APPENDIX B

Vulnerability Analysis

Livermore Climate Action Plan Update

prepared for

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prepared with the assistance of

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Table of Contents

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Subject: City of Livermore Climate Action Plan Update, Vulnerability Analysis

Executive Summary

This report provides a climate change vulnerability analysis for the City of Livermore which evaluates the potential impacts of climate change on community assets and populations. The most recent report from the Intergovernmental Panel on Climate Change (IPCC), the Fifth Assessment Report, defines vulnerability as “the propensity or predisposition to be adversely affected.” It adds that vulnerability “encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt” (IPCC, 2013). Understanding the vulnerabilities that the City may face due to climate change provides a foundation to prepare the Climate Action Plan Update (CAP) that includes climate adaptation programs and policies to increase Livermore’s resilience to climate change.

This analysis includes the following components:

- Objectives of the analysis
- Methodology used
- Vulnerability Components
    1. Exposure to changes in temperature, precipitation, and wildfire
    2. Sensitivity of community structures, community functions, and populations to exposures
    3. Potential Impacts of each exposure on community structures, community function, and populations
    4. Adaptive Capacity – Livermore’s ability to cope with climate change impacts
    5. Risk and Onset – the likeliness and expected timing of events

The major findings of this analysis are:

- 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
- Livermore has a low to medium adaptive capacity rating due to the variety of sustainability and adaptation measures developed yet low implementation rate of these measures.

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 (CEMA & CNRA 2020) 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 assessment, the years 1990, 2030, 2050, and 2100[1] were examined. The year 1990 provides recorded historic data, while the years 2030, 2050 and 2100 present projections of expected change in the future. The 2030 future year was selected to examine near-term climate impacts, and the years 2050 and 2100 serve as benchmark years to measure rates of change over time.

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

[1] When 2100 projections were not available, 2099 projections were used (e.g. Cal-Adapt projections)

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. Technical Appendix 1. Cal-Adapt provides a detailed explanation of the tool and how it was used for this analysis. As previously introduced, the California Adaptation Planning Guide defines five components to be analyzed in a vulnerability assessment. Each vulnerability component is analyzed with respect to Livermore in the proceeding sections of this memo.

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
Changed temperature and/or precipitation patterns	Changed seasonal patterns
Increased temperature	Heat waves

[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.

Increased temperature and/or changed precipitation	Intense rainstorms
Wildfire and/or increased precipitation	Landslides
Increased temperature and/or reduced precipitation	Drought, wildfire
Source: Modified from CEMA & CNRA 2012	

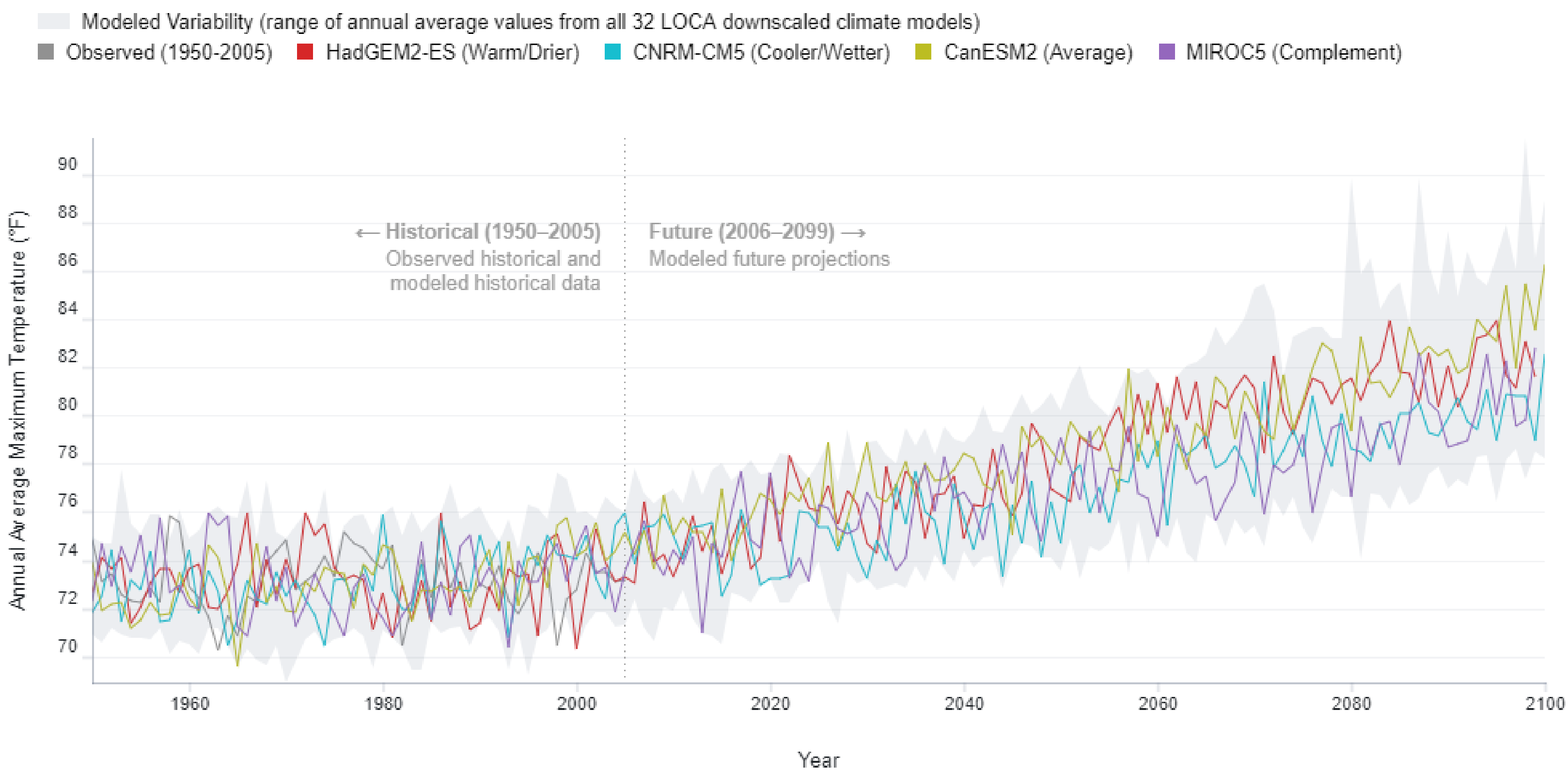
Temperature

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 (EPA n.d.) 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 (UC Berkeley & CEC n.d.) Below is a summary of key observations from Figure 1.

