San Bernardino County Vulnerability Assessment

INTRODUCTION

San Bernardino County is actively seeking to reduce greenhouse gas emissions, as described in its *Regional Greenhouse Gas Reduction Plan*[1]. At the same time, action must be taken to recognize and prepare for the impacts that may arise from a changing climate. Climate change may increase the frequency or severity of eight primary hazards in the County: extreme heat, wildfire, drought, flooding, air quality and other health and ecological hazards, severe weather, extreme wind, and mud- and landslides.

This report represents an assessment of these hazards on communities, assets, and ecosystems within the County. The first section of the report, *Climate Change in the County,* provides information on the scientific projections for the climate hazards in the County. The section *Priority Vulnerability Sectors* discusses potential impact these hazards might have on priority sectors in the County, such as disadvantaged communities, natural resources, and transportation and infrastructure. This vulnerability assessment provides information to develop possible adaptation strategies for addressing these impacts. A *Technical Appendix* provides further information relevant to each section.

The County will integrate the findings and recommendations from this report into the Countywide Plan, ensuring that both greenhouse gas mitigation and climate resilience will be core principles of future growth and development.

Greenhouse Gas Mitigation, Climate Change Adaptation and Climate Resilience: How Do They Relate?

Greenhouse gas mitigation *strategies combat climate change by reducing greenhouse gas emissions.*

Climate adaptation *strategies reduce the vulnerability of life, property, and natural resources to climate change effects.*

Climate resilience *refers to the ability of an asset, system, or organization to withstand the effects of climate change. Adaptation strategies are usually implemented with the goal of increasing climate resilience.*

[1] ICF International. 2014. San Bernardino County Regional Greenhouse Gas Reduction Plan. Final. March. (ICF 00543.12.) San Francisco, CA. Prepared for San Bernardino Associated Governments, San Bernardino, California. http://gosbcta.com/plans-projects/plans-greenhouse.html

SUMMARY OF KEY FINDINGS

The major findings of the vulnerability assessment are briefly summarized below. In the sections that follow, San Bernardino County discusses our approach, and findings regarding climate exposure and associated vulnerability in more detail.

San Bernardino County is projected to experience major increases in extreme heat days, particularly in the southeastern and central portions of the County. The parts of the county near the Colorado River and sections of the Mountain region – including the area near Big Bear Lake – could experience as many as 50 additional extreme heat days per year by mid-century. Furthermore, all areas of the county are projected to experience *at least* 27 additional extreme heat days (defined as days exceeding the 95th percentile of daily maximum temperatures over the historical baseline time period between 1976 and 2005).

This increase in extreme heat could particularly affect the densely populated Valley region of the County—including Rancho Cucamonga, the City of San Bernardino, and Ontario. These areas are not only projected to experience large increases in heat, but they also have relatively high social vulnerability. More frequent and intense heat in San Bernardino County also has the potential to negatively affect transportation and electric infrastructure, agricultural production, and heat-sensitive biological resources.

Wildfire risk is expected to continue to increase through end of century as a result of warmer temperatures, more frequent drought and an expanding urban-wildlife interface. In particular, the Mountain region and the elevated forested parts of the Valley region – including Rancho Cucamonga, Lake Arrowhead, and the I-15 corridor – are projected to experience up to 61 hectares burned (per 36 km^2 model grid cell) annually by mid-century (Westerling, 2018).

Increased wildfire risk could adversely affect most vulnerable populations included in this analysis; populations with reduced mobility may have a more difficult experience evacuating, and individuals with medical conditions may be especially vulnerable to wildfire smoke. Wildfire can also damage energy transmission infrastructure, power plants, transportation infrastructure such as pavement and road signals, and vital natural resources such as Joshua trees, and pinyon-juniper woodlands.

Due to climate change, droughts are expected to become more frequent and intense in San Bernardino County and, more broadly, throughout southern California by mid-century. Areas in San Bernardino County that are likely to be impacted by drought include those projected to experience more intense heat over this century. The Valley region and Victor Valley area – communities that are projected to experience 35 to 45 additional extreme heat days by mid-century – also have communities with high social vulnerability according to Cal-OES' social vulnerability index.

Drought may additionally constrain water resources, impacting availability for households and natural resources. The City of Ontario, for example, imports most of their water from upstate, so the effects of drought and decreased snowpack can have a significant effect on their water supply. Water shortages can particularly stress low-income households, which end up spending a greater percentage of their earnings on basic water service during shortages. Drought can also result in costly damages to the agricultural industry and harm water-reliant biological resources, such as marshes, conifer forests, pinyon-juniper woodlands, and grasslands.

Current FEMA 100- and 500-year floodplains will continue to be vulnerable to floods in the future, and climate change may expand the area vulnerable to flooding because heavy precipitation events are projected to become more frequent and severe. These current FEMA floodplains include areas near Barstow, Victorville, Twentynine Palms, Rancho Cucamonga, Ontario, and the City of San Bernardino.

Flooding could negatively affect communities in many ways and have a particularly negative impact on vulnerable communities such as homeless persons, individuals with disabilities, senior citizens living alone, and senior care centers. Flooding may also damage energy transmission and transportation infrastructure (such as bridges), affecting not only the assets themselves, but also more rural populations who may rely on this infrastructure for mobility. Rural populations face further dangers from flooding due to the potential of flash flooding in remote desert parts of the County.

Climate changes such as increasing air temperature and wildfire frequency may exacerbate air quality issues. Due to its geography downwind of the Los Angeles metropolitan area and constricted by high mountain ranges, the Valley region in San Bernardino County already experiences some of the worst air quality problems in the country (American Lung Association, 2019).

Poor air quality, and the impact it can have on human health, is disproportionately felt by disadvantaged communities. In the County, valley areas that are already susceptible to relatively worse air quality – such as Ontario and the City of San Bernardino as well as Barstow and Victorville – are also areas that have higher relative social vulnerability.

Extreme storms are projected to become more intense and frequent by mid-century as a result of climate change. Severe weather could have a particularly negative impact on communities with limited resources or mobility, including homeless persons, individuals with disabilities or existing medical conditions, migrant workers, and senior citizens.

Social vulnerability could exacerbate the impact of severe weather on populations. The Valley region of the County – home to the City of San Bernardino, Rancho Cucamonga, Ontario, and others – and western Victorville and Barstow have communities with higher relative social vulnerability. Severe weather can also impact transportation infrastructure, electricity resources, and natural resources.

Within San Bernardino County there are vulnerable populations and assets in landslide-prone areas that could be differentially impacted by these hazards. Landslide susceptibility is currently highest in mountainous terrain, such as the San Bernardino, San Gabriel and San Jacinto Mountains, where complex geology and fault zones intersect steep terrain prone to wildfire risk and heavy precipitation events. Mountains and hills within the Mojave Desert also have high landslide risks.

Landslides damage not only residences, but also transportation infrastructure, energy transmission infrastructure, communication services, and electrical services. While the most landslide-prone areas are sparsely populated, these areas may have populations with little access to emergency services or limited capacity for mobility, which could exacerbate consequences from landslides.

PROJECTED CHANGES IN SAN BERNARDINO COUNTY'S CLIMATE

To prepare this *Vulnerability Assessment*, San Bernardino County evaluated exposure to eight climate hazards that are projected to increase in frequency and/or severity due to climate change. San Bernardino County identified the following hazards as the primary climate-related hazards[2] in the subregion:

- Extreme heat
- Wildfire
- Drought
- Flooding
- Air quality, human health and ecological hazards

[2] Although earthquakes pose significant risks to Southern California, this assessment focuses on climate-related hazards and thus does not include earthquake impacts.

- Severe weather
- Extreme wind
- Mudslides and landslides

This section of the report discusses how these hazards are projected to evolve with climate change through mid-century and provides crucial context for effective adaptation and resilience planning.

