City of Livermore

GENERAL PLAN UPDATE

CLIMATE CHANGE VULNERABILITY ANALYSIS

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PREPARED FOR:

City of Livermore
1052 S. Livermore Avenue
Livermore, CA 94550

PREPARED BY:

PlaceWorks
2040 Bancroft Way, Suite 400
Berkeley, CA 94704

Table of Contents

Tables

Figures

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Climate Change Vulnerability Analysis

This report provides a summary of the Climate Change Vulnerability Analysis (Vulnerability Analysis or CCVA) prepared for the City of Livermore. Rincon Consultants prepared a Vulnerability Analysis for the City in 2020 as part of the City's Climate Action Plan Update. The 2020 Vulnerability Analysis was prepared consistent with the first version of the State's Adaptation Planning Guide released in 2012. In 2022, as part of the City's General Plan Update, PlaceWorks reviewed the 2020 Vulnerability Analysis; conducted scoring of the community's climate impacts, adaptive capacity, and vulnerability for inclusion in the Vulnerability Analysis; and updated this Vulnerability Analysis report. The 2022 revisions to the Vulnerability Analysis ensure consistency with the update of the Adaptation Planning Guide released in July 2020 and the State's requirements for Safety Elements.

The Vulnerability Analysis supports the City's ability to prepare for, respond to, withstand, and recover from disruptions created or caused by climate change. This summary report discusses the regulatory framework and method for preparing a vulnerability assessment, the climate change hazards affecting the resilience of Livermore, specific populations and assets included in the assessment, and a summary of the vulnerability assessment results. The Vulnerability Analysis provides findings that will help to inform the update and integration of climate adaptation and resilience policies into the General Plan by identifying a set of priority vulnerabilities in the City of Livermore. These policies and programs are discussed in the Opportunities section of this report. This Vulnerability Analysis summary is supported by the Existing Conditions Report prepared for the General Plan Update, including the Climate Change, Hazards, and Wildfire chapters.

1.1 REGULATORY FRAMEWORK

STATE REGULATION AND GUIDANCE

The City prepared the Vulnerability Analysis and this summary in conformance with State of California requirements to assess climate change vulnerability and address climate change adaptation and resilience as part of the General Plan Update (California Government Code Section 65302(g)). In 2015, the state adopted Senate Bill (SB) 379, amending Section 65302(g) of the California Government Code to require the Safety Element of the General Plan to include more information about wildfire hazards, flooding risks, and short-term and long-term threats posed by climate change. SB 379 requires local governments to conduct vulnerability assessments as part of their long-range planning efforts and to prepare resilience and adaptation policies that will protect against harm caused by climate change. This along with the update to the Safety Element, will help the City of Livermore meet the state's requirements.

The State of California prepared a guidance document, the *California Adaptation Planning Guide* (APG) to assist communities in addressing climate adaptation and resilience and complying with Section 65302(g) of the California Government Code, along with the guidance in the Office of Planning and Research's *General Plan Guidelines*. The APG presents a step-by-step process for gathering the best available climate change science, completing a climate change vulnerability assessment, developing adaptation strategies,

and integrating those strategies into general plans and other policy documents. The City's Vulnerability Assessment is consistent with the guidance and recommended methods provided in the APG.

LIVERMORE 2003-2025 GENERAL PLAN

Livermore's 2003-2025 General Plan is the legal document that serves as the city's "blueprint" or "constitution" for land use and development. State law requires every city and county in California to adopt and maintain a General Plan that is comprehensive and long-term. A General Plan must outline proposals for the physical development of the county or city and any land outside the jurisdiction's boundaries, which, in the jurisdiction's judgment, bears relation to its planning.[1] The General Plan must address the range of topics specified in state law, and cities may add additional topics that are relevant to their community.

The 2003-2025 General Plan includes the following elements:

1. Land Use. Establishes a comprehensive set of explicit goals, policies, and implementation actions to guide the future use and development of land in Livermore and the unincorporated area within its adjacent SOI.
2. Community Character. Provides information on visual and urban design resources, natural setting, and cultural resources and guidance to identify, protect, and enhance these features.
3. Circulation. Describes existing and proposed roadways and other means of transportation, such as public transit, bikeways, pedestrian routes, and parking facilities. Analyzes traffic conditions and needed improvements so that existing and projected transportation needs may be adequately met.
4. Infrastructure and Public Services. Identifies goals and policies to maintain adequate service levels for water facilities and service, wastewater collection and treatment, water recycling, and stormwater collection facilities as well as public services, such as schools, parks, and recreation.
5. Open Space and Conservation. Sets forth the City's goals and policies regarding the preservation of open space and the conservation, development, and use of natural resources.
6. Noise. Addresses noise to ensure land use compatibility in the community and analyzes and quantifies current and projected noise levels from a variety of sources. Includes guidance to address current and foreseeable noise problems.
7. Public Safety. Establishes goals and policies to protect the community from risks associated with the effects of seismic hazards, other geologic hazards, flooding, and wildland and urban fires.
8. Economic Development. Encourages the development of desired economic activities throughout the city, as well as ensures the fiscal vitality of the community. This element facilitates and maintains a balanced mix of economic activity and encourages the development of particular economic sectors in Livermore.
9. Climate Change. Establishes the policy direction to reduce greenhouse gas emissions and improve the community's resiliency against climate change.

[1] California Government Code Section 65300 et seq.

THE GENERAL PLAN UPDATE

The General Plan is the City of Livermore's fundamental land use and development policy document, which shows how the City will grow and conserve its resources. The purpose of the General Plan is to guide decisions about development and conservation in the city through 2045. This Vulnerability Analysis is part of the technical studies supporting the Livermore General Plan Update.

The General Plan Update will take place over a multi-year period by City staff and the consultant team, with regular and extensive input from the community, a General Plan Advisory Committee, the Planning Commission, and the City Council. The process will also include robust community outreach to ensure that the updated General Plan is a community-driven process. The General Plan Update process will also include preparation of an Environmental Impact Report (EIR), in compliance with the California Environmental Quality Act (CEQA), that investigates the possible impacts of this policy document on the physical environment.

1.2 INTRODUCTION

OBJECTIVES

The effects of climate change such as increased wildfire intensity, rising temperatures and reduced water resources are becoming increasingly present therefore Livermore's Climate Action Plan must be updated to reflect these impacts and adapt the City's mitigation practices. This Climate Action Plan will include measures to reduce Greenhouse Gas (GHG) emissions to reduce future climate change impacts while also addressing the existing events Livermore experiences related to climate change. To develop effective adaptation measures we must first understand the local impacts related to climate change. This vulnerability assessment is intended to help develop an understanding of the primary impacts of climate change on the community of Livermore and was completed to begin to evaluate the degree to which physical, socioeconomic, and natural factors are susceptible to, or unable to accommodate, the effects of climate change. Consistent with the California Adaptation Planning Guide [1] the assessment is comprised of the following five vulnerability components:

1. Exposure – the nature and degree to which the community experiences a stress or hazard.
2. Sensitivity – the aspects of the community (i.e., people, structures, and functions) most affected by the identified exposures.
3. Potential Impacts – the nature and degree to which the community is affected by a given stressor, change, or disturbance.
4. Adaptive Capacity – the ability to cope with extreme events, to make changes, or to transform to a greater extent, including the ability to moderate potential damages and to take advantage of opportunities; and
5. Risk and Onset – the likeliness and expected timing of impacts.

Together these components help contribute to an understanding of the overall vulnerability of a community and the specific aspects within that community that are most vulnerable to climate change.

Climate change will have the greatest impact on those people, structures, and functions that have the greatest exposure and sensitivity to climate change impacts, as well as the lowest adaptive capacity.

METHODOLOGY

For this Vulnerability Analysis the time periods 1961-1990 (representing the historical baseline), 2035-2064 (Mid-Century), and 2070-2100 (End-Century) were examined. This report was completed using infrastructure data provided by the City, including the location of trails, public facilities, and streets, and Cal-Adapt climate projection data. Cal-Adapt is an interactive, online platform developed by the University of California Berkeley to synthesize climate change projections and climate impact research for California's scientists and planners. Cal-Adapt is consistent with State guidance to use the "best available science" for assessing climate change vulnerability at the local level. This analysis uses Cal-Adapt to study potential future changes in average and extreme temperatures, precipitation, drought, wildfire, and storms under two greenhouse gas (GHG) emissions scenarios: Representative Concentration Pathway (RCP) 4.5 and RCP 8.5. RCP 4.5 describes a scenario in which emissions peak around 2040, decline over the next 30 years and then stabilize by 2100 while RCP 8.5 is the scenario in which emissions continue to rise through the middle of the century before leveling off around 2100. The climate projections used in this report are from four models selected by California's Climate Action Team Research Working Group and the California Department of Water Resources as priority models for research in California. These models include:

- A *warm/dry* simulation (HadGEM2-ES)
- A *cooler/wetter* simulation (CNRM-CM5)
- An *average* simulation (CanESM2)
- The model that presents a simulation most unlike these three, for full representation of possible forecasts (MIROC5) [2]

The average of the model projections is used in this report. Each vulnerability component is analyzed with respect to Livermore in the proceeding sections of this memo.

COMMUNITY PROFILE

Livermore is situated in the Livermore Valley, in eastern Alameda County. Livermore is in the easternmost portion of Alameda County and is part of the nine-county Bay Area region. The Livermore Valley is edged to the north, south, and east by rolling hills and to the west by the Cities of Dublin and Pleasanton. Livermore is bisected by Interstate 580 (I-580), which runs east to west through Alameda County. Livermore consists of a total area of approximately 27 square miles.

The City of Livermore was founded in 1869 by William Mendenhall. In the years leading up to incorporation in 1876, the Livermore Valley was used mainly for grazing land for cattle and sheep. Livermore's development as a city was based on the Western Pacific Railroad and the commerce the railroad brought with it, as well as cattle ranches and vineyards. Since its incorporation, Livermore has grown from its agricultural roots into a thriving suburban community. While retaining much of its agricultural heritage, Livermore now provides a variety of housing and employment opportunities.

The city's most significant industry is "Professional Scientific and Technical Services," but Livermore's economy also supports thousands of jobs in construction, manufacturing, and trade, which together account for over 40 percent of jobs in the city. Livermore hosts a diverse economy that includes highly skilled jobs such as those found at the labs and local professional services firms, but also is home to a wide variety of wholesale and retail trade, construction, and manufacturing jobs. In addition, a concentration of food service and hotel operations in the city supports significant employment in the hospitality industry. Major employers include Lawrence Livermore and Sandia National Laboratories, Valley Care Health Systems, US Foods and several local public agencies, including the City of Livermore, Livermore Area Recreation and Park District and the Livermore Valley Joint Unified School District.

Employment in Livermore has grown by nearly 30 percent since a low seen in 2010, with new jobs in Livermore attributable largely to new retail stores in the city, growth in manufacturing operations, and increased regional demand for all types of construction. Other notable growth sectors include hospitality and the arts. Furthermore, along with the greater Bay Area, technology jobs in Livermore have increased, with "Information" sector jobs exhibiting the greatest percentage growth of any industry between 2002 and 2018. The city's employment backbone in "professional, scientific, and technical services" remains by far the largest single employment sector, but has been less dynamic, adding just over 100 jobs during the same period.

The City of Livermore has added over 9,000 residents in the past decade, an increase of 11 percent, while the Tri-Valley overall grew by about 17 percent during the same time period. With over 91,000 residents, Livermore is the most populous city in the Tri-Valley region. While the 1990s was a period of robust growth in which Livermore added nearly 15,600 residents, population growth has slowed in recent years. Since 2000, other Tri-Valley cities have grown more rapidly than Livermore. In the most recent decade, the population of Livermore grew by about 13 percent, accounting for roughly 20 percent of total population growth in the Tri-Valley. Meanwhile, the rate of population growth in Livermore continues to exceed countywide growth. Across the Tri-Valley and county more broadly, the 2010s started out with robust growth, but population increases have subsided somewhat over the past five years.

Livermore's climate is typical for inland Bay Area valleys with warm to hot, dry summers and mild to cool, wet winters. Summer daytime temperatures range from 75 to 85°F, sometimes reaching 100°F and higher. Summer nighttime temperatures average in the 50 to 60°F range. Winter daytimes temperatures range 50 to 60°F with nighttime temperatures averaging in the 35 to 40°F range. Average annual rainfall is 14.6 inches occurring mainly from September to May.

Several creeks and arroyos traverse the city including Altamont Creek, Arroyo Seco, Arroyo Mocho, Arroyo Las Positas, Collier Canyon Creek, and Arroyo del Valle. Livermore is bisected by Interstate 580 which runs east-west through Alameda County. The Union Pacific Railroad, which also serves the ACE train commuter rail service, roughly parallels the freeway to the south. The Livermore Municipal Airport, located on the western edge of the city, is a general aviation airport which primarily serves the Tri-Valley Area.

1.3 VULNERABILITY COMPONENTS

VULNERABILITY COMPONENT 1 - EXPOSURE

Exposure is the nature and degree to which the community experiences a stress or hazard. Climate change is a global phenomenon that has the potential to impact local health, natural resources, agriculture, infrastructure, emergency response, tourism, and many other facets of society. The direct changes projected for Livermore include increases in temperature, and potential changes in precipitation patterns. Secondary impacts occur as a result of primary impacts, as shown in Table 1. Projected changes to climate are dependent on location. According to climate change projections provided by Cal-Adapt, climate change could lead to increasing temperatures and temperature extremes, and changes in precipitation in Livermore.[3] These conditions could lead to an increased exposure to drought, wildfires, and flooding in the region.