- **Projected temperature trends** in Livermore display consistent increases over time. Compared to 1990, annual average maximum temperatures in Livermore are expected to rise between 4.5°F and 8.7°F by the end of the century, depending on the GHG emissions scenario (UC Berkeley & CEC n.d.)
- **Annual average minimum temperatures** are expected to rise between 3.2°F and 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[4]



[4] 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)

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

- **Annual number of heat waves,** defined as four or more days over 102.7°F, is projected to increase from 0 to 3 heat waves by the end of the century, based on RCP 8.5 (UC Berkeley & CEC n.d.)
- **Annual number of extreme heat days,** defined as temperatures greater than 102.7°F, is projected to increase from 4 in 1990 to about 25 by the end of the century, based on RCP 8.5 (UC Berkeley & CEC n.d.)
- **Warm nights,** described as nights when daily minimum temperature is above the extreme heat threshold of 62.1°F, are expected to increase substantially from 11 in 1990 to about 101 by 2100 based on RCP 8.5 (UC Berkeley & CEC n.d.)
- **Longer heat waves** could occur due to the combination of temperature changes. Between 1950 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 just over 7 days under RCP 8.5 (UC Berkeley & CEC n.d.)

Table 2 Temperature Changes

Effect	1990 (Observed)	2030 (RCP 4.5 | RCP 8.5)	2050 (RCP 4.5 | RCP 8.5)	2099 (RCP 4.5 | RCP 8.5)
Annual average maximum temperature	73°F	76.1°F | 75.9°F	77.1°F | 77.1°F	77.5°F | 81.7°F
Annual average minimum temperature	47.1°F	48.1°F | 48.6°F	49.4°F | 50.3°F	50.3°F | 55.1°F
Average extreme heat days per year[1]	4	11 | 11	17 | 13	13 | 25
Average warm nights per year[2]	11	18 | 15	18 | 33	42 | 101
Average heat waves per year[3]	0	0.8 | 1.0	2.8 | 0.8	0.8 | 3.0
Max duration of heat wave (days)[4]	2	4.0 | 5.3	7.5 | 3.8	4.3 | 7.3

[1] Number of days in a year when daily maximum temperature is greater than heat threshold of 102.7° F

[2] Number of nights in a year when daily minimum temperature is above extreme heat threshold of 62.1° F

[3] Number of 4-day heat waves (daily maximum temperatures above extreme heat threshold of 102.7° F) by year

[4] Longest stretch of consecutive extreme heat (> 102.7° F) days by year

Source: UC Berkeley & CEC n.d.

Precipitation

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

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

Total annual precipitation in the United States and globally has increased since 1901 (EPA n.d.) However, shifts in weather patterns have led to substantial decreases in precipitation in certain locations, such as the Southwest of the United States (EPA n.d.)

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 by the end of the century, based on both RCP 4.5 and RCP 8.5 (UC Berkeley & CEC n.d.)
- **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 1 inch, is projected to increase from 3 in 1990 to about 5 mid-century, before dropping to 0 by the end of the century, based on RCP 8.5 (UC Berkeley & CEC n.d.)
- **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 1 inch, is projected to increase slightly midcentury from 1 to 1.5 and decrease to 0 at the end of the century, based on RCP 8.5 (UC Berkeley & CEC n.d.)

Figure 2 Historical and Projected Annual Average Precipitation in Livermore[7]