The San Bernardino County Vulnerability Assessment evaluates the County's potential exposure and vulnerability to climate hazards, such as extreme heat, wildfires and reduced air quality. While climate change may worsen the severity of these hazards in the future, in reality climate hazards already present risks to the County in the present day. In this way, the vulnerability assessment helps to plan for the kinds of climate impacts that San Bernardino County already experiences and contends with. Ultimately, actions taken to increase adaptive capacity to climate hazards will increase resiliency, economic vitality and community wellbeing in both the present and future.

To evaluate climate change-related hazards, San Bernardino County used recently updated climate projection datasets and state-of-the-art research prepared under California's 4th Climate Change Assessment. The climate projections used for this report focus on how climate conditions change from a recent baseline time period (1976 to 2005) to mid-century (2036 to 2065). The County opted to focus on the mid-century timeframe because (a) it is more aligned with planning horizons than the end-of-century timeframe, and (b) there is a significant amount of uncertainty associated with the end-of-century timeframe, not only in the climate projections themselves but also demographics, technology, land use, and other factors that could affect impacts and vulnerability. However, this report does provide end-of-century projections where appropriate to demonstrate potential high-end climate change in the longer term. Projections assume that global emissions follow current trends, which result in high greenhouse gas concentrations (and therefore greater climate impacts) through the 21st century. Climate projections and historical observations are maintained by the state Cal-Adapt database. For more information on the methodologies and underlying datasets, please see the Technical Appendix*, Data Sources and Methodology* sections.

EXTREME HEAT

San Bernardino County features a combination of climate types, ranging from hot summer Mediterranean and hot semi-arid in the Valley region to hot desert in many other locations. In contrast, the relatively humid San Bernardino Mountains experience a warm-summer Mediterranean climate and the highest elevations feature an alpine continental climate. Overall, the entire County is susceptible to extremely hot and dry summers. Southern California has also recently experienced record-breaking heat waves, with two heat wave events in July 2018 alone (CBS Local, 2018, CBS News, 2018) that resulted in six deaths in nearby Riverside County (KTLA, 2018). In June 2019, a Southern California heat wave drove temperatures as high as 107 degrees Fahrenheit in the city of Ontario, 18 degrees higher than the previous record of 89 degrees Fahrenheit set in 2018 (CBS Local, 2019).

Looking forward, temperatures are expected to increase steadily as a result of climate change (Bedsworth et al., 2018). Specific projected changes within the recent scientific literature include:

- Within the County, the annual average maximum temperature is projected to increase by 5-8°F through mid-century and 8-14°F through late 21st century relative to the historical baseline period (1976-2005), with the greatest temperature change in arid eastern portions of the County (Hall et al., 2018; Hopkins et al., 2018).
- The average hottest day of the year is expected to increase approximately 8-11°F by the end of century (Hall et al., 2018; Hopkins et al., 2018).
- At the same time, low temperature extremes are expected to warm through mid-century. For example, the number of days with freezing temperatures in Victorville are projected to decrease by roughly 80% through mid-century compared to the baseline time period (1980-2000) (Sun et al., 2015).

Stress from extreme heat can adversely affect San Bernardino County in several ways. For example, there could be challenges meeting peak energy needs as demand from air conditioning increases while efficiency of energy transmission decreases. Extreme heat causes negative health impacts on outdoor workers, seasonal residents and migrant workers, homeless persons, individuals with existing medical conditions, and senior citizens. Higher temperatures could also negatively affect air quality, agriculture, and water services.

For the vulnerability assessment, San Bernardino County used data from Cal-Adapt to spatially represent increases in temperature across the County. To do this, the County defined extreme heat days as those with temperatures hotter than 95% of daily maximum temperatures in the baseline time period. That is, the County looked at the time period of 1976 to 2005, and determined the temperature threshold at which, in an average year, only 18 days (5% of the year) were hotter than that threshold. Then, looking toward the future time period of 2036 through 2065, the County projected how many *additional* days would fall above this threshold. The exact threshold varies by geographic area, but ranges from 75 to 113°F, with an average of 103°F across the entire county.

Figure 1 shows the number of additional extreme heat days per year projected across San Bernardino County by mid-century. All areas are projected to experience at least 27 additional extreme heat days. The eastern desert near the Colorado River and parts of the Mountain region could experience as many as 50 additional extreme heat days per year.

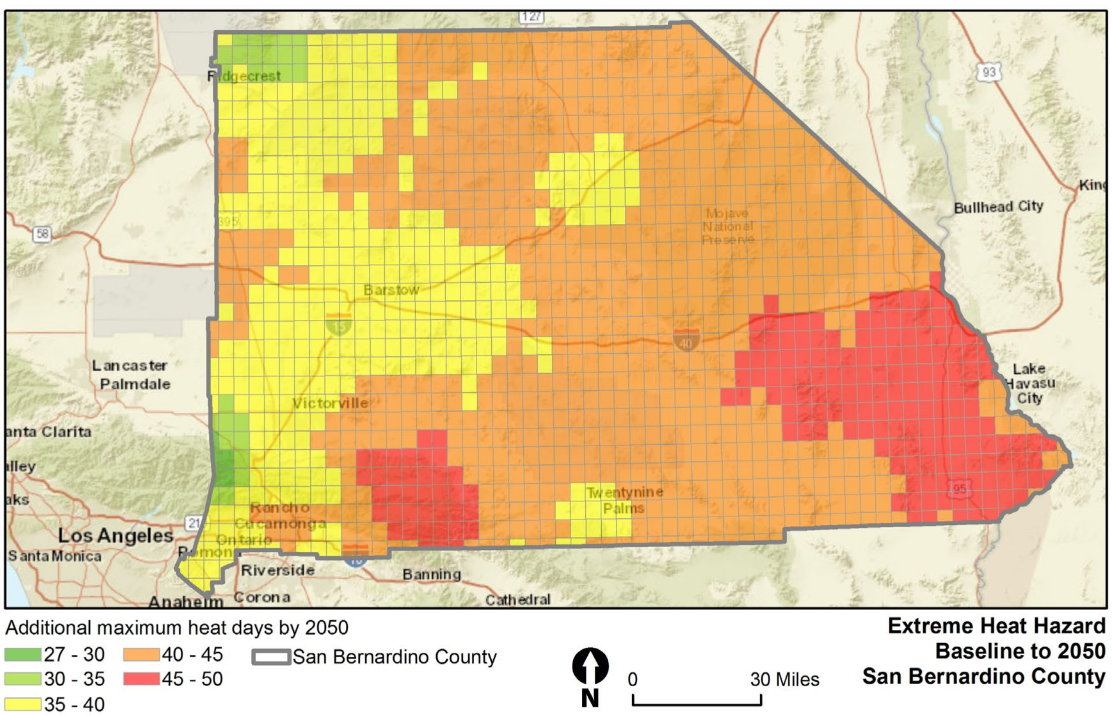

Figure 1: Change in Number of Extreme Heat Days (Baseline to 2050). Data source: Cal-Adapt.

WILDFIRE

Wildfire in San Bernardino County is influenced by a range of underlying factors, including:

- episodic droughts and severe wind events,
- increasing wildfire fuel through vegetation growth and drying,
- past wildfire suppression activity, and

- an expanding urban-wildland interface (Bedsworth et al., 2018).

While wildfire can start from both natural and human ignitions, climate change is expected to exacerbate wildfire risk by creating hotter and drier landscapes more susceptible to burning. Increases in wildfire activity in Southern California over the last 20 years is thought to be due, in part, to climate change (USGCRP 2017). Ultimately, wildfires pose risks to life and property, and can be greatly detrimental to air quality. For example, the 2017 Thomas Wildfire in nearby Santa Barbara and Ventura Counties caused two deaths, destroyed 1,063 structures, cost $2.2 billion in damages and resulted in severe air quality problems in the surrounding area for weeks (Cal Fire, 2018; Ding, 2018). The 1993 Old Fire engulfed the western San Bernardino Mountains and threatened San Bernardino and Highlands, while forcing the evacuation of 80,000 residents. In 2016, the Blue Cut Fire in the Cajon Pass destroyed 105 homes, 213 other structures, and at its peak, forced over 80,000 people to evacuate (LA Times, 2016). The Blue Cut Fire also jumped I-15, ultimately burning multiple pieces of highway infrastructure (WSP, 2018).

