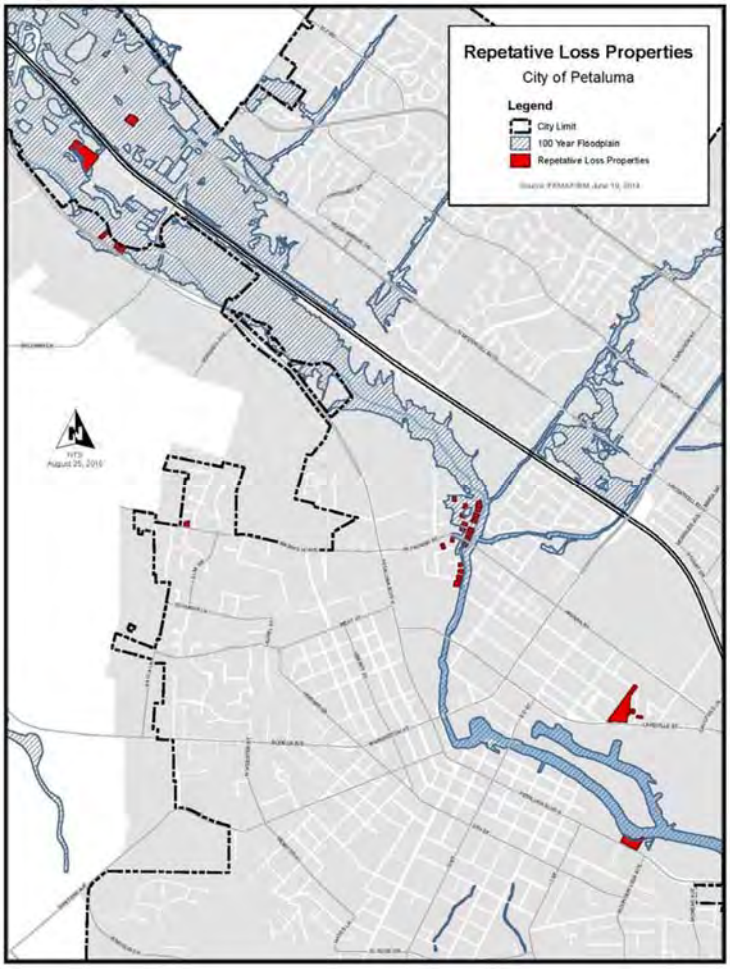
Table 4-28: City of Petaluma Parcels in Floodplains by Parcel Type and Flood Event

Repetitive Loss Component	Zones AE, A, A1-30, AO, AH	Zones B, C, X	Total
Total Buildings	28	2	30
Insured Buildings	13	0	13
Total Losses	84	5	89
Insured Losses	43	0	43
Total Payments	$3,119,975	$59,158	$3,179,133
Building related losses	$2,480,047	$43,565	$2,523,612
Contents related losses	$639,927	$15,593	$655,520
Insured Payments	$2,464,996	$0	$2,464,996
Building related payments	$2,019,948	$0	$2,019,948
Contents related payments	$445,048	$0	$445,048

Source: CIS Repetitive Loss report for the City of Petaluma (FEMA) 2019

Note: No repetitive loss information was noted for Zones VE, V, or V1-30; as such that column was excluded.

Figure 4-30: Repetitive Loss Properties in the City of Petaluma as of 2015



Source: City of Petaluma 2015

Property

This section summarizes the vulnerabilities to parcels and values at risk in the City. According to the information obtained via the GIS analysis, where the number and types of parcels falling in the 100- and 500-year floodplains was aggregated, Petaluma has 820 parcels with total values equating to $1.12 billion in both floodplains. A 25 percent damage factor was applied to the total value column of the tables below to estimate potential losses from flood related hazards to the City's parcels. 25 percent is the typical loss ratio associated with a 2-foot-deep flood, based on FEMA and Army Corp of Engineer depth-damage relationships. The total values were calculated by adding up the improved structure values of the parcels in the floodplains with the content values. These values were then estimated with the following formulas: a) residential and multi-family properties received contents valued at 50 percent of the parcel improved value; b) commercial and agricultural properties' contents were valued at 100 percent of the parcel improved value; and, c) vacant parcels received 0 percent content values. These valuation assignments are founded on FEMA's methodology for estimating contents within their loss estimation software, Hazus-MH.

Table 4-29 and Table 4-30 summarize the values at risk in the City's 100- and 500-year event floodplains. Figure 4-31 displays the location of these parcels in the flood areas. Overall, Petaluma has 200 parcels valued at roughly $424.4 million in the 100-year floodplain, $106 million of which is estimated to be a potential loss if a flood of this nature were to take place. 620 parcels valued at roughly $699.2 million are found in the 500-year floodplain, $174.8 million of which is estimated to be a potential loss if an event of this magnitude were to take place. Combined, the potential losses estimated from both events would total $280.9 million.

Table 4-29: City of Petaluma Parcels in Floodplains by Parcel Type and Flood Event

Flood Event	Parcel Type	Total Parcels	Improved Value	Contents Value	Total Value	Loss Estimate (25% of the Total Value)	Population at Risk
100-year	Residential	54	$9,994,745	$4,997,373	$14,992,118	$3,748,029	145
	Multi-Family	1	$63,059	$31,530	$94,589	$23,647	3
	Commercial	145	$204,698,304	$204,698,304	$409,396,608	$102,349,152	--
TOTAL		**200**	**$214,756,108**	**$209,727,206**	**$424,483,314**	**$106,120,829**	**147**
500-year	Residential	510	$118,374,972	$59,187,486	$177,562,458	$44,390,615	1,367
	Multi-Family	11	$122,909,517	$61,454,759	$184,364,276	$46,091,069	29
	Commercial	99	$168,655,657	$168,655,657	$337,311,314	$84,327,829	--
TOTAL		**620**	**$409,940,146**	**$289,297,902**	**$699,238,048**	**$174,809,512**	**1,396**
GRAND TOTAL		**820**	**$624,696,254**	**$499,025,108**	**$1,123,721,362**	**$280,930,340**	**1,544**

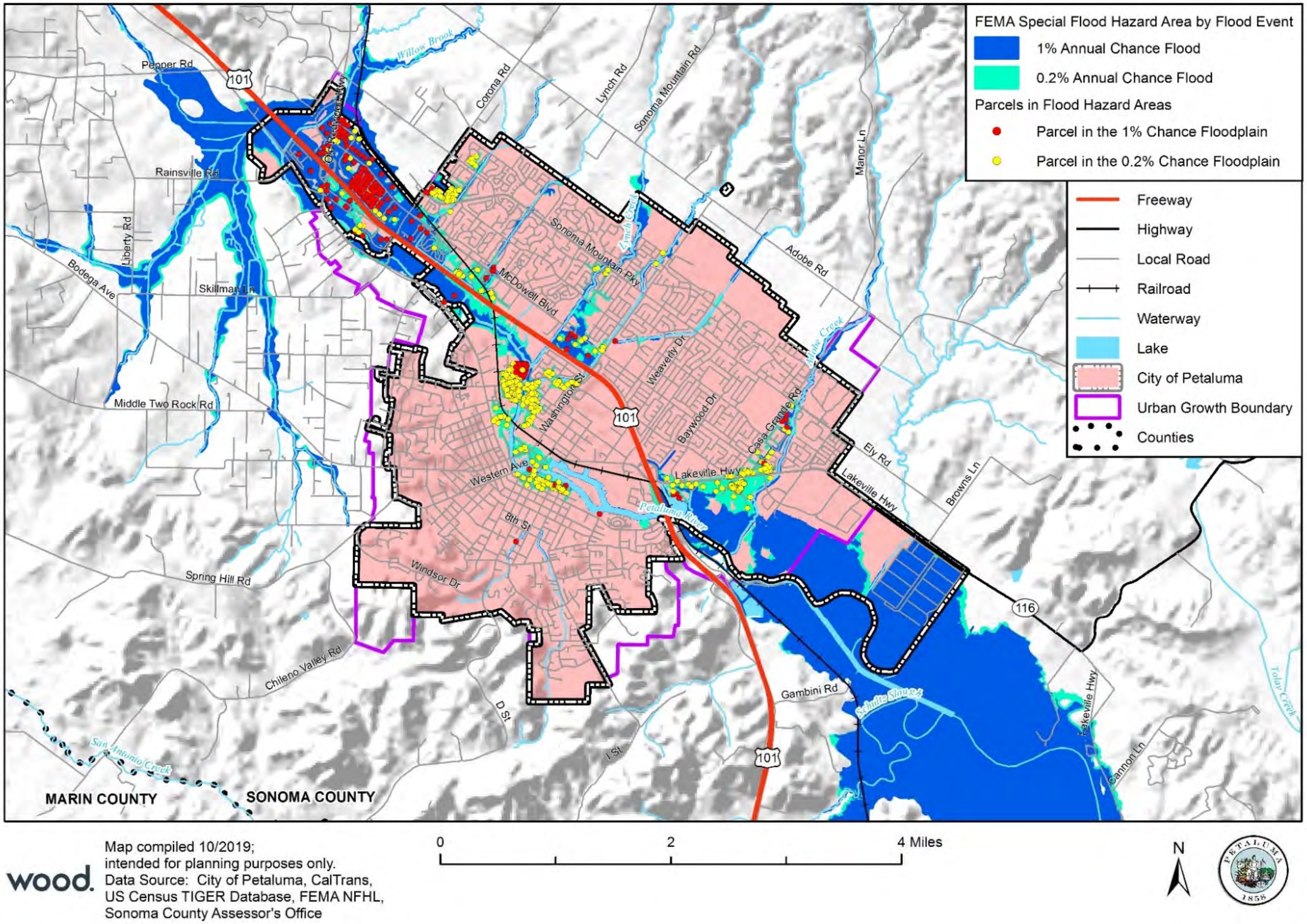
Sources: City of Petaluma GIS, Sonoma County Assessor's Office, FEMA NFHL, Wood Parcel Analysis

Table 4-30: City of Petaluma Flood Loss Estimates Summary by Parcel Type

Parcel Type	Total Parcels	Improved Value	Contents Value	Total Value	Loss Estimate (25% of the Total Value)	Population at Risk
Commercial	244	$373,353,961	$373,353,961	$746,707,922	$186,676,981	--
Residential	564	$128,369,717	$64,184,859	$192,554,576	$48,138,644	1,512
Multi-Family	12	$122,972,576	$61,486,288	$184,458,864	$46,114,716	32
TOTAL	**820**	**$624,696,254**	**$499,025,108**	**$1,123,721,362**	**$280,930,340**	**1,544**

Sources: City of Petaluma GIS, Sonoma County Assessor's Office, FEMA NFHL, Wood Parcel Analysis

Figure 4-31; City of Petaluma Parcels in the 100- and 500-Year Floodplains



People

Of greatest concern in the event of a flooding event is the potential for injury or loss of life. City of Petaluma 2018 U.S. Census Bureau estimates were obtained, which indicate the average persons per household for the City. The City's average household size is 2.68, and this metric was multiplied by the number of parcels of residential nature at risk of flooding to determine the total potential affected population. Population at risk estimates are summarized in the last column of Table 4-29 and Table 4-30 in the pages above, by flood event type and parcel type. The results were totaled for all the flood hazard zones. As the previous two tables indicate, there are around 1,544 people at risk of flooding caused by any of the flood events overlapping with residential properties, where 147 people are found in the 100-year floodplain and 1,396 people in the 500-year floodplain. Given the number of households and populations identified as socially vulnerable, disadvantaged, or sensitive in the City's planning area and the proximity of these census tracks and block groups to the flood zones, it is assumed that a portion of this population segment may also be disproportionately impacted during a flood event.

Economy

Similar to a dam inundation event which would affect infrastructure (e.g. roads), homes, and populations (possibly displacing families), impacts to the local economy could include business interruptions, lost or reduced wages from potential relocation of populations, infrastructure and resource downtime costs, and reduced city revenues from lack of tourism or inability to run/maintain certain services (like potable water based utilities). Other secondary hazard impacts such as reduced water quality or resource availability, which could in turn raise costs of water processing and distribution are also possible results from a severe flooding event, whether from riverine flooding, flash flooding, or an event caused by local stormwater/drainage infrastructure failures. Based on the history of flooding in Petaluma, the Payran neighborhood and nearby areas have historically been affected the most in terms of economic losses, which largely encompass damages to property (including disruption to business and commerce operations) and City infrastructure.

Critical Facilities and Infrastructure

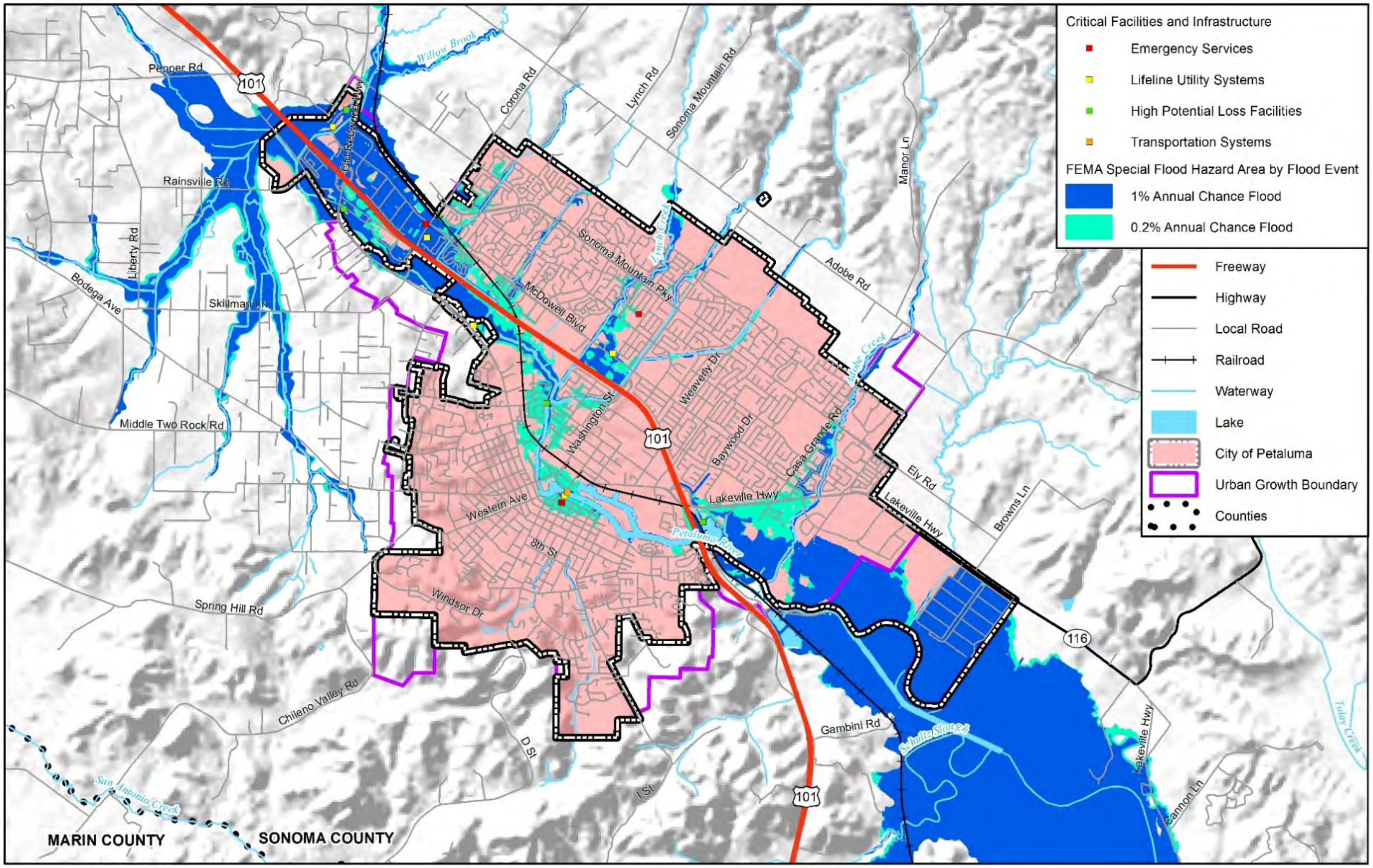
Critical facilities are those community components that are most needed to withstand the impacts of disaster as previously described. GIS was used to determine what City facilities and infrastructure occur within Petaluma's mapped flood hazard areas. The NFHL flood layers previously discussed were used to identify where the 100- and 500-year floodplains intersected with critical facilities. Figure 4-32 illustrates the locations of these critical facilities relative to the floodplains. Table 4-31 provides an inventory of the 15 facilities that occur within the floodplains. The impact to the community could be substantial if these critical facilities were damaged or destroyed during a flood event, particularly those which provide lifeline utilities or health/medical services. Overall, there are a total of five Emergency Service facilities in flooding areas, four High Potential Loss Facilities, five Lifeline Utility Systems, and one Transportation System found at risk in FEMA SFHAs.

Table 4-31: The City of Petaluma's Critical Facilities in the 100- and 500-Year Floodplains

Flood Event	Critical Facility Category	Critical Facility Type	Total Critical Facilities
100-year flood event	High Potential Loss Facilities	Day Care Facilities	1
		Government/Admin	1
	Lifeline Utility Systems	Electric Substations	1
		Water Facility	2
	Transportation Systems	Historic Drawbridge	1
TOTAL			**6**
500-year flood event	Emergency Services	Emergency Medical Service Station	2
		Fire Station	2
		Nursing Homes	1
	High Potential Loss Facilities	Community/Recreation Center	1
		Government/Admin	1
	Lifeline Utility Systems	Electric Substations	1
		Water Facility	1
TOTAL			**9**
GRAND TOTAL			**15**

Source: The City of Petaluma GIS, HIFLD, FEMA NFHL, Wood GIS Analysis

Figure 4-32: City of Petaluma Critical Facilities and Infrastructure in the 100- and 500-Year Floodplains



Map compiled 10/2019;
intended for planning purposes only.
Data Source: City of Petaluma, CalTrans, US Census TIGER Database, FEMA NFHL, HIFLD

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Historic, Cultural, and Natural Resources

The City of Petaluma has eight natural, historic, or cultural resources located in or nearby the Planning Area boundaries as previously described in Section 4.2 Asset Summary and Section 4.3.4 Fire: Urban and Wildland Fires, under the Historic, Cultural, and Natural Resources subsection. Climate change studies at the county and regional level indicate the likelihood that increasingly unpredictable flash flooding and uncertainty in storm occurrence will lead to a worsening in erosion and sedimentation conditions. However, natural areas within the floodplain often benefit from periodic flooding as a naturally recurring phenomenon, and these natural areas often reduce flood impacts by allowing absorption and infiltration of floodwaters. Nevertheless, other cultural or historical resources such as older buildings or districts may be more affected by these flooding hazards, given their likely older construction methods, weaker materials, and potential failure to meet current building code standards.

Future Development

The development trend in the City of Petaluma Planning Area is steady. The Petaluma City Profile Report published in 2018 notes the predicted population changes through the year 2022. The City is expected to grow around 3.2 percent in the next 5 years, to an estimated total of 62,700 people. Given these projections it is likely that the City will keep diversifying and expanding its economic base due to proximity to the San Francisco Bay area.

The potential for flooding may increase as stormwater is channelized due to land development. Such changes can create localized flooding problems inside and outside of natural floodplains by altering or confining natural drainage channels. Floodplain modeling and master planning should be based on buildout land use to ensure that all new development remains safe from future flooding. While certain local floodplain management and water quality regulations and policies exist, as well as specific regulatory control of building codes, flood insurance requirements, and other such aspects at the federal or state level, the cumulative effects of flood related hazards can have a negative impact on the floodplain and the community into the future. Water and flood control infrastructure such as dams and levees can additionally be stressed due to increased development and municipal water supply needs coupled with a changing environment which causes environmental and weather conditions to become more and more unpredictable (e.g. through storm events, climate change).

City floodplain management ordinances require that new construction be built with two feet of freeboard for first floor elevations above the BFE (per the General Plan 2025 Policy 8-P-37F). New development that adheres to the elevation requirements in addition to other requirements for maintaining elevation certificates, implementing stormwater program elements, and erosion or sediment controls for all new development in the floodplain may protect new constructions from 100-year and possibly other floods events.

The amount of growth in the City and nearby communities can also strain the capacity of the water management system, which includes water supply in addition to water control. When flood drainage and control structures are overwhelmed, the result is not only severe flooding. Significant losses to the water supply system may also occur.

Risk Summary

- Overall the significance of flood hazards is **Medium**.
- Floods impacts will vary by location and severity and will likely only affect certain areas of the City Planning Area at any one time.