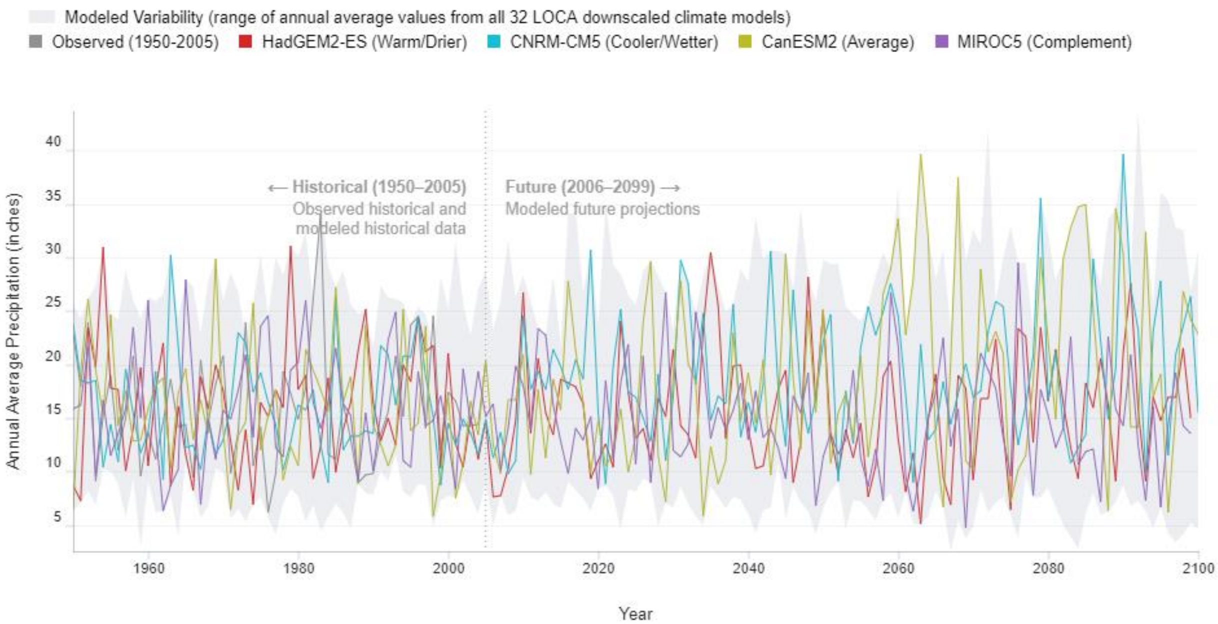


Table 3 Precipitation Changes

Effect	1990 (Observed)	2030 (RCP 4.5 | RCP 8.5)	2050 (RCP 4.5 | RCP 8.5)	2099 (RCP 4.5 | RCP 8.5)
Annual average precipitation (inches)	9.7	15.9 | 17.3	23.2 | 21.0	17.6 | 19.8
Extreme precipitation events by water year[1]	3	5 | 5	7 | 5	0 | 0
Max duration of consecutive extreme precipitation events by year[2]	1	2 | 1.3	2.8 | 1.5	0 | 0

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

[2] Longest stretch of consecutive days in a water year (Oct-Sep) with 2-day rainfall totals above extreme threshold of 1 inch

Source: UC Berkeley & CEC n.d.

Precipitation Extremes

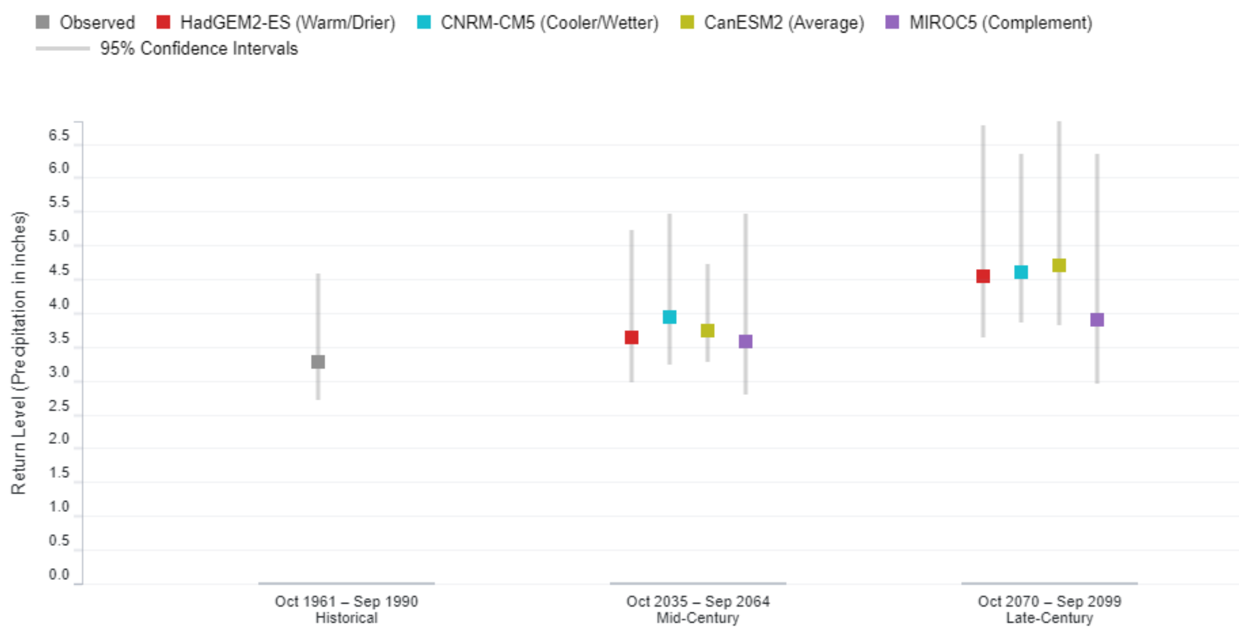
A warming climate is likely to influence the frequency and intensity of precipitation events. Heavy precipitation events have been on the rise in the United States since the 1980s. Across the country, nine of the top ten years for extreme one-day precipitation events have occurred since 1990 with the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

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

[7] 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)

precipitation event projections, with some models projecting little to no change while others project potentially increased intensity (UC Berkeley & CEC n.d.) These projections further vary depending on the return period[8] selected. Based on the 20 year return period select 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 4.71 inches of precipitation compared to 3.28 historically (1961 – 1990), based on RCP 8.5 (UC Berkeley & CEC n.d.) 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[9]



Wildfire

Wildfire is 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 vegetation fuels. Hot dry spells create the highest fire risk and increased temperatures may intensify wildfire danger by warming and drying out vegetation.