Looking forward, wildfire risk and annual area burned are expected to continue to increase through end of century as a result of warmer temperatures, more frequent drought and an expanding urban-wildlife interface (Westerling, 2018). Increased wildfire risk could adversely affect most populations included in this analysis, as well as energy transmission infrastructure, power plants, road signals and traffic control centers, Joshua trees, and pinyon-juniper woodlands.

Using projection data from Cal-Adapt, San Bernardino County completed a spatial assessment of how wildfire risk could change in the future. **Figure 2** and **Figure 3** show the projected change in annual hectares burned per 36 km^2 grid cell between the baseline time period (1976 to 2005) and mid-century and the expected number of annual hectares burned per grid cell by mid-century, respectively (Westerling, 2018). Projections represent the potential increase in wildfire severity through time. Projections assume business-as-usual population and land use trends.

According to these projections, the largest increases in wildfire risk may occur in communities near the San Bernardino and San Gabriel Mountains in and adjacent to the Mountain region, such as Yucaipa, Big Bear and Wrightwood. The eastern county borderline, near the city of Needles, is also projected to experience large increases in wildfire risk. In these locations, the annual area burned could increase to between 25 and 60 hectares per grid cell by mid-century.

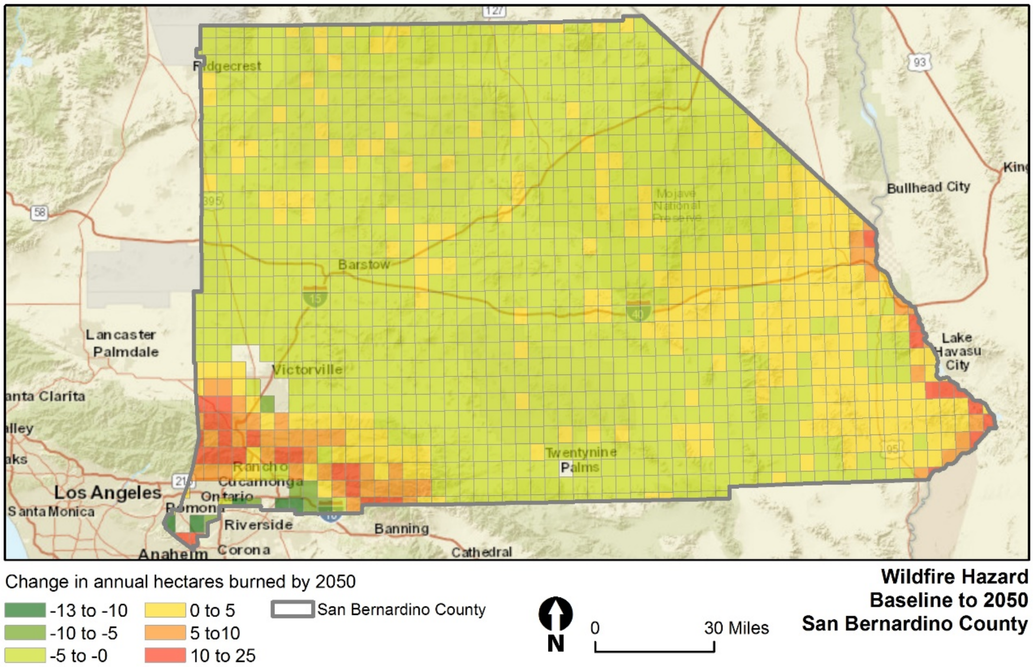

Figure 2: Change in Annual Hectares Burned by Wildfire (Baseline to 2050). Data source: Cal-Adapt (Westerling 2018).

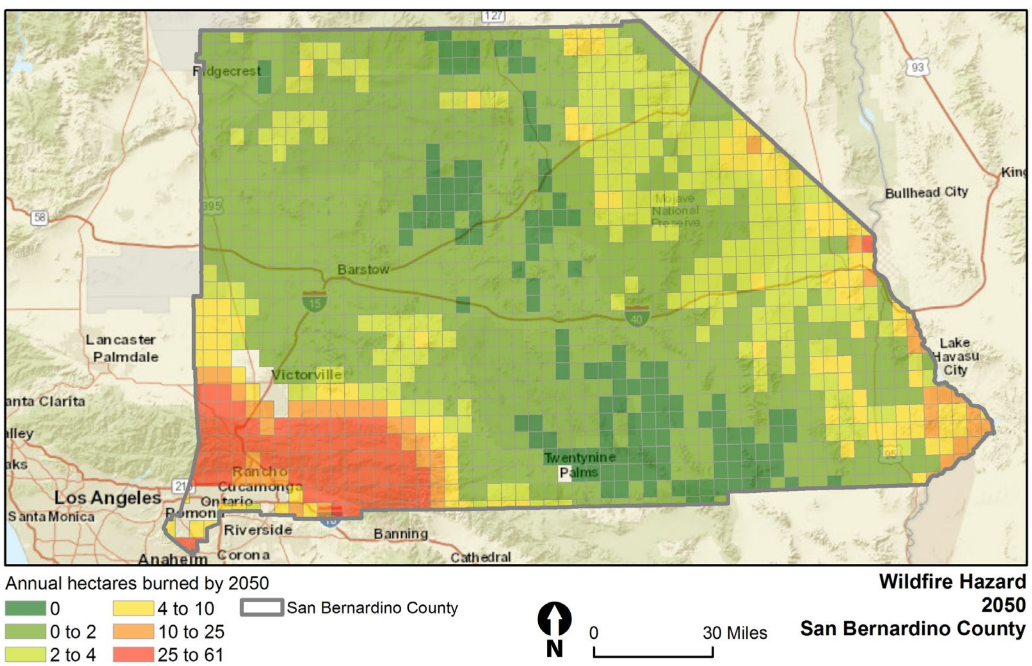

Figure 3: Annual Hectares Burned by Wildfire in 2050. Data source: Cal-Adapt (Westerling 2018).

DROUGHT

San Bernardino County depends on both local and imported water sources to supply customers. Many commercial and residential customers rely on groundwater pumping and direct extraction from surface water bodies, including lakes and rivers. In addition, the State Water Project delivers water from the Sierra Nevada Mountains to San Bernardino County. Unfortunately, Southern California is highly prone to drought conditions that reduces these vital water sources. In addition to affecting human water supply, drought can have a significant impact on biological resources such as pinyon-juniper woodlands, conifer forests, grasslands, and marshes and seasonal wetlands.

Due to climate change, droughts are expected to become more frequent and intense in San Bernardino County and, more broadly, throughout California by mid-century (Bedsworth et al., 2018). For example, recent scientific studies indicate:

- Climate change is projected to drive more frequent historically warm temperatures, reduced precipitation and snowpack, abnormally dry soils and, in turn, drought conditions (Hall et al. 2018).
- Modeling studies attribute more frequent coincident warm and dry years and more severe drought conditions in Southern California to climate change (Diffenbaugh et al., 2015).
- The incidence of extremely dry years (those occurring in 1 out of every 100 years over the historical period) could triple by the end of century (Pierce et al., 2018).
- The likelihood of long-duration droughts in San Bernardino County could increase significantly, with some studies showing a more than 80% chance of multidecadal drought by end of century (Cook et al., 2015).