Table 1 Primary and Secondary Climate Change Impacts in Livermore

Primary Impact	Associated Secondary Impacts
Increased Temperature	Heat waves, wildfire, drought, reduced air quality
Changes in Precipitation Patterns	Flooding, intense rainstorms, drought, landslides
Wildfire	Reduced air quality, landslides

Source: Modified from CEMA & CNRA 2012[4]

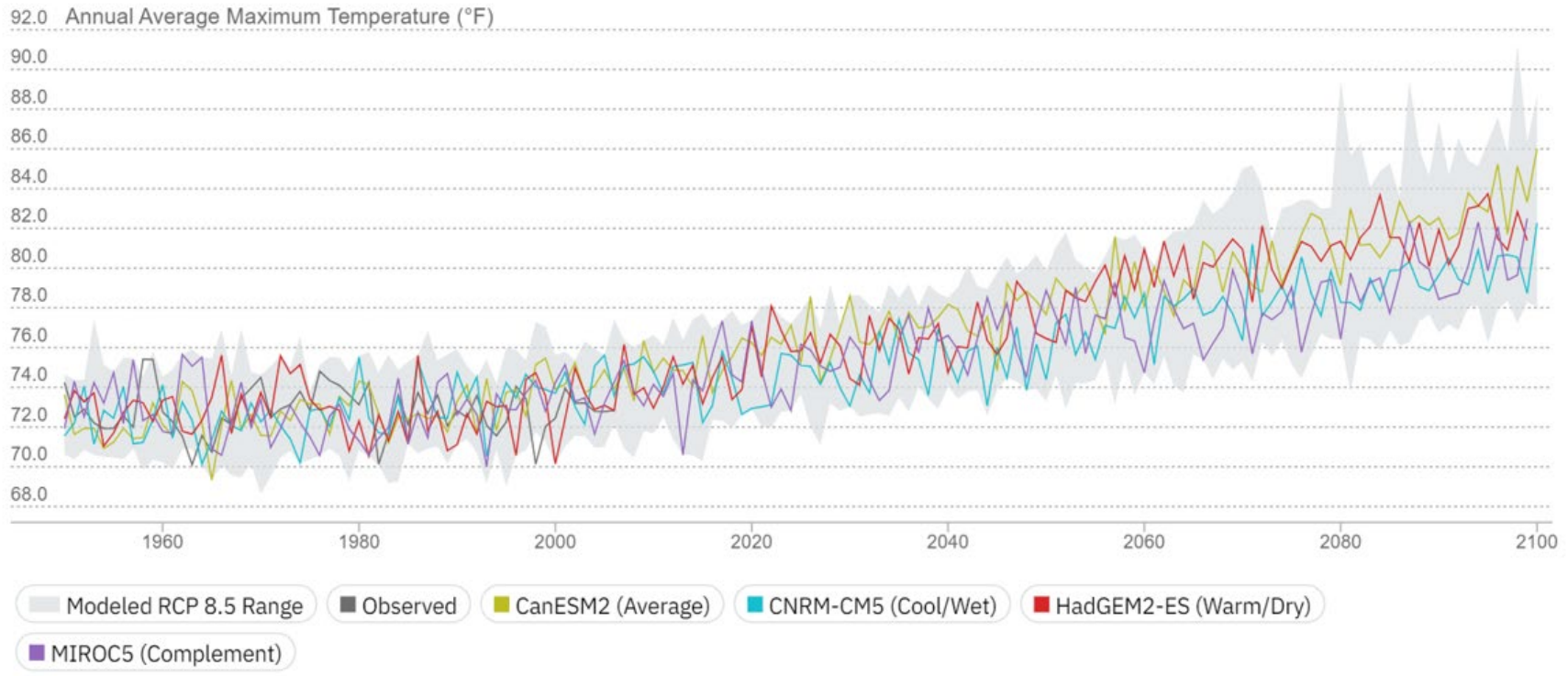
1.3.1.1 TEMPERATURE

Since 1901, average temperatures across the country have increased with eight of the top ten warmest years on record having occurred over the past 30 years[5] Average trends are increasing at both the local scale and the global scale.

Figure 1 below shows observed and projected annual average maximum temperature in Livermore (Cal-Adapt) Below is a summary of key observations from Figure 1.

- Projected temperature trends in Livermore display consistent increases over time. Compared to the 1961-1990 average temperature of 72.6°F, annual average maximum temperatures in Livermore are expected to rise between 76.3°F and 77.3°F by the middle of the century and to between 77.6°F and 80.4°F by the end of the century, depending on the GHG emissions scenario (Cal-Adapt.
- Annual average minimum temperatures are expected to rise from a historical average of 45.9°F to between 49.3°F and 50.2°F by the middle of the century and between 50.5°F and 53.8°F by the end of the century. Increasing annual average minimum temperatures trends also indicate less cooling off at night.

Figure 1 Historical and Projected Annual Average Maximum Temperature in Livermore [vi]



Source: Cal-Adapt. Data: LOCA Downscaled CMIP5 Climate Projections (Scripps Institution of Oceanography), Gridded Observed Meteorological Data (University of Colorado Boulder), LOCA Derived Products (Geospatial Innovation Facility).

Table 2 depicts observed and projected temperature changes in Livermore for both RCP 4.5, the "stabilizing" scenario[5] [vii], and RCP 8.5, the "high emissions" scenario[6] [viii]. Below is a summary of key observations from **Table 2**.

- **Annual number of heat waves,** defined as four or more days over 102.2°F, is projected to increase from 0 to 4 heat waves by the end of the century, based on RCP 8.5 (Cal-Adapt).
- **Annual number of extreme heat days,** defined as temperatures greater than 102.2°F, is projected to increase from 4 in 1990 to about 29 by the end of the century, based on RCP 8.5 (Cal-Adapt).
- **Warm nights,** described as nights when daily minimum temperature is above the extreme heat threshold of 62.4°F, are expected to increase substantially from 5 in 1990 to about 80 by 2100 based on RCP 8.5 (Cal-Adapt).
- **Longer heat waves** could occur due to the combination of temperature changes. Between 1961 and 1990, the longest stretch of consecutive extreme heat days per year in Livermore was 2.2 days, by the end of the century the average heat wave is projected to last approximately 8 days under RCP 8.5 (Cal-Adapt).

Table 2 Temperature Changes

Effect	Baseline (1961-1990) (Observed)	Mid-Century (2035-2064) (RCP 4.5 | RCP 8.5)	End-Century (2070-2090) (RCP 4.5 | RCP 8.5)
Annual average maximum temperature	72.6° F	76.3° F | 77.3° F	77.6° F | 80.4° F
Annual average minimum temperature	45.9° F	49.3° F | 50.2° F	50.5° F | 53.8° F
Average extreme heat days per year[1]	4	13 | 18	18 | 29
Average warm nights per year[2]	5	22 | 32	35 | 80
Average heat waves per year[3]	0	1 | 2	2 | 4
Max duration of heat wave (days)[4]	2	5 | 6	6 | 8

[1] Number of days in a year when daily maximum temperature is greater than heat threshold of 102.2° F.

[2] Number of nights in a year when daily minimum temperature is above extreme heat threshold of 62.4° F.

[3] Number of 4-day heat waves (daily maximum temperatures above extreme heat threshold of 102.2° F) by year.

[4] Longest stretch of consecutive extreme heat (> 102.2° F) days by year. Source: Cal-Adapt

1.3.1.3 PRECIPITATION

Total annual precipitation in the United States and globally has increased since 1901[ix] . However, shifts in weather patterns have led to substantial decreases in precipitation in certain locations, such as the Southwest of the United States[x] .

The Cal-Adapt projections show little change in total annual precipitation in Livermore with no clear or consistent trend during the next century, as illustrated in Figure 2. However, even small changes in precipitation can lead to significant impacts such as altered water availability throughout the year, decreased agricultural output in the region, and altered seasonal patterns which could cause increased droughts and/or flooding. Below is a summary of key observations from Table 3.

- Annual average precipitation, is projected to increase from a historic average to 16.2 inches per year to between 17.1 and 18.9 inches by the end of the century, based on both RCP 4.5 and RCP 8.5 (Cal-Adapt.
- Extreme precipitation events, defined as the number of days in a water year (October-September of the following year) with 2-day rainfall totals above extreme threshold of 0.67 inches, is projected to increase from 4 per year between 1961 and 1990 to about 5 mid-century and between 5 and 6 by the end of the century based on both RCP 4.5 and RCP 8.5 (Cal-Adapt).
- Max duration of consecutive extreme precipitation events, defined as the longest stretch of consecutive days in a water year (October-September) with 2-day rainfall totals above extreme threshold of 0.67 inches, is projected to remain relatively constant at 2 through the end of the century, based on both RCP 4.5 and RCP 8.5 (Cal-Adapt).

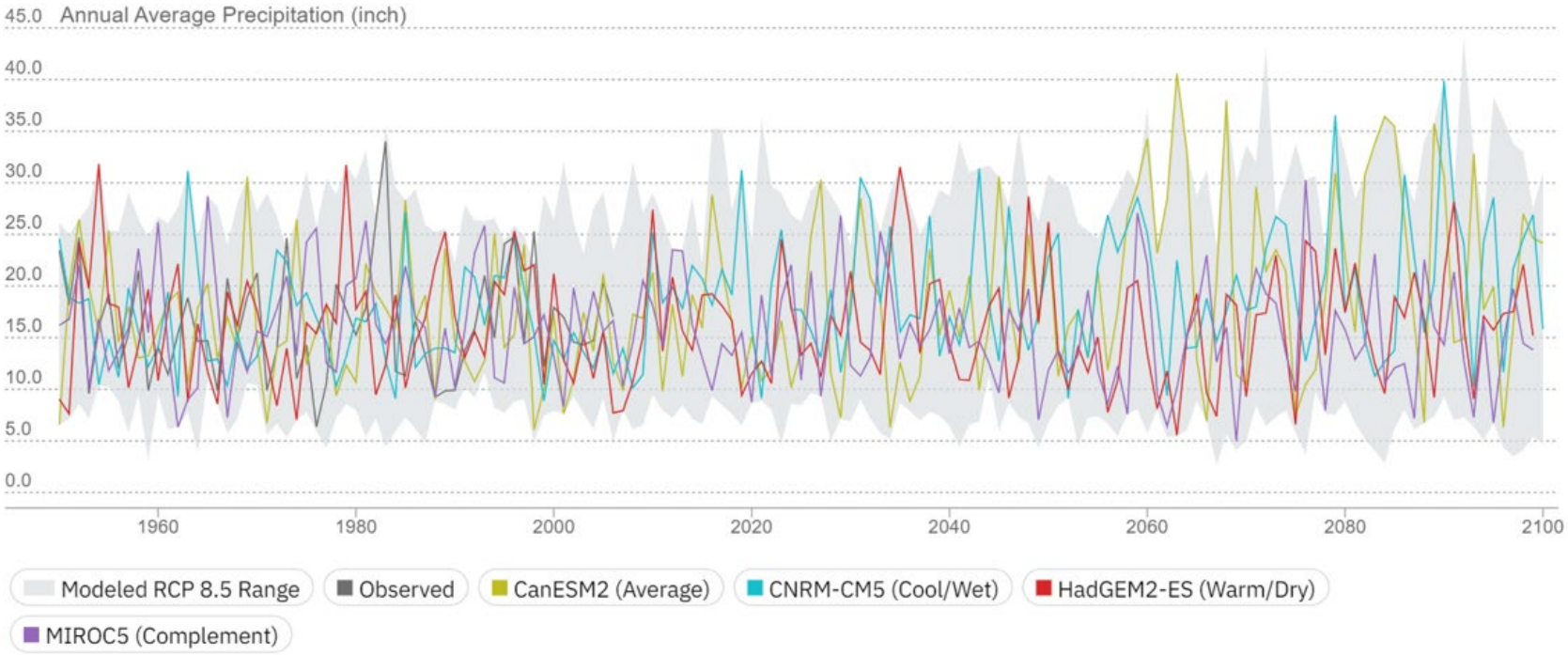
Table 3 Precipitation Changes

Effect	Baseline (1961-1990) (Observed)	Mid-Century (2035-2064) (RCP 4.5 | RCP 8.5)	End-Century (2070-2090) (RCP 4.5 | RCP 8.5)
Annual average precipitation (inches)	16.2	17.4 | 17.3	17.1 | 18.9
Extreme precipitation events by water year[1]	4	5 | 5	5 | 6
Max duration of consecutive extreme precipitation events by year[2]	2	2 | 2	2 | 2

[1] Number of days in a water year (Oct-Sep) with 2-day rainfall totals above extreme threshold of 0.67 inches

[2] Longest stretch of consecutive days in a water year (Oct-Sep) with 2-day rainfall totals above extreme threshold of 0.67 inches
Source: Cal-Adapt

Figure 2 Historical and Projected Annual Average Precipitation in Livermore [xi]



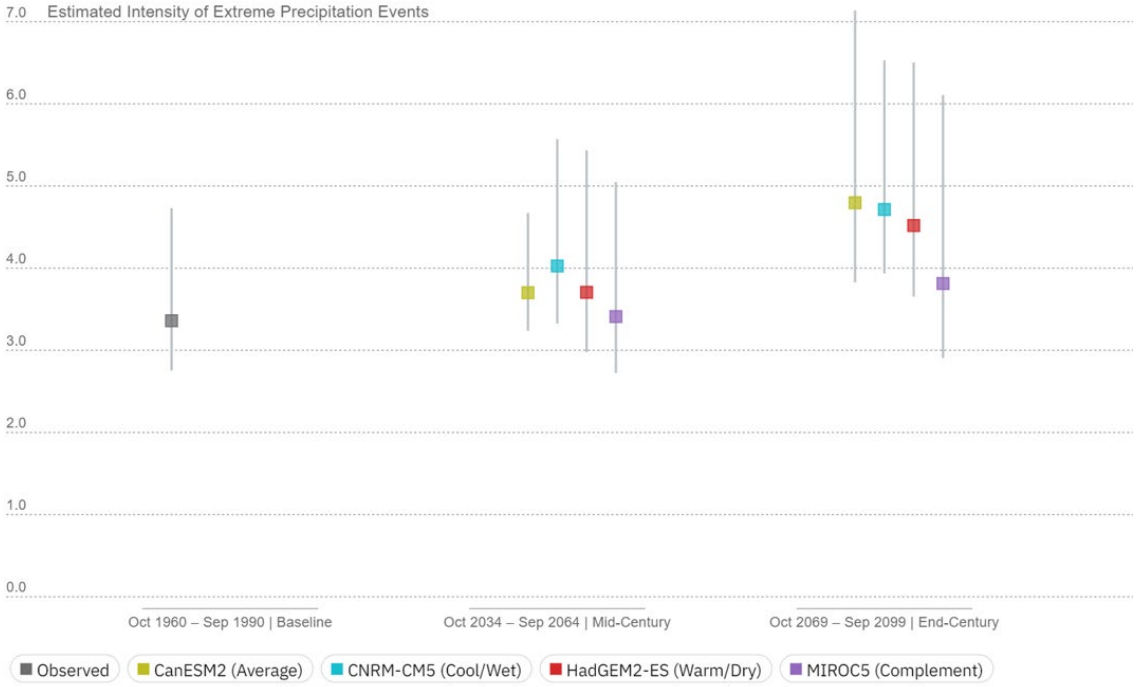
Source: Cal-Adapt. Data: LOCA Downscaled CMIP5 Climate Projections (Scripps Institution of Oceanography), Gridded Observed Meteorological Data (University of Colorado Boulder), LOCA Derived Products (Geospatial Innovation Facility).