- Based on the risk assessment, floods will continue to have economic impacts to certain areas of the City's Planning Area, and the estimated losses for properties amounts to $280.9 million (with a total of 1,544 potential people at risk), in addition to the 15 critical facilities which fall in the floodplains.
- 200 properties valued at roughly $424 million are located in the 100-year floodplains. 620 properties were found at risk of the 500-year (0.2 percent annual chance) floodplain, roughly valued at $699 million.
- Six noteworthy flooding events have taken place in Petaluma since 1982. These caused significant damages and several required evacuations, though other minor flooding cases have taken place. The worst two events to record for the City are the January 1982 flood, which caused $28 million in damages, and New Year's Eve flood of December 2005, which led to an estimated $56 million in damages. Based on the history of flooding in Petaluma, the Payran neighborhood and nearby areas have historically been affected the most in terms of economic losses which encompass damages to property (including disruption to business and commerce operations) and City infrastructure.
- Impacts that are not directly quantified but could be anticipated in large future events include: 1) injury and loss of life; 2) disruption of and damage to public infrastructure; 3) disruption to trade, commerce, commuting, mobility, and other activities that may rely on the road networks; 4) health hazards associated with mold and mildew; 5) significant direct and indirect economic impact (jobs, sales, tax revenue) upon the community; and 6) negative impact on commercial and residential property values.
- The 2018 California SHMP noted that Sonoma County was the top-ranking area in California to log NFIP repetitive loss cases, accounting for more than 48 percent of the total top 10 repetitive losses (Cal OES 2018)
- NFIP CIS insurance data indicates that as of July 10, 2019 there were 415 policies in place in the City, resulting in $145,671,200 of insurance in effect. Since the City began participating in the NFIP there have been 373 total closed losses, amounting to $8,703,708 in payments. There are 30 Repetitive Loss buildings (13 of which are insured) in Petaluma. Repetitive loss properties have incurred 89 total losses, 43 of which were insured cases, and these accrued to $3,179,133 in payments from both building- and contents-related losses

4.3.6 Sea Level Rise

Sea level rise is defined as the relative average rise in mean sea level. Global sea level rise refers to the long-term gradual increase of sea levels driven by the expansion of ocean waters as they warm, the addition of freshwater to the ocean from melting land-based ice sheets and glaciers, and extractions from groundwater. Regional and local factors such as tectonics and ocean and atmospheric circulation patterns result in relative sea level rise rates that can be higher or lower than the global average. Sea level rise also contributes to increased coastal flooding and more frequent and severe tidal inundation because there is less of a buffer between the ocean and coastal areas and infrastructure within these areas. This can exacerbate existing flood hazards from severe storms, as well as alter the function of the salt marsh and tidal flats near the confluence of Petaluma River and San Pablo Bay. Unlike flooding caused by severe storms, tidal inundation when combined with sea level rise would occur with predictable high tides and with some regularity. Tidal inundation and sea level rise combined with coastal storm events could also occur and result in greater impacts. Over time, existing low-lying tidal flat areas near the southern portion of Petaluma's Planning Area are expected to be semi-permanently inundated as a result of sea level rise.

Location

The southern portion of the City of Petaluma, the marsh and tidal lands within Petaluma Marsh Wildlife Area, the areas along Petaluma River, and existing urban development and natural resources in the City are already exposed to riverine and localized flooding, which will be exacerbated by sea level rise. The hazards in these areas are projected to become more severe when combined with sea level rise. The creeks and rivers that drain to the Petaluma River in confluence with San Pablo Bay result in an ecologically diverse range of low-lying habitats including coastal wetlands, tidal salt marsh, and mudflats. These ecological areas extend from the southern portion of the City Planning Area along Petaluma River and between U.S. Highway 101 and Highway 116 to outside the Planning Area near Point Sonoma and San Pablo Bay. The portion within the Planning Area where sea level rise may occur over time under the more extreme projections includes downtown Petaluma and a number of open space and recreation areas, such as Steamer Landing Park and Shollenberger Park. The southern portion of the City also contains the Petaluma Marina and Ellis Creek Water Recycling Facility. In summary, the geographic area of the City exposed to sea level rise is limited to a small portion of the entire planning area.

Extent (Magnitude/Severity)

Negligible – USGS has developed the Coastal Storm Modelling System (CoSMoS) to make detailed predictions of coastal storm (wave-driven) flooding, beach and cliff erosion, and sea level rise over a large geographic scale. In the City of Petaluma, sea level rise is projected to expand the flood zone under varying scenarios, but specifically in the low-lying areas along the Petaluma River and the coastal areas located south of downtown. The potential extent of flooding associated with sea level rise and various storm scenarios, such as the average annual tidal conditions, and 100-year wave event are summarized and depicted in the vulnerability assessment. It is worth noting that sea level rise modeling used for the vulnerability assessment assumes some level of shoreline protection or adaptation strategies, such as large-scale levees are in place (e.g. CoSMoS includes levee structures that are visible on LiDAR data and can be included in digital elevation models).

The California Ocean Protection Council (OPC) summarized the best available science on sea level rise in *Rising Seas in California: An Update on Sea Level Rise* report released in 2017, which was later used to update the OPC's guidance on sea level rise in 2018. This guidance is also referenced as the best available science in the California Coastal Commission (CCC) *Sea Level Rise Policy Guidance: Interpretive Guidelines for Addressing Sea Level Rise in Local Coastal Programs and Costal Development Permits* document last updated in November 2018 (CCC 2018).

The OPC Guidance projects sea level rise for various emission scenarios and uses a probabilistic approach to generate a range of projections at a given time horizon (Kopp et al. 2014). The CCC Sea Level Rise Policy Guidance recommends using projections associated with a high emissions scenario given that worldwide emissions are currently following the high emissions trajectory, whereas the OPC Guidance provides a risk decision framework that explains when to use a low or a high risk aversion in the planning process (CCC 2018; OPC 2018). With these frameworks, probabilistic projections inform decision-making processes regarding the likely extent of sea level rise rather than trying to estimate the exact rate or occurrence of sea level rise based on an individual scenario or projection.

For the 2050 time horizon the likely range of sea level rise is between 0.6 to 1.1 feet and there is a 66 percent probability that sea level rise will fall within this likely range (Kopp et al. 2014). The likely range of sea level rise at 2100 is 1.6 to 3.4 feet for a high emissions scenario. The upper end of the likely range is recommended to use as a projection for low-risk tolerance situations, where sea level rise impacts can be easily mitigated. The CCC recommends the high-risk tolerance range to be used when considering resources where the consequences of sea level rise are limited in scale. In other words, this would apply where there would be minimal disruption and where there would be a low impact on communities and critical infrastructure.

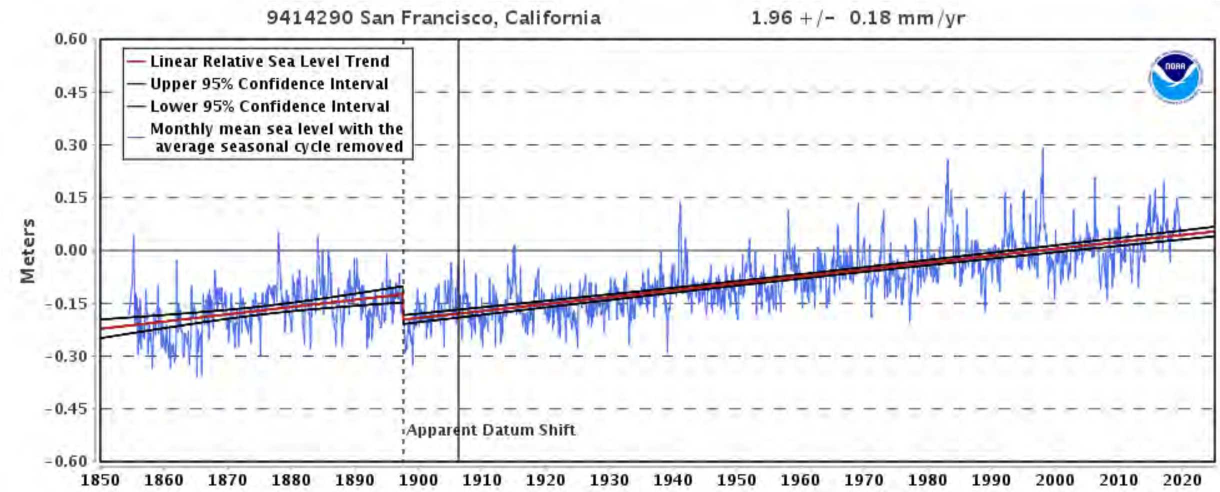
For medium-high risk tolerance situations, more conservative projections for sea level rise are recommended by the OPC Guidance. The medium-high risk aversion scenario projects 1.9 feet of sea level rise could occur by 2050, and 6.9 feet of sea level rise could occur by 2100. These projections have a 0.5 percent probability of occurring, or a 1 in 200 chance, at a given time horizon. These projections would be appropriate for projects where damage from coastal flood hazards exacerbated by sea level rise would result in higher consequences, or the community or project would have less ability to adapt. The medium-high risk tolerance situation may be applicable to residential and commercial development in Petaluma.

The OPC Guidance also includes a specific stand-alone scenario, referred to as H++, where up to 6.6 feet of sea level rise could occur by 2080, and 10.2 feet of sea level rise could occur by 2100. This scenario is based on scientific studies that predict the instability of the Antarctic ice sheet could make extreme sea-level rise outcomes more likely than predicted by other studies (Griggs et al., 2017). Based on the extreme uncertainty of the H++ scenario, it is most appropriate to consider when planning development that poses a high risk to public health and safety, natural resources, and critical infrastructure (OPC 2018).

Previous Occurrences

Sea levels are rising at different rates in different regions of the California due to local differences in tectonic uplift/subsidence and other factors such as tidal and wetland zones. Typically, the highest sea level readings along California's coastline and within the San Pablo Bay occur during periods of heavy rain that coincide with high tides, causing coastal flooding, such as those experienced during the 1982 to 1983 and 1997 and 1998 El Niño events. Sea level rise in the San Francisco Bay Area has risen seven to eight inches in the past century (NRC 2012; Heberger et al 2012). Sea level at the San Francisco tide gauge has also risen eight inches over the past century (NOAA 2018). While the Petaluma River already experiences flooding, sea level rise will exacerbate these natural events. The San Francisco Tide Gauge located north of Chrissy Field in the City of San Francisco reports the local sea level rise rate at approximately 1.96 (+/-0.18) millimeters per year (mm/year) based on mean sea level data from 1897 to 2018. This is equivalent to a change of 0.64 feet in 100 years (NOAA 2018), which equates to roughly 1.95 mm/year (see Figure 4-33). This rate compares to the global average annual rate of 3.2 mm/year (Griggs et. al. 2017) and the rate near the mouth of San Francisco Bay that has recorded approximately 7 inches in sea level rise variation over the past 100 years. The growth trend is projected to increase in future years (NOAA 2017).

Figure 4-33: Tide Record and Sea Level Rise Trend from San Francisco Tide Gauge (NOAA Station 9414190)



Source: NOAA 2018

Probability of Future Occurrences

Occasional - Scientific understanding of sea level rise is advancing at a rapid pace; projections of future sea level rise continue to change as new studies become available. Future climate change is projected to particularly affect sea levels as the glaciers, polar ice packs, and ice sheets retreat. The predicted sea level rise over the course of this century varies widely. Since 1992, trends in sea level rise have been monitored by satellites and recorded by tide gauges. Given the variables involved, it is not yet possible to determine the actual rate of sea level increase. The OPC suggests that sea level rise in the San Francisco Bay Area could occur on the order of 0.5 to 1.0 foot by 2030, 1.1 to 2.7 feet by 2050, and 2.4 to 10.2 feet by 2100 (Table 4-32). The likely ranges discussed above fall within these sea level rise scenarios because they are based on various projections of global GHG emissions. The probabilities also take into account uncertainties related to each of these scenarios.

As previously discussed, the *Rising Seas in California: An Update on Sea-Level Rise Science* guidance document identifies an extreme sea level rise scenario (H++). This scenario projects 10.2 feet of sea level rise by 2100 based on a trajectory of high GHG emissions and an accelerated rate of Arctic and Antarctic ice sheet loss (Griggs et. al. 2017). There is a high level of uncertainty associated with the H++ scenario (as well as all the sea level rise projections and timing) and given the emerging nature of sea level rise science, these estimates are intended to be used as a guide only and are subject to refinement over time. If this extreme sea level rise scenario were to occur, the modeled elevations of sea level rise and associated hazards could be experienced substantially sooner than the projected horizon year.

Table 4-32: Sea Level Rise Projections for San Francisco Bay Area

Projected Horizon Year / Time	66% Probability SLR meets or exceeds	0.5% Probability SLR meets or exceeds	H++ Extreme SLR Scenario (no probability assigned)
2030	0.5 ft	0.8 ft	1.0 ft
2050	1.1 ft	1.9 ft	2.7 ft
2080	2.4	4.5	6.6 ft
2100	2.4-3.4 ft	5.7-6.9 ft	10.2.ft

Note: Probabilities based on projections by the OPC for both low and high GHG emissions scenarios at the San Francisco tide gauge (Griggs et. al. 2017).

Climate Change Considerations

As ocean temperatures warm as a result of climate change, the water in the ocean expands and occupies more volume, resulting in a rise in sea levels. In addition, global sea levels rise from the additional volume of water added to the oceans from the melting of mountain glaciers and ice sheets on land. The rate at which sea levels will rise is largely dependent on the melting of the ice, which changes the land cover from a reflective ice surface to open ocean water; the ocean continues to absorb more of the sun's energy and subsequently increases the rate of ice melt. In other words, sea level rise is a direct consequence of climate change. However, the uncertainties associated with the rate at which ice melt occurs is largely responsible for the wide variation in sea level rise projections in the latter half of this century (i.e., between 2050 and 2100) and explain the H++ scenario.

The time scales for sea level rise are related to complex interactions between the atmosphere and the oceans, delays in stabilizing GHG levels in the atmosphere, and the dissolution of those gases into the ocean. The Intergovernmental Panel on Climate Change (IPCC) has published scientific evidence that sea levels will be rising for the next several thousand years due to the GHGs that have already been released into the atmosphere. Much of the scientific advancement in recent years has been in understanding the contribution and rate of ice melt to global sea levels. Studies also show the potential for extreme sea level rise resulting from rapid acceleration of ice melt as noted under the H++ scenario. In general, the higher the GHG emissions, the higher the temperature, the more rapid the ice melt, and the higher the rate of sea level rise.

Vulnerability Assessment

The vulnerability to sea level rise within the City of Petaluma Planning Area relies on the best available science and modeling and methodology from a range of sources including FEMA and the *OPC 2018 State of California Sea-Level Rise Guidance Update* (OPC 2018). Data was derived from the USGS CoSMoS Version 2.1 model, and previous studies that quantify historic rates of coastal storms and provide evidence for future trends (NOAA 2019b; USGS 2018). This assessment is further guided by FEMA's *Local Mitigation Planning Handbook* (2013), which provides strategies to describe and quantify hazards risk in the context of individual jurisdictions. As previously discussed, sea level rise modeling used for the vulnerability assessment assumes no shoreline protection or adaptation strategies, such as levees or floodwalls are in place. Adaptation actions, such as floodplain management and engineering solutions could substantially change the flood extent associated with sea level rise.

For the vulnerability assessment, the City of Petaluma HMPC wanted to model the 30-year and 50-year sea level rise scenarios both with and without the 100-year coastal storm event. Given sea level rise projections linked to planning horizons can change with new scientific data, the sea level rise scenarios were selected based on sea level rise elevation. The probabilistic projections based on the high emissions scenario (business as usual) for 2050 and 2070 translates to 1.1 foot by 2050 and 1.9 feet by 2070 (or 2.4 feet by 2080 as shown in Table 4-31), both which have a 66 percent probability of occurrence. The conservative approach for 2050 and 2070 have a 0.5 percent probability of occurrence and translate to 1.9 feet by 2050 and 4.0 feet by 2070 (or 4.5 feet by 2080 as shown in Table 4-31). The City HMPC also considered one conservative scenario to assess potential future impacts to critical infrastructure. These projection recommendations roughly convert to the 25 cm (1 foot or 0.25 meters), 75 cm (2.7 feet or 0.75 meters), and 200 cm (6.6 feet or 2 meters) sea level rise datasets provided in the CoSMoS 2.1 model. As shown in Table 4-31, these can these three elevations could apply to a range of sea level rise projections and associated planning years.

A GIS overlay analysis was performed to determine parcels and critical facilities that may be affected by sea level rise based on three inundation layers from the CoSMoS 2.1 model. The GIS analysis conducted follows the same methodology used with other hazard layers assessed in this plan, where the hazard layer is overlaid with critical facilities or parcel centroids, all of which are shown as points. The parcel centroids are determined based on developed parcel polygons, so that each parcel or critical facility either falls in or outside of each hazard area based on the spatial analysis intersection performed.

For this overlay analysis the 25 cm, 75 cm, and 200 cm datasets of sea level rise inundation data were used, based upon currently available (November 2019) modeling representative of the best available science and on the CoSMoS Version applicable to the City of Petaluma area, which is version 2.1 (USGS CoSMoS 2.1). This dataset provides detailed projections of tidal inundation, which refers to the predicted average annual tidal inundation conditions. It also includes detailed projections of coastal flood hazards, which refers to the 100-year coastal flood event that accounts for coastal wave and storm surge intervals, for the area north of Golden Gate Bridge in San Francisco Bay.

Scenarios within this area of interest are consistent with the full spectrum of sea level rise (0 to 2 meters, 5 meters) and storms (daily to 100-year return) used on the outer coast. However, storm events used inside the Bay were derived from numerically modeled wind-wave heights driven by wind projections from one Global Climate Model (GCM) known as the Geophysical Fluid Dynamics Laboratory Earth System Model 2M (USGS 2019). These scenario and specification options allow flexibility for managers to specify degrees of risk tolerance based on future projections as well as geographic variability in the study areas on the coast. CoSMoS models all relevant physics of a coastal storm, such as tides, waves, and storm surges, which are then scaled down to local flood projections for use in community-level coastal planning and decision-making processes (USGS 2019). Also, rather than relying on historic storm records, the CoSMoS model uses wind and pressure from GCMs to project coastal storms under changing climatic conditions during the 21st century (USGS 2019).

CoSMoS Version 2.1 is the most recent version of the program modeling to date, and is based on GCMs developed by the IPCC which considers region-specific factors such as oceanographic conditions, backshore types (beach, bluff or estuarine), long-term changes in the shoreline, river and stream drainages, wind patterns, and seasonal changes. The CoSMoS modeling identifies areas along the coast where significant flooding may occur under both a non-storm scenario (i.e. average spring tide inundation) and 100-year coastal storm scenario (i.e. coastal wave-driven 100-year flooding). With CoSMoS data, for each modeled increase in sea level elevation, there is a minimum, average and maximum range of uncertainty that is accounted for in the model. The maximum uncertainty scenario was modeled, which includes conservative assumptions for marsh accretion, subsidence, and vegetation. The H++ scenario was also used for the purposes of this analysis, and effectively models a worst-case scenario for each given sea level rise scenario.

The analysis includes three ranges of sea level rise across the two scenarios used: one with 100-year coastal storm event flooding and one without it (i.e. no storm, equivalent to the average annual tidal inundation), to take into account the high degree of uncertainty associated with predicting when and at what rate sea level rise will occur. Sea level rise scenarios selected for the analysis are based on projections for the City of Petaluma and according to the OPC's *State of California Sea Level Rise Guidance* (OPC 2018) under a worst case, or extreme risk aversion scenario (H++ scenario within Table 4-32 above). The scenarios were selected for analysis as the intent is to identify infrastructure and critical facilities that could be irreversibly damaged by sea level rise, or would be significantly costly to repair, and hence carry considerable impacts to public safety, health, or environmental resources. The first phase of analysis models property and critical facility exposure to an average annual tidal inundation at the following increments:

- Area extent of average annual tidal inundation with 25cm (approximately 1.0 ft) increase in sea level rise
- Area extent of average annual tidal inundation with 75cm (approximately 2.7 ft) increase in sea level rise
- Area extent of average annual tidal inundation with 200cm (approximately 6.6 ft) increase in sea level rise[1]

These hazard zones show the projected maximum extent of what will be regularly flooded by average annual tidal movements under the selected sea level rise elevations. The three elevations in sea level rise (25, 75, and 200 cm) were also selected to apply to a range of sea level rise projections and their associated planning year.

The second scenario of analysis uses the same sea level rise elevations previously described but on top of it models the area extent of inundation associated with a 100-year coastal storm event (or 1 percent annual chance of a coastal flood, based on a wave storm surge event). The addition of the flooding worsens the extent of the overall inundation and represents how coastal and estuarine flooding will be exacerbated by sea level rise in the future.

- Area extent of flooding from 100-year coastal storm event with 25cm (approximately 1.0 ft) increase in sea level rise
- Area extent of flooding from 100-year coastal storm event with 75cm (approximately 2.7 ft) increase in sea level rise
- Area extent of flooding from 100-year coastal storm event with 200cm (approximately 6.6 ft) increase in sea level rise

An exposure analysis was performed to identify the counts of improved properties, values of those properties, and critical facilities located within the six scenarios. The number of parcels and critical facilities were then aggregated by parcel type or critical facility type and category. Improved value totals for parcels in Petaluma were calculated by adding the improved values of the parcels of each type, as summarized in the following tables. As a clarification, improved values are the values of the developments in the parcels, or improvements, not land value. The analysis does not predict damage loss, as property and content values may change in the future, and it is assumed that some property will eventually be relocated or removed prior to permanent inundation. The analysis also does not account for undeveloped

[1] 6.6 feet of sea level rise under the H++ scenario is not projected to occur until 2080.

parcels that might be permanently inundated by sea level rise in the future since there are not improvements accounted for with those parcels. The inundation events become progressively more extensive with the addition of the deeper sea level rise levels, thus a property or critical facility that is inundated in the 25 cm and 75 cm scenarios is also inundated in the 200 cm scenario (if applicable), and is totaled as such unless noted otherwise.

General Property

Public and private property vulnerable to sea level rise generally includes buildings and infrastructure built within the salt marshes in the central and eastern portions of the City's Planning Area. Vulnerable private development primarily includes residential and commercial buildings in, as well as some agricultural lands along Highway 116 towards the unincorporated community of Lakeville.