Snowpack plays a key role in water supply in the region. Snowpack in the Sierra Nevada Mountains replenishes the watersheds and reservoirs used as state water resources. Unfortunately, snowpack in California has decreased over the last 60 years (Bedsworth et al., 2018). A 2018 study projects that snowpack in the Sierra Nevada is expected to decline by as much as a 33% and 66% by mid-century and end of century, respectively, relative to the historical baseline (Bedsworth et al., 2018). Snowmelt is expected to occur earlier in the year, which would disrupt the normal timing of water recharge in rivers and groundwater. Ultimately, reduced snowpack is projected to lead to more frequent water shortages and less water available to the State Water Project and other water supply systems.

FLOODING

San Bernardino County has recently experienced dangerous flooding events. In 2014, a flash flood in the County overturned a vehicle and killed its driver (LA Times, 2014). More recently in February 2019, firefighters in San Bernardino County rescued several people trapped on islands surrounded by floodwaters; resulting in several injuries and hospitalizations (SB Sun, 2019). Finally, in the aftermath of the 2018 Cranston Fire, the National Weather Service issued a flash flood watch for parts of San Bernardino County that had recently burned and were made more vulnerable to mudslides (LA Times, 2018).

Although it is difficult to precisely estimate the increase in flood risk due to climate change, there are several indications in recent scientific literature that flood risk could increase in the future:

- Climate models suggest that extreme precipitation events may become more frequent and intense, primarily because warmer temperatures increase the amount of water vapor in the atmosphere (AghaKouchak et al., 2018; Pierce et al., 2018).
- Extremely wet seasons (those with a 4% chance of occurring in any given year based on the historical record) are projected to occur twice as frequently by mid-century in Southeastern California (Swain et al. 2018).
- Precipitation increases are projected to be greatest during the winter season and during El Niño events (Zecca et al., 2018), whereas spring becomes more than 10% drier relative to the historical baseline (1976-2005) (Pierce et al., 2018).
- Looking forward, projections show the amount of precipitation occurring on the wettest day of the year could increase by up to 25% towards the end of century relative to the historical baseline in San

Bernardino County, suggesting that heavy precipitation events causing flooding could become more intense (Pierce et al., 2018).

- In addition, warmer temperatures are projected to drive earlier and more rapid snow melt and more frequent rain on snow events, which dramatically increases the risk of riverine flooding.

Flooding could negatively affect communities in many ways, and have a particularly negative impact on homeless persons, incarcerated persons, individuals with disabilities, senior citizens living alone, and senior care centers.

Projection data are not available for flood risks. As a proxy, San Bernardino County looked at the FEMA 100- and 500-yr flood zones, as defined by the Federal Emergency Management Agency (FEMA). These maps do not explicitly account for climate change, which could potentially bring flooding to new areas. Although these flood maps represent present day risks, the flood zones indicate which areas are most likely to flood first, or more frequently, as the climate changes.

The results are shown in Figure 4.[3] This spatial assessment shows that, in general, low-lying areas and river systems within sparsely vegetated hillsides and mountain ranges are susceptible to flooding in San Bernardino County.

In addition, short-lived flash floods can occur during periods of heavy rainfall throughout the county. Flash floods form in areas where the land surface is impervious to heavy rainfall and within mountainous and hilly terrain. In San Bernardino County, flash floods have occurred in rural desert or mountain communities where they can damage roads and other infrastructure.

[3] A 100-year flood is expected to occur once every 100 years, and thus has a 1% chance of occurring in any given year, based on historic observations. Similarly, 500-year floods have a 0.2% chance of occurring in any given year and highlight more extensive flooding possible during the most extreme flooding events.

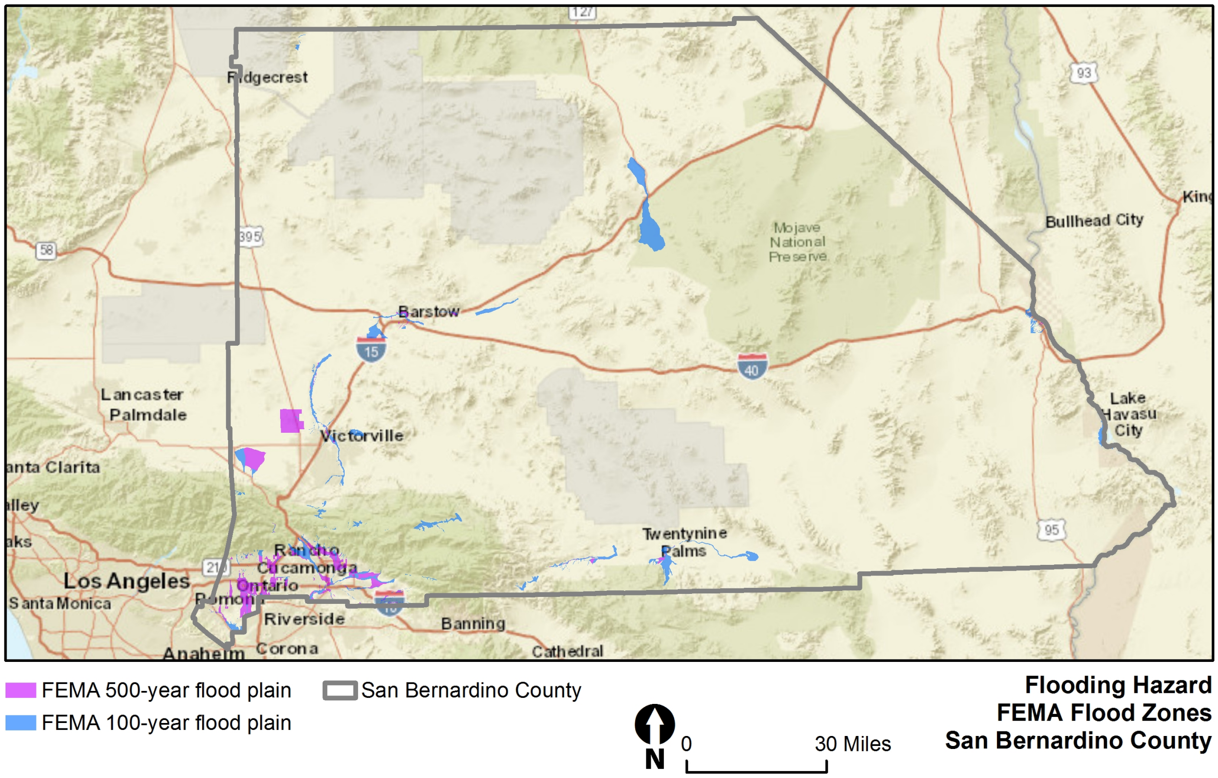

Figure 4: FEMA 100-year and 500-year Flood Zones. Data source: FEMA Flood Map Service Center.

AIR QUALITY, HUMAN HEALTH AND ECOLOGICAL HAZARDS

Due to its geography downwind of the Los Angeles metropolitan area and constricted by high mountain ranges, the Valley region in San Bernardino County already experiences some of the worst air quality problems in the country (American Lung Association, 2019). Climate changes such as increasing air temperature and wildfire frequency may compound these issues and drive a range of air quality, human health, and ecological risks in San Bernardino County.

For example, air quality problems—and their associated health impacts—could worsen due to climate change. Projections show that San Bernardino County could experience more than seven additional days per year with unhealthy ozone levels by mid-century due to warmer temperatures accelerating the formation of ground level ozone production (Shen et al., 2016). Increased ozone levels are linked to a multitude of health hazards, including aggravation of lung diseases such as asthma, emphysema and chronic bronchitis. In addition, climate change could exacerbate atmospheric dust pollution and allergens.

More frequent and larger wildfires could release fine particulate air pollution that present local and regional health hazards (Kinney, 2008). Elevated air pollution occurred during the November 2018 wildfires in northern California, when the EPA monitored hazardous air quality in the region for weeks. Air pollution and associated human health hazards will likely have an enhanced impact on homeless persons, elderly and outdoor workers.