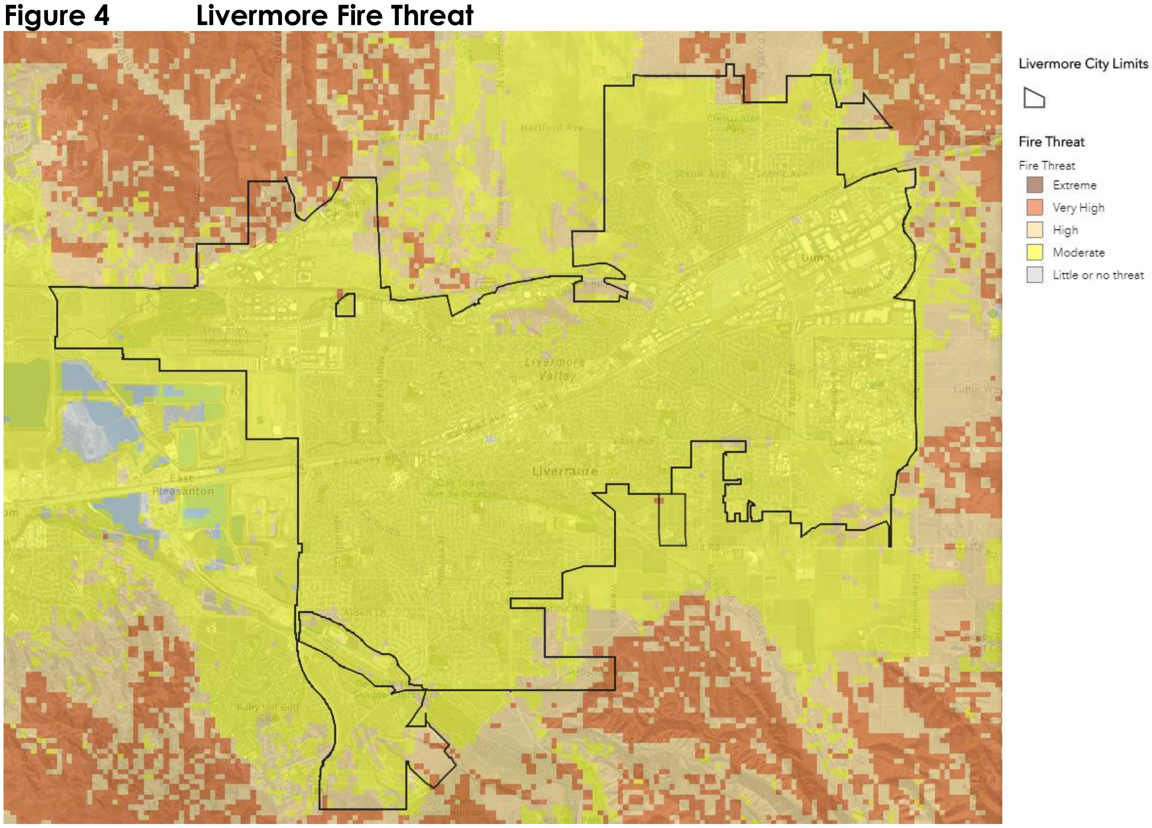
[8] Average time between extreme events (e.g. "1 in 100 year event")

[9] 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 0.67 inches.

The California Department of Forestry and Fire Protection (CAL FIRE) has determined that there are no Very High Fire Hazard Severity Zones in Livermore. 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. Figure 4 shows that 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.

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 (TIME 2018). Wildfire smoke is comprised of air pollutants including particulate matter, known to be a public health risk (CDC 2013). 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 (CDC 2013). The increasing number and extent of wildfires in the Western United States may pose a substantial risk to public health in Livermore.

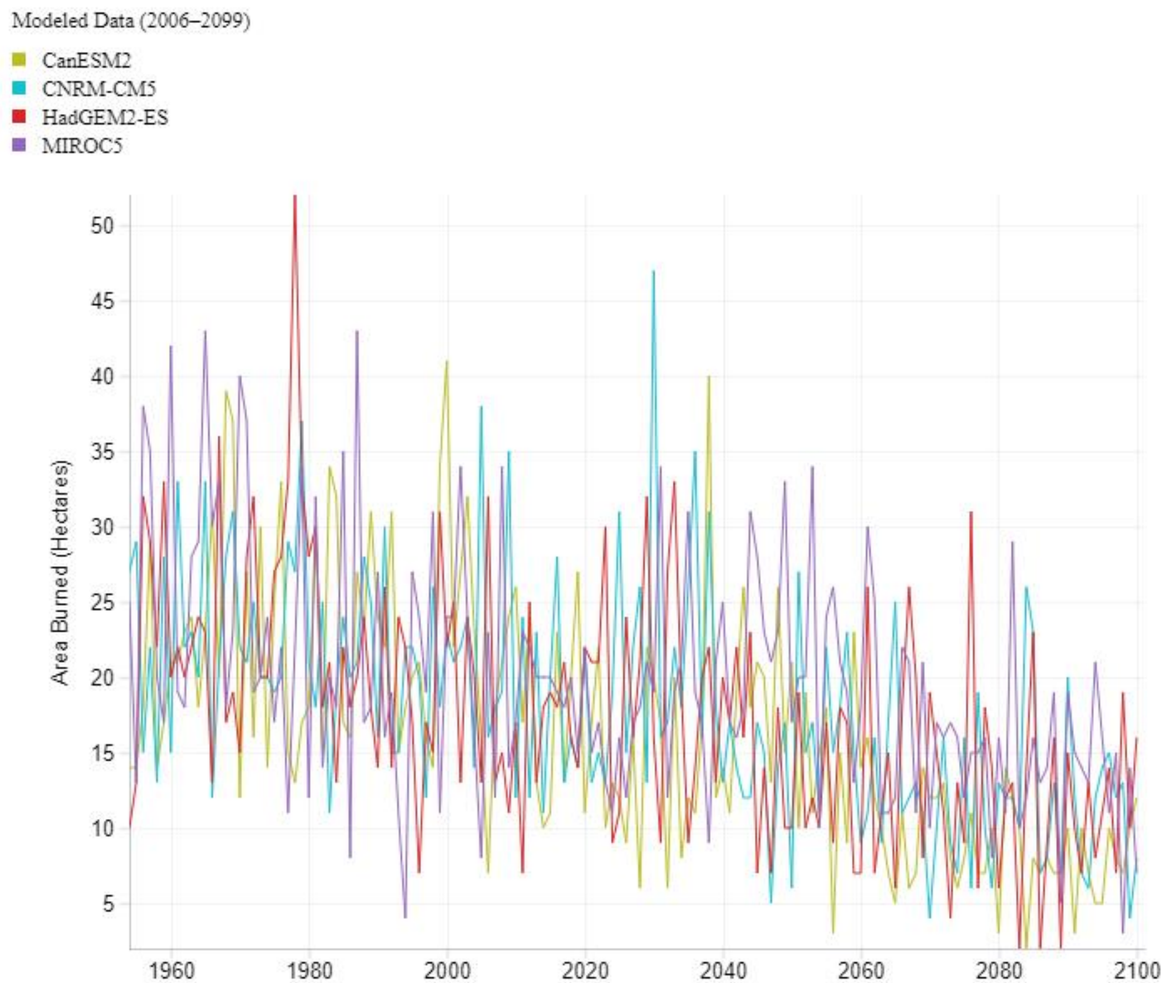
Figure 4 Livermore Fire Threat



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community | Esri, NASA, NGA, USGS, FEMA | Esri, HERE, Garmin, SafeGraph, INCREMENT P, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, US Census Bureau, USDA | California Department of Forestry and Fire Protection | Alameda County Registrar of Voters, 2011

Cal-Adapt fire hazard maps project a decrease in acres burned by the end of the century (Figure 5). Average annual hectares burned is projected to decrease from 19.3 in 2020 to approximately 9.5 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 (Westerling 2018). 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 (UC Berkeley & CEC n.d.)