Table 4-33 and Table 4-34 depict the count of exposed parcels and values of improvements within the City's Planning Area on those parcels for the sea level rise scenarios, both with and without the 100-year coastal storm event for the 75 cm and 200 cm scenarios. There were no risks to parcels within the Planning Area under the 25 cm scenario with the average annual tidal inundation or the 100-year coastal storm event. Those parcels inundated by the provided scenarios are depicted in Figure 4-34 and Figure 4-35.

Table 4-33: Parcels Exposed to Average Annual Tidal Inundation with Sea Level Rise

Sea Level Rise Event	Parcel Type	Total Parcels	Improved Value	Content Value	Total Value	Population at Risk
25 cm	NA	0	0	0	0	0
75 cm	Commercial	1	$4,481,126	$4,481,126	$8,962,252	--
TOTAL		**1**	**$4,481,126**	**$4,481,126**	**$8,962,252**	**0**
200 cm	Commercial *	32	$64,260,591	$64,260,591	$128,521,182	
	Residential	56	$18,030,947	$9,015,474	$27,046,421	150
	Multi-Family	2	$26,118,842	$13,059,421	$39,178,263	5
TOTAL		**90**	**108,410,380**	**86,335,486**	**$194,745,866**	**155**
GRAND TOTAL		**90**	**$112,891,506**	**$90,816,612**	**$203,708,118**	**155**

* The 75 cm Commercial parcel is considered in the 200 cm category as well, since it overlaps with the larger inundation layer (meaning that this same parcel is inundated by both scenarios). Therefore, the grand total is the same as the total under the average annual tidal inundation with 75 cm of sea level rise scenario.

Source: CoSMoS v2.1, City of Petaluma, Sonoma County Assessor, U.S. Census, Wood Plc analysis

Table 4-34: Parcels Exposed to 100-Year Coastal Storm Event Inundation with Sea Level Rise

Sea Level Rise Event	Parcel Type	Total Parcels	Improved Value	Content Value	Total Value	Population at Risk
25 cm	NA	0	0	0	0	0
75 cm	NA	0	0	0	0	0
200 cm	Commercial	138	$197,452,315	$197,452,315	$394,904,630	--
	Multi-Family	17	$77,390,564	$38,695,282	$116,085,846	46
	Residential	228	$51,627,780	$25,813,890	$77,441,670	611
TOTAL		**383**	**$326,470,659**	**$261,961,487**	**$588,432,146**	**657**

Source: CoSMoS v2.1, City of Petaluma, Sonoma County Assessor, U.S. Census, Wood Plc analysis

According to the parcel analysis, there was little to no risk to existing development under both the 25 cm and 75 cm scenarios. The majority of the risk impacts were under the 200 cm scenario, which is considered the high-risk aversion situation. This scenario also did not account for adaptation actions in the analysis. For the risks under the 200 cm scenario, the greatest vulnerability from the sea level rise scenarios occurs along the Petaluma River in the central and eastern portions of the Planning Area and within downtown Petaluma. The highest number of parcels exposed to this hazard are residential (with a total of 58 of type "residential" and "multi-family" in the tidal inundation analysis, and 245 in the sea level rise plus the 100-year coastal storm event), followed by 32 commercial parcels in the tidal inundation scenario (1 of which falls in both 75cm and 200cm flooding extents), and 138 in the sea level rise plus the 100-year coastal storm event. The commercial parcels account for the highest total values at risk of sea level rise, with around $532 million between both tidal inundation and sea level rise plus the 100-year coastal storm event scenarios. Overall, there are $203.7 million at risk in the tidal inundation scenario, and $588 million at risk in the sea level rise plus the 100-year coastal storm event from parcel total values, as summarized in Table 4-33 and Table 4-34 above. As displayed in Figure 4-34 and Figure 4-35 below, there are parcels exposed to the sea level rise plus 100-year coastal flood event in the City's downtown area, to the east of Western Avenue, south of the Petaluma River.

The results of the parcel analysis are projected estimates based on available data and modeling results, which are subject to change according to the actual rate of sea level rise and the frequency and duration of coastal storms. They also do not account for the implementation of future adaptation actions, such as floodplain management activities or the construction of structural projects, such as floodwalls and levees. Sea level rise alone is not anticipated to be the primary cause of damage, but rather sea level rise as it exacerbates existing flood and coastal hazards, including damage caused by severe storms and the frequency, duration, and extent of tidal flooding. The implementation of future mitigation strategies may minimize these impacts.

Figure 4-34: Parcels Exposed to Average Annual Tidal Inundation with Sea Level Rise

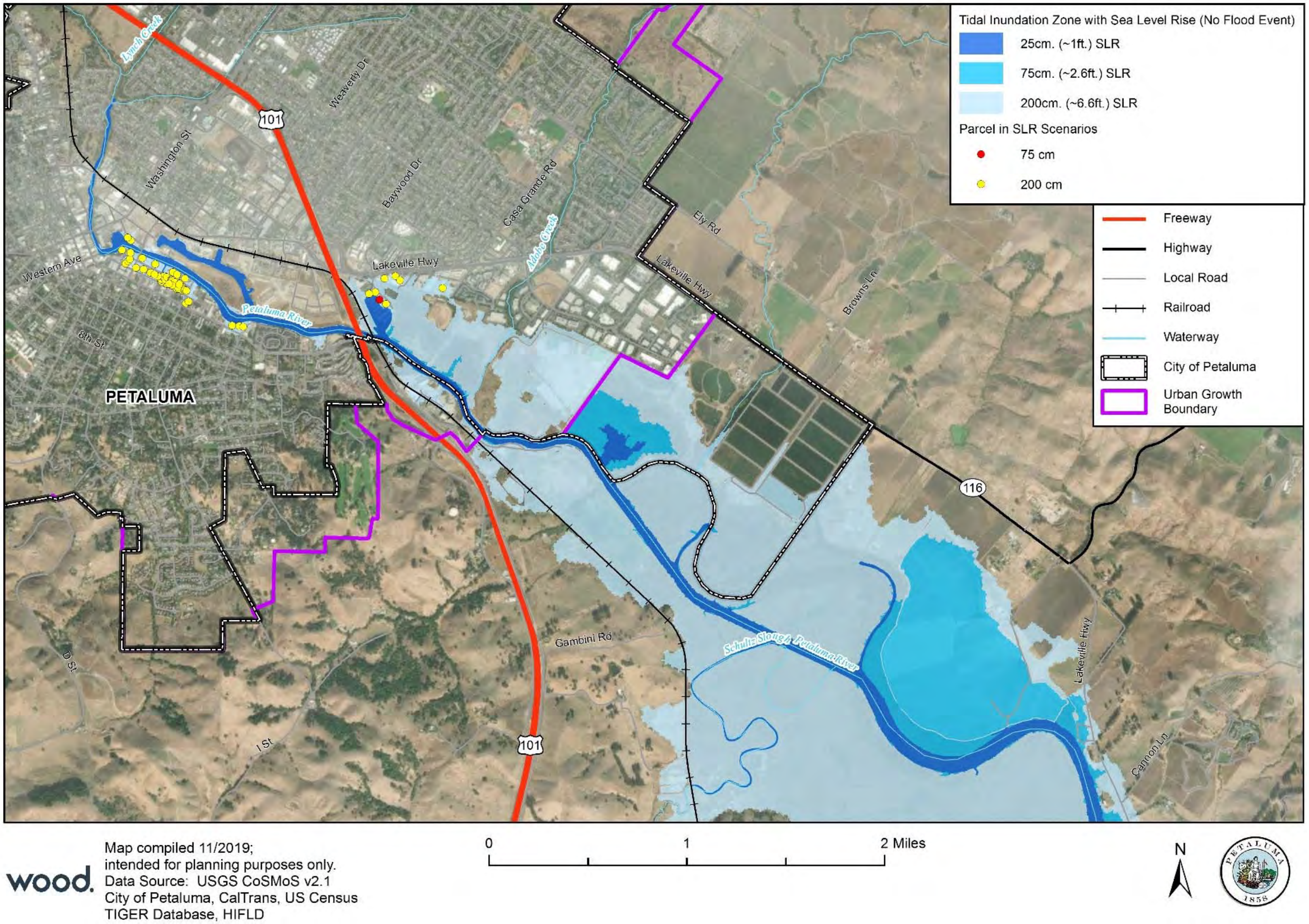
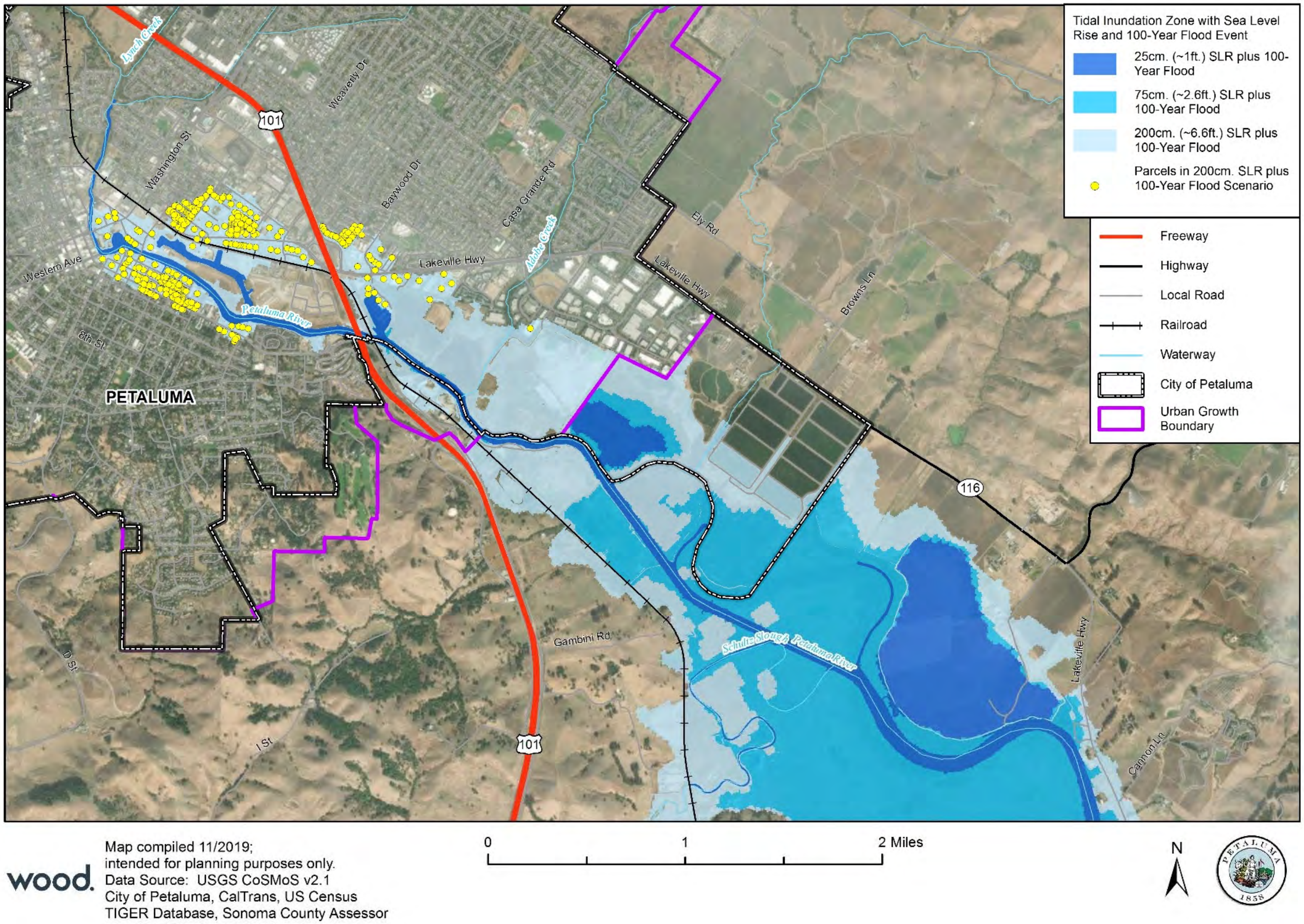


Figure 4-35: Parcels Exposed to 100-Year Coastal Storm Event Inundation with Sea Level Rise



People

Some populations are more vulnerable to flooding and sea level rise impacts due certain sensitivities, an increased likelihood of exposure, or a lower adaptive capacity (Public Health Institute Center for Climate Change and Health 2016). Demographic characteristics including health conditions that affect physical ability, or socioeconomic factors that amplify risk factors for poor health conditions, may affect the abilities of individuals or households to prepare for, respond to, and recover from coastal hazards (EPA 2017). Specific attributes may create additional stresses on individuals and communities resulting in reduced resiliency in the event of a flooding hazard event. Many of these factors may also be exacerbated by the specific, localized nature of flooding, erosion, and other impacts associated with sea level rise.

Based on the parcel analysis summarized in Table 4-33 and Table 4-34 above for the 75 and 200 cm scenarios, it estimated that a total of 155 people may be exposed to the tidal inundation with sea level rise scenario, while 657 people may be at risk under the 100-year coastal storm event with sea level rise. These population totals were estimated by multiplying the average persons per household value based on current U.S. Census figures (which is 2.68 per home) by the total parcels of residential nature in the City. Two people are at risk based on the "multi-family" category in the tidal inundation scenario, and 17 in the 100-year coastal storm event with sea level rise scenario; the remaining exposed populations fall under the general "residential" category, and 56 of those are found in parcels within the tidal inundation extents, while 228 fall in the 100-year coastal storm event with sea level rise scenario extents.

The downtown area of the City of Petaluma and areas along the Petaluma River with a high Social Vulnerability Index (SVI) inform which communities are more susceptible to adverse impacts of flooding and sea level rise. Based on the SVI data presented and discussed in Subsection 2.5, populations in downtown Petaluma are expected to be highly vulnerable to the hazards discussed herein. Again, these results do not account for adaptation actions under consideration by the City.

Critical Facilities and Infrastructure

Critical facilities that are vulnerable to sea level rise may include assets related to public transportation, wastewater treatment and water supply infrastructure, schools, law enforcement facilities, and community centers, among others. Essential education facilities such as the Valley Oaks Elementary and High School or the San Antonio High School may be subject to flooding exacerbated by future sea level rise. Law enforcement facilities in close proximity to the Petaluma River also prove vulnerable to flooding.

Regional and local-serving public and utility infrastructure vulnerable to sea level rise include roads, bridges, railroad lines and crossings, wastewater treatment plants, culverts, water lines, communication line and towers, stormwater outlets, bike lanes, bike facilities, airports, and fiber optic lines. Utility infrastructure containing hazardous materials that are vulnerable to sea level rise include hazardous material facilities, underground tanks, and the City's Wastewater Treatment Plant (Hopper Street Sewer Plant). Facilities that are impacted by flood hazards that may be exacerbated by sea level rise could also result in a release of hazardous materials or deteriorating water or air quality, as well as disruption to key public and utility services to the wider community. Low-lying transportation infrastructure is vulnerable to the impacts of sea level rise, including City roads and state highways in the unincorporated portion of Sonoma County. Vulnerable roads may include short sections of U.S. Highway 101 and State Highway 116.

Based on the GIS overlay analysis conducted with the critical facility layer, the following nine facilities and structures were found to be vulnerable under the 200 cm sea level rise scenario with the 100-year coastal storm event (though several of those are also vulnerable to the average annual tidal inundation with sea level rise scenario, as indicated in the subsequent tables):

- Petaluma Fire Department Station Number 1 & Emergency Medical Service Station
- Fire Station 1 (Headquarters)
- San Antonio High School
- Valley Oaks Elementary and High School
- Petaluma Marina
- Parks and Recreation Maintenance Building
- Petaluma Station C
- Hopper Street Sewer Plant (specifically two of the storage ponds)
- D Street Bridge House

However, the inundation extent shown in the following two maps (Figure 4-36 and Figure 4-37) shows that that the Ellis Creek Water Recycling Facility ponds and other property assets may also be at risk of potential future damages. Wastewater treatment plants and related infrastructure located in low-lying areas along the Petaluma River and near the southern portion of the City's Planning Area may be vulnerable to projected sea level rise, but according to the HMPC only the Ellis Creek Water Recycling Facility storage ponds would be affected and the plant is expected to remain operation during flooding (Walker 2020). In the tidal inundation with sea level rise scenario there are five exposed facilities, including the Historic Drawbridge, which also falls in the 75 cm extent, and the others in the 200 cm event. In the 100-year coastal storm event plus sea level rise scenario there are nine facilities falling in the 200 cm extent, falling under all four of the facility categories (2 in the Emergency Services, 4 in the High Potential Loss Facilities, 2 in the Lifeline Utility Systems, and 1 in the Transportation Systems category). Results are displayed in Figure 4-36 and Figure 4-37.

Table 4-35 summarizes the critical facilities in the average annual tidal inundation with sea level rise extent for both the 75 cm and 200 cm scenarios, while Table 4-36 summarizes those nine facilities within the 100-year coastal storm event with sea level rise for both the 75 cm and 200 cm scenarios (which were previously included in the bullet list above, based on the facility name). No critical facilities were within the average annual tidal inundation with 25 cm of sea level rise or the 100-year coastal storm event with sea level rise scenarios.

Table 4-35: Critical Facilities Exposed to Average Annual Tidal Inundation with Sea Level Rise

Sea Level Rise Event	Critical Facility Category	Critical Facility Type	Total Critical Facilities
25 cm	NA	NA	0
75 cm	Transportation Systems	Historic Drawbridge	1
TOTAL			**1**
200 cm	Emergency Services	Emergency Medical Service Station	1
		Fire Station	1
	High Potential Loss Facilities	Community/Recreation Center	1
	Lifeline Utility Systems	Electric Substations	1
	Transportation Systems	Historic Drawbridge	1
TOTAL			**5**
GRAND TOTAL			**5**

Source: CoSMoS v2.1, City of Petaluma, HIFLD, Wood Plc analysis

Table 4-36: Critical Facilities Exposed to 100-Year Coastal Storm Event Inundation with Sea Level Rise

Sea Level Rise Event	Critical Facility Category	Critical Facility Type	Total Critical Facilities
25 cm	NA	NA	0
75 cm[1]	NA	NA	0
200 cm	Emergency Services	Emergency Medical Service Station	1
		Fire Station	1
	High Potential Loss Facilities	Community/Recreation Center	1
		Government/Admin	1
		Public Schools	2
	Lifeline Utility Systems	Electric Substations	1
		Wastewater Treatment Plant	1
	Transportation Systems	Historic Drawbridge	1
TOTAL			**9**

[1] - The Historic Drawbridge was subject to tidal inundation with 75 cm of sea level rise, but because the 75 cm with the 100-year coastal storm event is based on different CoSMoS model inputs the Historic Drawbridge was not within this sea level projection.