Climate change may also allow pathogens and pests to proliferate in San Bernardino County. For example, warmer air temperatures and wetter winters could support larger numbers of mosquitos, and vector-borne diseases such as West Nile virus and hantavirus pulmonary syndrome. Simultaneously, heat waves could exacerbate the risk of heat stroke and hyperthermia, particularly among elderly populations. In addition, studies have shown that pests in agricultural settings become more active in warmer climates, resulting in the need for increased use of chemicals and pesticides with the potential for subsequent economic, human health and environmental costs (Rosenzweig et al., 2001).

Climate hazards can also cause proliferation of other pests that reduce the County's ecological health. For example, California's recent drought weakened trees so that they were more vulnerable to bark beetle infestations, which inhibits water and nutrients within trees and increases the likelihood of tree mortality. In turn, dead trees provide ample fuel for wildfire, greatly increasing regional fire risk. Massive tree die-offs have already occurred in the San Bernardino National Forest; in 2014, the U.S. Forest Service estimated that 4,000 acres of trees in the forest had died, representing a 10-fold increase from the previous year (Bergthold, 2018). With projections of more frequent and intense drought in the future, the County may expect to see greater tree die-off, and an associated increase in fire susceptibility.

SEVERE WEATHER AND WIND

While severe weather and extreme wind were evaluated separately in the vulnerability assessment, we discuss them together here to provide a more cohesive view of how severe weather events may change in the face of climate change. Extreme storms are projected to become more intense and frequent by mid-century as a result of climate change. Severe weather could have a particularly negative impact on homeless persons, incarcerated persons, individuals with disabilities, individuals with existing medical conditions, seasonal residents and migrant workers, and senior citizens.

In California, severe weather comes in the form of rain or snowstorms, often driven by atmospheric rivers. An atmospheric river is a narrow band of the atmosphere that transports large amounts of water vapor and produces heavy precipitation across Southern California during the cold season (NOAA, 2015). Atmospheric rivers can last for several days, bringing several feet of snow to mountainous regions and heavy rains to lower elevations. Storms associated with atmospheric rivers can comprise up to 50% of California's annual precipitation. As a result, atmospheric rivers can lead to risks associated with heavy precipitation, flooding and wind.

Recent studies project that future atmospheric rivers could be approximately 25% longer and wider, while carrying larger amounts of water vapor compared to historical conditions (Espinoza et al., 2018). As a result, precipitation associated with atmospheric river events in Southern California could increase nearly 40% increase in by the end of the 21st century (Hall et al., 2018). Atmospheric river events also are projected to become more frequent, with a possible doubling of days by end of century (Hall et al. 2018). In part due to expected increases in the severity of atmospheric river storms, the magnitude of 100-year return period rainfall event[4] is projected to increase up to 20% by mid-century in San Bernardino County (WSP, 2019). Increases are projected to be largest (~5 to 20%) within the elevated terrain of the San Gabriel and San Bernardino Mountains and surrounding hill country and smaller (~0 to 5%) elsewhere in the County (WSP, 2019).

Snowfall patterns are projected to change as temperatures rise and storms (including atmospheric rivers) become more intense. Climate projections show an increase in winter precipitation in San Bernardino County, but progressively warmer temperatures mean that more precipitation falls as rain rather than snow, and snow that does accumulate melts faster (Pierce et al., 2018). At the same time, individual snow events could produce greater snowfall rates due to more intense storms. Reduced winter snowfall and the predicted decline in springtime precipitation could diminish spring snowpack in the Sierra Nevada and San Bernardino Mountains. Together, these trends are projected to exacerbate stress on regional water resources (Pierce et al., 2018).

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[4] A 100-year return period storm has a 1% chance of occurring annually. The magnitude of the 100-year return period rainfall event refers to the amount (i.e., depth) of rainfall associated with these types of storms.

Severe weather also includes thunderstorms and hail. Although climate projections are unclear about the frequency of these events in the future, they are likely to persist through mid-century and beyond. Thunderstorms may result in flash flooding, and lightning strikes have the potential to start fires. Thunderstorms can also bring about severe winds and hail, both of which can cause damage to infrastructure and agriculture and endanger public safety.

There is uncertainty in future changes to extreme winds known as Santa Ana events, with some studies showing an increases and others finding that the number of Santa Ana events may decrease around 20% in the future (Hall et al., 2018). Santa Ana winds blow in an offshore direction in parts of Southern California and are caused by the formation of large high-pressure systems over eastern California, Nevada and Utah, producing winds that are strong (>18 mph) and extremely dry. Santa Ana winds can also act as catalysts for wildfires. Projections developed for the 4th California Climate Change Assessment indicate a small decrease in the frequency of Santa Ana wind events over the 21st century but that the strongest winds could also become drier, further increasing wildfire risk (Pierce et al., 2018).

Although there remains uncertainty concerning future severe wind events, projections from the 4th California Climate Change Assessment illustrate where and how severe winds could change in response to climate change (Pierce et al., 2018). Using Cal-Adapt data, San Bernardino completed a spatial analysis to show the change in the projected number of severe wind days per year between the baseline time period and mid-century; **Figure 5** shows the results. Severe wind days are defined as those exceeding the 95th percentile of daily maximum wind speeds over the baseline time period. In this analysis, severe wind projections represent both Santa Ana events and winds that occur at other times. Projections show the frequency of severe winds across San Bernardino County experience a small reduction through mid-century. This analysis suggests that the largest reductions (5 to 4 days per year) could occur in the interior and eastern sections of the County. In contrast, low-lying areas east of Victorville could see small increases of one day per year.

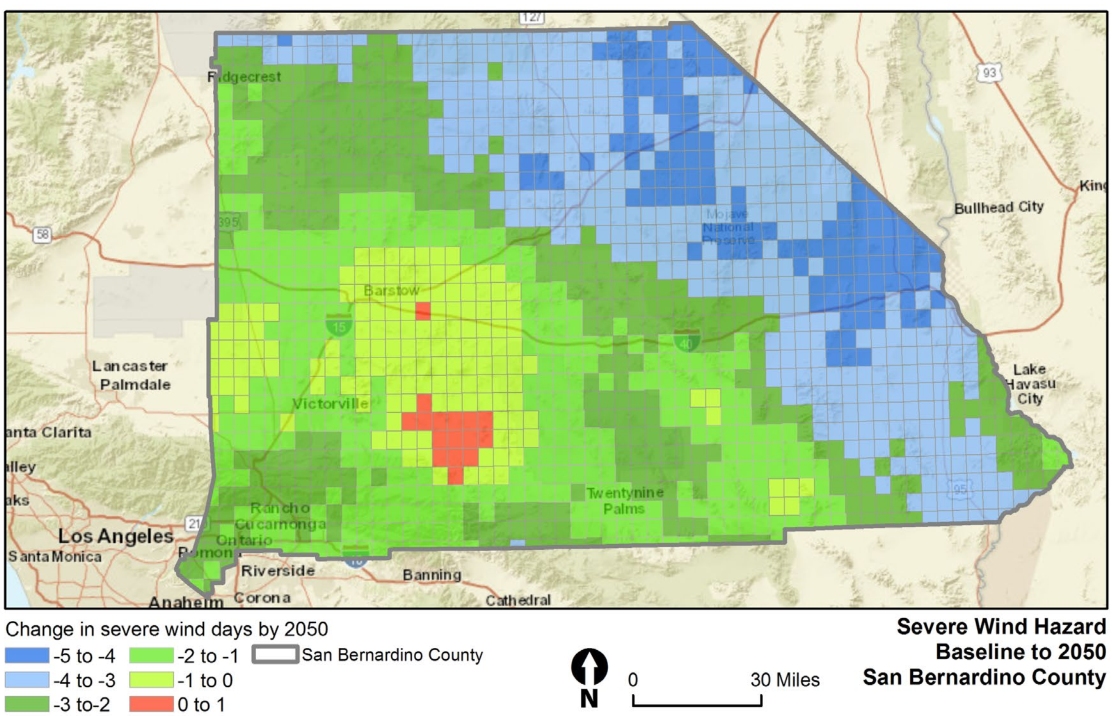

Figure 5: Change in Number of Severe Wind Days (Baseline to 2050). Data source: Cal-Adapt.