Figure 5 Annual Average of Area Burned in Livermore[10]



Vulnerability Component 2 - **Sensitivity**

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[10] Chart shows annual average area burned for Livermore (Grid Cell 37.65625, -121.78125) under RCP 8.5 emissions scenario.

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 (CEMA & CNRA 2020). 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 91,411 (City of Livermore n.d.). 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).

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

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

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

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.

Populations

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

- Seniors
- 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

Vulnerable populations are more susceptible than others to climate related exposures such as people who 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 (CNRA 2009). According to the Census, Livermore residents under 65 that reported no insurance was 4.1% and the proportion of people living in poverty is about 4.6%.

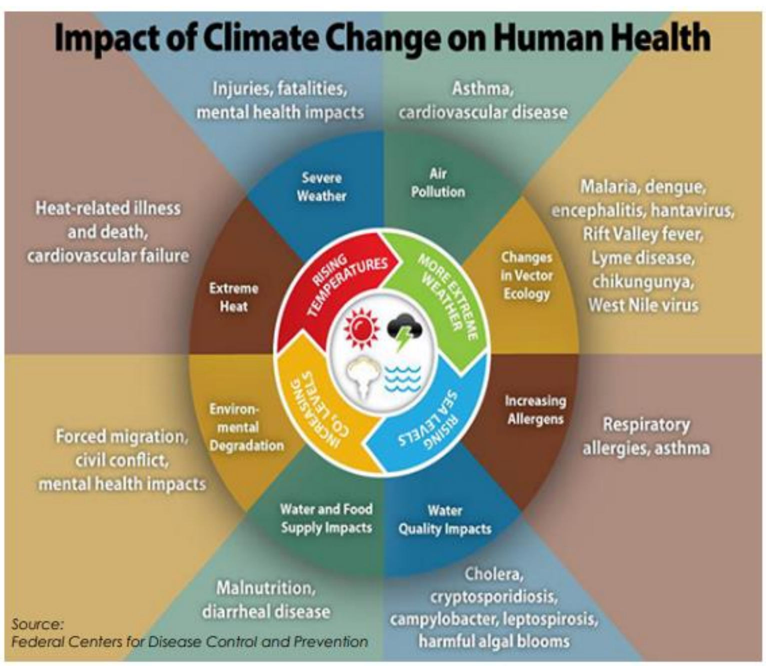
Moreover, the Census estimates that in 2019, 12.9% of the population was 65 years or older and 23.5% of the population was under the age of 18. These individuals may face unique impacts related to climate change. According to the findings from a United Nations Children's Fund (UNICEF) study, children 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 (UNICEF 2011).

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 (Census n.d.)

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



Temperature

As describe 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 5.3°F and 9.3°F by the end of the century (UC Berkeley & CEC n.d.) 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

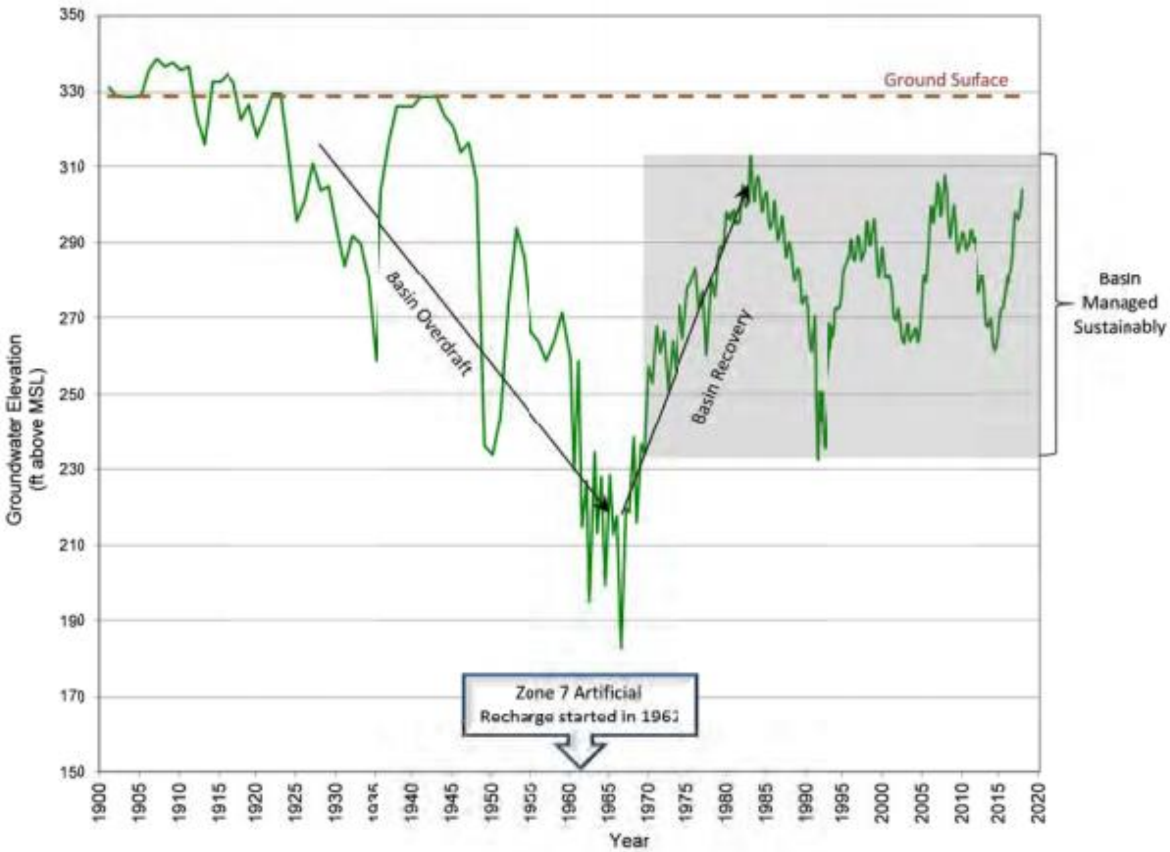
Community infrastructure and the City's transportation system may be impacted by increased temperatures. Long periods of intense heat may result in increased use of electricity for home cooling purposes that could tax the system and result in electricity restrictions or black-outs. In addition, cyclists 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 (CNRA 2009). Increased temperatures could therefore result in decreased potable water supply for the City which relies on local groundwater, surface water, and imported water (Cal Water 2016). 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 (Zone 7 2019). 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.