Source: CoSMoS v2.1, City of Petaluma, HIFLD, Wood Plc analysis

Figure 4-36: Critical Facilities Exposed to Average Annual Tidal Inundation with Sea Level Rise

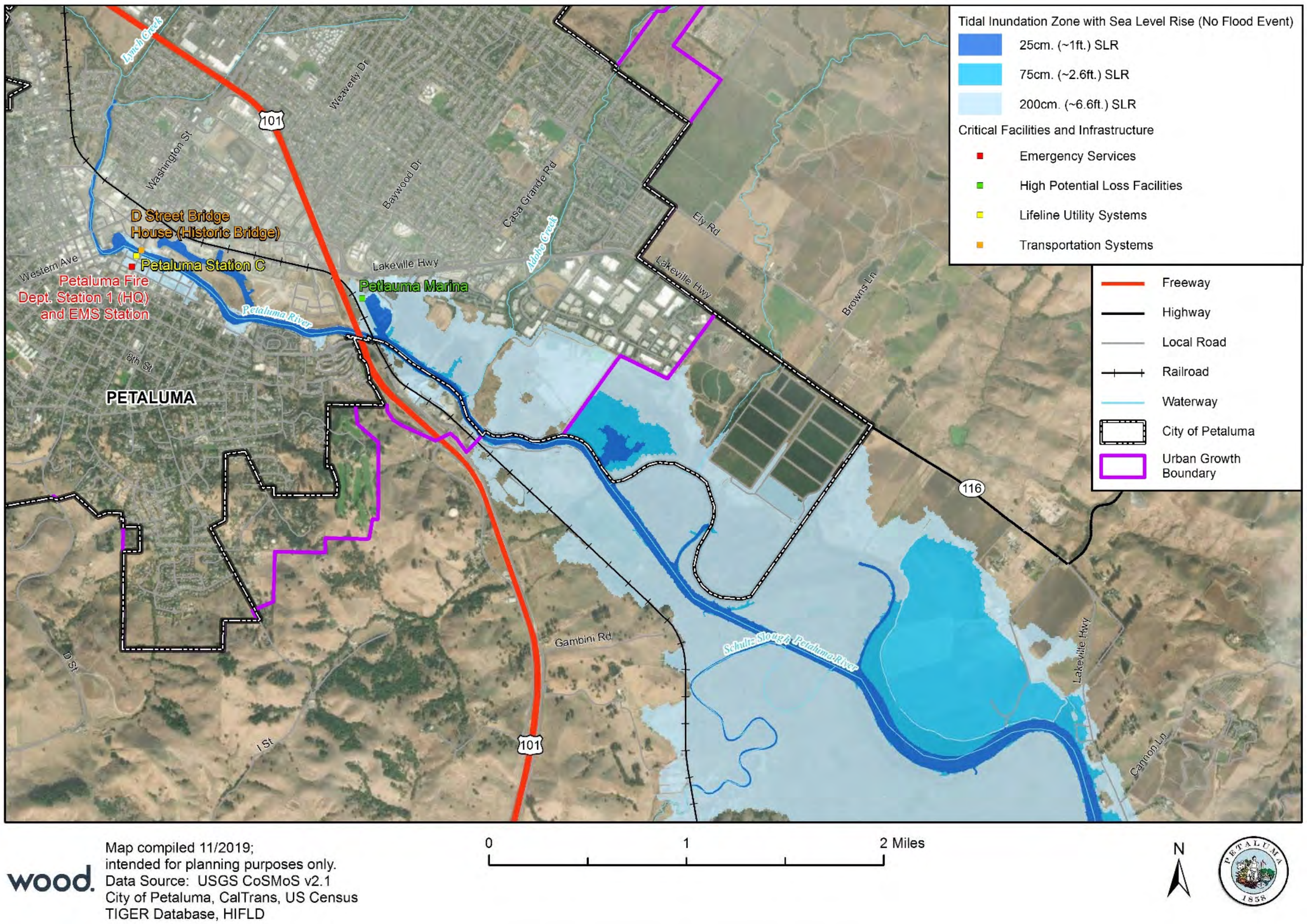
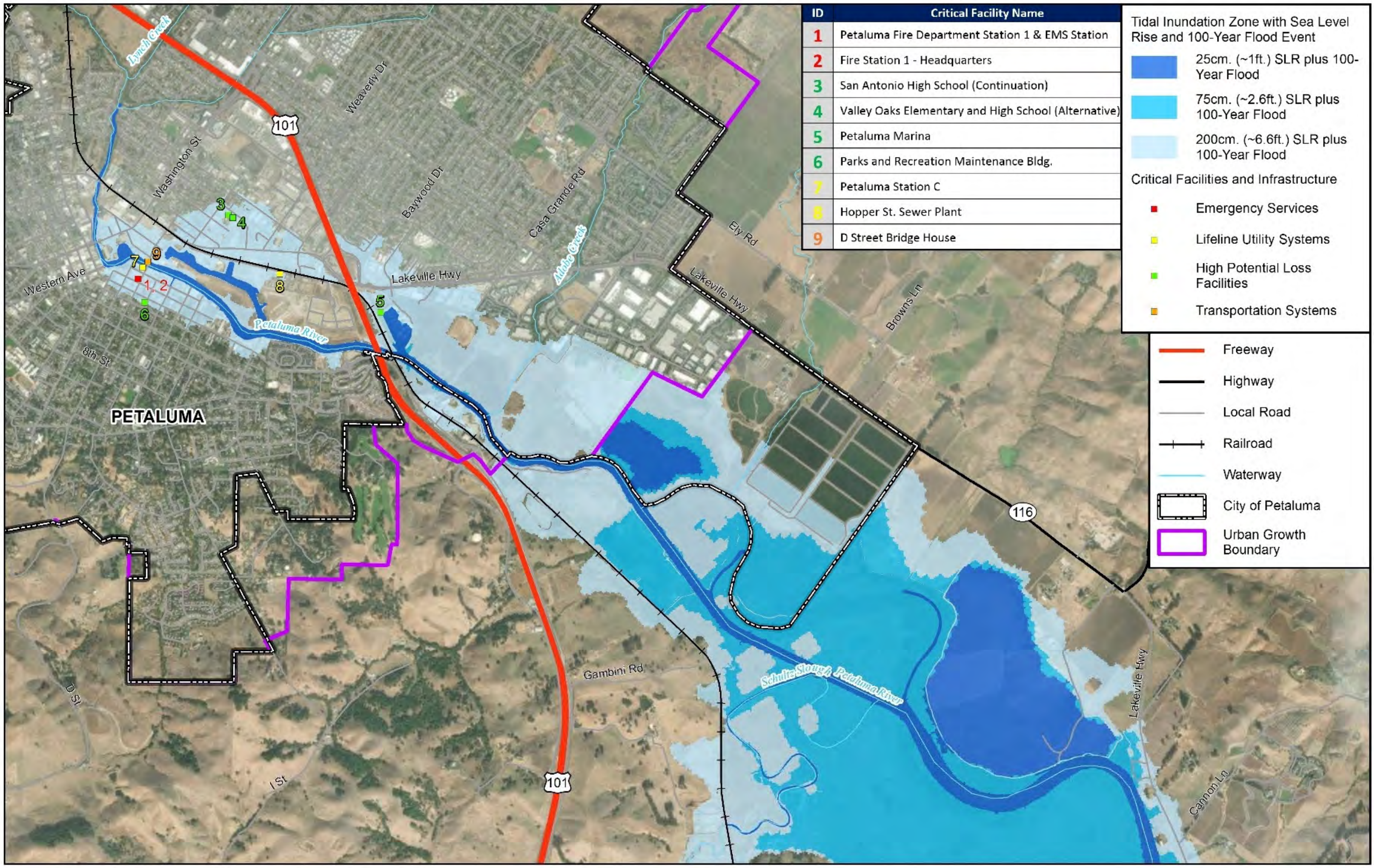


Figure 4-37: Critical Facilities Exposed to 100-Year Coastal Storm Event Inundation with Sea Level Rise



Map compiled 11/2019;
intended for planning purposes only.
Data Source: USGS CoSMoS v2.1
City of Petaluma, CalTrans, US Census
TIGER Database, HIFLD

0 1 2 Miles

N

Economy

The major economic industries in the City include retail; arts, entertainment, tourism accommodations and food services; and construction and manufacturing (ACS 2017). Developed areas in the City of Petaluma that are important to tourism include the historic downtown, as well as the Petaluma Marina. Undeveloped areas that are important to tourism include the park and open space areas, such as Steamer Landing Park and Shollenberger Park. Many Petaluma businesses depend on tourism and sales tax revenues. Flooding impacts to the historic downtown, to the north end of the City, and around the marina that are exacerbated by projected sea level rise could decrease economic activity and affect the local economy.

The Petaluma Marina is a popular access point for recreation activities, such as boating, water skiing, and fishing and may be impacted by rising sea levels, which could in turn also impact the local economy. *Photo Credit: Petaluma Star*

Historic, Cultural, and Natural Resources

Historic resources within Petaluma's downtown, include locally designated historic landmarks, nationally registered historic sites and landmarks, the historic commercial district, and important habitat resource areas. Historic resources close to Petaluma River include the historic commercial district, local historic residential homes, the Old Petaluma Opera House, and Public Library.

While sea level rise may have little effect on historic and cultural resources, the combination of sea level rise, shifting precipitation patterns, and the frequency and intensity of storms can have effects on coastal ecosystems, including salt marshes located within the southern portion of the City's Planning Area. However, the salt marshes located within the southern portion of the City are currently designated as open space and parks and restricted from future urban development. While these salt marshes may be semi-permanently inundated in the future, they will also provide a beneficial value, such as functioning as a natural buffer from tidal inundation that may reduce sea level rise impacts within the City. Nonetheless, the combined influence of sea level rise and flood hazards may also result in species and habitat impacts, specifically the migration of species to different elevations, or a transition to different habitat types, but more resilient species may adapt.

A study underway by USGS and Western Ecological Research Center (WERC) research ecologists has begun modeling sea level rise in the San Francisco Bay Estuary, including the San Pablo Bay National Wildlife Refuge. In 2009 and 2010, elevation and vegetation points survey points were collected in the salt marsh at 12 study sites around San Francisco Bay providing land owners with informative baseline data on current sea levels. Two of the twelve study sites are located along the Petaluma River, including the Gambinini and Petaluma marshes. Currently the percent of time the Gambinini and Petaluma Marsh is inundated varies throughout the year by season, with the most inundation during the winter (USGS 2018).

As part of the study, a marsh accretion model, referred to as WARMER, was developed to assess risk of sea level rise to salt marshes in San Francisco Bay. According to the WARMER model most salt marsh around San Francisco Bay could transition from high to mid marsh by 2040, to low marsh by 2060 and to mudflat by 2080, but the model accounts for variation around the Bay Area.

Future Development

The vulnerability of future development to rising sea levels would be similar to the vulnerability assessment findings discussed in flood hazards in Section 4.3.5. As mentioned in that section, the development trend in the City of Petaluma Planning Area is steady. The City is expected to grow by 3.2 percent in the next 5 years, to an estimated total of 62,700 people.

The potential for flooding may increase as stormwater is channelized due to land development, and it may be intensified due to sea level rise. Floodplain modeling should account for sea level rise projections and infill development and master planning should be based on buildout land use to ensure that all new development remains safe from future flooding. While certain local floodplain management and water quality regulations and policies exist, as well as specific regulatory control of building codes, flood insurance requirements, and other such aspects at the federal or state level, the cumulative effects of flood and sea level rise related hazards can have a negative impact on the floodplain and the community into the future. Water and flood control infrastructure such as dams, floodwalls, and levees and local storm drainage systems can become stressed due to increased development. Future development may also stress the municipal water supply needs when coupled rising sea levels and changing weather conditions that become more unpredictable.

Risk Summary

- Overall the significance of sea level rise is **Low**.
- Future sea level rise may exacerbate flood hazards in the City's Planning Area and is projected based on the best available science and modeling.
- There is no risk to very low risk under the average annual tidal inundation with 25 cm and 75 cm of sea level rise and no risk to very low risk under the 100-year coastal storm event with 25 cm and 75 cm of sea level rise scenarios. This is largely due to the protection of the salt marshes located within the southern portion of the City's Planning Area.
- Average annual tidal inundation in combination of up to 200 cm in sea level rise would put 90 parcels at risk, with one falling in the 75 cm of sea level rise extent and the other 89 within the 200 cm of sea level rise extent, which is more extreme projection scenario. Most of these exposed parcels are residential in nature. The total values at risk amount to $203.7 million. The model and analysis assumed no adaptation strategies such as levees, floodwalls, or other floodplain management or engineering solutions would be in place. The implementation of adaptation actions would minimize impacts.
- Under the 100-year coastal storm event with 200 cm of sea level rise scenario, 228 single family residential and 17 multi-family parcels would be impacted by rising sea levels, followed by 138 commercial parcels (all of which fall in the 200 cm event extent). The commercial parcels account for the highest total values at risk of sea level rise, with $394.9 million. Overall there are $588.4 million at risk in parcel total values, including the residential and multi-family parcels.
- Approximately 155 people may be at risk under the average annual tidal inundation in combination with up to 200 cm of sea level rise scenario.
- A total of 657 people may be at risk of inundation under the 100-year coastal storm event with 200 cm of sea level rise scenario; these totals are based on multiplying the average persons per household value by the total parcels of residential nature in the City.

- Five critical facilities are exposed to the average annual tidal inundation with up to 200 cm of sea level rise, and nine would be exposed to flooding with a 100-year coastal storm event when combined with up to 200 cm of sea level rise. Facilities at risk include emergency services, high potential loss facilities, lifeline utility facilities, and transportation systems.
- Rising sea levels alone are not anticipated to be the primary cause of vulnerabilities and potential damages to resources, property and infrastructure within the City; rather impacts may be caused by severe coastal storm patterns that may increase in frequency and duration as a result of sea level rise and climate change.
- If sea levels continue to rise at higher projected rates, flooding impacts that already occur during large coastal storm events could become more frequent, as predictable high tides may regularly inundate low-lying tidal marsh areas located within the southern portion of the City Planning Area.
- Given the sea level rise vulnerability assessment does not account for the incorporation of adaptation actions, floodplain management programs and the implementation of structural adaptation projects, such as levees and floodwalls should minimize impacts.

4.3.7 Severe Weather: General

Severe weather is generally any destructive weather event, but usually occurs in the Planning Area as localized thunderstorms that bring heavy rain, hail, lightning, high winds, and dense fog. Severe weather can also include extreme heat events.

The NOAA NCEI has been tracking severe weather since 1950. Their Storm Events Database tracks severe weather events on a county basis and contains data on the following: all weather events from 1993 to current (except from 6/1993-7/1993); and additional data from the Storm Prediction Center, which includes tornadoes (1950-1992), thunderstorm winds (1955-1992), and hail (1955-1992). This database contains 225 severe weather events that occurred in Sonoma County between January 1, 1950, and July 31, 2019. Table 4-37 summarizes these events.

Table 4-37: NCEI Hazard Event Reports for the Sonoma County* 1950-2019

Type	# of Events	Property Loss ($)	Crop Loss ($)	Deaths	Injuries
Debris Flow	49	25,916	20,000	1	0
Dense Fog	3	100,000	0	0	2
Dense Smoke	3	0	0	0	0
Extreme Cold/Wind Chill	2	0	0	1	0
Flash Flood	44	8,018,000	164,000	1	1
Flood	169	208,097,400	6,150,000	1	0
Frost/Freeze	3	60,000	3,000,000	0	0
Funnel Cloud	1	0	0	0	0
Hail	15	0	0	0	0
Heat	5	0	0	1	0
Heavy Rain	22	383,500	20,000,000	1	2
High Wind	71	713,500	0	2	0
Landslide	6	1,132,000	0	0	0
Lightning	2	1,000,000	0	0	0
Strong Winds	140	3,141,200	0	3	5
Tornado	13	1,558,500	500	0	1
Wildfire	10	505,000	5,000	0	1

Type	# of Events	Property Loss ($)	Crop Loss ($)	Deaths	Injuries
Total**	**558**	**$224,735,016**	**$29,339,500**	**11**	**12**

Source: NOAA's National Centers for Environmental Information https://www.ncdc.noaa.gov/stormevents/

*Note any reference to a coastal type weather event for Sonoma County has been excluded from this table.

**Losses reflect totals for all impacted areas, inclusive of Sonoma County

The NCEI table above summarizes severe weather events that have occurred in Sonoma County. Only a few of the events resulted in state and federal disaster declarations. While the HMPC recognizes these inconsistencies, this data provides value in depicting the County's "big picture" hazard environment.

As previously mentioned, several state and federal disaster declarations including the City of Petaluma have been a result of severe weather. For this plan, severe weather is broken down as follows:

- Extreme Heat
- Heavy Rain/Thunderstorm/Hail/Lightning/Dense Fog
- High Winds

4.3.8 Severe Weather: Extreme Heat

Hazard Description

Extreme heat events can have severe impacts on human health and mortality, natural ecosystems, the agriculture sector and other economic sectors. According to information provided by FEMA, extreme heat is defined as temperatures that hover 10 degrees or more above the average high temperature for the region and last for several weeks. Heat kills by taxing the human body beyond its abilities. In a normal year, about 175 Americans succumb to the demands of summer heat. According to the National Weather Service (NWS), among natural hazards, only the cold of winter takes a greater toll nationally — not lightning, hurricanes, tornadoes, floods, or earthquakes. However, there are a lack of cold weather and extreme cold temperatures events in Sonoma County. During the 40-year period from 1936 through 1975, nearly 20,000 people were killed in the United States by the effects of heat and solar radiation. In the heat wave of 1980, more than 1,250 people died. The 2018 California SHMP notes the heat wave during the summer of 2006 lead to 650 deaths in a 13-day period (Cal OES 2018), and in the past 15 years heat waves have claimed more lives in California than all other declared disaster events combined (California Climate Adaptation Strategy 2018).

Heat disorders generally have to do with a reduction or collapse of the body's ability to shed heat by circulatory changes and sweating or a chemical (salt) imbalance caused by too much sweating. When heat gain exceeds the level the body can remove, or when the body cannot compensate for fluids and salt lost through perspiration, the temperature of the body's inner core begins to rise, and heat-related illness may develop. The elderly, small children, patients with chronic medical conditions, those on prescription medication therapy, and people with weight or alcohol problems are particularly susceptible to heat reactions, especially during heat waves in areas where moderate climate usually prevails. Figure 4-38 illustrates the relationship of temperature and humidity to heat disorders.

Figure 4-38: National Weather Service Heat Index

NWS Heat Index — Temperature (°F)

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

Likelihood of Heat Disorders with Prolonged Exposure or Strenuous Activity

Caution | Extreme Caution | Danger | Extreme Danger

Source: National Weather Service

Note: Since heat index values were devised for shady, light wind conditions, exposure to full sunshine can increase heat index values by up to 15°F. Also, strong winds, particularly with very hot, dry air, can be extremely hazardous.

Location

Severe weather events have the potential to happen anywhere in the Planning Area. According to the City and HMPC, extreme heat, occasional heavy rain and thunderstorms, and wind events have occurred in the City.

Extent (Magnitude/Severity)

Limited – The City of Petaluma begins to experience hot weather in June or July of each year, and the heat continues throughout the summer months. According to the Western Regional Climate Center (WRCC), the average high temperature for the City of Petaluma in July is 81.8°F. Temperatures that are 10 degrees above normal are considered excessive. The California OES Contingency Plan for Excessive Heat Emergencies (2014) indicates that through the use of historical weather and mortality data, the NWS and the California Department of Public Health (CDPH) have identified five major types of climate regions within California to account for climate differences among regions in order to recognize what constitutes an excessive heat event in each of the regions. When temperatures spike for two or more consecutive days without an adequate drop in nighttime temperature to cool the outdoor and indoor environments, there is a significant increase in the risk to vulnerable populations.

The NWS has in place a system to initiate alert procedures (advisories, watches, and warnings) when high temperatures are expected to have a significant impact on public safety. The expected severity of the heat determines which type of alert is issued. During past heat waves, the City of Petaluma has designated facilities as Cooling Centers. In 2017 the Petaluma Community Center at Lucchessi Park was designated as a City Cooling Center. The Center also accepted cats and dogs on leashes or inside appropriate pet carriers. In summary, extreme heat impacts would likely be limited in the Planning Area, with 10 to 25 percent of the Planning Area affected. Extreme heat will have an impact on vulnerable populations and could also impact livestock and crops if the event occurs during certain times of the year.

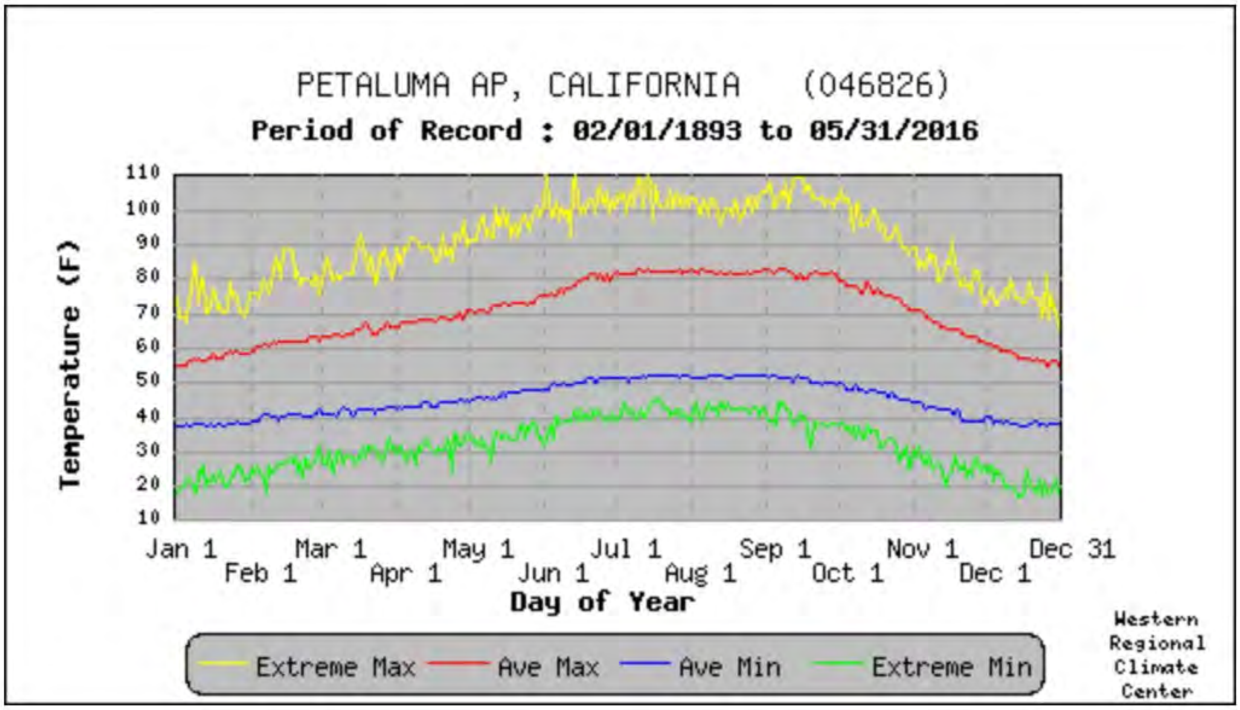
Previous Occurrences

Information from the closest weather station with the most comprehensive data, the Petaluma Fire Station 3 Weather Station (046826), is summarized below and in Figure 4-39 to illustrate daily temperature averages in the City's Planning Area.

The City of Petaluma (Petaluma Fire Station 3 Weather Station, Period of Record 1893 to 2016)

In the City of Petaluma, monthly average maximum temperatures in the warmest months (May through October) range from the mid-70s to the upper 80s. Monthly average minimum temperatures from November through April range from the upper 50s to mid-60s. The highest recorded daily extreme was 110°F on June 2, 1960. The lowest recorded daily extreme was 16°F on December 14, 1932. In a typical year, maximum temperatures do not exceed 81°F and minimum temperatures do not fall below 40°F.