MUDSLIDES AND LANDSLIDES

Landslides are events where a mass of earth or rock moves down a slope, which can be triggered by both geologic (e.g., earthquake) and climatologic factors. Mudslides are a type of landslide that contain significant amounts of water and rapidly surge down hillsides. Wildfires and heavy rainfall increase the likelihood of mudslides by burning vegetation, saturating soil and, in turn, destabilizing the landscape. This cascading sequence of hazards produced recent large mudslides in Ventura and Santa Barbara Counties following the 2017 Thomas Fire. Within San Bernardino County there are vulnerable populations and assets in landslide-prone areas that could be differentially impacted by these hazards, including homeless persons, bridges, energy transmission infrastructure, communication services, and electrical services.

From a climatological perspective, it is difficult to project exactly where and how mudslides and landslides will change in the future, given the many factors that create slide conditions. However, studies suggest that the combination of increasing temperatures, wildfire likelihood and extreme precipitation events could trigger more frequent, and potentially larger, mudslides and landslides in San Bernardino County by mid-century (Moser et al., 2018). Landslide susceptibility is currently highest in mountainous terrain, such as the San Bernardino, San Gabriel and San Jacinto Mountains, where complex geology and fault zones intersect steep terrain prone to wildfire risk and heavy precipitation events. These areas are adjacent to densely populated communities and critical infrastructure, including small power houses and hydroelectric power plants that ensure electric supply to mountain towns. Mountains and hills within the Mojave Desert also have high landslide risks. While sparsely populated, these areas may have populations with little access to emergency services or limited capacity for mobility, which could exacerbate consequences from landslides.

PRIORITY VULNERABILITY SECTORS

San Bernardino County selected seven priority sectors based on their importance to the growth and success of the County and their potential vulnerability to climate change and the hazards discussed above. The County selected these sectors based on A) the precedent set by the 2014 West Riverside Council of Governments Adaptation Strategy, which is being used as a model for San Bernardino's vulnerability assessment, and B) the findings of the vulnerability assessment conducted for this report (for details, please refer to the Technical Appendix). The vulnerability assessment looked at specific sensitivities across population types, infrastructure types, services, and natural resources; using those results, the County then zeroed in on the most vulnerable and critical sectors to determine which should be priority sectors for focus.

The following sections detail potential climate impacts on these priority sectors (in no particular order):

1. Disadvantaged Communities and Social Vulnerability
2. Extreme Weather-Resilient Development
3. Transportation Infrastructure and Operations
4. Electricity Resources and Reliability
5. Water Sources and Reliability
6. Natural Resources (Biological Resources and Agriculture)
7. Plan Maintenance

PRIORITY SECTOR 1: DISADVANTAGED COMMUNITIES AND SOCIAL VULNERABILITY

Climate change has disproportionate negative impacts on disadvantaged communities (California Air Resources Board, 2014). California Senate Bill 535 defines disadvantaged communities as:

“(a) Areas disproportionately affected by environmental pollution and other hazards that can lead to negative public health effects, exposure, or environmental degradation.

(b) Areas with concentrations of people that are of low income, high unemployment, low levels of homeownership, high rent burden, sensitive populations, or low levels of educational attainment” (California Legislative Information, 2012).

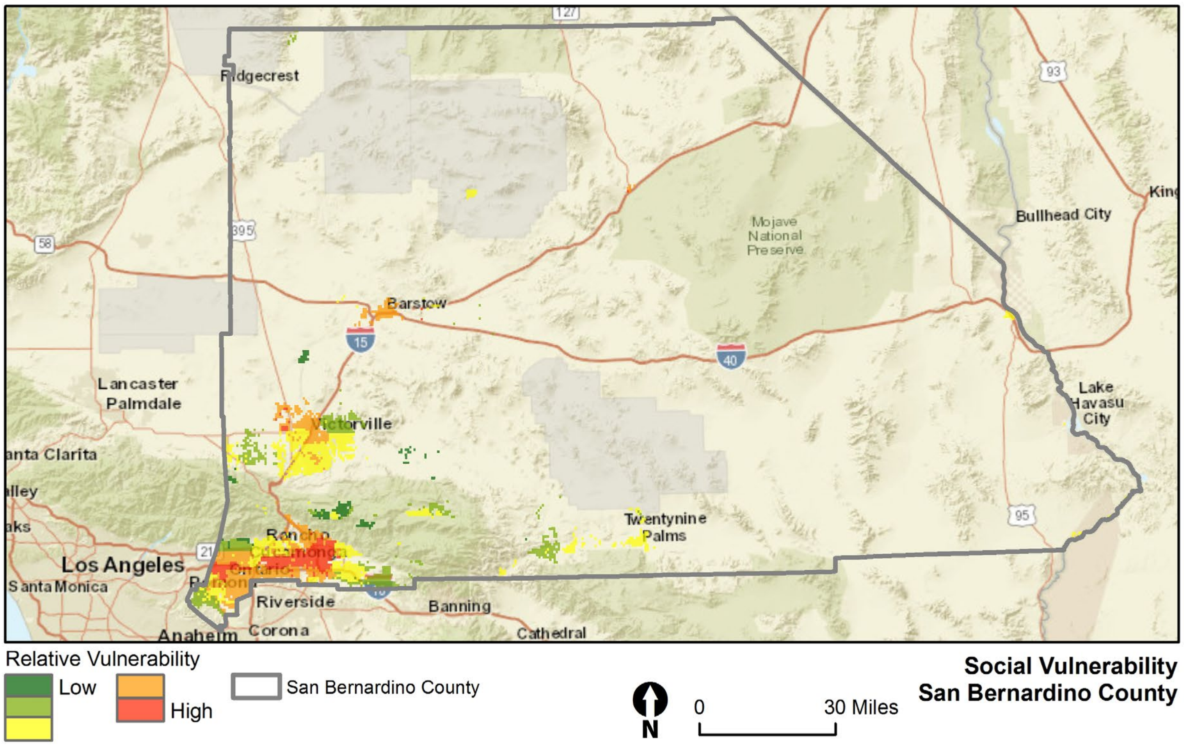

Figure 6. Map of relative social vulnerability in San Bernardino County. Grid cell size is approximately one square kilometer. Red cells indicate more vulnerable areas. Cells with populations less than seventy-five people are not mapped.

Figure 6 shows a social vulnerability map developed by the California Governor’s Office of Emergency Services for the California State Hazard Mitigation Plan (Cal-OES, 2018). The social vulnerability index is drawn from a suite of population metrics, including poverty/income, disabilities, food access, education, linguistic isolation, age, minority status and housing tenure[5]. Areas with populations smaller than seventy-five people are not mapped. Based on this metric, many communities in the Valley region, including San Bernardino City and Fontana, as well in Victorville, are considered the most socially vulnerable. Comparing this map to the hazard maps in *Climate Change in the County* above, it appears that extreme heat is projected to be a pressing threat to these communities (**Figure 7**). Other primary threats include fire, reduced air quality and flooding. Extreme weather and drought can also bring about impacts specific to disadvantaged communities.

[5] A detailed explanation of the Social Vulnerability Index developed by Cal-OES is given in the Impact and Adaptive Capacity section of the Technical Appendix.