Precipitation Extremes

A warming climate is likely to influence the frequency and intensity of precipitation events. Heavy precipitation events have been on the rise in the United States since the 1980s. Across the country, nine of the top ten years for extreme one-day precipitation events have occurred since 1990 with the occurrence of abnormally high annual precipitation totals also increasing[12] .

Both increased temperatures and altered precipitation patterns can lead to altered seasons and intense rainstorms in Livermore. As depicted in **Figure 3**, there is a high degree of variability in these extreme precipitation event projections, with some models projecting little to no change while others project potentially increased intensity[13] These projections further vary depending on the return period[8 14] selected. Based on the 20-year return period depicted in Figure 3, the estimated intensity of extreme precipitation events (return level) may increase slightly by the end of the century. The Average (CanESM2) model, for example, is projecting an increase to 3.65 inches of precipitation compared to 3.29 historically (1961 – 1990), based on RCP 8.5[15] Despite this projected increase, it is important to consider the confidence intervals provided, which describe 95% confidence that the true mean of precipitation extremes will fall within the given range (grey bars). Given that the confidence intervals for all projections overlap with the confidence interval for the historical data, it is not clear whether the intensity of storms will increase or decrease in Livermore. However, increasing intensity of rainstorms could result in more flooding, which could impact human health and safety in Livermore and should be considered as part of planning efforts.

Figure 3 Changes in Intensity of Extreme Precipitation Events in Livermore [16]



Source: Cal-Adapt. Data: LOCA Downscaled CMIP5 Climate Projections (Scripps Institution of Oceanography), Gridded Observed Meteorological Data (University of Colorado

1.3.1.4 WILDFIRE

Wildfire frequency and intensity are determined by climate variability, local topography, land cover and human activity. Climate change has the potential to affect multiple elements of the wildfire system including fire behavior, ignitions, fire management, and availability of vegetation fuels. Hot dry spells create the highest fire risk and increased temperatures may intensify wildfire danger by warming and drying out vegetation.

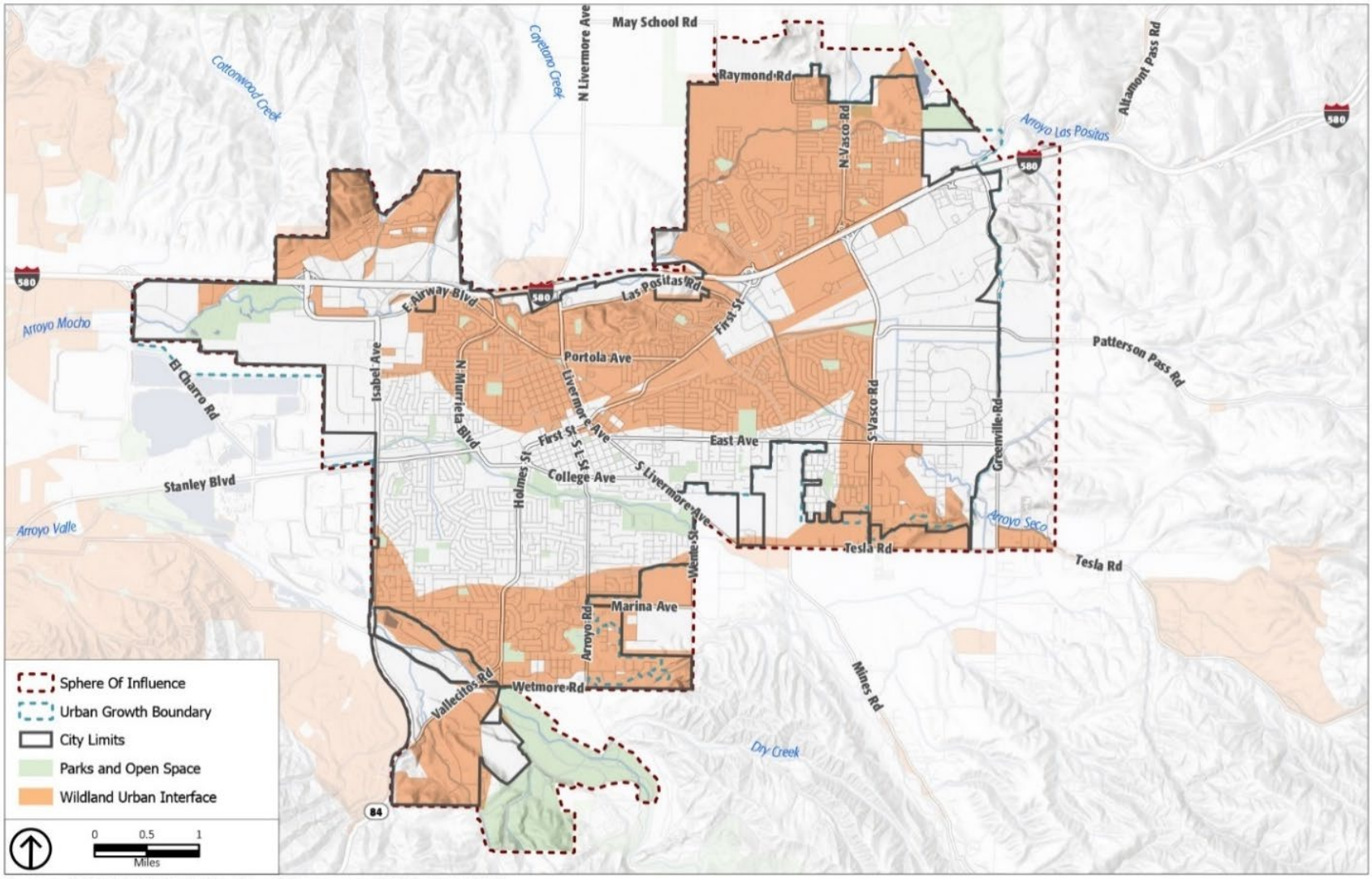
The California Department of Forestry and Fire Protection (CAL FIRE) has determined that there are no Very High Fire Hazard Severity Zones in Livermore[17]. Though there are no Very High Fire Hazard Severity Zones in Livermore, there are Moderate and High Fire Hazard Severity Zones to the north, east, and south of Livermore. There is moderate wildfire threat in the entire city, and some very high fire threats in the north and south of the city. Government Code §51181 requires CAL FIRE to periodically reassess and update the Very High Fire Hazard Severity Zones as needed. Due to amount and extent of the wildfires recently, the fire hazard severity zones are currently being reassessed throughout the State. Livermore contains significant area where natural ecosystems, such as woodlands, scrub, and human development closely intermingle, commonly referred to as the WUI. A WUI is an area in which wildlands and communities are sufficiently close to each other to present a credible risk of fire spreading from one to the other.[ii] Development within the WUI not only increases the probability of wildfire ignition but also increases the probability that a wildfire will result in significant damage to property and loss of life. **Figure 4** shows the WUI in the City of Livermore.

Not only do wildfires pose a threat to life and property in the communities in which they burn, their smoke can threaten the health of communities up to thousands of miles beyond the areas in which they burn [18]. Wildfire smoke is comprised of air pollutants including particulate matter, known to be a public health risk [19]. The effects of exposure to these pollutants range from eye and respiratory tract irritation to reduced lung function, pulmonary inflammation, bronchitis, exacerbation of asthma, other lung diseases, and cardiovascular disease, and premature death[20]. The increasing number and extent of wildfires in the Western United States may pose a substantial risk to public health in Livermore.

Cal-Adapt fire hazard maps project a decrease in acres burned by the end of the century (**Figure 5**). Average annual acres burned is projected to decrease from a historical average of 340 between 1961 and 1990 to approximately 252 by the end of the century. Research has shown that there is great spatial variability in wildfire risk based on climate variability and trends, and in some regions, vegetation may be reduced by drought conditions and thus reduce fuel available to burn[21]. It is unclear whether this is the scenario applicable to Livermore, so despite the projected decline in wildfire risk for the Livermore area, it is recognized that wildfire is a serious hazard to public health and safety that may increase with climate change in other parts of the state.[22]

[ii] Diablo Fire Safe Council. 2015. *Community Wildfire Protection Plan Update Alameda County*. http://www.diablofiresafe.org/pdf/2015_Draft_AlCo_CWPP_Update.pdf, accessed on September 23, 2021.

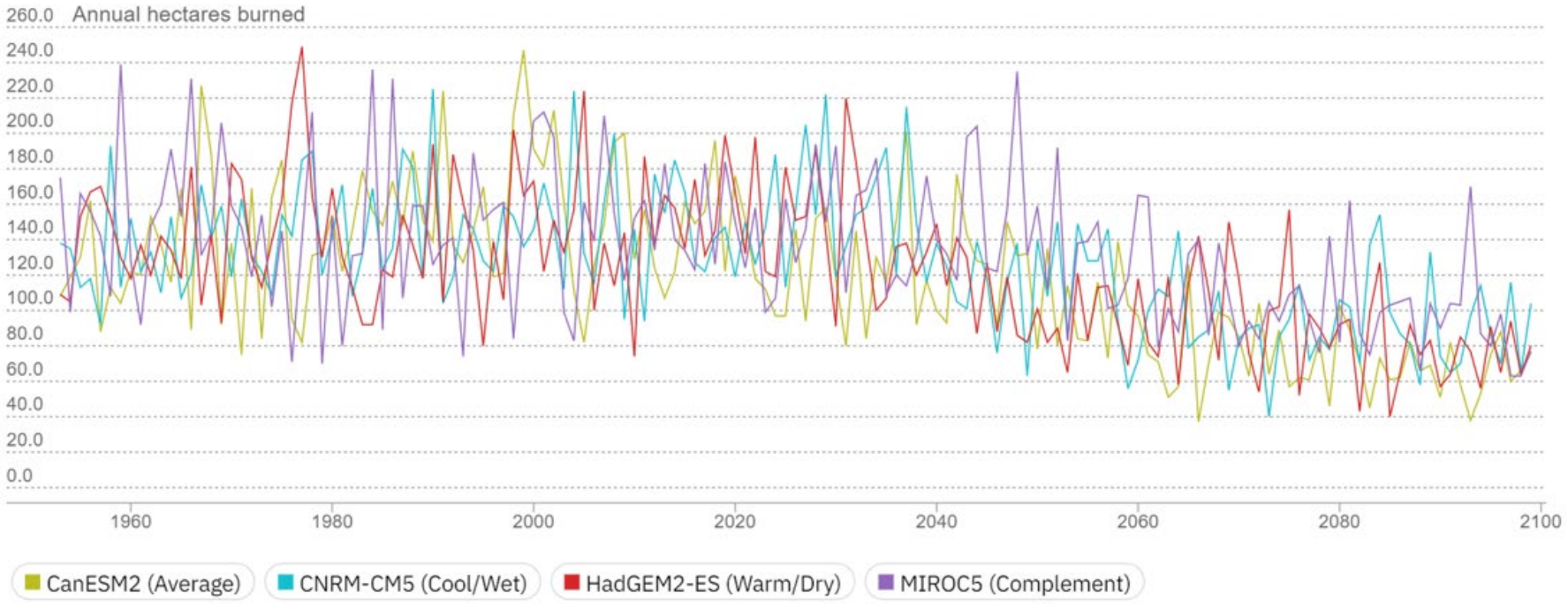
Figure 4 Wildland-Urban Interface Area



Source: CalFIRE FRAP, 2021; City of Livermore, 2021; Esri, 2021.

CLIMATE CHANGE VULNERABILITY ANALYSIS

Figure 5 Annual Average of Area Burned in Livermore [23]



Source: Cal-Adapt. Data: Wildfire Simulations for California's Fourth Climate Change Assessment (University of California Merced), Wildfire Simulations Derived Products (Geospatial Innovation Facility).

VULNERABILITY COMPONENT 2 – SENSITIVITY

Sensitivity describes the aspects of the community (i.e., people, structures, and functions) most affected by the identified exposures. As described in the exposure section above, Livermore may experience a variety of impacts from climate change, including rising temperatures and variable precipitation, which could impact community structures, functions, and populations. This section of the Vulnerability Analysis lists potentially affected community resources using the Sensitivity Checklist provided in the California Adaptation Planning Guide[24]. The Potential Impacts section of the analysis estimates how the impacts will occur and their projected severity. The points of sensitivity, or potentially affected community resources (community structure, community functions, and populations) in Livermore, are described below.

Livermore Community Overview

The City of Livermore is the easternmost city in the San Francisco Bay Area, making it the gateway to the Central Valley. The City encompasses an area of approximately 26.44 square miles and has a population of approximately 91,763 (Census, 2022). Livermore is home to prominent science and technology centers, Lawrence Livermore National Laboratory and Sandia National Laboratory, making it a science and technology hub. These labs along with the Livermore Valley Joint Unified School District and Valley Care Health System Lifestyle Rx Fitness Center are the economic foundation of the City, providing a large portion of employment opportunities in Livermore (City of Livermore 2019).