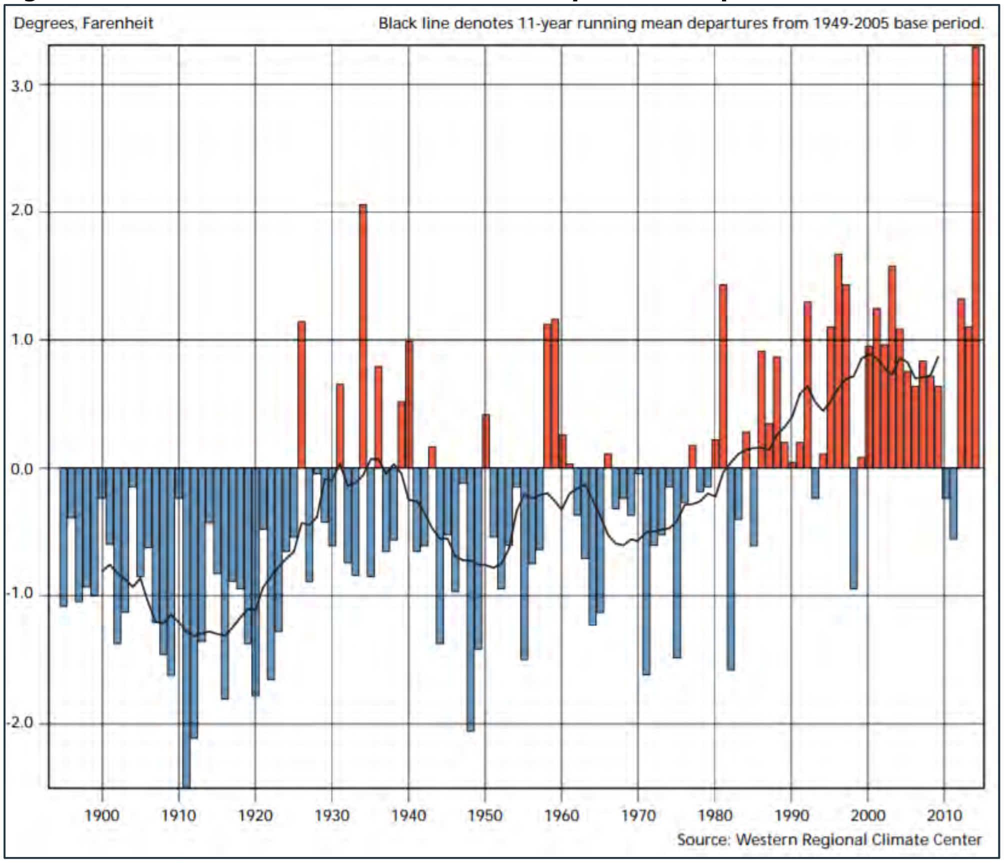
Figure 4-39: The City of Petaluma's Daily Temperature Averages and Extremes



Source: Western Regional Climate Center, www.wrcc.dri.edu/

The California statewide mean temperature departures from the 1900s to mid-2010s are displayed in Figure 4-40. This graphically highlights the general warming trend across the state, and how climate change can have significant implications in future water supply availability, higher mean temperatures.

Figure 4-40: California's Statewide Mean Temperature Departure, 1900-2014



Source: Drought in California Report (CA DWR; Natural Resources Agency; State of California, 2015)

Probability of Future Occurrences

Likely – Temperatures of extreme heat are likely to continue to occur annually in the Planning Area.

Climate Change Considerations

Heat waves are likely to become more frequent, which will have direct impacts on human health in terms of heat related illness. With the general trend of increased warming of average temperatures, extreme high temperatures will likely also increase. Cascading impacts include increased stress on water quantity and quality, degraded air quality, and increased potential for more severe or catastrophic natural events such as heavy rain, droughts, and wildfire. Another cascading impact includes increased duration and intensity of wildfires with warmer temperatures. According to the 2013 document, Preparing California for the Extreme Heat, Cal-Adapt projects that throughout California urban and rural population centers will experience an average of 40 to 53 extreme heat days by 2050 and an average of 40 days by 2099 (CalAdapt 2013). This compares to a historical average of four days per year (CalAdapt 2013).

Extreme heat has also been shown to accelerate wear and tear on the natural gas and electrical infrastructure (California Natural Resources Agency 2018). Projected increases in summer demand associated with rising temperatures may increase risks to energy infrastructure and may exceed the capacity of existing substations and distribution line infrastructure and systems.

A recent study on extreme heat released by the Union of Concern Scientists in July 2019 analyzed three global climate scenarios associated with different levels of heat-trapping emissions and future warming. The results of the analysis showed that with no actions taken to reduce heat-trapping emissions by midcentury (2036-2065) the average number of days per year in the United States with a heat index above 100°F will double, while the number of days per year above 105°F will quadruple. The modeling completed for the study showed that the most dramatic transformations will be felt in areas where the climate has been temperate. The City of Petaluma could experience up to 11 more times as many days per year in which the heat feels like 90 degrees (KQED 2019). According to Cal-Adapt Climate Projections for the Bay Area Region as stated in the 2017 Climate Change Health Profile Report for Sonoma County, by 2100 the number of heat waves in the Bay Area Region is expected to be between 6 to 10 heatwaves per year.

Based on Sonoma County's 2016 CAP, climate change is also expected to result in higher average temperature and more extreme heat events. If future GHG emissions are mitigated or reduced over time, summer high temperatures are expected to rise by 1 to 2°F. Whereas, if GHG emissions are not mitigated average summer high temperatures will increase by up to 9 to 11°F by 2100 (RCAP 2016).

Vulnerability Assessment

Property

Recent research indicates that the impact of extreme heat, particularly on populations, has been historically under-represented. The risks of extreme heat are often profiled as part of larger hazards, such as drought or wildfire. However, as temperature variances may occur independent of other hazards or outside of the expected seasons, but still incur large costs, it is important to examine them as stand-alone hazards. Extreme heat can overload demands for electricity to run air conditioners in homes and businesses during prolonged periods of exposure and presents health concerns to individuals who are outside.

Extreme heat may also be a secondary effect of droughts or may cause temporary drought-like conditions. For example, several weeks of extreme heat increases evapotranspiration and reduces moisture content in vegetation, leading to higher wildfire vulnerability for that time period even if the rest of the season is relatively moist. Extreme heat can cause infrastructure damage to roads. In summary, all property is vulnerable from extreme heat.

People

Traditionally, the very young and very old are considered at higher risk to the effects of extreme heat, but any populations outdoors during periods of extreme temperatures are exposed, including otherwise young and healthy adults and homeless populations. While everyone is vulnerable to extreme heat incidents, some populations are more vulnerable than others. Extreme heat poses the greatest danger to outdoor laborers, such as highway crews, police and fire personnel, and construction workers. The elderly, children, people in poor physical health, and the homeless are also vulnerable to exposure. Arguably, the young-and-otherwise-healthy demographic may also experience a higher vulnerability of exposure, due to the increased likelihood that they will be out in temperatures of extreme heat, whether due to commuting for work or school, conducting property maintenance such as lawn care, or for recreational reasons.

It is difficult to isolate the City's specific vulnerability to this hazard, as the impacts from extreme heat can be spread across an entire state or region. In general, all the population of the City can be considered at-risk to this hazard.

Economy

Extreme heat impacts on the economy may be more indirect compared to other hazards. Infrastructure such as roads could be damaged and lead to increased need for repaving. Critical facilities may be vulnerable to the indirect impact of prolonged excessive heat (i.e., electrical power outages), which may impact response capabilities or care capabilities for hospitals and clinics. Hospitals and clinics may see a surge in patients during the heat event as the exposed population suffers from the effects of the heat, but it is not anticipated that these increases will overwhelm the capacities of hospitals and clinics in Petaluma. Essential infrastructure, especially the electrical distribution system, is also posed to be stressed during extreme heat events as demand increases to run air conditioning. Peak demand exceeding the local utility's capacity for supply can lead to blackout or brownout conditions.

Critical Facilities and Infrastructure

Extreme heat can affect road infrastructure, but direct impacts to critical infrastructure is expected to be minimal. Critical infrastructure that relies on public utility systems that could be overloaded may result in impacts during extreme heat events. The loss of utilities or power outages during extreme heat events could also result in adverse secondary impacts to sensitive populations.

Historic, Cultural, and Natural Resources

Extreme heat may cause temporary drought-like conditions. For example, several weeks of extreme heat increases evapotranspiration and reduces moisture content in vegetation, leading to higher wildfire vulnerability for that time period even if the rest of the season is relatively moist. Changing heating and cooling patterns globally can have destructive secondary impacts, intensifying a variety of weather-related disasters that directly impact jurisdictions.

Future Development

Since structures are not usually directly impacted by severe temperature fluctuations, continued development is less impacted by this extreme heat than others in the plan. Continued development implies continued population growth, which raises the number of individuals potentially exposed to temperature variations. Public education efforts should continue to help the population understand the risks and vulnerabilities of outdoor activities, property maintenance, and regular exposures during periods of extreme heat.

Risk Summary

- The highest recorded temperature in Planning Area is 110°F on June 2, 1960.
- Extreme heat can have severe impacts on human health, the natural environment, and the economy.
- The very young, the elderly, people with poor physical health, and the homeless are more susceptible to the impacts of extreme temperatures.
- The average number of days per year in the United States with a heat index above 100°F will double, while the number of days per year above 105°F will quadruple if no actions to reduce heat-trapping emissions are taken.
- Climate change is expected to result in higher average temperature and more extreme heat events.

- Overall, the significance of extreme heat is **Medium.**

4.3.9 Severe Weather: Heavy Rain/ Thunderstorm/ Hail/ Lightning/ Dense Fog

Hazard Description

Severe storms in the Planning Area are generally characterized by heavy rain accompanied by strong winds, and lightning. Approximately 10 percent of the thunderstorms that occur each year in the United States are classified as severe. A thunderstorm is classified as severe when it contains one or more of the following phenomena: hail that is three-quarters of an inch or greater, winds in excess of 50 knots (57.5 mph), or a tornado.

Heavy Rain

Atmospheric rivers, a climate pattern that leads to adverse weather in the City, are responsible for up to 50 percent of California's precipitation annually and 65 percent seasonally (Arcuni, 2019). An atmospheric river (AR) is a long, narrow region of the atmosphere, like a river in the sky, that transports most of the water vapor outside of the tropics. ARs can be 300 miles wide, a mile deep and more than 1,000 miles long and carry an amount of water vapor roughly the same as the average flow of water at the mouth of Mississippi River (NOAA 2015). Warm water storms over the Pacific Ocean lead to evaporation and create a high concentration of moisture in the air, while prevailing winds create the distinctive river shape, which is often compared "to a fire hose pointed at California" (Arcuni 2019). When an atmospheric river reaches land, it releases the water vapor in the form of rain or snow. Atmospheric rivers play an important role in the global water cycle and are closely tied to both water supply and flooding risk.

Research suggests that atmospheric rivers contributed to the collapse of both Orville Dam spillways in February 2017 (NASA Global Hydrology Resource Center 2018), as well as the winter flooding in 1861-1862, which inundated Sacramento and is considered the worst flood event in California's history (Ingram 2013). When an atmospheric river forms in the tropical regions of the Pacific near Hawaii it is known as a "Pineapple Express". This type of atmospheric river can produce as much as five inches in one day (NOAA 2018). In 2018, two Pineapple Express ARs hit California causing significant heavy precipitation events throughout state.

Sonoma Water entered into a cooperative agreement with Scripps Institution of Oceanography and the Center for Western Extremes (CW3E) to advance the research in ocean science and meteorology. Three projects have come from the initial agreement: 1) research to help define the role of atmospheric rivers in filling Lake Mendocino and potentially offering predictability in retaining water without increasing flood risk; 2) a NOAA-funded climate program project to study the role of atmospheric rivers in ending droughts on the Russian River; and 3) cooperation in developing a feasibility assessment for potential use of forecast-informed reservoir operations for Lake Mendocino in cooperation with the U.S. Army Corps of Engineers.

Hail

Hail is formed when water droplets freeze and thaw as they are thrown high into the upper atmosphere by the violent internal forces of thunderstorms. Hail is sometimes associated with severe storms within the Planning Area. Hail falls when it becomes heavy enough to overcome the strength of the updraft and is pulled by gravity towards the earth. Hailstorms occur throughout the spring, summer, and fall in the region, but are more frequent in late spring and early summer. Hailstones are usually less than two inches in diameter and can fall at speeds of 120 mph. Hail causes nearly $1 billion in damage to crops and property each year in the United States. Hail is also one of the requirements which the NWS uses to classify thunderstorms as 'severe.' If hail more than ¾ of an inch is produced in a thunderstorm, it qualifies as severe. Severe hailstorms can be quite destructive, causing damage to roofs, buildings, automobiles, vegetation, and crops.

The NWS classifies hail by diameter size, and corresponding everyday objects to help relay scope and severity to the population. Table 4-38 under the Extent subsection below indicates the hailstone measurements utilized by the NWS.

Dense Fog

Fog results from air being cooled to the point where it can no longer hold all of the water vapor it contains. For example, rain can cool and moisten the air near the surface until fog forms. A cloud-free, humid air mass at night can lead to fog formation, where land and water surfaces that have warmed up during the summer are still evaporating water into the atmosphere. This is called radiation fog. A warm moist air mass blowing over a cold surface also can cause fog to form, which is called advection fog.

Sonoma County is made up of three major climactic zones, with the major climatic influence being the Pacific Ocean. The City of Petaluma falls within the marine zone, which is under direct ocean influence. The prevailing weather and winds tend to come from the Pacific Ocean from the northwest. Areas such as Petaluma tend to receive more precipitation in the fall and winter and more wind and fog in early morning of the summer months.

Lightning

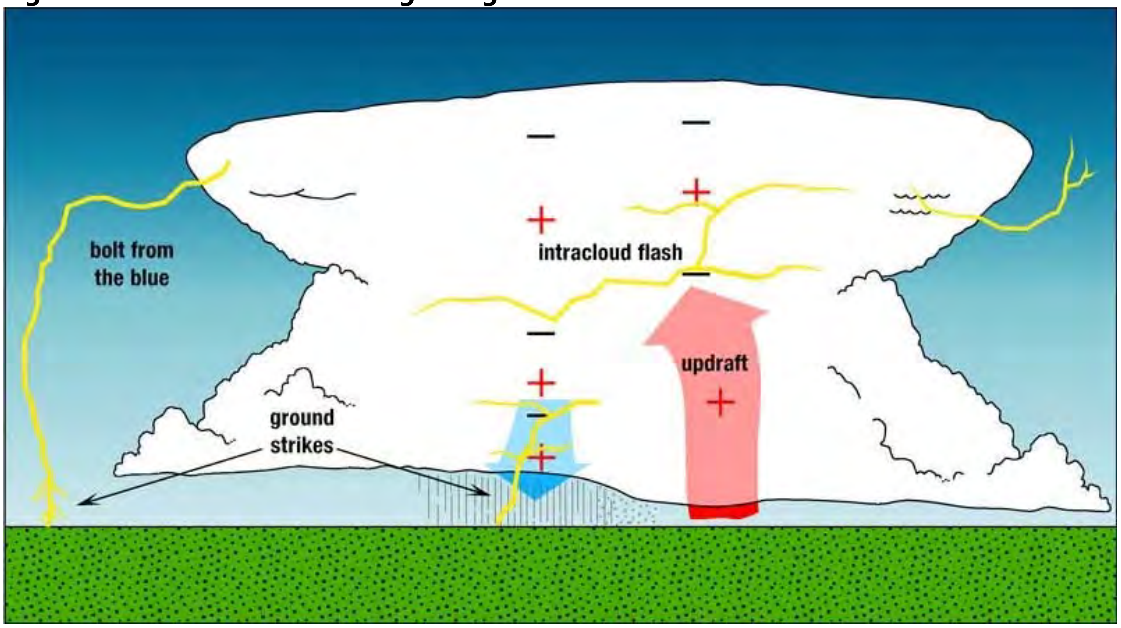
Lightning is an electrical discharge between positive and negative regions of a thunderstorm. A lightning flash is composed of a series of strokes with an average of about four. The length and duration of each lightning stroke vary, but typically average about 30 microseconds.

Lightning is one of the more dangerous weather hazards in the United States. Each year, lightning is responsible for deaths, injuries, and millions of dollars in property damage, including damage to buildings, communications systems, power lines, and electrical systems. Lightning also causes forest and brush fires, and deaths and injuries to livestock and other animals. According to the National Lightning Safety Institute, lightning causes more than 26,000 fires in the United States each year. The Institute estimates property damage, increased operating costs, production delays, and lost revenue from lightning and secondary effects to be in excess of $6 billion per year. Impacts can be direct or indirect. People or objects can be directly struck, or damage can occur indirectly when the current passes through or near it.

Intra-cloud lightning is the most common type of discharge. This occurs between oppositely charged centers within the same cloud. Usually it takes place inside the cloud and looks from the outside of the cloud like a diffuse brightening that flickers. However, the flash may exit the boundary of the cloud, and a bright channel, similar to a cloud-to-ground flash, can be visible for many miles.

Cloud-to-ground lightning is the most damaging and dangerous type of lightning, though it is also less common. Most flashes originate near the lower-negative charge center and deliver negative charge to earth. However, a large minority of flashes carry positive charge to earth. These positive flashes often occur during the dissipating stage of a thunderstorm's life. Positive flashes are also more common as a percentage of total ground strikes during the winter months. This type of lightning is particularly dangerous for several reasons. It frequently strikes away from the rain core, either ahead or behind the thunderstorm. It can strike as far as 5 or 10 miles from the storm in areas that most people do not consider to be a threat (see Figure 4-41). Positive lightning also has a longer duration, so fires are more easily ignited. And, when positive lightning strikes, it usually carries a high peak electrical current, potentially resulting in greater damage.

Figure 4-41: Cloud to Ground Lightning



Source: National Weather Service Pueblo Office

The ratio of cloud-to-ground and intra-cloud lightning can vary significantly from storm-to-storm. Depending upon cloud height above ground and changes in electric field strength between cloud and earth, the discharge stays within the cloud or makes direct contact with the earth. If the field strength is highest in the lower regions of the cloud, a downward flash may occur from cloud to earth.

Location

Heavy rains and severe storms have the potential to occur anywhere in the Planning Area.

Extent (Magnitude/Severity)

Limited – Extent for severe weather, particularly severe storms that involve heavy rain and hail, can be measured according to hail by diameter size, as it corresponds to everyday objects to define the severity to the population (Table 4-38).

Common problems associated with severe storms include the loss of utilities or immobility. Loss of life is uncommon but can occur during severe storms. Immobility can occur when roads become impassable due to dense fog, flooding, downed trees, ice, or a landslide. Fog specifically poses a risk to commuters and driving conditions as fog typically forms rapidly in the early morning hours. Nighttime driving in the fog is dangerous and multi-car pileups have resulted from drivers using excessive speed for the conditions and visibility.

Loss of utilities can occur when severe thunderstorms cause trees or tree limbs to fall and damage power lines. Lightning can also cause severe damage and injury, particularly when it causes wildfires.

The NWS classifies hail by diameter size, and corresponding everyday objects to help relay scope and severity to the population. Table 4-38 indicates the hailstone measurements utilized by the NWS.

Table 4-38: Hail Measurements

Average Diameter	Corresponding Household Object
.25 inch	Pea
.5 inch	Marble/Mothball
.75 inch	Dime/Penny
.875 inch	Nickel
1.0 inch	Quarter
1.5 inch	Ping-pong ball
1.75 inch	Golf-Ball
2.0 inch	Hen Egg
2.5 inch	Tennis Ball
2.75 inch	Baseball
3.00 inch	Teacup
4.00 inch	Grapefruit
4.5 inch	Softball

Source: National Weather Service

There is no clear distinction between storms that do and do not produce hailstones. Nearly all severe thunderstorms probably produce hail aloft, though it may melt before reaching the ground. Multi-cell thunderstorms produce many hailstones, but not usually the largest hailstones. In the life cycle of the multi-cell thunderstorm, the mature stage is relatively short so there is not much time for growth of the hailstone. Supercell thunderstorms have sustained updrafts that support large hail formation by repeatedly lifting the hailstones into the very cold air at the top of the thunderstorm cloud. In general, hail two inches (5 cm) or larger in diameter is associated with supercells (a little larger than golf ball size which the NWS considers to be 1.75 inch.). Non-supercell storms are capable of producing golf ball size hail.

In all cases, the hail falls when the thunderstorm's updraft can no longer support the weight of the ice. The stronger the updraft the larger the hailstone can grow. When viewed from the air, it is evident that hail falls in paths known as hail swaths. They can range in size from a few acres to areas 10 miles wide and 100 miles long. In some instances, piles of hail have been so deep that snow plows were required to remove them, and occasionally hail drifts have been reported.

Lightning is measured by the Lightning Activity Level (LAL) scale, created by the NWS to define lightning activity into a specific categorical scale. The LAL is a common parameter that is part of fire weather forecasts nationwide. The City of Petaluma is at risk to experience lightning in any of these categories. The LAL is reproduced in Table 4-39.

Table 4-39: Lightning Activity Level Scale

LAL 1	No thunderstorms
LAL 2	Isolated thunderstorms. Light rain will occasionally reach the ground. Lightning is very infrequent, 1 to 5 cloud to ground strikes in a five-minute period
LAL 3	Widely scattered thunderstorms. Light to moderate rain will reach the ground. Lightning is infrequent, 6 to 10 cloud to ground strikes in a five-minute period.
LAL 4	Scattered thunderstorms. Moderate rain is commonly produced. Lightning is frequent, 11 to 15 cloud to ground strikes in a five-minute period.
LAL 5	Numerous thunderstorms. Rainfall is moderate to heavy. Lightning is frequent and intense, greater than 15 cloud to ground strikes in a five-minute period.
LAL 6	Dry lightning (same as LAL 3 but without rain). This type of lightning has the potential for extreme fire activity and is normally highlighted in fire weather forecasts with a Red Flag warning.