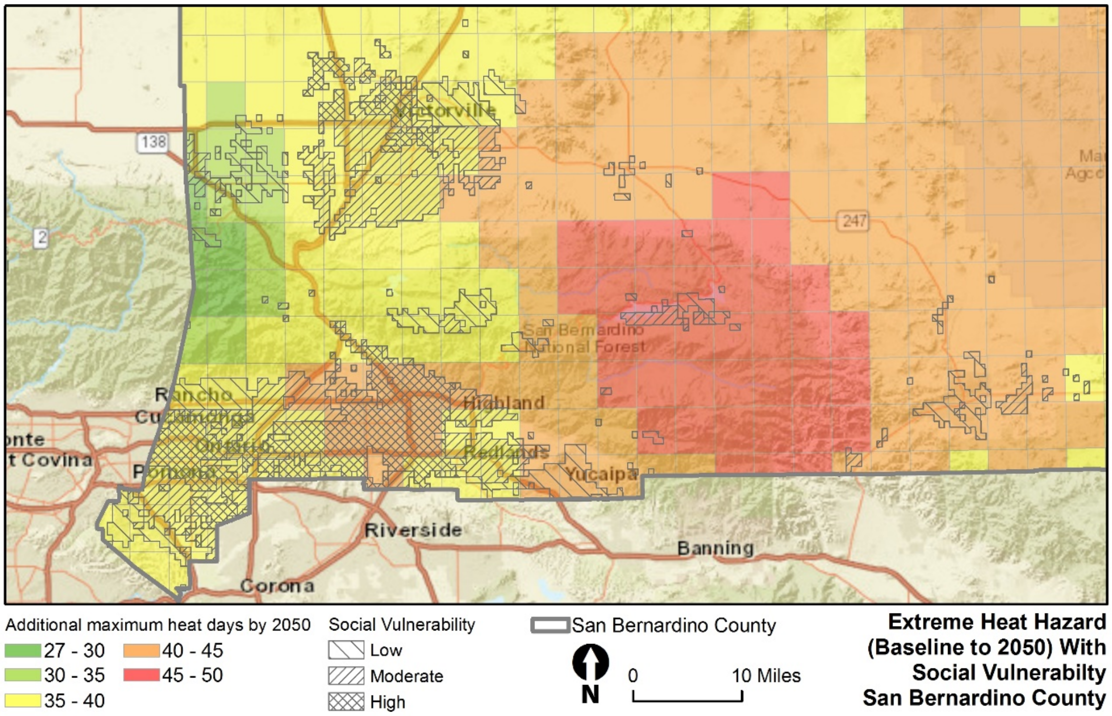

Figure 7. The intersection of heat exposure and social vulnerability.

In San Bernardino County, the following areas have high social vulnerability, according to Cal-OES' Index (in alphabetical order):

- Barstow
- Fontana
- Highland
- Ontario
- Rancho Cucamonga
- Redlands
- Rialto
- City of San Bernardino
- Western Victorville

The ways in which a population is disadvantaged can influence the ways in which climate change will affect that population. In this report, San Bernardino County considered populations that are disadvantaged economically, physically, culturally, and those that have little control over their ability to put adaptation strategies in place, such as children, renters, and incarcerated persons.

Over 18% of the population of San Bernardino County are below the poverty level (U.S. Census Bureau). For those that are economically disadvantaged (e.g., the homeless, households in poverty, low-income households, cost-burdened households, and mobile home residents), an inability to pay for adaptation strategies exacerbates the impacts of climate hazards.

For those that are physically disadvantaged (e.g., persons with disabilities and/or existing medical conditions, senior citizens, pregnant and nursing women, and people living on single access roads), the ability to safely evacuate in the case of an emergency is jeopardized. These persons may also be limited in their ability to prepare for emergency conditions.

There are also populations that are vulnerable due to the fact that safety and adaptation strategies are typically implemented at a higher decision-making level, which then cover an entire group of people. In particular, homeless persons, incarcerated persons, outdoor workers, and seasonal residents and migrant workers had higher vulnerability scores across hazards in the vulnerability assessment. For example, outdoor workers are by nature of their trade exposed to the elements, and worker protections are typically implemented by employers, often in response to specific regulations. When faced with the option of job or no job, school or no school, people might either accept more risk than they want. Or, they may not even be aware of the risk or potential ways to reduce the risk. This creates population-level vulnerability, and results in a lower chance that appropriate levels of adaptation will be achieved if it is incumbent on the individual to act.

HEAT

Seasonal and migrant workers face the greatest vulnerability to heat. Their outdoor work environments expose them to climate hazards, but their ability to adapt without risk of unemployment is low, so they must rely on employers or regulators to take adaptive action.

Other populations are particularly susceptible to heat due to their physical conditions. For example, children have a limited ability to regulate their internal temperature and are less aware of the symptoms of heat-related illness. Children have less physical and political/decision-making power to protect themselves from climate impacts and are to some extent dependent upon adults and caregivers. Persons with existing medical conditions may also face vulnerability to heat due to restricted mobility, reliance on electric devices that may become compromised during brownouts or blackouts, and use of medications that can affect thermoregulatory capacity. Senior citizens can be particularly heat-sensitive, and senior citizens living alone may have limited ability to move to an air-conditioned location or request aid in the event of extreme heat.

Economically vulnerable persons and households are less likely to be able to afford to air condition their homes, potentially aggravating the impact of heat waves on persons living in these households. Homeless persons are more likely to be exposed to the outdoor environment without access to air conditioning or other measures to protect themselves against heat.

City centers can provide shelter for the above populations in extreme events, though these refuges may become overwhelmed in severe events. This may require additional cooling centers in heavily populated communities, which could involve the need to partner with utilities to more efficiently and reliably supply power to these facilities, as well as coordination to ensure vulnerable populations have easy access to cooling centers.[6]

Incarcerated persons have extremely limited ability to modify their living conditions, and prisons and jails already have harsh climatic conditions that may be made worse by events such as heat waves or flooding. However, the presence of prison managers, as well as regulations requiring they provide basic standards of living, affords some basic protections to incarcerated persons.

WILDFIRE

In the event of fires, evacuation is a major concern for disadvantaged communities. Persons with disabilities and/or existing medical conditions may have impaired mobility and may rely on medication or devices that are difficult to take with them in the event of evacuation. Similarly, senior citizens may have impaired mobility, ability to drive, and in certain cases such as those with Alzheimer's or other cognitive conditions, may become disoriented or confused if moved from their homes. These groups – individuals with disabilities and/or existing

[6] San Bernardino Community Vital Signs Meeting, May 20, 2019

medical conditions and senior citizens (particularly those living alone) – had among the highest vulnerability scores across hazards in the vulnerability assessment. Pregnant and nursing women have somewhat reduced mobility in later stages of pregnancy and when accompanied by an infant. People living on single access roads may have their main evacuation option blocked if a hazard impacts the road.

In addition, evacuation may be challenging for incarcerated persons, as appropriate alternative sites may be limited, and evacuation may require supervision.

For linguistically isolated persons, it may be difficult to receive and interpret warning messages and evacuation notices. These groups may rely on their own social network or aid groups that can translate necessary news. Undocumented persons may be reluctant to listen to authorities or to seek out news and resources about a hazard event. They may be reluctant to evacuate from their community or go to public relief centers for fear of legal consequences. In the event of an evacuation, support from extended families or community organizations may be limited, due to disruption of existing support networks.

Additionally, Native American tribes face unique vulnerabilities to climate disasters. These populations often have limited resources, and therefore their ability to adapt without additional economic resources is low (U.S. DOE, 2015). Furthermore, Native Americans may have strong cultural ties to natural resources and place-based landmarks, and so have the potential to be severely impacted in the case of destructive events (e.g., wildfires or floods). A disaster may permanently destroy culturally important natural resources, taking cultural heritage, history, and identity with it.

AIR QUALITY/HUMAN HEALTH

As mentioned in the section above on Air Quality, Human Health and Ecological hazards, the valley in San Bernardino County already experiences some of the worst air quality problems in the country and climate change will only exacerbate this issue (American Lung Association, 2019). The City of Victorville, for example, experienced smoke from the 2018 Woolsey fire,[7] and the City of Ontario sits in a basin that regularly collects air pollutants from its surroundings.[8] The valley area includes communities that have higher relative social vulnerability, as shown in **Figure 6**. Hazards such as poor air quality, and the impacts they have on human health, are disproportionately felt by disadvantaged communities. For example, the Union of Concerned Scientists found that communities of color and low-income communities in California experienced greater exposure to particulate matter smaller than 2.5 micrometers in diameter (PM2.5) from cars, trucks, and buses than their white and wealthier counterparts (Union of Concerned Scientists, 2019). San Bernardino County is one of six counties in California that has an average exposure of PM2.5 from on-road transportation greater than the state average (Union of Concerned Scientists, 2019). Exposure to PM2.5 has been linked to health impacts such as asthma attacks, cardiovascular disease, and even lung cancer. Children chronically exposed to PM2.5 can experience slowed lung-function growth, asthma, and other health impacts (Union of Concerned Scientists, 2019).