1.3.1.5 COMMUNITY STRUCTURES

The following community structures can be potentially affected by exposure to climate change impacts such as extreme heat and flooding:

- Residential
- Commercial
- Industrial
- Government
- Institutions (schools, churches, hospitals, etc.)
- Parks and open space
- Recreational facilities
- Transportation facilities and infrastructure
- Communication infrastructure
- Water treatment plant and delivery infrastructure
- Wastewater treatment plant and collection infrastructure
- Energy infrastructure
- Flood control infrastructure
- Solid waste facilities

Essential facilities such as medical facilities, police and fire stations, emergency operations centers, evacuation shelters, and schools are essential to the health and welfare of the population of Livermore and are especially important following climate-influenced hazard events. The following community structures within Livermore would be particularly sensitive to climate change impacts such as flooding and wildfire:

- Municipal buildings, including the three Livermore Public Library branches
- Hospitals, doctor's offices, and other medical entities, including Kaiser Permanente and the Stanford Health Care ValleyCare
- Educational facilities including the 19 schools in Livermore Valley Joint Unified School District and Las Positas Community College
- Childcare facilities
- Senior living facilities
- Livermore Police Department and Livermore – Pleasanton Fire Stations #5 through #10

Sensitive facilities, such as water and wastewater treatment plants, where damage would have large environmental, economic, or public safety consequences, are also considered particularly vulnerable to climate change. These sensitive facilities include:

- City water system including groundwater wells and distribution pipelines
- Wastewater systems such as the Livermore Water Reclamation Plant, and approximately 286 miles of sanitary sewer lines.
- Lawrence Livermore National Laboratory and Sandia National Laboratories

1.3.1.6 COMMUNITY FUNCTIONS

Community functions that may be disrupted by climate change in Livermore include:

- Government continuity
- Water, sewer, and solid waste
- Energy delivery
- Emergency services
- Public health and safety
- Emotional and mental health
- Business continuity
- Housing access
- Employment and job access
- Food security
- Mobility, transportation, and access
- Quality of life
- Social services
- Ecological function
- Tourism
- Recreation
- Agriculture, including farms and vineyards
- Industrial operations
- Communication services
- Solid waste collection and management

Transportation systems such as roads, bridges, overpasses, rail, bikeways and trail networks, and the Livermore Transit Center may be particularly threatened by the impacts of climate change such as floods, landslides, severe winds, and wildfires. The City maintains a variety of roadways ranging from a freeway and highway to local streets and special rural routes which travel through City-identified vineyard lands. Roadways play a critical role in how people and goods are transported throughout the city. The major roads running through the city are Interstate 580 (I-580) and State Route 84 (SR-84). Local public transit, provided by Livermore Amador Valley Transit Authority (LAVTA), is an important component of the City's transportation network, providing the community with alternatives to automobile travel. Rail freight through Livermore is served by the Union Pacific Railroad, which is an east-west route originating in Oakland and tying into two major north-south routes in the San Joaquin Valley. Additionally, the City provides a comprehensive, safe network of bikeways and trails for transportation and recreational purposes for a variety of non-vehicular users. In 2003, the city had a total of 66.5 miles of multi-use trails (Class I) and bike lanes (Class II). Impacts to the regional transportation system could critically impact mobility, transportation, and access in Livermore.

Lifeline utility systems such as potable water, wastewater, fuel, natural gas, electric power, and communication systems in Livermore may also be particularly sensitive to increased climate related events such as flooding, drought, wildfires, and landslides. These lifeline utility systems are essential to the health and safety of the Livermore community.

1.3.1.7 POPULATIONS

Populations that may be sensitive to climate change exposures described above include:

- Seniors
- Seniors living alone
- Children
- Individuals with disabilities
- Individuals with compromised immune systems
- Individuals who are chronically ill
- Individuals without access lifelines (e.g., car or transit, phones)
- Disadvantaged communities
- Low-income, unemployed, or underemployed communities
- Individuals with limited English skills
- Renters
- Students
- Seasonal residents
- Individuals uncertain about available resources because of citizenship status
- Cost-burdened households
- Households in poverty
- Outdoor workers
- Overcrowded households
- Persons experiencing homelessness
- Persons living on single access roads
- People living in mobile homes
- Persons without a high school degree

Vulnerable populations are more susceptible than others to climate related exposures. Such people may require special response assistance or special medical care after a climate-influenced disaster. The disproportionate effects of climate change on vulnerable populations are caused by physical, social, political, and/economic factors which are further exasperated by climate impacts. In the event of a climate-influenced disaster such as wildfire, flood, or landslide, vulnerable populations may have less access to emergency response information and lack the resources needed to cope with and recover from climate impacts. The 2009 California Climate Adaptation Strategy identifies those most at risk and vulnerable to climate-related illness as the elderly; individuals with chronic conditions such as heart and lung disease, diabetes, and mental illnesses; infants; the socially or economically disadvantaged; and those who work outdoors [25]. According to the Census, Livermore residents under 65 that reported no insurance was 1.0% and the proportion of people living in poverty is about 6.6%.

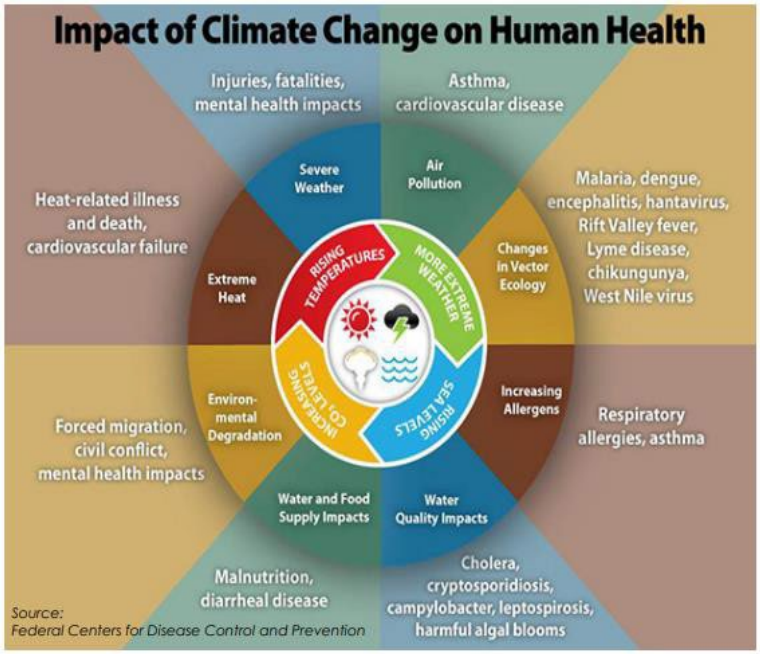
Moreover, the Census estimates that in 2020, 13.2% of the population was 65 years or older and 22.6% of the population was under the age of 18. These individuals may face unique impacts related to climate change. According to the findings from a United Nations Children's Fund (UNICEF) study, children are "physiologically and metabolically less able than adults at adapting to heat." The study recognizes that geography plays a role on the impacts of climate change that may affect specific populations and acknowledges the fact that those with fewer resources have a more difficult time adapting [26].

Financial wellbeing also impacts climate change sensitivity, as well as preparation, because those with greater access to resources have a greater ability to prepare and adapt. In addition, more than 20% of Livermore residents speak a language other than English at home, which may result in language barriers in dissemination of information related to climate change preparation and emergency response.[27]

VULNERABILITY COMPONENT 3 – POTENTIAL IMPACTS

Potential impacts are the nature and degree to which the community is affected by a given stressor, change, or disturbance. As climate change continues to progress, increased stress to vulnerable populations and sectors of society are expected. In the City of Livermore, the most likely primary impacts of climate change include increasing temperatures and altered precipitation patterns. Climate change impacts may damage infrastructure, reduce economic viability, influence water supply, and decrease public health and safety (Figure 6). The potential impacts of increasing temperature extremes, altered precipitation, and increasing wildfire in Livermore and the greater San Francisco Bay Area are discussed below.

Figure 6 Impact of Climate Change on Human Health



1.3.1.8 TEMPERATURE

As described in the Exposure section above, Livermore may experience a variety of impacts from climate change, which include an increase of average annual maximum temperature between 5.0°F and 7.8°F by the end of the century[28]. This increase in temperature may result in changes in seasonal patterns, possible heat waves, drought, and potentially increased storm frequency and intensity. The potential impacts to community structures, functions, and populations are described below.

Community Structures – Potential Temperature Impacts

Community infrastructure and the City's transportation system may be impacted by increased temperatures. Extended periods of intense heat may result in increased use of electricity for home cooling purposes that could tax the system and result in electricity restrictions or black-outs. Extreme heat events

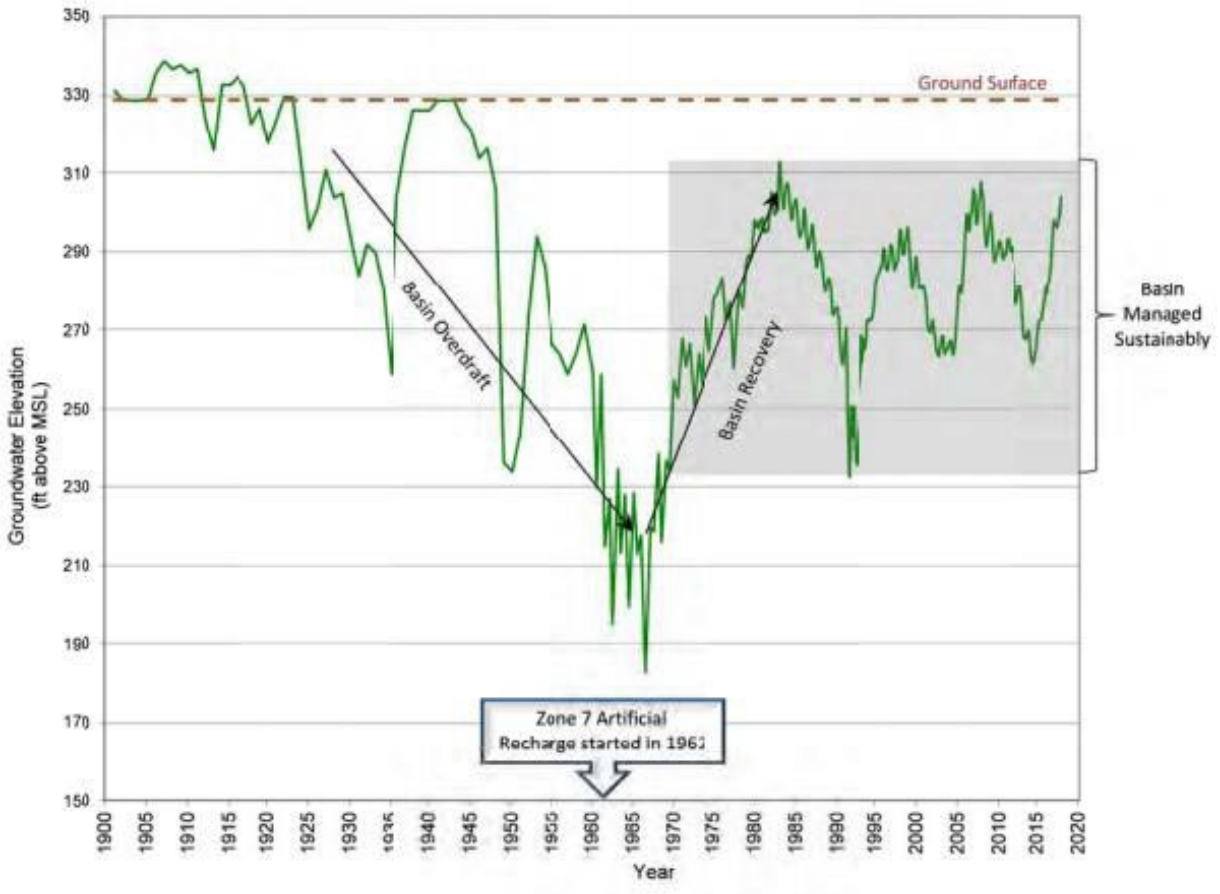
and prolonged periods of high temperatures can crave, heave, or deform roadway materials[29]. This can damage major roads and highways and increased maintenance costs. Some roadways may become difficult to drive on if pavement materials deform. Road maintenance activities be delayed during extreme heat events for worker health and safety[30]. In addition, cyclists and active commuters could be impacted by increased temperatures and could suffer from heat related illnesses making them less inclined to ride their bikes for transportation if the temperatures continue to rise. This would increase demand on other aspects of the transportation system including public transit and roadways, which may exacerbate worsening air quality conditions.

Community Functions – Potential Temperature Impacts

As mentioned above in the Sensitivity section, increases in temperature could also have a substantial impact on the City's economy. Vineyards and farms are an essential part of the City's community and economy and could be affected by climate change through crop failure, transportation system issues, and decreased labor from heat exposure.

High temperatures may also contribute to a reduced water supply. For instance, higher temperatures will melt the Sierra snowpack earlier and drive the snowline higher. Higher temperatures, in addition to a reduction in precipitation falling as snow, would result in less snowpack to supply water to California users [31]. Increased temperatures could therefore result in decreased potable water supply for the City. The City relies on local groundwater, surface water, and imported water to meet its water needs [32]. Zone 7 Water Agency (Zone 7) has managed and imported local surface water and groundwater resources for beneficial uses in the Livermore Valley Groundwater Basin for more than 55 years. According to the Annual Report for the Sustainable Groundwater Management Program and as shown in Figure 7, Zone 7 replenished the groundwater basin in 1962 after decades of basin overdraft. Since then, Zone 7 has been sustainably managing the Livermore Valley Groundwater Basin[33]. With temperatures expected to increase and snowpack expected to decrease, there may be an increase in the reliance on the Livermore Valley Groundwater Basin, putting pressure on local water supply.

Figure 7 Bernal Key Well Hydrograph



Vulnerable Populations – Potential Temperature Impacts

Public health may be negatively impacted by increases in average temperature and frequency and intensity of extreme heat events. These conditions could lead to increase incidence of heat-related illness among individuals with disabilities or compromised immune systems, children playing outdoors, tourists, farm workers and others working outdoors. Potential health impacts of heat exposure include cardiovascular disease; exacerbation of asthma, allergies, and chronic obstructive pulmonary disease; increased risk of skin cancer and cataracts; premature death; cardiovascular stress and failure; and heat-related illnesses such as heat stroke, heat exhaustion, and kidney stones[34]. Figure 8 shows a profile of health outcomes and inequities specific to Alameda County, the number of people in the County, or state of California, and the relative percentage for the County or State[35]. Disparities among race/ethnicity groups and poverty groups are apparent, as is the heightened vulnerability of obese and disabled individuals to heat effects.

Those in Livermore without health insurance (2.8%) and living in poverty (4.3%) are particularly vulnerable to high temperatures and their associated health impacts. **Figure 9** displays the profile of social vulnerabilities and climate risks in Alameda County[36]. There is currently one census tract within Livermore (Census Tract 4514.04, **Figure 10**) that is designated as an Opportunity Zone [37] or economically distressed community where new investments in Caltrans transportation projects, Air Resources Board low carbon projects, and High-Speed rail investments are a priority[38] Additionally, three census block groups[39] have been identified as disadvantaged communities by the State, as shown in **Figure 11**[40] . With anticipated increases in minimum and maximum temperatures, economically disadvantaged residents may find it more difficult or impossible to afford the additional costs of cooling their homes. Consequently, many low-income households, especially those of seniors and individuals with disabilities, will be particularly vulnerable to the effects of extreme heat events.