Source: National Weather Service

The heavy precipitation that is possible in the City of Petaluma and all of California is often the result of an atmospheric river. Atmospheric rivers are categorized by a unit of measurement known as the Integrated Water Vapor Transport (IVT), which takes into account the amount of water vapor in the system and the wind that moves it around. For a storm to be classified as an atmospheric river it has to reach an IVT threshold of 250 units; 1,000 IVT or more is considered to be “extreme” (Arcuni, 2019). In 2019 a system for categorizing the strength and impacts of atmospheric rivers was developed by the Center for Western Weather and Water Extremes (CW3E), out of the Scripps Institution of Oceanography at the University of California San Diego. The newly developed scale ranks ARs into five categorizes from weak to exceptional. Unlike the Fujita scale for tornadoes that focuses on potential damages, the AR scale accounts for both storms that may be hazardous and storms that can provide benefits to the local water supply. A category one AR is considered to be primarily beneficial, generally lasting only 24 hours and produces modest rainfall. On the other end of the scale, a category five AR is considered “exceptional” and primarily hazardous, lasting for several days and associated with heavy rainfall and runoff that may cause significant damages. Table 4-40 describes the scale further. The Center developed the scale as a tool for officials with an operational need to assess flooding potential in their jurisdictions before the storms makes landfall.

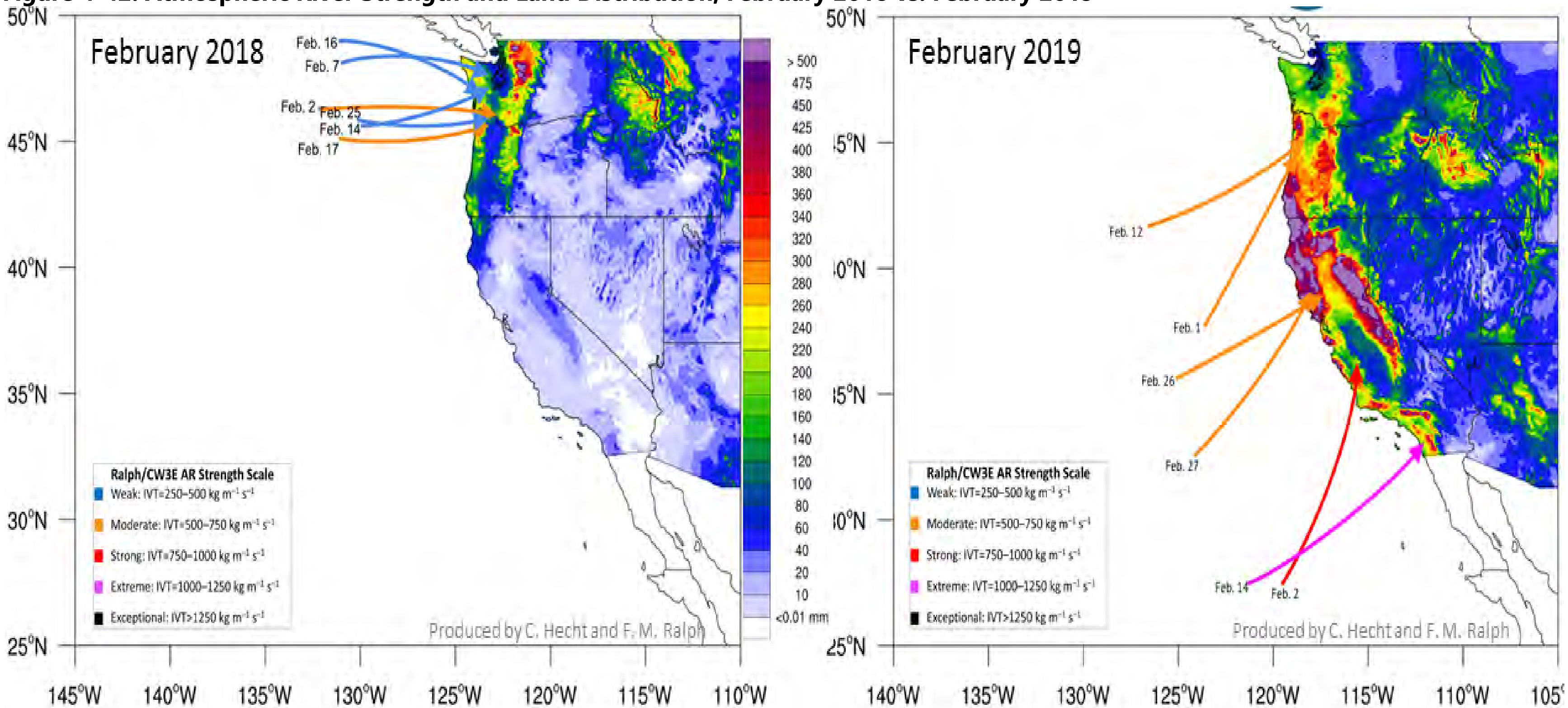
In both February 2018 and 2019 the West Coast experienced six atmospheric rivers. But as Figure 4-42 from the Center for Western Weather and Water Extremes shows, California experienced vastly different precipitation totals due to the location of where the atmospheric river made landfall as well as each atmospheric river’s IVT. Using the AR scale developed by CW3E, the ARs in February 2019 were all considered to be moderate to extreme and concentrated more on California, resulting in heavy precipitation.

Table 4-40: Atmospheric River Categories

Category	Potential Impacts
AR Cat 1: Weak	Primarily beneficial. For example, a Feb. 2, 2017 AR hit California, lasted 24 hours at the coast, and produced modest rainfall.
AR Cat 2: Moderate	Mostly beneficial, but also somewhat hazardous. An atmospheric river on Nov. 19-20, 2016 hit Northern California, lasted 42 hours at the coast, and produced several inches of rain that helped replenish low reservoirs after a drought.
AR Cat 3: Strong	Balance of beneficial and hazardous. An atmospheric river on Oct. 14-15, 2016 lasted 36 hours at the coast, produced 5-10 inches of rain that helped refill reservoirs after a drought, but also caused some rivers to rise to just below flood stage.
AR Cat 4: Extreme	Mostly hazardous, but also beneficial. For example, an atmospheric river on Jan. 8-9, 2017 that persisted for 36 hours produced up to 14 inches of rain in the Sierra Nevada and caused at least a dozen rivers to reach flood stage.
AR Cat 5: Exceptional	Primarily hazardous. For example, a Dec. 29, 1996 to Jan. 2, 1997 atmospheric river lasted over 100 hours at the Central California coast. The associated heavy precipitation and runoff caused more than $1 billion in damages.

Source: Center for Western Weather and Water Extremes, Scripps Institution of Oceanography at UC San Diego. Scale was developed by F. Martin Ralph Director of CW3E in collaboration with Jonathan Rutz of NWS

Figure 4-42: Atmospheric River Strength and Land Distribution, February 2018 vs. February 2019



Source: Center for Western Weather and Water Extremes, Scripps Institution of Oceanography at UC San Diego

Previous Occurrences

Heavy rains and severe storms occur in the Planning Area primarily during the late fall and winter. According to information obtained from the WRCC the majority of precipitation is produced by storms during January and other winter months. Precipitation during the summer months is in the form of rain showers and is rare. Snowstorms and ice storms occur infrequently in the City of Petaluma. The Storm Events Database records one snow event in the City, January 28, 2002 with one to two inches of snow falling in the vicinity of Petaluma; the Database notes this was "quite a rare event". The NCEI records 42 hail, heavy rain, lighting and dense fog events that have taken place in Sonoma County in the past 68 years (1950 –2018). Table 4-41 is a summary of the most significant severe weather events for Sonoma County. An asterisk(*) indicates events where the City of Petaluma was specifically mentioned.

Table 4-41: Severe Weather Events recorded in Sonoma County (1950-2018)

Hazard Type	Date	Hazard Description
Dense Fog	February 8, 2012	Dense fog is blamed in 11 crashes on Highway 37 near Skaggs Island Rd. There were 31 vehicles involved in the crashes. Two people suffered minor injuries. $100,000 in property damages were recorded.
	December 10-11, 2018	Widespread dense fog impacted the Bay Area blanketing the Bay and interior valleys. Numerous reports of dense fog with visibility less than 1/4 mile. A Dense Fog Advisory was issued for the North and East Bay Valleys as well as the San Francisco Peninsula and surrounding bay coastline. Fog caused numerous diverts at KSFO.
Hail	Jan. 19, 2018*	A cold front swept through the region late on the 18th. Small scattered thunderstorms were generated behind the front bringing pea sized hail (0.25 in.) to the region.
	Jan. 25, 2018*	Isolated thunderstorms developed behind a cold front that passed through the area on the 25th. These thunderstorms caused minor roadway flooding and small hail (0.25 in.)
	March 14, 2018*	The Press Democrat in Santa Rosa showed multiple reports of accumulating small hail in downtown Petaluma (0.25 in.); An upper level disturbance moved through the area on the afternoon of the 14th. This disturbance created scattered thunderstorms that resulted in lightning and accumulating hail in the North and East Bay areas.
Lightning	March 14, 2018*	The Press Democrat in Santa Rosa reported that lightning struck a PG&E circuit at 11 am the morning of the 14th causing a power outage for 25 Petaluma residents lasting through the evening. An upper level disturbance moved through the area on the afternoon of the 14th. This disturbance created scattered thunderstorms that resulted in lightning and accumulating hail in the North and East Bay areas.
Heavy Rain	December 15, 2008	Heavy rain caused a fatality of a 32-year-old man when his vehicle collided with another vehicle. Highways 116 and 121 were closed for about three hours after the collision. A cold core low pressure system produced winter storm conditions causing low elevation snow, minor flooding and isolated strong wind through the period December 15 through 17, 2009. $25,000 in property damages is recorded.
	December 22, 2012	A series of storm systems, part of a large Atmospheric River type of pattern, impacted the area during late December 2012. From the 21st through 26th of December, heavy rain, gusty winds, flooding, and mudslides occurred across the Bay Area in these consecutive events. Downed trees, powerlines, and flooded roadways impacted residents over

Hazard Type	Date	Hazard Description
		the Christmas holiday season. $30,000 in property damages were recorded.
	December 11, 2014	An Atmospheric River event brought heavy rain and gusty winds with a strong winter storm that impacted the Bay Area for several days in mid-December. Many locations around the entire Bay Area had flooding: urban flooding of streets and highways, flooding of creeks and even one large river in the North Bay. Eventually the NCFR (narrow cold frontal rainband) slowed around the Big Sur Coast. The stalling was likely due to another 'wave' in the atmosphere, farther to the southwest, riding along the boundary. The end result was to have the weakened NCFR lift back northward, almost like a quasi-warm front, producing another round of moderate to locally heavy rainfall around the Bay Area, compounding flooding concerns. The event was followed by several weaker storm systems that week that brought additional rainfall, continued flooding and mudslide concerns to the area.
	January 16, 2019	A moderate to strong atmospheric river impacted much of California in the middle of the month. A weak surface low developed off the coast on January 15th bringing moderate to heavy rainfall to portions of the region. Over the next 24 to 36 hours a second strong low-pressure system moved to the north and east bringing heavy rain, destructive winds, high surf, flooding, and thunderstorms to the Bay Area. Numerous reports were received of downed trees and power lines. Winds were recorded between 60 and 100 mph. Downed trees resulted in two fatalities.

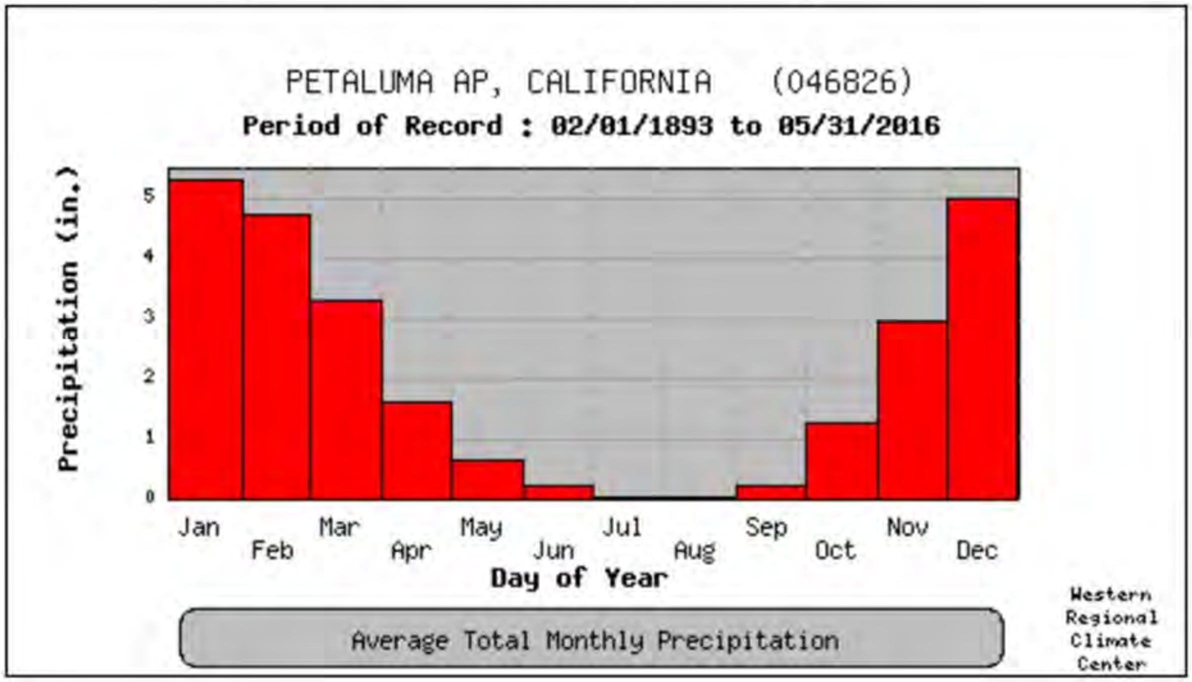
Source: National Centers for Environmental Information, Strom Events Database.

*Notes events that were specific to the City of Petaluma

City of Petaluma—Petaluma Fire Station 3 Weather Station (Period of Record 1893 to 2016)

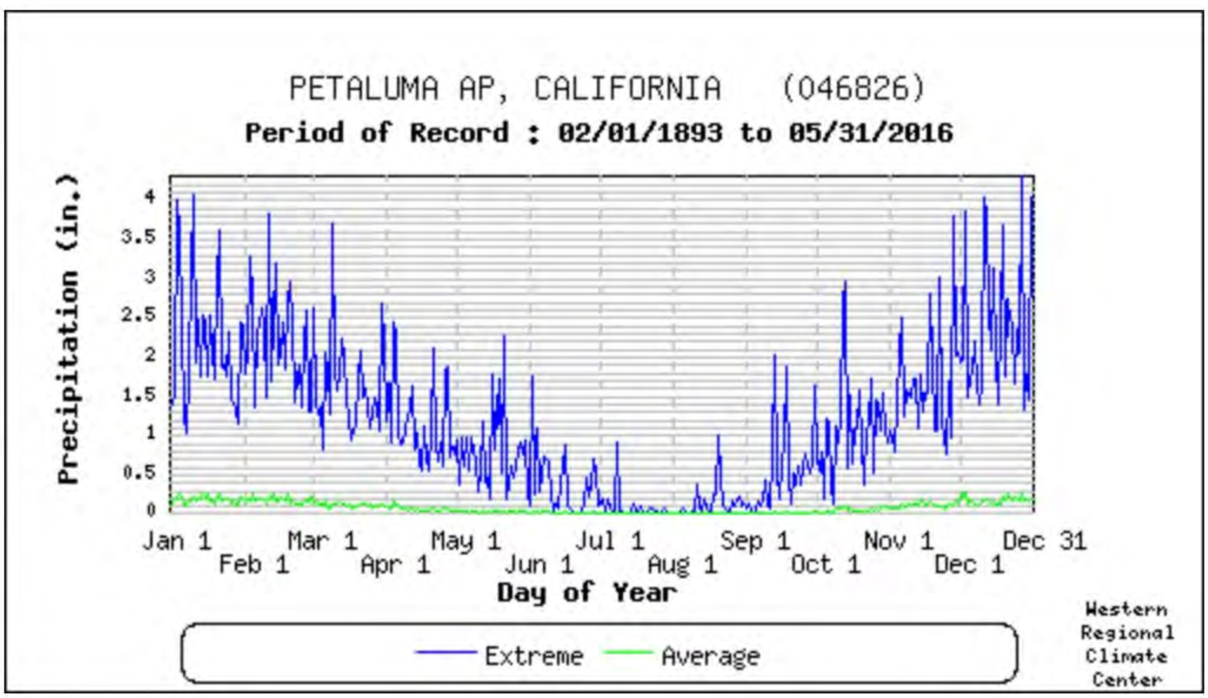
Information from the closest weather station with the most comprehensive data, the Petaluma Fire Station 3 Weather Station, is summarized below in Figure 4-43 and Figure 4-44. Average annual precipitation in the Planning Area is 24.89 inches per year. The highest recorded annual precipitation was 31.48 inches in 1998; the highest recorded precipitation for a 24-hour period is 4.29 inches on December 12, 2004. The lowest recorded annual precipitation was 8.98 inches in 1976.

Figure 4-43: The City of Petaluma's Monthly Average Total Precipitation



Source: Western Regional Climate Center, www.wrcc.dri.edu/

Figure 4-44: The City of Petaluma's Daily Average and Extreme Precipitation



Source: Western Regional Climate Center, www.wrcc.dri.edu/

Probability of Future Occurrences

Likely – Heavy rain, thunderstorms, hail, and lightning wind and fog events are well-documented seasonal occurrences that will continue to occur annually in the Planning Area.

Climate Change Considerations

As average temperatures increase over time, this generally will result in higher extreme temperatures and more warming in the atmosphere can trigger climate changes, which could result in more frequent extreme weather events. According to California's Fourth Climate Change Assessment, the number of days each year on which the atmospheric rivers bring "extreme" amounts of rain and snow to the region are expected to increase under the projected climate change for the state, possibly increasing more than a quarter. Pacific Northwest National Laboratory researchers found that atmospheric rivers will reach the West Coast more frequently if GHG emissions continue to rise under business as usual conditions. Currently, the West receives rain or snow from these atmospheric rivers between 25 and 40 days each year. By the end of this century, days on which the atmospheric rivers reach the coast could increase by a third this century, between 35 and 55 days a year. Meanwhile, the number of days each year on which the atmospheric rivers bring "extreme" amounts of rain and snow to the region could increase by more than a quarter.

It is difficult at this point in time to summarize the effects climate change may have on these hazards. However, as average temperatures increase over time, this generally will result in higher extreme temperatures. More warming in the atmosphere can trigger climate changes, which could result in more frequent extreme weather events. Much of the U.S. has already experienced prolonged periods of heavy downpours and severe flooding as a result of more extreme heavy rain and thunderstorm events.

Vulnerability Assessment

Property

Based on historic information, these storms have not directly resulted in significant injury or damages to people and property, or the losses are typically covered by insurance. It is the secondary hazards caused by weather, such as floods, that have had the greatest impact on the City's Planning Area. But while the primary effects may not result in significant injury or property damage, all property is vulnerable during sever weather events; properties in poor condition or closer to overhead power lines and large trees may be more vulnerable to damage.

People

Exposure is the greatest danger to people from severe thunderstorms. People can be hit by lightning, pelted by hail, and caught in rising waters. However, serious injury and loss of human life is rarely associated with hailstorms.

Reduced visibility is the greatest risk to people when heavy fog is prevalent. Particularly when fog is dense, it can be hazardous to drivers, mariners, and aviators and contributes to numerous accidents each year. To reduce injury and harm, people should avoid driving when dense fog is prevalent, if possible. If driving is pertinent, emergency services advise driving with lights on low beam, avoiding stopping on highways, and avoiding crossing traffic lanes.

While national data shows that lightning causes more injuries and deaths than any other natural hazard except extreme heat, there does not seem to be any trend in the data to indicate that one segment of the population is at a disproportionately high risk of being directly affected. Anyone who is outside during a thunderstorm is at risk of being struck by lightning. Aspects of the population who rely on constant, uninterrupted electrical supplies may have a greater, indirect vulnerability to lightning. As a group, the elderly or disabled, especially those with home health care services rely heavily on an uninterrupted source of electricity. Resident populations in nursing homes, residential facilities, or other special needs housing may also be vulnerable if electrical outages are prolonged. If they do not have a back-up power source, rural residents and agricultural operations reliant on electricity for heating, cooling, and water supplies are also vulnerable to power outages. Thunderstorms have the potential energy and strong winds to topple dead trees and injure people. As a result, power outages that occur from severe weather can be life threatening and these populations could face more exposure and could experience greater secondary effects of the hazard. Refer to the Vulnerability Assessment for Severe Weather: High Winds hazards below for analysis related to electricity dependent populations in the City of Petaluma.

Economy

Economic impacts of severe weather are typically short term. Lightning can cause power outages and fires. Hail can destroy exposed property; an example is car lots, where entire inventories can be damaged. Generally, long-term economic impacts center around hazards that cascade from a severe thunderstorm, including wildfires ignited by lightning and flooding due to heavy rain.

Critical Facilities and Infrastructure

Due to the unpredictability of severe thunderstorm strength and path, most critical infrastructure that is above ground is equally exposed to the storm's impacts. According to historical data the Planning Area has experienced power outages in the past due to severe storms, but due to the random nature of these hazards, a more specific risk assessment was not conducted for this plan. Heavy rain and thunderstorms, particularly those that result in hail could significantly impact motorists travelling along U.S. Highway 101 and State Highway 116. Depending on the severity of the storm, these events could slow traffic, reduce visibility, and increase the likelihood of vehicle accidents along the highway, which may result in greater traffic delays. These effects are also likely to occur along highway segments in adjacent counties.