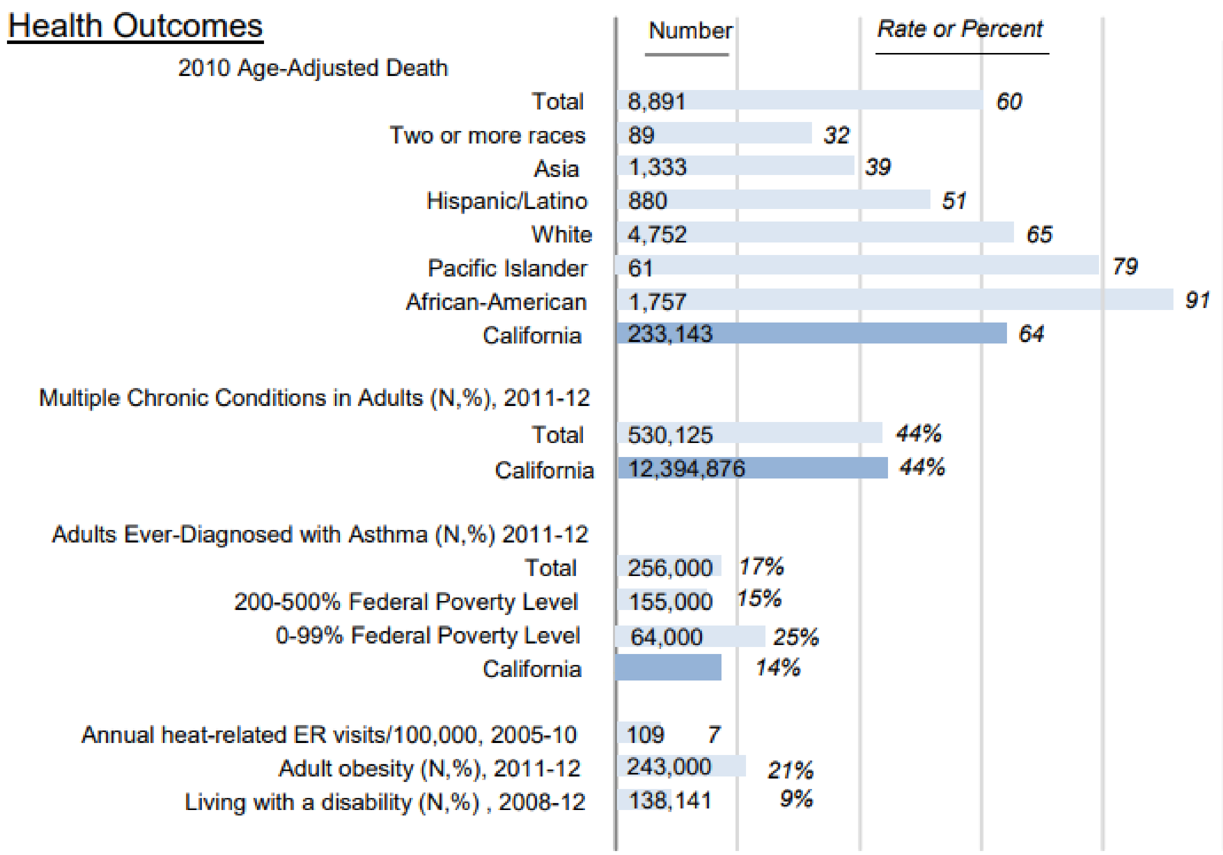
Figure 7 Bernal Key Well Hydrograph



Vulnerable Populations – Potential Temperature Impacts

Public health may be negatively impacted by a changing climate as a result of changing environmental conditions (e.g., extreme weather events; changes in temperature and rainfall that decrease water supply; worsening air quality; and increases in allergens and air pollutants). This could lead to hazardous conditions, such as heat stroke and respiratory ailments for individuals with disabilities or compromised immune systems, children playing outdoors, tourists, farm workers and others working outdoors. Potential impacts to public health 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 (CEMA & CNRA 2012). 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 (Maizlish et al. 2017). 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 (4.1%) and living in poverty (4.6%) are particularly vulnerable. Figure 9 displays the profile of social vulnerabilities and climate risks in Alameda County (Maizlish et al. 2017). There is currently one census tract within Livermore (Census Tract 4514.04, Figure **10**) that is designated as an Opportunity Zone[11] (CA.gov) 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 (State of California n.d.) Additionally, three block groups have been identified as disadvantaged communities by the State, as shown in Figure 11 (DWR n.d.) 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



* Groups with less than 20 observations are not presented.

[11] 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.”