Figure 8 Profile of Health Outcomes and Inequities in Alameda County

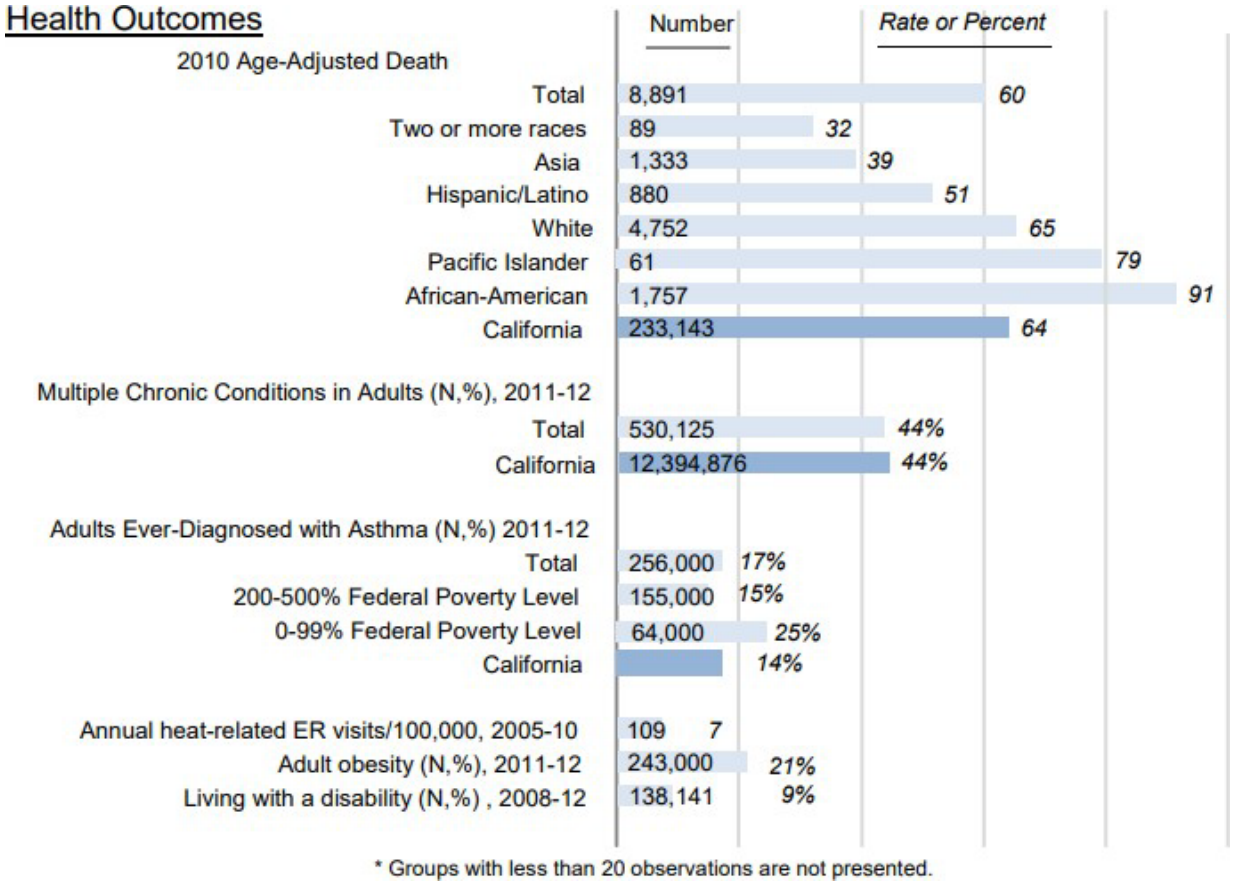
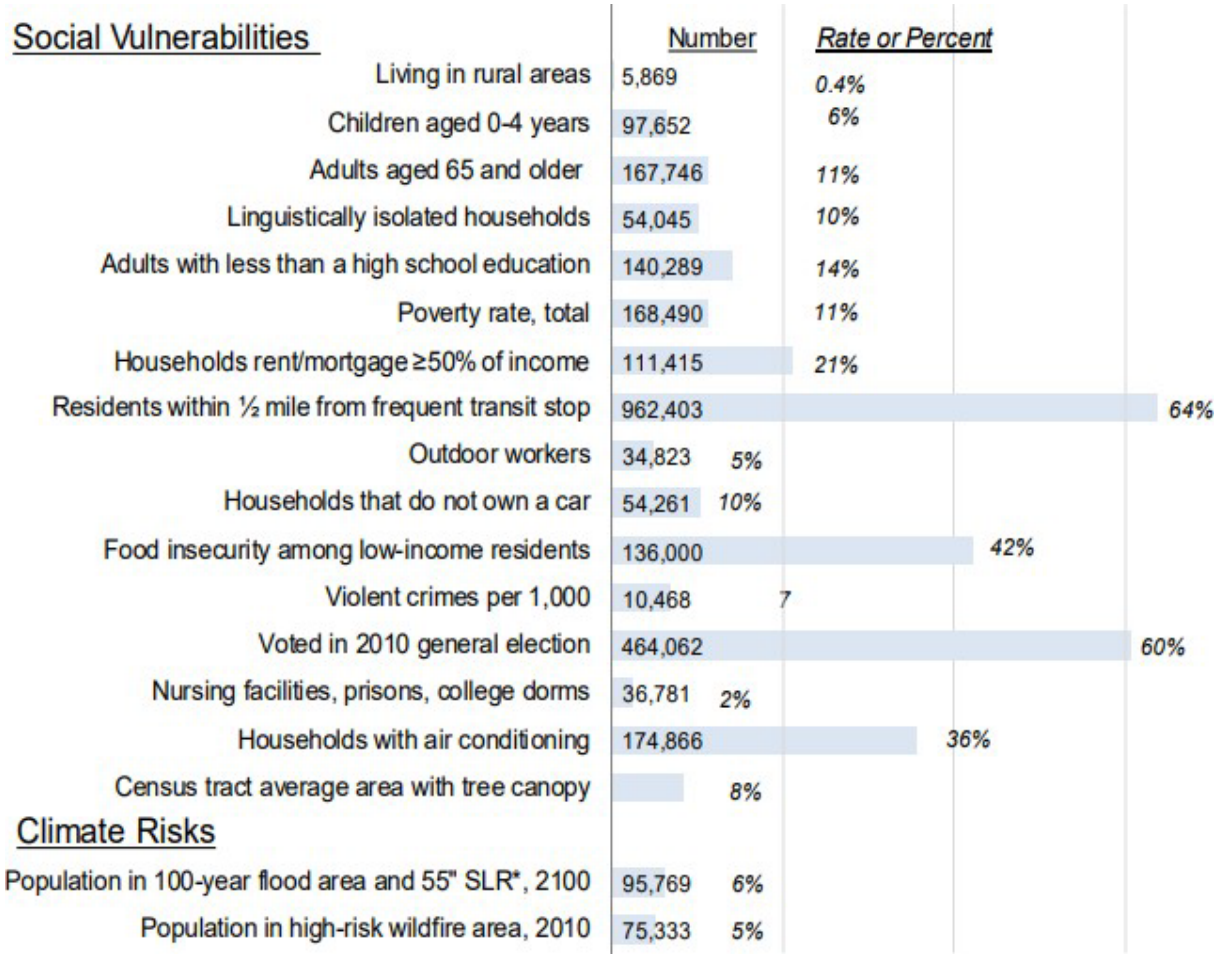


Figure 9 Profile of Social Vulnerabilities and Climate Risks in Alameda County



CLIMATE CHANGE VULNERABILITY ANALYSIS

Figure 10 Opportunity Zone

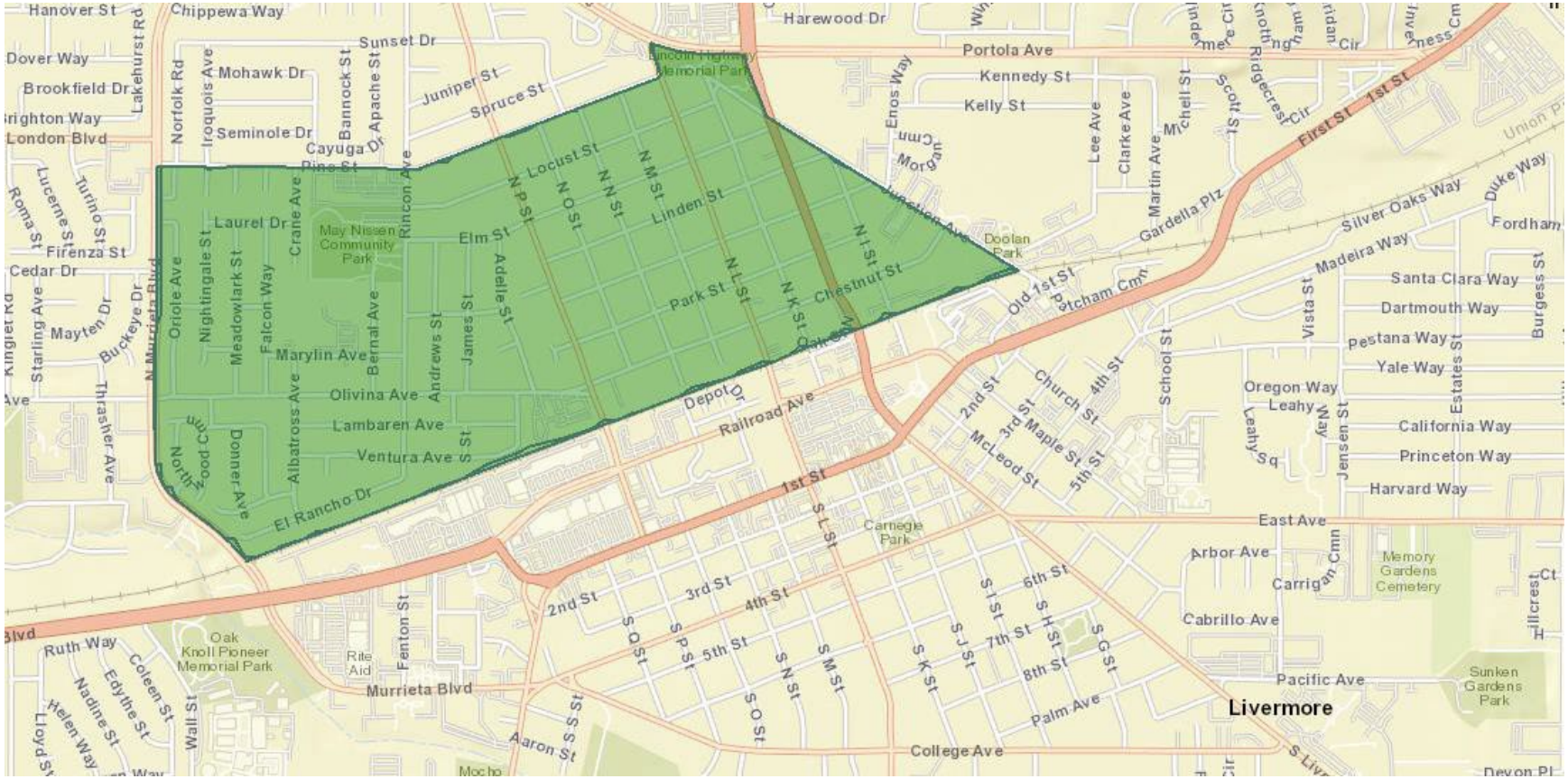
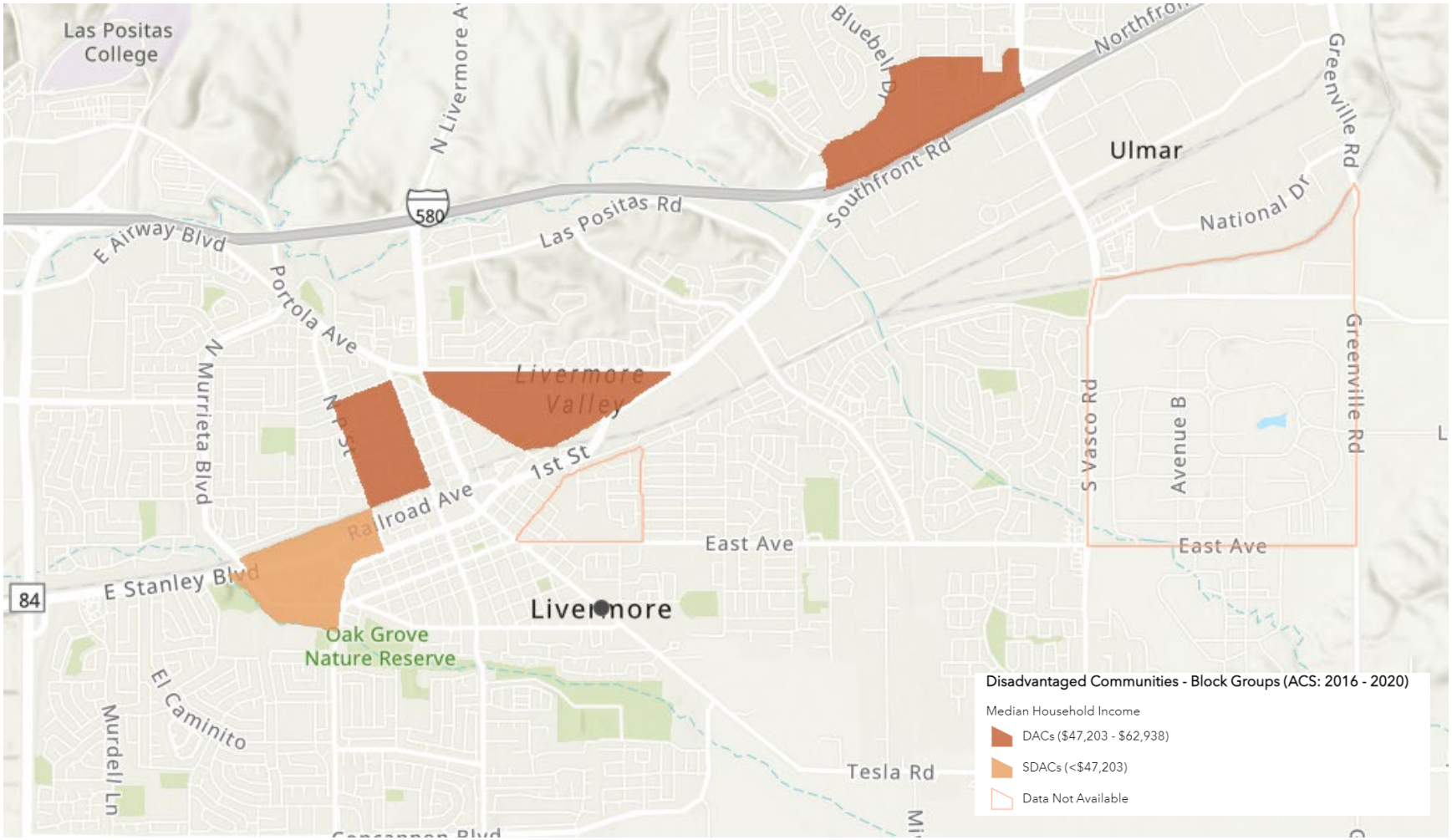


Figure 11 Disadvantaged Communities



Increasing temperatures may also impact vulnerable youth populations. Due to their less-developed physiology and immune system, children are especially vulnerable to air and water quality, temperature, humidity, and vector-borne infections. These health concerns are not just physical; children can be impacted psychologically as well, which could result in a loss of self-confidence, nervousness, and insomnia[41]. This additional stress on children's systems could affect them into adulthood and result in lifelong ailments.