Fog can have devastating effects on transportation corridors in the City and throughout the County. Dense fog may increase the potential for transportation accidents along U.S. Highway 101 and State Highway 116 which could in turn cause longer traffic delays and timely movement of goods and services. Multi-car pileups have resulted from drivers using excessive speed for the conditions and visibility.

These accidents can cause multiple injuries and deaths and could have serious implications for human health and the environment if a hazardous or nuclear waste shipment were involved. Other disruptions from fog include delayed emergency response vehicles and school closures.

Historic, Cultural, and Natural Resources

Severe thunderstorms are a natural environmental process. Environmental impacts include the sparking of potentially destructive wildfires by lightning and localized flattening of plants by hail. As a natural process, the impacts of most severe thunderstorms by themselves are part of the overall natural cycle and do not cause long-term consequential damage.

Future Development

New critical facilities, such as communication towers should be built to withstand heavy rain, lighting, and hail damage. Population and commercial growth in the City will increase the potential for complications with traffic accidents and commerce interruptions associated with dense fog. Future development projects should also consider severe weather hazards at the planning, engineering and architectural design stage with the goal of reducing vulnerability. Storm water master planning and site plan review should account for building to withstand severe weather events and be considered for all new development. Future development in the City is not expected to be vulnerable to the hazard, but all development will be affected by severe weather and storm events and population growth will increase potential exposure to hazards such as lightning and hail.

Risk Summary

- Sonoma County has experienced 42 hail, heavy rain, lighting, and dense fog events in past 68 years.
- The average annual precipitation is 24.89 inches.
- The highest recorded annual precipitation was 31.48 inches in 1998.
- The highest recorded precipitation for a 24-hour period was 4.29 inches on December 12, 2004.
- Overall significance for severe weather hazards such as heavy rain, thunderstorms, hail, lightning, and dense fog is **Medium.**

4.3.10 Severe Weather: High Winds

Hazard Description

High winds, often accompanying severe thunderstorms, can cause significant property and crop damage, threaten public safety, and have adverse economic impacts from business closures and power loss. The wind patterns in Petaluma are strongly influenced by the Petaluma Gap, the region from the Estero Lowlands to San Pablo Bay (BAAQMD 2003). The predominant wind pattern is out of the northwest and tends to be light in the morning and windier in the afternoon when the sea breeze arrives.

Windstorms in the City of Petaluma are typically straight-line winds. Straight-line winds are generally any thunderstorm wind that is not associated with rotation (i.e., is not a tornado). These winds can exceed 100 miles per hour (mph) and are responsible for most wind damage related to thunderstorms. These winds can overturn mobile homes, tear roofs off houses, topple trees, snap power lines, shatter windows, and sandblast paint from cars. Other associated hazards include utility outages, arcing power lines, debris blocking streets, dust storms, and an occasional structure fire. Table 4-42 outlines the Beaufort scale, describing the damaging effects of wind speed.

Table 4-42: Beaufort Wind Scale

Wind Speed (mph)	Description—Visible Condition
0	Calm; smoke rises vertically
1-4	Light air; direction of wind shown by smoke but not by wind vanes
4-7	Light breeze; wind felt on face; leaves rustle; ordinary wind vane moved by wind
8-12	Gentle breeze; leaves and small twigs in constant motion; wind extends light flag
13-18	Moderate breeze; raises dust and loose paper; small branches are moved
19-24	Fresh breeze; small trees in leaf begin to sway; crested wavelets form on inland water
25-31	Strong breeze; large branches in motion; telephone wires whistle; umbrellas used with difficulty
32-38	Moderate gale whole trees in motion; inconvenience in walking against wind
39-46	Fresh gale breaks twigs off trees; generally, impedes progress

Wind Speed (mph)	Description—Visible Condition
47-54	Strong gale slight structural damage occurs; chimney pots and slates removed
55-63	Whole gale trees uprooted; considerable structural damage occurs
64-72	Storm very rarely experienced; accompanied by widespread damage
73+	Hurricane devastation occurs

Source: NWS

High winds and tornadoes can cause damage to property and loss of life. Property damage can include damage to buildings, fallen trees and power lines, broken gas lines, broken sewer and water mains, and the outbreak of fires. Agricultural crops and industries may also be damaged or destroyed. Access roads and streets may be blocked by debris, delaying necessary emergency response.

Location

Strong winds have the potential to happen anywhere in the City's Planning Area. The resulting damage from wind events may be most severe in the downtown area of the City where there are more large trees, infrastructure, and higher density development.

Extent (Magnitude/Severity)

Limited – The prevailing winds in Petaluma come from the northwest and are strongly influenced by the Petaluma Gap helping to push marine air towards the City. Winds tends to be lighter in the morning and windier in the afternoon as the ocean air arrives.

Based on NCEI records between 1950 and July 31, 2019 there have been 211 high and strong wind events in Sonoma County, causing a total of $3,854,700 in property damage. The most damaging event took place on December 27, 2006 and was a 30 mph wind event that resulted in over $1 million of property damage to both commercial and residential structures. The highest magnitude event recorded occurred on February 14, 2019 and was in association with an atmospheric river that moved through the region. Recorded winds were as high as 80-mph and resulted in downed trees, power outages, and property damages.

High wind events in the County have led to five recorded fatalities and five injuries. Overall, high wind event impacts would likely be limited, with a majority of impacts being related to property damages caused by down trees as well as power outages. Overall, impacts from high wind events would likely be limited, with 10 to 25 percent of property severely damaged.

Previous Occurrences

Despite being nearly 20 miles from the coast of the Pacific Ocean, Petaluma's climate tends to be similar to coastal communities. Similar to a community along the coast, the City of Petaluma tends to experience wind events regularly. High wind events in Petaluma have also led to downed trees and power outages throughout the City. The following events are recorded in the NCEI Storm Events Database that are specific to the City of Petaluma Planning Area.

January 18, 2010 - Strong wind uprooted a large oak tree forcing it onto Bennett Valley Road near Enterprise Road in the hills east of Petaluma partially blocking one lane of traffic. The roots had grown under the roadway, and when they were torn out of the ground they took about seven inches of asphalt with them leading to the closure of the eastbound lane. Also, in the hills east of Petaluma, another tree was reported to be uprooted on Sonoma Mountain Road at Pressley Road. Power outages across central Sonoma County numbered 3,584 customers.

April 8, 2013 - Strong wind blew down small tree branches and debris onto streets in the City. Strong and gusty northwest winds impacted much of the Bay Area resulting in downed trees, downed power lines, rough seas and even broken windows. The rather strong northerly pressure gradient helped to produce widespread wind gusts in excess of 35 mph with a few locations over 60 mph. Numerous reports of downed trees and power lines were received as a result of the strong winds.

November 21, 2013 - Strong winds gusted across the greater Bay Area during the evening and overnight hours of November 21 into the early morning of November 22. Numerous trees and power lines were knocked down by the winds, causing power outages for thousands of residents and even sparking wildfires across the North Bay. A tree was felled by strong winds onto a car driving on US Highway 101 in Petaluma, injuring the car's occupant.

December 30, 2014 - A strong windstorm struck the Bay Area on December 30 during the afternoon and evening hours. Strong winds brought down numerous trees and power lines across the area. The combination of recent heavy rains earlier in the month brought weakened ground conditions. Additionally, there were numerous dead trees across the area from years of ongoing drought. Major disruptions to the evening commute due to downed trees and the accidents they caused were observed. Wind gusts of 40 to 55 mph were widespread across the area. Despite most areas not reaching 60 mph, there was widespread wind damage and impacts due to the reasons above. A large tree was blown down and blocked both lanes of Old Redwood Highway near Petaluma.

February 6, 2015 - A strong winter storm impacted California following on nearly a month and a half of no rain and the driest January on record. The storm brought heavy rain, gusty winds, and damage to trees and power lines along with some minor flooding of urban areas. Impacts to the planning areas included a tree blown down across the roadway at Magnolia Avenue and Thompson lane about three miles west of Petaluma. Winds gusted 50 to 70 mph with the highest gusts in the mountains of the region.

October 23, 2019 - A series of offshore wind events plagued much of California towards the end of October 2019. Cut off lows (also known as insider sliders) moved into the Great Basin as an upper ridge sat over the eastern Pacific. Strong surface high pressure also building over the Great Basin and a trough along the California coast provided the set up for strong and dry offshore winds over the greater Bay Area. Two more events would go on to occur before the end of the month providing what would be historic critical fire weather conditions for the region. The first event brought strong north to northeast winds to the region, particularly the North Bay, where gusts of 50 to 70 mph were observed. Healdsburg Hills North Station had a peak gust of 76 mph the night of October 23rd. These conditions fed the rapid growth of the Kincade Fire that broke out late in the evening of October 23rd, and at the end of the month the Kincade Fire was still burning. Additionally, near record breaking high temperatures were observed in parts of the area on the 24th and 25th. Prior to the event on October 9th PG&E shut off power to roughly 1 million people across the state of California.

Probability of Future Occurrences

Likely – A total of 211 combined high and strong wind events have occurred in Sonoma County over 68 years of record keeping, which equates to an average of three events in a typical year. Historical wind activity within the Planning Area indicates that the area will likely continue to experience high wind events during adverse weather conditions. The actual risk of a wind event to the City is dependent on the nature and location and the magnitude of a high wind event.

Climate Change Considerations

There presently is not enough data or research to quantify the magnitude of change that climate change may have related to wind frequency and intensity. Studies referenced in California's Fourth Climate

Assessment indicated that extreme fire weather, particularly in the form of hot and dry winds, can strongly influence shrub-land fire regimes. Strong winds have also been associated with severe forest fires in California, meaning climate change impacts on wind patterns may also affect forest health and wildfire susceptibility. Lastly, other ongoing research compiled in the recent climate assessment has resulted in different conclusions on the effect of climate change on wind regimes, particularly extreme wind events, such as the Santa Ana and Diablo winds that created some of the most devastating wildfires (California Natural Resources Agency 2018a). At this time, these changing factors are not well understood and are still being incorporated into state and regional research and risk analysis.

Vulnerability Assessment

Property

General damages from high wind events can be both direct and indirect. Direct impacts refer to what the wind physically destroys, while indirect impacts includes additional costs, damages and losses attributed to secondary hazards spawned by the event, or resulting from the direct damages caused by the wind event. Construction practices and building codes can help maximize the resistance of the structures to damage.

Secondary impacts of damage caused by wind events often result from damage to infrastructure. Downed power and communications transmission lines, coupled with disruptions to transportation, create difficulties in reporting and responding to emergencies. These indirect impacts of a wind event put tremendous strain on a community.

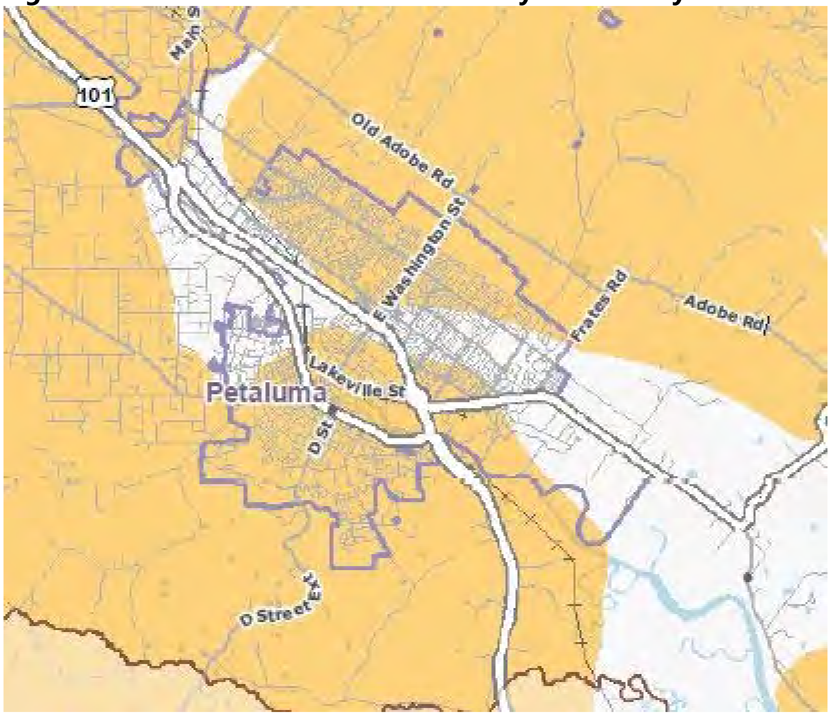
People

Community members are the most vulnerable to high wind events. However, there are also segments of the population that are especially exposed to the indirect impacts of high winds, particularly the loss of electrical power. These populations include the elderly or disabled, especially those with medical needs and treatments dependent on electricity. Nursing homes, community-based residential facilities, other special needs housing facilities, and other socially susceptible populations are vulnerable if electrical outages are prolonged, since backup power generally operates only minimal functions for a short period of time.

The U.S. Department of Health and Human Services ePOWER Mapping tool (https://empowermap.hhs.gov/) provides information on Medicare beneficiaries who rely on electricity-dependent medical equipment such as ventilators to live independently in their homes. According to the tool there are 13,631 Medicare beneficiaries located in the City of Petaluma (within the zip codes of 94952 and 94954). Of these individuals, 382 are considered electricity dependent and are highly vulnerable to power outages as a result a high wind event.

Following the unprecedented 2018 wildfire season in California, Pacific Gas & Electric (PG&E) announced it will be conducting Public Safety Power Shutoffs (PSPS) when there are high winds and dry conditions and generally a heightened fire risk forecasted. The outages could last several days, and PG&E has suggested customers be prepared for outages that could last longer than 48 hours. A majority of Sonoma County could be affected by the power outages including almost the entirety of the City of Petaluma. Figure 4-45 shows the areas (orange) in the City of Petaluma that could potentially be impacted by the power outages. PG&E does have a plan to install a resource area at the Sonoma-Marin Fairgrounds within 24 hours of a PSPS, and will offer power, air conditions and updates for local residents.

Figure 4-45: Areas of Petaluma Potentially Affected by the PG&E Public Safety Power Shutoffs



Source: The Press Democrat https://www.pressdemocrat.com/news/9898428-181/pge-map-sheds-light-on?artslide=2

Economy

Winds typically don't have long-term impacts on the economy. The most common problems associated with high winds are loss of utilities. Downed power lines can cause power outages, leaving large parts of the City isolated, and without electricity, water, and communication. Damage may also limit timely emergency response and the number of evacuation routes.

In the event of a PSPS during red flag warnings, as described above, large portions of the City could be without power including several businesses. At this time, it is unclear what the economic impacts may be due to the PSPS, and it may depend on the length of the shutoff. However, given the recent planned PSPS in October 2019, economic impacts were reported across northern California as many businesses and restaurants and other tourism-based operations had to close due to limited to no power supply. In 2018, PG&E abruptly shut down the power in the Napa Valley region and the City of Calistoga reported that numerous small business lost tens of thousands of dollars in missed revenue and inventory (Argus-Courier 2019).

Critical Facilities and Infrastructure

Public gathering places such as schools, community centers, shelters, nursing homes, and churches may have increased impacts at certain times of day. Due to the random nature of the hazard, a more specific risk assessment was not conducted for this plan.

Historic, Cultural, and Natural Resources

High winds can cause massive damage to the natural environment, uprooting trees and other debris. This is part of a natural process, however, and the environment will return to its original state over time. Wind damage to historic or cultural resources on the other hand may result in more severe temporary and permanent damage that could temporarily impact the historic aesthetic of downtown Petaluma or require extensive restoration and rehabilitation of certain structures.

Future Development

As the City continues increasing in population, the number of people and housing developments exposed to the hazard increases. Proper education on building techniques and the use of sturdy building materials, basements, attached foundations, and other structural techniques may minimize the property vulnerabilities. Public shelters at parks and open spaces may help reduce the impacts of high wind events on the recreational populations exposed to storms.

Risk Summary

- Increase in post-failure or secondary hazards such as flooding, mudslides, landslides, and long-term power outages can occur.
- The U.S. Department of Health and Human Services lists 382 individuals in the City as electricity dependent, and highly vulnerable to power outages due to high wind events.
- Damage to natural resource habitats and other resources may result from severe weather associated wind.
- Severe wind events could result in the loss of water, communication lines, or power; closures to roads and transportation lifelines, which could impact, strand, and/or impair mobility for emergency responders and/or area residents.
- Economic losses (jobs, sales, tax revenue) associated with loss of commercial structures and/or inability to move through transportation lifelines could occur.
- Severe wind hazards could result in loss or damages to historic and cultural resources, which could severely impact the social fabric downtown Petaluma;
- Timely removal of debris, specifically downed trees must be addressed, as this can impact the severity of the severe weather events and the secondary impacts (e.g. localized flooding, loss of power).
- Overall the significance of severe weather associated with wind is **Medium.**

4.4 Human-Caused Hazard Profiles and Risk Assessment

The DMA does not require an assessment of human-caused hazards, but the City of Petaluma and HMPC decided to include human-caused hazards in this LHMP to several reasons. First, the City wants to inform the public about all hazards, including both natural and human-caused hazards. The City is also interested in the impact human-caused hazards could have on their community and on the daily movement of goods and services through the City. The City intends to take a proactive approach to disaster preparedness, and the HMPC feels that preparation for and response to a human-caused disaster involves the same training and commitment of City resources as a natural hazard. Lastly, the City recognizes that the likelihood of some human-caused hazard events in the Planning Area is greater than several of the natural hazard events identified in the plan.

The City also recognizes that while Sonoma County has several hazardous material management and planning procedures in place through their Certified Unified Program Agency (CUPA) administered through their Environmental Health Department, it is equally important to highlight the hazardous material hazards present in the City's Planning Area in this plan for the purpose of public education and awareness. The City wants to ensure that these hazards do not exacerbate secondary impacts associated with natural hazard events.

The following human-caused hazards are discussed in this plan:

- Hazardous Materials
- Cyber Threats

Other potential human-caused hazards, such as human-health hazards and terrorism threats were dismissed from further study. The City and HMPC noted that human-health hazards are adequately covered by the planning mechanisms administered by Sonoma County's Fire Prevention Division and Environmental Health Department.

4.4.1 Hazardous Materials

Hazard Description

Generally, a hazardous material is a substance or combination of substances which, because of quantity, concentration, or physical, chemical, or infectious characteristics, may either cause or significantly contribute to, an increase in mortality or an increase in serious, irreversible, or incapacitating reversible, illness. Hazardous materials may also pose a substantial present or potential hazard to human health or environment when improperly treated, stored, transported, disposed of, or otherwise managed. Hazardous material incidents can occur while a hazardous substance is stored at a fixed facility, or while the substance is being transported along a road corridor or railroad line or via an enclosed pipeline or other linear infrastructure.

The U.S. Department of Transportation (DOT), U.S. Environmental Protection Agency (EPA) and the Occupational Safety and Health Administration (OSHA) all have responsibilities relating to the transportation, storage, and use of hazardous materials and waste. The Right-to-Know Network (RTK NET), maintained by the EPA's National Response Center (NRC), is a primary source of information on the use and storage of hazardous materials, as well as data regarding spills and releases. The California EPA and Department of Toxic Substances Control (DTSC) are authorized by the U.S. EPA to enforce and implement federal hazardous materials laws and regulations within the state. At the local level, Sonoma County's Fire Prevention Division and Hazardous Materials Division (also known as Permit Sonoma) is the approved CUPA responsible for administration of permitting, inspections, and enforcement for hazardous waste and hazardous materials programs. The CUPA administers the Hazardous Material Business Plan (HMBPs), California Accidental Release Prevention (Cal-ARP) program, and the Aboveground Storage Act, as well as permitting and inspection activities for hazardous waste generators, and onsite hazardous waste treatment facilities, and underground storage tanks.

Hazardous materials can be divided into the following classes:

- Explosives
- Compressed gases: flammable, non-flammable compressed, poisonous
- Flammable liquids: flammable (flashpoint below 141 degrees Fahrenheit) combustible (flashpoint from 141 - 200 degrees)
- Flammable solids: spontaneously combustible, dangerous when wet
- Oxidizers and organic peroxides
- Toxic materials: poisonous material, infectious agents
- Radioactive material
- Corrosive material: destruction of human skin, corrodes steel

It is also common to see hazardous materials releases as escalating incidents resulting from other hazards such as floods, wildfires, and earthquakes. The release of hazardous materials can greatly complicate or even eclipse the response to the natural hazards disaster that caused the spill.

The Safety Element of the City of Petaluma General Plan contains goals, policies, and implementation measures pertaining to hazardous materials. Additionally, Sonoma County has prepared and adopted the Sonoma County Operational Area Hazardous Materials Incident Response Plan, in accordance with the California Health and Safety Code (HSC) (Division 20, Chapter 6.95, §25500 et seq.) and California Code of Regulations (CCR) (Title 19, Article 3, §2270 et seq.). This plan describes the policies and procedures relating to hazardous materials emergency response throughout Sonoma County, and is reviewed and updated every three years.

Location

Hazmat incidents can occur at a fixed facility or during transportation. Hazardous materials facilities are identified and mapped by the counties they reside in, along with the types of materials stored there; facilities generally reside in and around communities. The Petaluma Fire Department and Hazardous Materials Division manages the prevention, control and mitigation of dangerous conditions related to hazardous materials and enforces state and local laws regulating the storage, use, dispensing and handling of hazardous materials. The Division is responsible for the enforcement of the regulatory-based HMBP Program, Hazardous Waste Program, Underground Storage Tank Program, Above Ground Petroleum Storage Tank Program, Accidental Release Program, and the portions of the California Fire Code that address hazardous materials. Inspections of businesses are conducted on a routine basis, and the Division.