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

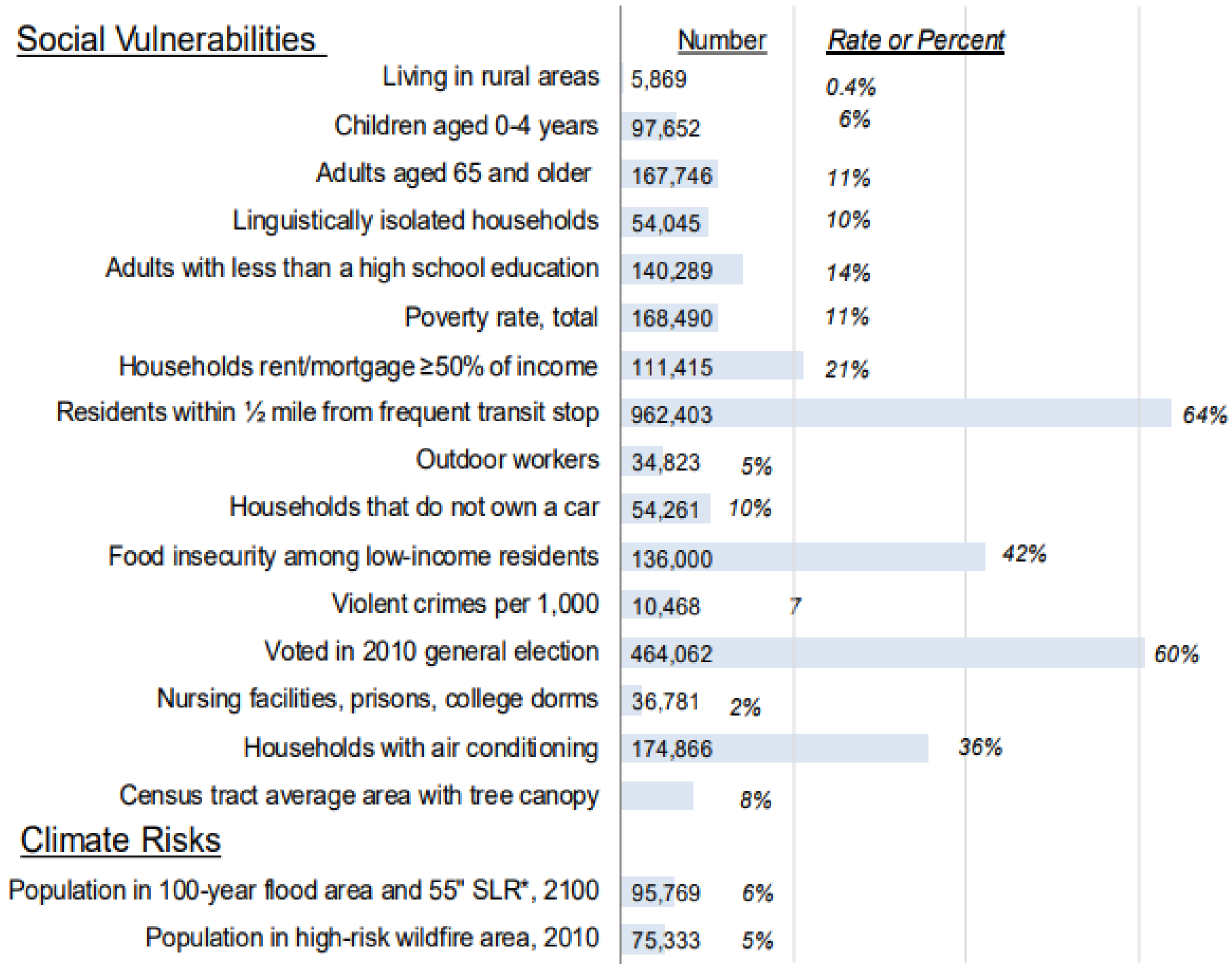


Figure 10 Opportunity Zone

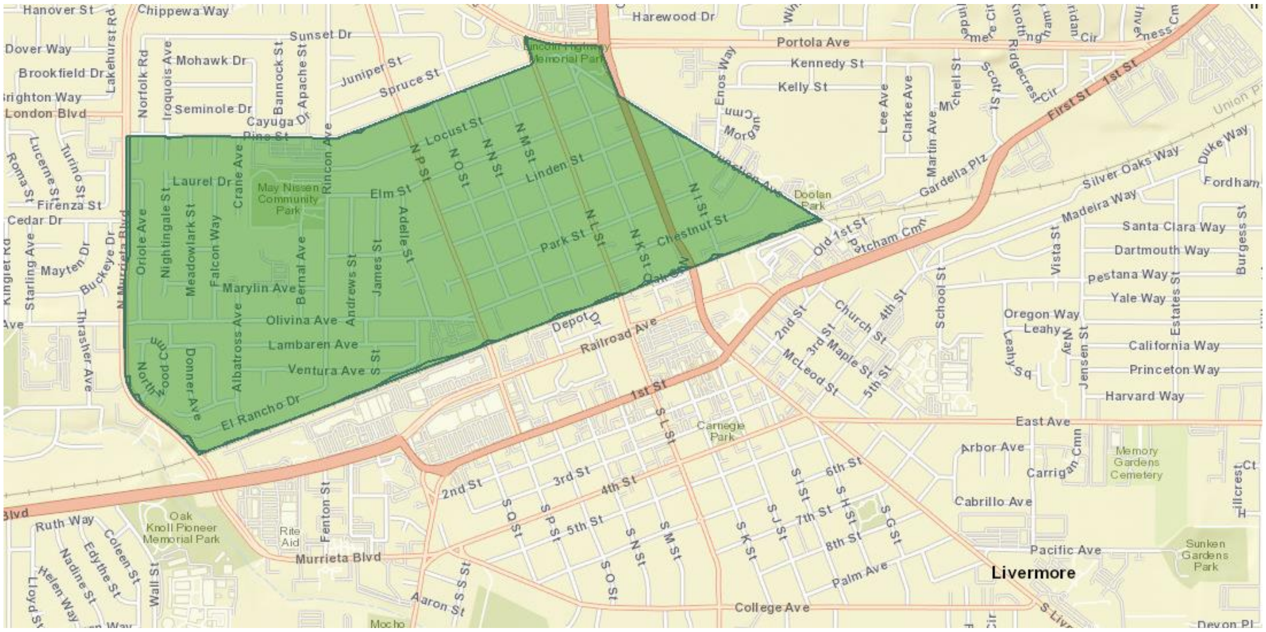


Figure 11 Disadvantaged Communities

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 (UNICEF 2011). 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 (WHO 2018). 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.