Additionally, rising temperature may also indirectly impact human health through impacts to biological species and natural habitat, such as increases in the incidence of vector borne disease (WHO 2018). Insects have no internal control over their body temperature, and as ambient temperatures rise, the distribution of insects may expand through increased reproductive rate, biting behavior, and survival. Moreover, the incubation period for pathogens within vectors is also temperature-dependent, and the period often becomes shorter as conditions warm[42] . This will result in pathogens developing and spreading more quickly; susceptibility to disease may increase.

As rising temperature impacts public health, community resources such as hospitals and various doctors' offices and medical entities may be impacted by an increased need for various health care services including heat and respiratory care.

1.3.1.9 PRECIPITATION

Future precipitation projections show variability over time, generally with longer dry periods punctuated by periods of heavy rain or severe storms. Periods of decreased precipitation may result in more frequent and persistent droughts, especially in combination with increased temperatures. Droughts could result in decreased water supply, water quality and public health; reduced viability of natural landscapes; and increased risk of wildfires in the region. As mentioned in the Exposure section above, the frequency and severity of storm events could increase with climate change. This could result in impacts to community structure, functions and human health and safety, particularly related to flooding.

Community Structures – Potential Precipitation Impacts

Increased flooding may result in water and wastewater treatment plants being unable to handle increases in intense rainfall events and associated runoff. This could impede the proper functioning of on-site septic systems or overwhelm sewers and centralized sewage treatment plants. As a result, untreated water, with a full load of toxics and organic waste, could enter streams and the ocean.

There are several locations within Livermore that contain known flood hazard areas. These include Las Positas Golf Course, Springtown Golf Course, Altamont Creek Park.

Flooding may also impact the City's transportation network inhibiting movement of people and goods. Several major roadways in Livermore could be affected by flooding, including 1st Street, Holmes Street, East Stanley Boulevard, South Vasco Road, East Avenue, Las Positas Road, West Jack London Boulevard/ El Charro Road, Club House Drive, Arroyo Mocho, Arroyo del Valle, Airway Boulevard, Arroyo Las Positas, Arroyo Seco, Stanley Boulevard/Murrieta Boulevard, Patterson Pass Road, Robertson Park Road, and

Greenville Road. Flooding can cause affected roadways to become impassable, preventing people from evacuating during emergencies.

Emergency response systems would similarly be affected by flooding through restricted access to and from emergency response systems, increasing wait times for these crucial services. Communication to these entities may also be impacted if electricity transmission is interrupted or if water and other natural resources are unavailable.

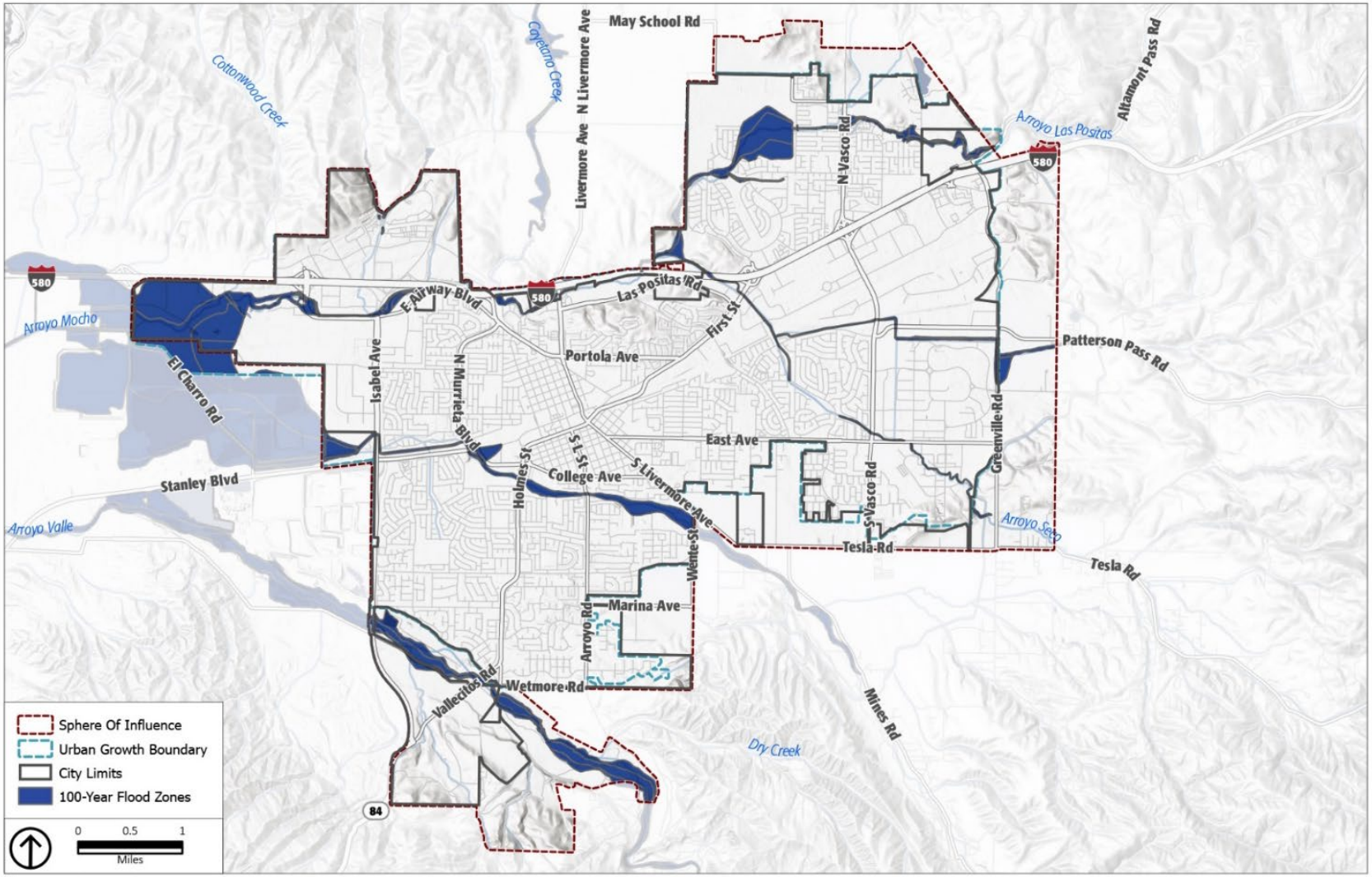
FEMA determines floodplain zones to assist cities in mitigating flooding hazards through land use planning. FEMA also outlines specific regulations for any construction within a 100-year floodplain. The 100-year floodplain is defined as an area that has a 1 percent chance of being inundated during a 12-month period. FEMA also prepares maps for 500-year floods, which mean that in any given year, the risk of flooding in the designated area is 0.2 percent. The portions of the SOI that are within the 100-year floodplain are shown on Figure 12.

The Tri-Valley Local Hazard Mitigation Plan assessed the flood loss potential to critical facilities exposed to flood risk. Critical facilities include medical and health services, emergency services, educational facilities, government facilities, utilities, transportation facilities, and hazardous materials. Both Lawrence Livermore National Laboratory and Sandia National Laboratory are considered high profile critical facilities because they house hazardous materials. The plan estimated the following flood-related risks:

- A 10-percent annual chance flood event (i.e., flood of a magnitude historically expected every 10 years on average) would affect 12 facilities and on average the facilities would receive a 4.12 percent damage to the structure and 27.03 percent damage to the contents.
- A 1-percent annual chance flood event (i.e., flood of this magnitude historically expected every 100 years on average) would affect 21 facilities and on average the facilities would receive a 7.33 percent damage to the structure and 27.78 percent damage to the contents.
- A 0.2-percent annual chance flood event (i.e., flood of this magnitude historically expected every 500 years on average) would affect 66 facilities and on average the facilities would receive a 15.18 percent damage to the structure and 39.94 percent damage to the contents.

CLIMATE CHANGE VULNERABILITY ANALYSIS

Figure 12 100-Year Floodplain



Source: Federal Emergency Management Agency, 2020; City of Livermore, 2021; Esri, 2021.

Community Functions – Potential Precipitation Impacts

During intense storms and precipitation events, the local economy may be impacted through more frequent disruption to community services, such as power outages. Additionally, a flooded structure or agricultural field could result in increased expenses and disruption to work.

Populations – Potential Precipitation Impacts

Public health and safety may be directly impacted by injury and or death of community members resulting from large floods. Flooding can damage homes and render them uninhabitable due to mold or mildew growth, which could expose residents to disease vectors. Public health may also be indirectly impacted by reduced access to emergency response and health centers resulting from infrastructure impacts discussed above.

Populations most vulnerable to flooding impacts include those who lack the financial resources to floodproof their homes or repair flood damage, those who would encounter significant barriers to timely evacuation, those whose physiology makes them particularly vulnerable to the health effects of flooding, those directly exposed to floodwaters or heavy precipitation, and those whose work would be interrupted by heavy precipitation or flooding.

1.3.1.10 WILDFIRE

Community Structures – Potential Wildfire Impacts

Cal-Adapt projects that wildfire risk in Livermore will decrease over this century. Therefore, direct impact of wildfire to community structures in the City are expected to remain low. However, the community may be affected by smoke and other indirect impacts of wildfire occurring in neighboring regions.

Community Functions – Potential Wildfire Impacts

Similar to community structures, direct impacts of wildfire to the economy in Livermore are unlikely. However, secondary impacts of decreased air quality could indirectly affect the economy by impacting vulnerable workers, reducing tourism, and directly impacting health of community members as noted below.

Wildfire and wildfire smoke could interrupt agricultural operations, damage agricultural lands, threaten agricultural worker safety, threaten animal safety, and introduce pollutants to agricultural soil and water sources. If not burned too badly, grape vines can recover and produce grape clusters again the following year[43]. However, grapes exposed to smoke absorb chemicals that can alter—and sometimes ruin—the taste and smell of resultant wines[44].

Populations – Potential Wildfire Impacts

Despite the low risk of direct wildfire impacts to Livermore, the potential of increasing wildfires in the greater San Francisco Bay Area and Central Valley could impact populations through increasing secondary impacts such as poor air quality, changes in water quality, and erosion. Vulnerable populations such as individuals with compromised immune systems, seniors, children, the homeless, and outdoor workers are likely to be impacted most by these secondary impacts.

The Livermore community could be affected by public safety power shutoffs (PSPS) designed to reduce the risk of regional wildfires. By cutting off power to the community, PSPS could threaten resident health and interrupt business operations.

VULNERABILITY COMPONENT 4 – ADAPTIVE CAPACITY

Adaptive capacity is the ability to cope with extreme events, to make changes, or to transform to a greater extent, including the ability to moderate potential damages and to take advantage of opportunities. Adaptive capacity is the current ability to address the potential impacts of climate change and includes adjustments in behavior, resources, and technologies[45]. The City of Livermore has actively taken steps to increase the City's adaptive capacity, which include promoting hazard mitigation, disaster preparedness, and proactive planning through stream and stormwater management programs. Table 4 lists the City's guiding documents and programs that have an underlying emphasis on adaptive capacity.

Table 4 Livermore Planning Documents and Programs

Document	Year Established
Climate Action Plan	2012, currently being updated
General Plan Climate Change Element	2009
Bicycle, Pedestrian, and Trails Active Transportation Plan	2018
East Alameda County Conservation Strategy	2010
Stream and Stormwater Management Programs	Ongoing
Tri-Valley Local Hazard Mitigation Plan	2018, currently being updated
Alameda County Local Hazard Mitigation Plan	2021
2005 GHG inventory Report	2007
East Bay Energy Watch (EBEW) GHG Inventory Reports	2005, 2010, 2015, 2017
Green Infrastructure Plan	2018
Livermore Emergency Operations Plan	2018

The City has approximately 200 sustainability and adaptation related measures from the existing planning documents listed above. Most of these measures can be grouped into four major categories: energy, water, transportation, waste, and land use. The two major exposures expected in Livermore are higher temperatures and potentially increasing frequency and intensity of storms, and a variety of measures address these exposures indirectly. Many energy measures have been developed which could increase the City's adaptive capacity related to increased temperatures. PG&E, EBCE, and BayREN offer financial

assistance for weatherization and energy efficiency upgrades, which may help financially stressed households adapt to high heat by conserving energy and reducing interior temperatures.

The City is also capable of taking steps to ensure that utility service is not interrupted by wildfire and heat hazards. Every year, the City of Livermore prepares for the fire season by completing vegetation management and weed abatement activities in open space areas that border residential neighborhoods and around city-owned facilities, creeks, parks, and right of ways. These activities include mowing, weeding, and trimming and are performed by City staff and contractors.

Whenever Red Flag Warnings are issued, Livermore Municipal Water fills and maintains water tanks near capacity. During a PSPS event, the Water Resources Division will switch to backup generators to power pump stations, the Livermore Water Reclamation Plant, and other key facilities to keep drinking water flowing and keep treating wastewater. The Water Reclamation Plant (WRP) Emergency Generator project will install an emergency generator at the WRP that will allow the Plant to sustain wastewater treatment during a power outage. Zone 7 works with PG&E to ensure that they receive as much advance notice of PSPS events as possible so that they can prepare and initiate a response. Zone 7 maintains standby generators at both water treatment plants that provide full power to these facilities. Portable generators have been stationed at designated critical facilities to keep these pumping plants running, and arrangements have been made to keep all generators fueled during power outages. Staff can deploy additional portable generators and pumps as needed.