Under Chapter 6.95 of the California Health and Safety Code and the Federal Resource Conservation and Recovery Act (RCRA), any business storing quantities of hazardous materials greater than 55 gallons of liquid, 500 pounds of solid or 200 cubic feet of some compressed gasses must file a HMBP annually that establishes incident prevention measures, hazardous material handing protocols and emergency response and evacuation procedures.

CalARP is a statewide initiative to reduce the likelihood and severity of consequences of extremely hazardous materials releases. CalARP requires certain facilities (referred to as "stationary sources") which handle specified chemicals (termed "regulated substances") to take specified actions to proactively prevent and prepare for chemical accidents. Because the CalARP program is implemented at the local government level by the CUPAs, they can work directly with regulated facilities. The Petaluma Fire Department administers CUPA and provide response and mitigation services to the City.

Some facilities contain extremely hazardous substances; these facilities are required to generate Risk Management Plans (RMPs) and resubmit these plans every five years. According to the RTK NET, the City of Petaluma Wastewater Treatment Plant is the only RMP facility located in the planning area. This site stores 18,000 pounds of chlorine, used as part of the sewage treatment process.

In transit, hazardous materials generally follow major transportation routes, including road, rail and pipelines, creating a risk area immediately adjacent to these routes. The City's nearby transportation network, primarily U.S. Highway 101, has the potential for hazardous material incidents. Railroad lines (nearby Northwestern Pacific Railroad Authority lines) and the Petaluma Municipal Airport may also transport hazardous materials.

According to the Federal Motor Carrier Safety Administration and the National Hazardous Materials Route Registry, U.S. Highway 101 running through Petaluma is designated as a hazardous materials route. However, local deliveries of hazardous materials can be found on any of the City's major roads.

Hazardous materials releases can also result from natural disasters, such as floods or earthquakes that may cause containment systems to fail. In summary, hazardous material incidents have the potential to occur in business and industrial areas (where fixed facilities are located). Often these facilities are concentrated in the Planning Area due to their manufacturing operations. Hazardous material incidents are also located in agricultural areas surrounding the Planning Area; these types of facilities typically use pesticides, fertilizers, and other agricultural chemicals that are harmful to people and the environment. Illegal drug operations and dumping sites have also been known to pose a hazardous threat.

Lastly, pipelines can transport large quantities of hazardous materials. The National Pipeline Mapping System (NPMS) shows the approximate location of multiple pipelines passing through the City, primarily transporting gas or fuels.

Extent (Magnitude/Severity)

Limited – Hazardous materials come in the form of explosives, flammable and combustible substances, poisons and radioactive materials. Hazards can occur during production, manufacturing, storage, transportation, use, or disposal. Numerous factors influence the impacts of a hazardous materials release, including method of release, the type of material, location of release, weather conditions, and time of day. This makes it difficult to predict precise impacts. Impacts from hazardous waste releases can include:

- Injury
- Loss of life (human, livestock, fish and wildlife)
- Evacuations
- Property damage
- Air pollution
- Surface or ground water pollution/contamination
- Interruption of commerce and transportation

CAL FIRE notes several additional factors that can contribute to the impact of hazardous materials releases from a fixed facility or transportation incident:

- Solid, liquid, and/or gaseous hazardous materials can be released from fixed or mobile containers either accidentally or on purpose.
- The resulting release can last for hours or for days.
- The substances released may be corrosive or otherwise damaging over time, and they may cause an explosion and/or fire.
- Contamination may be carried out of the incident area by people, vehicles, water, and/or wind.
- Weather conditions will directly affect how the hazard develops.
- The micrometeorological effects of buildings and terrain can alter travel and duration of agents.
- Shielding in the form of sheltering in place can protect people and property from harmful effects.
- Noncompliance with fire and building codes as well as failure to maintain existing fire protection and containment features can substantially increase the damage from a hazardous materials release.

The release or spill of hazardous materials also requires different emergency response depending on the amount, type, and location of the spill incident.

The Planning Area has energy pipelines, railroad tracks which carry many types of hazardous materials, and state highways running through its boundaries. A variety of hazardous materials originating in the Region or elsewhere are transported along these routes and could be vulnerable to accidental spills.

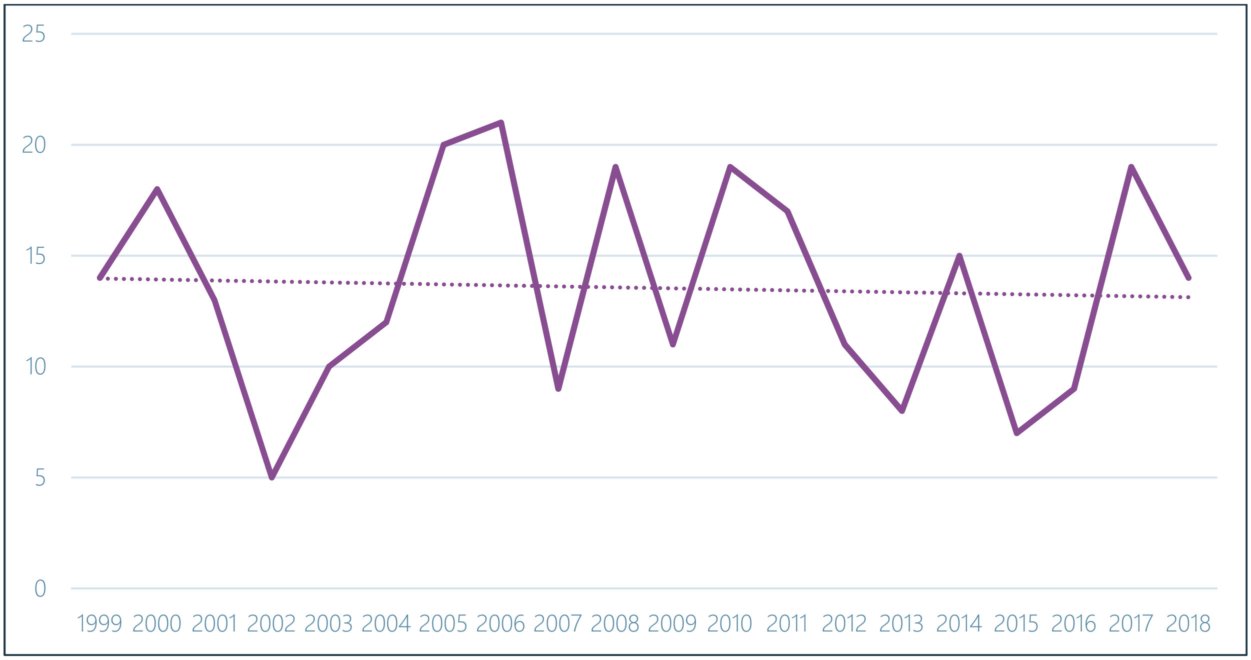
Consequences can vary depending on whether the spill affects a populated area versus an unpopulated but environmentally sensitive area.

Potential losses can vary greatly for hazardous material incidents. For even a small incident, there are cleanup and disposal costs. In a larger scale incident, cleanup can be extensive and protracted. There can be deaths or injuries requiring doctor's visits and hospitalization, disabling chronic injuries, soil and water contamination can occur, necessitating costly remediation. Evacuations can disrupt home and business activities. Large-scale incidents can easily reach $1 million or more in direct damages.

Previous Occurrences

The City of Petaluma experiences multiple hazardous materials incidents every year. The vast majority of these incidents are minor with very localized impacts. The Cal OES Warning Center reports 271 hazardous materials incidents in Petaluma from 1999 through 2018; this works out to an average of 13.6 incidents per year. Even this total likely excludes a large number of unreported minor spills. Figure 4-46 below shows the number of incidents within the City limits reported to Cal OES over the last twenty years. While the number of incidents can vary considerably from year to year, the number of hazardous materials spills or accidents in the City has remained steady over the last twenty years. This is in contrast to the statewide trend, which has seen hazardous materials incidents increase by 30 percent during the same time period.

Figure 4-46: Hazardous Materials Spills/ Accidents in the City of Petaluma Reported to Cal OES: 1999-2018



Source: Cal OES Spill Release Reporting (https://www.caloes.ca.gov/cal-oes-divisions/fire-rescue/hazardous-materials/spill-release-reporting), analysis by Wood

The vast majority of hazardous materials incidents have only minimal life safety impacts. Of the 271 incidents reported above, only seven (3 percent) result in any injuries, fatalities, or evacuations. This translates to an average of one damaging hazardous materials incident roughly every three years. In all, Cal OES records seven injuries, one fatality, and one evacuation are associated with those 271 incidents.

Probability of Future Occurrence

Likely – As discussed above, the City experiences anywhere from five to twenty reportable hazardous materials incidents per year, with various degrees of impact; there is effectively a 100 percent chance that the City will see a hazardous materials incident in any given year. However, hazardous materials incidents that cause deaths, injuries, or evacuations are far rarer, occurring once every three years on average. These can occur at any time and with little predictability given the presence of major transportation routes in the City's Planning Area.

Climate Change Considerations

There are no known effects of climate change on human-caused hazards, such as hazardous material incidents. However, hazmat incidents may indirectly increase the risk by increasing the frequency, severity, or range of other hazards, such as severe storms or fires. It is possible that an increase in these other hazards may increase the likelihood of an accidental hazardous materials release.

Vulnerability Assessment

Property

The impact of a fixed hazardous facility, such as a chemical processing facility, will likely be localized to the property where the incident occurs. The impact of a small spill (i.e. liquid spill) may also be limited to the extent of the spill and remediated if needed. A blanket answer for potential impacts is hard to quantify, as different chemicals may present different impacts and issues. Property within a half mile in either direction of designated hazardous materials routes are at increased risk of impacts. While cleanup costs from major spills can be significant, they do not typically cause significant long-term impacts to property.

People

People living near hazardous facilities in the Planning Area may be at a higher risk of exposure, however; few people live near these facilities as most industrial land uses are sited away from residential land uses. Still, people living downstream and downwind from a hazardous material facility (or hazardous material release) could be more vulnerable. For example, a toxic spill or a release of an airborne chemical in a populated area like the City of Petaluma could have a greater potential for loss of life, particularly if is spreads towards residential areas surrounding the downtown area.

In addition to the immediate health impacts of releases, a handful of studies have found long term health impacts such as increased incidence of certain cancers and birth defects among people living near certain chemical facilities. However, there has not been sufficient research done on the subject in the Planning Area to allow detailed analysis.

Critical Facilities and Infrastructure

Impacts from hazardous material incidents on critical facilities would be localized. That is, they will be limited to the area or facility where they occurred, such as at a transit station, airport, fire station, hospital, or railroad. Whereas hazardous material incidents to major transportation infrastructure would be localized to some extent, they may also be further reaching if they result in major delays in the movement of goods and services and if they result in long-term traffic delays and road closures. These incidents would be more severe if they result in traffic delays or road closures along U.S. Highway 101.

Economy

The primary economic impact of hazardous material incidents result in lost business, delayed deliveries, property damage, and potential contamination. Large and publicized hazardous material-related events can deter tourists and recreationists too. If incidents occur along major transportation corridors, they can temporarily close routes and result in traffic delays. Economic effects from major transportation corridor closures can be significant.

Historic, Cultural, and Natural Resources

Hazardous material incidents may affect a small area at a regulated facility or cover a large area outside such a facility. Widespread effects occur when hazards contaminate the groundwater and eventually the municipal water supply, or they migrate to a major waterway or aquifer.

Future Development

The City of Petaluma anticipates experiences the greatest growth in the downtown area. Future development in central Petaluma is close to major roads and local thoroughfares, as well as some operations that are known to store, handle, and transport hazardous materials. As a result, future development would be exposed to potential hazardous material releases to some extent. Careful review and management of HMBPs and implementation of Hazardous Materials Incident Response Plans during events should minimize major risks.

Risk Summary

- There is one RMP facility located within the City limits.

- Over the last twenty years the City has averaged 13.6 hazardous materials incidents per year. However, hazardous materials incidents that cause deaths, injuries, or evacuations are far rarer, occurring once every three years on average.
- Incidents at hazardous facilities will likely be localized to the property where the incident occurs.
- People living near, downstream, or downwind of hazardous facilities could be more vulnerable to airborne or water quality related contamination associated with a hazardous material incident.
- Hazardous materials releases can complicate response to and recovery from natural disasters such as foods and earthquakes.
- Hazardous Materials incidents can cause injuries and fatalities, as well as long term health problems like increased cancer risks.
- Impacted properties and infrastructure can require cleanup, but the effects are usually localized to the site of the release.
- Extended road closures can result in economic losses and impact tourism.
- Overall significance level for hazardous materials is **Medium.**

4.4.2 Cyber Threats

Hazard Description

The California SHMP identifies cyber threats as "attempts by cyber criminals to attack a government, organization, or private party by damaging or disrupting a computer or computer network, or by stealing data from a computer or computer network for malicious use." A recent survey by the United States Government Accountability Office (GAO) found that "agencies having high-impact systems identified cyber-attacks from nation-states as the most serious and most frequently-occurring threat to the security of their systems."

There are many types of cyber-attacks. Among the most common is a direct denial of service, or DDoS attack. This is when a server or website will be queried or pinged rapidly with information requests, overloading the system and causing it to crash.

Cyber-attacks use malicious code to alter computer operations or data. The vulnerability of computer systems to attacks is a growing concern as people and institutions become more dependent upon networked technologies. The Federal Bureau of Investigation (FBI) reports that "cyber intrusions are becoming more commonplace, more dangerous, and more sophisticated," with implications for private- and public-sector networks.

Malware, or malicious software, can cause numerous problems once on a computer or network, from taking control of users' machines to discreetly sending out confidential information. Ransomware is a specific type of malware that blocks access to digital files and demands a payment to release them. Hospitals, school districts, state and local governments, law enforcement agencies, businesses, and even individuals can be targeted by ransomware. One 2017 study found ransomware payments over a two-year period totalled more than $16 million. Even if a victim is perfectly prepared with full offline data backups, recovery from a sophisticated ransomware attack typically costs far more than the demanded ransom. However according to a 2016 study by Kaspersky Lab, roughly one in five ransomware victims who pay their attackers are still not able to retrieve their data.

Cyber spying or espionage is the act of illicitly obtaining intellectual property, government secrets, or other confidential digital information, and often is associated with attacks carried out by professional agents working on behalf of a foreign government or corporation. According to cybersecurity firm

Symantec, in 2016 "…the world of cyber espionage experienced a notable shift towards more overt activity, designed to destabilize and disrupt targeted organizations and countries."

Major data breaches - when hackers gain access to large amounts of personal, sensitive, or confidential information - have become increasingly common. The Symantec report says more than seven billion identities have been exposed in data breaches over the last eight years. In addition to networked systems, data breaches can occur due to the mishandling of external drives, as has been the case with losses of some state employee data.

Cybercrime can refer to any of the above incidents when motivated primarily by financial gain or other criminal intent. The most severe type of attack is cyber terrorism, which aims to disrupt or damage systems in order to cause fear, injury, and loss to advance a political agenda.

The adopted City of Petaluma budget for FY2019 notes an increase in spending on cyber security measures, specifically to combat malware and ransomware.

Location

Cyber disruption events can occur or impact virtually any location where computing devices are used. Incidents may involve a single location or multiple geographic areas. A disruption can have far-reaching effects beyond the location of the targeted system; disruptions that occur far outside the state can still impact people, businesses, and institutions within the City of Petaluma.

Extent (Magnitude/Severity)

Critical –The extent of a cyber disruption event is variable depending on the nature of the event. A disruption affecting a small, isolated system could impact only a few functions and processes. Disruptions of large, integrated systems could impact many functions and processes, as well as many individuals that rely on those systems.

There is no universally accepted scale to quantify the severity of cyber-attacks. The strength of a DDoS attack is sometimes explained in terms of a data transmission rate. One of the largest DDoS disruptions ever, which brought down some of the internet's most popular sites on October 21, 2016, peaked at 1.2 terabytes per second.

Data breaches are often described in terms of the number of records or identities exposed.

Previous Occurrences

The City of Petaluma IT Department noted there are potential ransomware attacks on the City's IT system on a daily basis. Specific cyber incidents were not discussed.

Symantec reports there were a total of 1,209 data breaches worldwide in 2016, 15 of which involved the theft of more than 10 million identities. While the number of breaches has remained relatively steady, the average number of identities stolen has increased to almost one million per incident. The report also found that one in every 131 emails contains malware, and the company's software blocked an average of 229,000 web attacks every day.

The Privacy Rights Clearinghouse, a non-profit organization based in San Diego, maintains a timeline of 2,631 data breaches resulting from computer hacking incidents in the United States from 2005-2019. The database lists 522 data breaches in California during this timeframe, including attacks on private sector facilities, government agencies, schools and media entities. While none of those security breaches were specifically targeted at systems in the City of Petaluma, some of them included information on individuals who live in the community. Similarly, Petaluma residents were almost certainly affected by national and international data breaches.

While Petaluma itself has not been the victim of major cyber or ransomware attacks, examples from across the country show both the prevalence of cyber-attacks and potential impacts.

The City of Atlanta was also hit by a major ransomware attack in 2018, recovery from which cost a reported $2.6M, significantly more than the $52,000 ransom demand. A similar attack against the City of Baltimore in 2019 affected the city government's email, voicemail, property tax portal, water bill and parking ticket payment systems, and delayed more than 1,000 pending home sales.

Probability of Future Occurrences

Occasional – Cyber-attacks occur daily, but most have negligible impacts at the city level and are blocked by the city's existing cyber security systems. The possibility of a larger disruption affecting the City exists at all times, but it is difficult to quantify the exact probability due to such highly variable factors as the type of attack and intent of the attacker. Minor attacks against business and government systems have become commonplace occurrences but are usually stopped with minimal impact. Similar data breaches impacting the information of residents are almost certain to happen in coming years. Major attacks or breaches specifically targeting systems in the county are less likely but cannot be ruled out.

Climate Change Considerations

Climate change is not expected to have any direct impacts on the vulnerability of cyber systems to an attack.

Vulnerability Assessment

Property

While specific types of cyber-attacks can cause physical damage to systems and equipment, property damage from cyber-attacks is typically limited to computer systems.

People

Cyber-attacks can have a significant cumulative economic impact. Symantec reports that in the last three years, businesses have lost $3 billion due to spear-phishing email scams alone. A major cyber-attack has the potential to undermine public confidence and build doubt in their government's ability to protect them from harm.

Injuries or fatalities from cyber-attacks would generally be a cascading result of specific system failure (i.e. injuries or fatalities caused by secondary incidents due to a compromised traffic light system) or a compromised electrical grid. Refer to the Vulnerability Assessment under Section 4.3.10 High Winds for details on the number of Medicare beneficiaries that are electricity dependent in the City of Petaluma.

Economy

Economic impacts are entirely dependent on the types of successful attacks that occur, and what the specific attack's goals were. In an electronic-based commerce society, any disruption to daily activities can have disastrous impacts to the economy. Economic impacts from cyber threats around the world include disruptions in commerce, ransom demands, and restoration costs. McAfee notes that cyber threats cost the global economy as much as $600 billion in 2017.

Critical Facilities and Infrastructure

Critical facilities, infrastructure and systems can make inviting targets for cyber threats, with the potential to cause widespread and damaging impacts. Ultimate impacts of a cyber-attack depend on both the method and success of the attack, as well as the type of critical asset affected. Most attacks affect only data and computer systems. Sabotage of utilities and infrastructure from a major cyber terrorist attacks could potentially result in system failures that damage property on a scale equal with natural disasters. Facilities and infrastructure may become unusable as a result of a cyber-attack.

Future Development

Traditionally, cyber threats should not have any bearing on future development. The prevalence and evolution of cyber threats does require continued City efforts to upgrade security systems to meet evolving threats.

Risk Summary

- City systems are attacked multiple times a day; most attacks thwarted by existing security systems
- The City and surrounding county are proactive in cybersecurity and cyber prevention measures.
- Evolving cyber threats require a matching evolution in protection and deterrence techniques to match the threat.
- While the City of Petaluma hasn't suffered a specific, large-scale cyber infiltration, examples from around the world show how devastating these types of attacks can be on communities.
- Successful cyber incidents can have a variety of impacts, based on the targeted system(s), attack type, attack goals, and ultimate success of the attack.
- Overall the significance associated with cyber threats is **Medium.**

4.5 Hazard Summary

Table 4-43 summarizes the results of the hazard identification and hazard profiles for the Planning Area based on the hazard identification data and input from the HMPC. For each hazard profiled in Section 4.2 on natural hazards and in Section 4.3 on human-caused hazards, this table includes the likelihood of future occurrence and whether the hazard is considered a priority hazard for the Planning Area.

Table 4-43: Hazard Identification and Determination of Priority Hazard

Hazard	Priority Hazard
Natural Hazard	
Drought	Yes
Earthquake	Yes
Fire: Urban and Wildfire	Yes
Flood: 100-, 200-, and 500-Year Events	Yes
Sea Level Rise (addressed in Flood Hazards)	No
Severe Weather: Extreme Heat	No
Severe Weather: Heavy Rain/Thunderstorm/ Hail/Lightning/Dense Fog	Yes
Severe Weather: Wind	No
Human-Caused Hazards	
Hazardous Materials	Yes
Cyber Threats	Yes

Source: HMPC 2018

The HMPC determined that drought, earthquake, flooding, heavy rain/thunderstorm/hail/lightning, and wildfire are the most significant hazards in the Planning Area. These hazards have also been categorized as priority hazards by the HMPC.