Precipitation

The precipitation projections show variability over time. Periods of decreased precipitation may result in more frequent and persistent droughts, especially in combination with increased temperatures which would 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

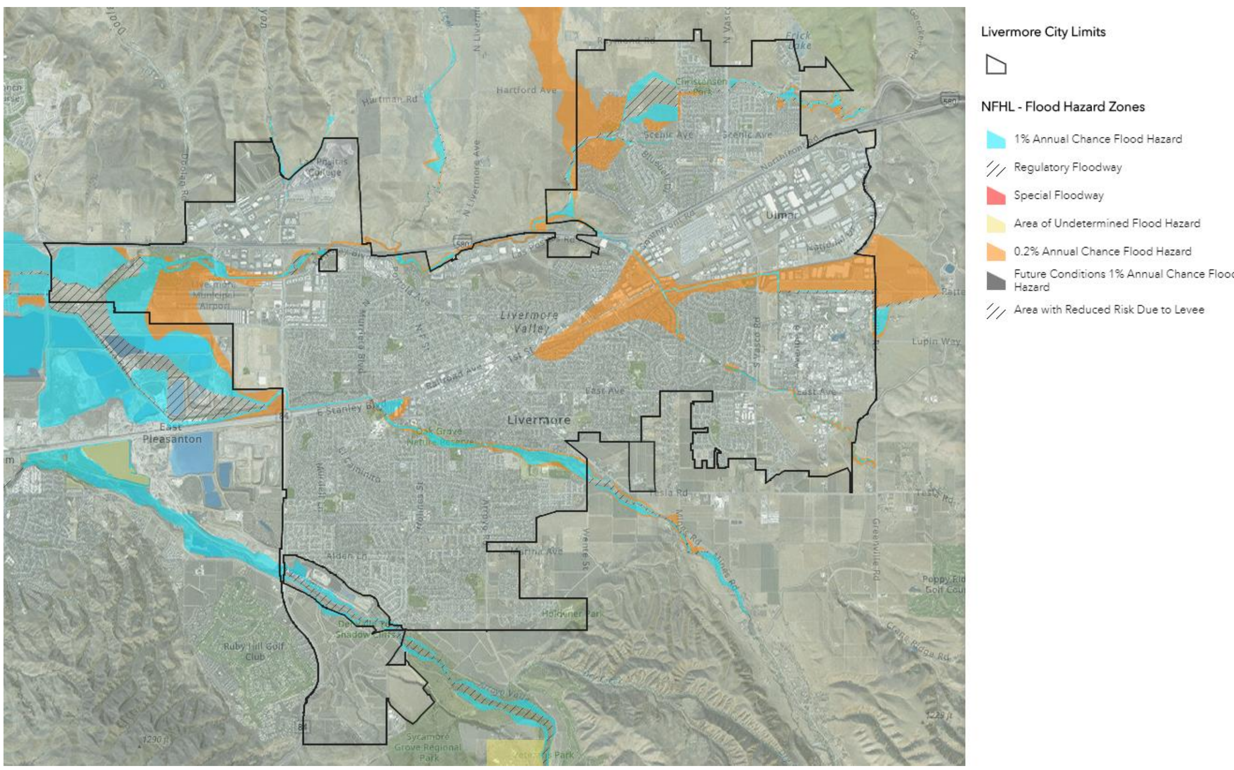
Increased flooding may result in water and wastewater treatment plants being unable to handle increases in intense rainfall events and associated runoff. This could impede the proper functioning of on-site septic systems or overwhelm sewers and centralized sewage treatment plants. As a result, untreated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

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.

Figure 12 Livermore Flood Hazard Zones



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community | Esri, NASA, NGA, USGS, FEMA | Esri Community Maps Contributors, Esri, HERE, Garmin, SafeGraph, INCREMENT P, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, US Census Bureau, USDA | Alameda County Registrar of Voters, 2011

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. Public health may also be indirectly impacted by reduced access to emergency response and health centers resulting from infrastructure impacts discussed above.

Wildfire

Community Structures – Potential Wildfire Impacts

The Cal-Adapt projections for wildfire risk in Livermore is projected to decrease over this century. Because of this, the direct impact of wildfire to community structures in the City are expected to remain low.

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.

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, and outdoor workers are likely to be impacted most by these secondary impacts.

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 (CEMA & CNRA 2012). 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
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
2005 GHG inventory Report	2007
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, however, most of these 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.

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 (CEMA & CNRA 2012). 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, IPCC 2007		

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

Table ***5*** and secondary impacts explored in the Exposure section of this assessment (Table 6). Expected near-term secondary climate impacts to Livermore include changed seasonal patterns, heat waves, and intense rainstorms. 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

Conclusion

Climate change will affect populations throughout the state, nation, and world differently based on their actual and perceived vulnerabilities. This assessment serves as an assessment to better understanding Livermore's vulnerability to climate change impacts and inform the development of additional adaptive measures. The major findings of this analysis are:

- 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
- Livermore has a low to medium adaptive capacity rating due to the variety of sustainability and adaptation measures developed yet low implementation rate of these measures

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 vulnerable communities such as in the opportunity zone and disadvantaged communities highlighted in Figure 10 and Figure 11. Some 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

- Provide infrastructure improvements such as cool pavements, green roofs, and planting trees and vegetation in disadvantaged communities
- Communicate 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
- Incentivize and/or require the installation of heat pump HVAC units which provide energy efficient heating and cooling
- Increase distributed energy resources and therefore electricity security through the implementation of microgrids and battery storage
- Strengthen water supply systems to meet forecasted demands of residents, businesses, and visitors as variability in water resources increases

The Climate Action Plan will provide the framework for Livermore to prepare for and adapt to the impacts of climate change that may affect the city and focus efforts on vulnerable populations, structures, and functions to minimize the residual effects of climate change and prepare Livermore for long term climate resiliency. The CAP 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.

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