However, most of the City's heat and severe weather resiliency strategies have been determined to be low quality (due to the lack of a clear objective, strategy to obtain objective, funding, metrics to measure progress, and/or lead responsible party). Furthermore, few of these measures have been implemented. The same is true for sustainability measures related to water and land use.

The City has developed both reactive and proactive measures to addressing climate change adaptation. The Stream and Stormwater Management Programs is a collaborative effort between the City, Parks District, and Water Agency to provide habitat enhancements around stream and flood channels. This form of stream maintenance and repair increases the City's adaptive capacity related to higher precipitation rates and the potential for flooding. The City also participates in Living Arroyos, a partnership between the City of Livermore, City of Pleasanton, Livermore Area Parks and Recreation District (LARPD), and Zone 7 Water Agency. The program aims to engage the community renewing and enhancing urban stream and riparian habitats in the Livermore-Amador.

The City regulates development in the floodplain through zoning restrictions, requiring residential and commercial structures to be raised or constructed on engineered fill, and map revisions filed with the Federal Emergency Management Agency (FEMA). These measures reduce the potential for floodwater to damage commercial buildings. The City of Livermore provides a Leaf Pick-Up program which starts the week after Thanksgiving and ends by mid-February. This program may help prevent flood control infrastructure from becoming blocked or overwhelmed. The City's Capital Improvement Plan (CIP) includes a variety of projects to address existing drainage problems, perform maintenance work along the arroyos, install new trash capture devices, and increase the size of storm drain trunklines for new developments, improving the ability of this infrastructure to respond to flood waters.

Zone 7 conducts routine stormwater infrastructure maintenance which includes: regular channel inspections to ensure all banks are stable; regular trash and debris abatement to ensure channels flow freely; embankment and drain structure repairs as-needed; and sediment removal, which is removal of fine-grained sands and clay that have settled out of the water and built up, reducing channel capacity. These measures ensure that flood control infrastructure is able to respond to flooding.

The Livermore WRP produces recycled water for irrigation and fire protection uses. An average of 2 million gallons of recycled water is used every day in the City's recycled water service area. Ninety-seven percent of Livermore's recycled water is used for irrigation at commercial properties, the Las Positas Municipal Golf Course, and public parks and facilities. Three percent of the recycled water is used for fire protection, construction uses, street sweeping, and toilet/urinal flushing. The City's CIP includes projects to increase potable water storage capacity and to improve existing pipelines and facilities. Additionally, Chapters 13.25, 13.26, and 13.27 of the Livermore Municipal Code discuss design and irrigation requirements for water efficient landscapes; water shortage contingency planning, conservation measures, exemptions, and penalties; and wasteful water practices and penalties.

Though the City has a vast number of sustainability measures developed, few have been successfully implemented, giving the City a low to medium adaptive capacity rating. While the City does have some level of emergency preparedness, such as through the Livermore Emergency Operations Plan, there are few implemented measures in place to address long-term effects of climate change such increased heat and decreased air quality.

VULNERABILITY COMPONENT 5 – RISK AND ONSET

Risk is defined as the likelihood or probability that a certain magnitude, extent, or scale of potential impact will occur [46]. For each impact, a level of uncertainty, based on the probability of the primary or secondary exposures is assigned (Table 5). According to the Intergovernmental Panel on Climate Change, temperature changes have a greater than 90% probability of occurring, providing a high certainty rating for this impact. Precipitation changes have a greater than 66% probability of occurring, providing a medium certainty rating.

Table 5 Probability of Global Primary Impacts

Driver	% Probability (IPCC)	Certainty Rating
Temperature Change	>90%	High
Precipitation Change	>66%	Medium

Source: Adapted from CEMA & CNRA 2012[47], IPCC 2007[48]

For each associated secondary impact (e.g., heat waves, intense rainstorms, drought, etc.), a certainty rating and timeline for expected impacts to Livermore were assessed based on the conservative estimates from

Secondary impacts are explored in the Exposure section of this assessment. Expected near-term secondary climate impacts to Livermore include changed seasonal patterns, heat waves, and intense rainstorms (Table 6). These impacts may occur in the near-term (2020 – 2040) because they occur, in part, as a result of increased temperature, which has a high certainty rating globally and high exposure risk in Livermore. Drought and wildfire are expected to occur in the mid-term largely due to the variability of precipitation projections in Livermore.

Table 6 Probability of Secondary Impacts Based on Global Models

Primary Impact	Associated Secondary Impacts	Certainty Rating	Timeline for Expected Impacts to Livermore[1]
Changed temperature and/or precipitation patterns	Changed seasonal patterns	Medium	Near-term
Increased temperature	Heat wave	High	Near-term
Increased temperature and/or changed precipitation	Intense rainstorms	Medium	Near-term
Increased temperature and/or reduced precipitation	Drought and wildfire	Medium	Mid-term

[1] *Near-term: 2020 – 2040; Mid-term: 2040-2070; and Long-term: 2070-2100*

Source: CEMA & CNRA 2012

1.4 FINDINGS AND IMPLICATIONS

Climate change will affect populations throughout the state, nation, and world differently based on their actual and perceived vulnerabilities. This assessment offers a better understanding of Livermore's vulnerability to climate change impacts and inform the development of additional adaptive measures. As this century proceeds, the following climatic changes are projected to occur in Livermore:

- Maximum and minimum temperatures are expected to increase.
- Precipitation variability is expected to increase over the century.
- Increased temperature and associated impacts have a high certainty of occurring in the near-term.
- Intense rainstorms and changes in seasonal patterns are expected to occur in the near-term.

Extreme heat, wildfire and poor air quality, and flooding are projected to pose the greatest risks to the Livermore community.

As the extreme weather events emblematic of climate change become more frequent, the City may find that its financial and emergency response resources are called upon with greater frequency and may be tasked with responding to a greater variety of emergency events within shorter windows of time. Meanwhile, gradual increases in temperature and increased frequency of drought may strain community health and resources, presenting continuous challenges to community wellbeing even if they never acquire emergency status.

Some of Livermore's individuals and communities are more vulnerable to the effects of climate change than others. Households in poverty, individuals with precarious citizenship status, outdoor workers,

people living in mobile homes, and individuals experiencing homelessness are some of Livermore's most vulnerable members. These communities and individuals may lack the material resources needed to prepare for or recover from climate change hazards, may be more directly exposed to climate change than other members of the community, and may be excluded from or overlooked in the policymaking process or may encounter other barriers to political self-advocacy and community participation.

Contributors to social vulnerability can co-occur. For example, individuals can be outdoor workers, possess precarious citizenship status, and belong to a household whose income places them below the poverty line. Recognizing that individuals and communities can be susceptible to the effect of climate change along multiple axes helps orient resilience-building resources towards the communities that are most vulnerable and the actions which have the greatest potential for reducing their vulnerability.

While all sectors of the Livermore community will likely be affected by climate change, some sectors, services, and facilities are more vulnerable than others. The areas in which the City of Livermore is most vulnerable to climate change include:

Energy: Livermore's energy infrastructure and services are especially vulnerable to extreme heat, wildfire, and landslides. Extreme heat can regularly cause power outages due to a combination of mechanical failure of electrical grid equipment, heat damage to the wires themselves, and high demand for electricity as a result of cooling equipment, all of which causes stress on the grid. As extreme heat events before more frequent and intense, disruptions in service are likely to become more frequent. Energy infrastructure can be damaged by wildfire and landslide, which could interrupt energy delivery.

Water and wastewater: Livermore's water and wastewater systems are vulnerable to wildfire and extreme heat to the extent that they are dependent on electricity provided by PG&E, which may be interrupted during a PSPS event, high heat event, or wildfire. These facilities could also be damaged by landslide. Increased flooding may result in water and wastewater treatment plants being unable to handle increases in intense rainfall events and associated runoff. This could impede the proper functioning of on-site septic systems or overwhelm sewers and centralized sewage treatment plants. As a result, untreated water, with a full load of toxics and organic waste could enter waterbodies.

Transportation: Extreme heat events and prolonged periods of high temperatures can crave, heave, or deform roadway materials[49]. Some roadways may become difficult to drive on if pavement materials deform, and the City's road maintenance costs may increase. Meanwhile, road maintenance activities may be delayed during extreme heat events for worker health and safety[50]. Climate change may shift transportation patterns as extreme heat and wildfire smoke exposure make it more difficult to wait outside for the bus or use active transportation. These shifts could increase frequency of private vehicle use, exacerbating roadway damage and worsening air quality. Transportation infrastructure may be damaged and public transit services may be interrupted by flooding or landslide.

Emergency services and public health and safety: Exposure to wildfire and wildfire smoke, extreme heat, and flooding could all cause widespread and severe health impacts to members of the Livermore community. These events may simultaneously increase demand for emergency services and, by blocking roads, damaging community facilities, and interrupting energy delivery, make it harder for emergency services to be delivered.

Agriculture: Agriculture is vulnerable to all climate change effects, but especially high heat, wildfire and poor quality, and drought. Crop growth and quality is dependent on seasonal weather patterns which may be interrupted by climate change, including extreme heat, warmer winter temperatures, and exposure to wildfire smoke. High heat can increase crops' water demand and increase the salt content of soils, the impacts of which may be exacerbated by drought conditions. High heat and wildfire smoke may threaten outdoor worker health and interrupt local and regional agricultural operations.

Like populations, City infrastructure and services could be affected by more than one climate change hazard within a relatively short period of time. The City should keep this in mind while allocating funding for program implementation, infrastructure maintenance, and investment in capital projects.

EQUITY AND UNCERTAINTY

When addressing vulnerability and adaptation through general plan policies and the associated implementation plan, the *Adaptation Planning Guide* and *General Plan Guidelines* recommend consideration of equity and uncertainty.

Equity means that all people are justly and fairly included in society, and that everyone is able to participate, prosper, and achieve their full potential. Equitable climate adaptation planning involves identifying persons who are most vulnerable to climate change hazards, and ensuring that the planning process, distribution of resources, and efforts to address systematic wrongs are all conducted in an equitable manner. This Vulnerability Assessment identifies 22 vulnerable populations, several of which share characteristics with California Office of Health Hazard Assessment's Disadvantaged Communities designation and assesses climate change impacts and the ability of these populations to prepare for, respond to, and recover from climate change hazards.

Uncertainty is the second component to consider when determining how hazardous conditions may affect Livermore. Climate change is driven by the concentration of GHGs in the atmosphere, which is affected by how our communities use resources and how we regulate those uses through local, state, federal, and international GHG-reduction goals, regulations, plans, and programs. As more action is taken to reduce GHG emissions, the less severe the effects of climate change are expected to be. Climate change models consider the concentrations of atmospheric GHG emissions and the changes in these levels over time to project future extent or intensity of hazardous events.

Even with the extensive modeling, potential impacts are projections of more likely future conditions and are not certain. Similarly, there is also substantial uncertainty about the future state of technology, socioeconomic conditions, and other factors. According to recent studies, the best approach to uncertainty is to minimize inaction by developing "no regrets" strategies that are beneficial without the presence of climate change and where the costs are low compared to the benefits. The State and the City have ample evidence to support science-based policy and decision-making.

OPPORTUNITIES

The City has a variety of planning documents and programs that provide a low to medium rating in adaptive capacity. There are opportunities to further improve adaptive capacity to climate change

exposure described in this analysis. In addition to focusing on the implementation of high priority measures that address effects of increasing temperatures and storms, it will be important to focus these efforts in Livermore's vulnerable communities such as those described in this analysis and highlighted in Figure 10 and Figure 11. Examples of measures that could be implemented to improve adaptive capacity include:

- Encouraging green building practices in new and redevelopment with a focus on disadvantaged communities.
- Providing infrastructure improvements such as cool pavements, green roofs, and planting trees and vegetation in disadvantaged communities, along active transportation corridors, and at bus stops.
- Communicating heat warning information and appropriate responses to the public, especially to the most vulnerable members of the community, and provide community cooling centers in areas with low-income, elderly, and young populations.
- Incentivizing and/or require the installation of heat pump HVAC units which provide energy efficient heating and cooling.
- Increasing distributed energy resources and therefore electricity security through the implementation of microgrids and battery storage.
- Strengthening water supply systems to meet forecasted demands of residents, businesses, and visitors as variability in water resources increases.
- Ensuring that new or retrofitted stormwater infrastructure is sized to accommodate larger flood events.
- Expanding City services and community-based partnerships serving the homeless community, low-income community, outdoor workers, and individuals with uncertain or precarious citizenship status.

In addition to the General Plan Update, the City's updated Climate Action Plan will work in unison with the City's planning documents (Table 4) to provide strategies for the City to prepare, adapt, and mitigate the impacts of climate change.

CONCLUSION

The Vulnerability Assessment identifies which hazards are expected to harm sensitive populations and assets, and which assets are most vulnerable to various hazards that are projected to intensify with climate change. A comprehensive set of results is in Table 7. Understanding how climate change will affect the community and identifying the vulnerable populations and assets will enable Livermore to implement effective GHG-reduction measures and climate adaptation strategies to create a safer, more sustainable, and healthier community.

As the climate continues to change and GHG emissions rise, climate change hazards will continue to harm populations, infrastructure and buildings, economic drivers, and key community services in Livermore. The General Plan Update will integrate adaptation and resilience strategies into goals, policies, and implementation measures that will help increase resiliency and reduce vulnerability throughout the city.

Table 7 Vulnerability Assessment Results Matrix

POPULATIONS AND ASSETS	WILDFIRE AND AIR QUALITY	DROUGHT	EXTREME HEAT	FLOODING	LANDSLIDE
Populations					
Children	V4	-	V4	V3	V3
Cost-burdened households	V3	-	V3	V4	V3
Disadvantaged communities	V4	-	V4	V4	V3
Households in poverty	V4	-	V4	V4	V4
Households on single access roads	V3	-	-	V3	V3
Households without access to lifelines	V3	-	V3	V3	V3
Individuals uncertain about available resources because of citizenship status	V5	V4	V4	V4	V4
Individuals who are chronically ill	V4	V2	V5	V3	V2
Individuals with compromised immune systems	V4	-	V3	V4	-
Individuals with disabilities	V3	-	V3	V4	V3
Linguistically isolated populations	V3	V3	V3	V3	V3
Low-income households, unemployed, or underemployed communities	V3	V3	V4	V4	V3
Outdoor workers	V5	V5	V5	V4	V4
People living in mobile homes	V4	V3	V4	V4	V4
Persons experiencing homelessness	V5	V4	V5	V5	V4
Persons in overcrowded households	V3	V3	V3	V3	V2

CLIMATE CHANGE VULNERABILITY ANALYSIS

POPULATIONS AND ASSETS	WILDFIRE AND AIR QUALITY	DROUGHT	EXTREME HEAT	FLOODING	LANDSLIDE
Persons without a high school degree	V3	V3	V3	V3	V3
Students	V3	V3	V3	V3	V3
Sensitive Facilities					
City water system	V4	-	V2	V3	V4
Wastewater systems	V4	-	V2	V3	V4
Laboratories	V2	V2	V1	V2	-
Essential Facilities					
Childcare facilities	V2	-	V2	V2	V2
Educational facilities	V2	-	V2	V2	V2
Medical facilities	V2	-	V3	V3	V3
Municipal buildings	V2	-	V2	V2	V2
Public safety buildings	V3	-	V2	V2	V3
Senior living facilities	V2	-	V2	V2	V2
Community Structures	V2	-	V2	V2	V2
Commercial	V2	-	V2	V2	V2
Communication infrastructure					
Energy infrastructure	V3	-	V2	V3	V3
Flood control infrastructure	V3	-	V3	V2	V2
Government	V4	V3	V4	V3	V4
Industrial	-	-	-	V3	V3

POPULATIONS AND ASSETS	WILDFIRE AND AIR QUALITY	DROUGHT	EXTREME HEAT	FLOODING	LANDSLIDE
Institutions	V3	-	V2	-	V2
Parks and open space	V3	-	V2	V4	V2
Recreational facilities	V3	-	V2	V3	V3
Residential	V3	V3	V2	V2	V4
Solid waste facilities	V3	-	V3	V3	V3
Transportation facilities and infrastructure	V3	-	V2	V4	V3
Water treatment plant and delivery infrastructure	V2	-	V3	-	V2
Agriculture	V3	-	V4	V4	V4
Business continuity	V2	-	V2	V4	V4
Communication services	V4	V4	V5	V3	V3
Ecological function	V4	V3	V3	V3	V2
Community Functions					
Emergency services	V4	V2	V4	V4	V3
Emotional and mental health	V4	V3	V3	V4	V3
Employment and job access	V3	V2	V3	V3	V2
Energy delivery	V4	V2	V5	V3	V4
Food security	V3	V4	V4	V2	V2
Government continuity	V3	-	V1	V2	V2
Housing access	V4	-	-	V3	V3

CLIMATE CHANGE VULNERABILITY ANALYSIS

POPULATIONS AND ASSETS	WILDFIRE AND AIR QUALITY	DROUGHT	EXTREME HEAT	FLOODING	LANDSLIDE
Industrial operations	V3	V3	V3	V4	V2
Mobility, transportation, and access	V4	-	V4	V4	V3
Public health and safety	V5	V3	V4	V4	V3
Quality of life	V5	V2	V4	V3	V3
Recreation	V4	V3	V5	V3	V3
Social services	V3	V3	V3	V3	V2
Tourism	V5	V3	V3	V3	V3
Water, sewer, and solid waste	V2	V3	V4	V4	V4

The table above shows the complete set of vulnerability scores. A score of V1 indicates minimal vulnerability, V2 low vulnerability, V3 Moderate vulnerability, V4 high vulnerability, and V5 severe vulnerability. If a given cell is unscored, this indicates that the given population or asset is not considered vulnerable to the given hazard.

Endnotes

[1] California Emergency Management Agency and California Natural Resources Agency (CEMA & CNRA). 2012. California Adaptation Planning Guide. Accessible at: http://resources.ca.gov/docs/climate/01APG_Planning_for_Adaptive_Communities.pdf

[2] There were 10 California GCM models that were ranked from 1-10 by California's Climate Action Team Research Working Group and the California Department of Water Resources for different temperature and precipitation factors. The models ranged from the "warm/dry" model which had all metrics closest to 1 to the "cool/wet" model which had all metrics closest to 10. The MIROC5 displays a pattern of ranking that is most unlike the other 3 models and therefore, is included to represent the full spread of all 10 model simulations.

[3] Cal-Adapt provides projections for temperature, precipitation, and wildfire, and these projections will be discussed in the Exposure section of the document. Drought, which does not have associated Cal-Adapt projections is addressed under temperature and precipitation exposure, as well as in the Potential Impacts and Risk and Onset sections.

[4] California Emergency Management Agency and California Natural Resources Agency (CEMA & CNRA). 2012. California Adaptation Planning Guide. Accessible at: http://resources.ca.gov/docs/climate/01APG_Planning_for_Adaptive_Communities.pdf

[5] United States Environmental Protection Agency (EPA). n.d. Climate Change Indicators. Accessed May 2020 at: https://www.epa.gov/climate-indicators/weather-climate

[vi] Chart shows annual average maximum temperature for Livermore (Grid Cell 37.65625-121.78125) under RCP 8.5 (emissions continue to rise strongly through 2050 and plateau around 2100)

[vii] RCP 4.5: Scenario in which emissions peak around 2040 and then decline

[viii] RCP 8.5: Scenario in which emissions continue to rise throughout the 21st century before leveling off

[ix] United States Environmental Protection Agency (EPA). n.d. Climate Change Indicators. Accessed May 2020 at: https://www.epa.gov/climate-indicators/weather-climate

[x] United States Environmental Protection Agency (EPA). n.d. Climate Change Indicators. Accessed May 2020 at: https://www.epa.gov/climate-indicators/weather-climate

[xi] Chart shows annual average maximum temperature for Livermore (Grid Cell 37.65625 -121.78125) under RCP 8.5 (emissions continue to rise strongly through 2050 and plateau around 2100)

[12] United States Environmental Protection Agency (EPA). n.d. Climate Change Indicators. Accessed May 2020 at: https://www.epa.gov/climate-indicators/weather-climate

[13] University of California, Berkeley and California Energy Commission (UC Berkeley & CEC). n.d. Cal-Adapt. Accessed May 2020 at: https://cal-adapt.org/

[14] Average time between extreme events (e.g. "1 in 100 year event")

[15] University of California, Berkeley and California Energy Commission (UC Berkeley & CEC). n.d. Cal-Adapt. Accessed May 2020 at: https://cal-adapt.org/

[16] Chart shows estimated intensity (*Return Level*) of Extreme Precipitation events which are exceeded on average once every 20 years (*Return Period*) for Livermore (Grid Cell 37.65625,-121.78125) under RCP 8.5 emissions scenario. Extreme precipitation events are described as days during a water year (Oct-Sept) with 2-day rainfall totals above an extreme threshold of 1 inch.

[17] California Department of Forestry and Fire Protection (CAL FIRE). 2007. Fire Hazard Severity Zones Maps. Accessed May 2020 at: https://osfm.fire.ca.gov/media/6439/fhszs_map1.jpg
[18] TIME. 2018. "Smoke from California Wildfires Is Reaching the East Coast, Here's What That Means for the Air Near You. Accessed September 2020 at: https://time.com/5364151/california-wildfire- smoke-east-coast/
[19] Centers for Disease Control and Prevention (CDC). 2013. Wildfire Smoke. Accessed September 2020 at: https://www.cdc.gov/disasters/wildfires/smoke.html
[20] Centers for Disease Control and Prevention (CDC). 2013. Wildfire Smoke. Accessed September 2020 at: https://www.cdc.gov/disasters/wildfires/smoke.html
[21] Westerling, Anthony Leroy. 2018. Wildfire Simulations for California's Fourth Climate Assessment: Projecting Changes in Extreme Wildfire Events with a Warming Climate. California's Fourth Climate Change Assessment. University of California, Merced and the California Energy Commission. Accessible at: https://www.energy.ca.gov/sites/default/files/2019- 11/Projections_CCCA4-CEC-2018-014_ADA.pdf
[22] University of California, Berkeley and California Energy Commission (UC Berkeley & CEC). n.d. Cal-Adapt. Accessed May 2020 at: https://cal-adapt.org/
[23] Chart shows annual average area burned for Livermore (Grid Cell 37.65625, -121.78125) under RCP 8.5 emissions scenario.
[24] California Emergency Management Agency and California Natural Resources Agency (CEMA & CNRA). 2012. California Adaptation Planning Guide. Accessible at: http://resources.ca.gov/docs/climate/01APG_Planning_for_Adaptive_Communities.pdf
[25] California Natural Resources Agency (CNRA). 2009. California Climate Adaptation Strategy. Accessible at: http://www.energy.ca.gov/2009publications/CNRA-1000-2009-027/CNRA-1000-2009-027-F.PDF
[26] United Nations Children's Fund (UNICEF). 2011. Children and Climate Change: Children's Vulnerability to Climate Change and Disaster Impacts in East Asia and the Pacific. Accessible at: http://www.unicef.org/media/files/Climate_Change_Regional_Report_14_Nov_final.pdf
[27] United States Bureau of the Census (Census). n.d. QuickFacts. Accessed April 2020 at: https://www.census.gov/quickfacts/fact/table/livermorecitycalifornia,US/PST045219
[28] University of California, Berkeley and California Energy Commission (UC Berkeley & CEC). n.d. Cal-Adapt. Accessed May 2020 at: https://cal-adapt.org/
[29] Caltrans. 2019. Caltrans Climate Change Vulnerability Assessment Summary Report: District 8. https://dot.ca.gov/-/media/dot-media/programs/transportation-planning/documents/2019-climate-change-vulnerability-assessments/ada-remediated/d8-summary-report-a11y.pdf.
[30] Caltrans. 2019. Caltrans Climate Change Vulnerability Assessment Summary Report: District 8. https://dot.ca.gov/-/media/dot-media/programs/transportation-planning/documents/2019-climate-change-vulnerability-assessments/ada-remediated/d8-summary-report-a11y.pdf.
[31] California Natural Resources Agency (CNRA). 2009. California Climate Adaptation Strategy. Accessible at: http://www.energy.ca.gov/2009publications/CNRA-1000-2009-027/CNRA-1000-2009-027-F.PDF
[32] California Water Service Company (Cal Water). 2016. 2015 Urban Water Management Plan. Accessible at: https://www.calwater.com/docs/uwmp2015/liv/2015_Urban_Water_Management_Plan_Final_ (LIV).pdf
[33] Zone 7 Water Agency (Zone 7). 2019. Annual Report for the Sustainable Groundwater Management Program, 2018 Water Year, Livermore Valley Groundwater Basin. Accessible at: file:///C:/Users/cbobroff/Downloads/GMP2018AnnRpt-FinalRev.pdf
[34] California Emergency Management Agency and California Natural Resources Agency (CEMA & CNRA). 2012. California Adaptation Planning Guide. Accessible at: http://resources.ca.gov/docs/climate/01APG_Planning_for_Adaptive_Communities.pdf
[35] Maizlish N, English D, Chan J, Dervin K, English P. 2017. Climate Change and Health Profile Report: Alameda County. Sacramento, CA: Office of Health Equity, California Department of Public Health. Accessed May 2020 at: https://www.cdph.ca.gov/Programs/OHE/CDPH%20Document%20Library/CHPRs/CHPR001Alam eda_County2-23-17.pdf

[36] Maizlish N, English D, Chan J, Dervin K, English P. 2017. Climate Change and Health Profile Report: Alameda County. Sacramento, CA: Office of Health Equity, California Department of Public Health. Accessed May 2020 at: https://www.cdph.ca.gov/Programs/OHE/CDPH%20Document%20Library/CHPRs/CHPR001Alam eda_County2-23-17.pdf
[37] Census tract defined by the Internal Revenue Service (IRS) as "economically-distressed community where new investments, under certain conditions, may be eligible for preferential tax treatment."
[38] State of California. n.d. California Opportunity Zones. Accessed May 2020 at: https://opzones.ca.gov/oz- map/
[39] A geographical unit used by the United States Census Bureau which is between the Census Tract and the Census Block. It is the smallest geographical unit for which the bureau publishes sample data. Typically, Block Groups have a population of 600 to 3,000 people.
[40] State of California Department of Water Resources (DWR). n.d. DAC Mapping Tool. Accessed May 2020 at: https://gis.water.ca.gov/app/dacs/
[41] United Nations Children's Fund (UNICEF). 2011. Children and Climate Change: Children's Vulnerability to Climate Change and Disaster Impacts in East Asia and the Pacific. Accessible at: http://www.unicef.org/media/files/Climate_Change_Regional_Report_14_Nov_final.pdf
[42] World Health Organization (WHO). 2018. Climate Change and Health. Accessed May 2020 at: https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health
[43] Thach, Liz. 2018. "The Amazing Resilience of Wine Grape Vineyards." Wine Economics and Poliy 7(1): 1-2.
[44] Madhusoodanan, Jyoti. 2021. "Wildfires pos a burning problem for wines and winemakers." PNAS 118(34).
[45] California Emergency Management Agency and California Natural Resources Agency (CEMA & CNRA). 2012. California Adaptation Planning Guide. Accessible at: http://resources.ca.gov/docs/climate/01APG_Planning_for_Adaptive_Communities.pdf
[46] California Emergency Management Agency and California Natural Resources Agency (CEMA & CNRA). 2012. California Adaptation Planning Guide. Accessible at: http://resources.ca.gov/docs/climate/01APG_Planning_for_Adaptive_Communities.pdf
[47] California Emergency Management Agency and California Natural Resources Agency (CEMA & CNRA). 2012. California Adaptation Planning Guide. Accessible at: http://resources.ca.gov/docs/climate/01APG_Planning_for_Adaptive_Communities.pdf
[48] Intergovernmental Panel on Climate Change (IPCC). (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp. Accessible at: https://www.ipcc.ch/
[49] Caltrans. 2019. Caltrans Climate Change Vulnerability Assessment Summary Report: District 8. https://dot.ca.gov/-/media/dot-media/programs/transportation-planning/documents/2019-climate-change-vulnerability-assessments/ada-remediated/d8-summary-report-a11y.pdf
[50] Caltrans. 2019. Caltrans Climate Change Vulnerability Assessment Summary Report: District 8. https://dot.ca.gov/-/media/dot-media/programs/transportation-planning/documents/2019-climate-change-vulnerability-assessments/ada-remediated/d8-summary-report-a11y.pdf