The City of San Bernardino and Muscoy are part of the South Coast Air Quality Management District and were selected as a “Year 1” AB 617 community. AB 617’s goal is to address the disproportionate impacts of air pollution on environmental justice communities and requires local air districts to take action to reduce air pollution. As one of the selected communities, San Bernardino and Muscoy now have a steering committee dedicated to developing a community emissions reductions plan and a community air monitoring plan. The community steering committee and members of the public worked together to identify the following categories of air concerns (in order, starting with the highest concern): truck idling and truck traffic related to warehousing,

[7] Personal Communication: City of Victorville Fire Department, May 22, 2019
[8] Personal Communication: City of Ontario, May 15, 2019

BNSF railyard, sensitive receptors, warehousing, railroads, traffic on freeways and major roadways, Omnitrans bus yard, and cement manufacturing (South Coast Air Quality Management District, 2019).

FLOOD

As with fire, evacuation in the event of flooding is a major concern for disadvantaged communities (and for the same reasons as those described under the Fire section above).

Economically disadvantaged communities can be especially vulnerable to destructive hazards such as flooding due to less expensive housing often being sited in higher risk areas. In the aftermath of disaster, economically disadvantaged populations may not have the savings or resources necessary to respond and rebuild.

Flooding can have particularly impactful consequences in rural areas, in the mountains just east of San Bernardino City. Roadways are limited in these areas, and many locations are only accessible from a single road, and so communities can quickly become isolated if these roads are damaged or blocked. In the mountains, the steep slopes can lead to rapid runoff and flash flooding, potentially blocking evacuations. It can also be more difficult for emergency responses to quickly reach and respond to hazards in rural areas. If electrical or communication lines are in need of repair, it may take longer for these systems to come back online in more remote areas.

DROUGHT

Recent droughts in California have demonstrated the potential impacts of water shortages on disadvantaged communities. A 2017 study found that during the 2012-2017 California drought, a large portion of drought-impacted water systems and household outages were in “Disadvantaged and Cumulatively Burdened Communities,” which include those with lower median household incomes and higher environmental burdens and socioeconomic vulnerability. Additionally, an increase in the cost of water during droughts meant that low-income households spent a greater percentage of their earnings on basic water service, raising concerns regarding access to water (Feinstein, et al., 2017). As droughts are projected to become more severe throughout California over the next century, disadvantaged communities will likely continue to face these challenges without intervention to offset costs and ensure access.

Areas in San Bernardino County that will likely feel the impacts of drought include those projected to experience more intense heat over this century. As shown in **Figure 7**, the Valley region and Victorville – places that are projected to experience 35 to 45 more maximum heat days by 2050 – have high social vulnerability according to Cal-OES’ index.

PRIORITY SECTOR 2: EXTREME WEATHER-RESILIENT DEVELOPMENT

Of the eight hazards, the four related to extreme weather (wildfire, flood, mudslides, and severe weather) may require the most robust preparation, starting with the development of resilient infrastructure. Other hazards like extreme heat and drought are projected to affect all of San Bernardino County and require region-wide efforts to plan and prepare for them. Furthermore, flexible adaptation strategies can address heat and drought as they steadily worsen incrementally through time. On the other hand, impacts from extreme weather tend to be more acute, devastating and confined to specific geographic regions. Thus, certain communities disproportionately shoulder the risk. Extreme wind aligns with these four hazards as an event that can cause destruction, but the vulnerability assessment did not find wind to have as much of an impact as these three hazards, partly due to lack of significant projected increases in wind. Thus, San Bernardino County may consider including extreme weather-resilient development in their key priorities.

San Bernardino County already has infrastructure located in high-risk areas for these hazards, so this infrastructure may already be somewhat adapted to the hazards they face today. However, climate change can expand the areas in which these hazards occur, bringing new infrastructure that was not previously at risk into exposure zones. Furthermore, climate change can also intensify the hazards or make them occur more frequently in high-risk areas. In this case, the infrastructure that exists there may require even further adaptation to stay resilient. Development in high-risk areas can also exacerbate the impacts of wildfires, floods, mudslides, and severe weather by adding more fuel to burn or more structures to fail and fall down a hillside.

All four of these hazards are destructive on their own, but their impacts on critical infrastructure can also cause indirect damage. Heat from fire can cause road buckling, and in electricity infrastructure it can decrease transmission capacity or even result in power outages. The resulting reduction in road and traffic signal function can result in major disruptions if an evacuation were to be issued during a wildfire event.

Flooding can also disrupt evacuations by making roads impassable or damaging energy transmission infrastructure to the point of a power outage. Increased occurrence of floods may also overwhelm wastewater systems, stormwater systems, dams, and other water management infrastructure if these systems are not built to withstand the magnitude of heavy floods in the future. If these systems were overfilled with water or debris from a severe event, they may lose operability or be damaged, resulting in heavy costs. Areas in the County prone to elevated flash flood risk include rural areas mostly located in eastern San Bernardino County, remote desert regions, and in the San Bernardino and San Gabriel Mountains. These places may experience more frequent flash flooding in a wetter climate, due to the lack of vegetation in rural areas and the steep slopes in mountain communities.

Mudslides are similar to floods in that they result in a deluge of water and debris that can obstruct transportation, electricity, and water infrastructure. They can be much more destructive, however, as they can dislodge key infrastructure completely rather than just covering them, such as by breaking highways or bridges, and cause overtopping of dams and other key infrastructure. Major floods can do this as well, though mudslides often also contain debris, which may result in more significant impacts. Recovery time and costs after a mudslide may also take longer than for floods. It can be difficult to predict where mudslides will take place in specific locations around hillsides, and the probability of an event occurring increases if heavy rain events follow a wildfire. Some parts of the County are particularly sensitive; for example, the City of Victorville and inland high-desert communities use I-15 as the main access route, so if wildfires or mudslides were to block this transportation route, Victorville and similar communities would be isolated and the transportation of critical resources would be delayed or compromised.[9]

Finally, severe weather events such as thunderstorms, snow, and hail can also cause damage to critical infrastructure. Atmospheric rivers can create impacts similar to those caused by heavy precipitation, and hail can also cause damage to vehicles and buildings. Wildfires may not occur in just high-risk wildfire zones; thunderstorms, which can cover broader or different areas, may result in lightning strikes that can start fires. These ignitions may be much more dangerous in a high-risk wildfire zone, but they can still cause damage out of wildfire zones, so the County must emphasize fire-resilient development whenever possible. Higher elevations in San Bernardino County, such as the Big Bear Lake area, may experience large amounts of snowfall during snowstorms. This could result in road closures or exacerbate other climate-related incidents; for example, when extreme flooding disabled two highways in Big Bear Lake, traffic issues on the remaining roads were compounded by heavy snowfall.[10]

The damage resulting from these hazards can have an even greater impact on disadvantaged populations, particularly communities that are low-income or individuals who have low mobility or control over their housing. While working on increasing wildfire-, flood-, and mudslide-resilient development, then, San Bernardino County should keep in mind the particular sensitivities that disadvantaged populations face and make sure their needs are addressed. This would involve prioritizing reinforcements on both existing and new development in socially

[9] Personal Communication: City of Victorville Fire Department, May 22, 2019

[10] Personal Communication: SBCTA Planners Workshop, April 24, 2019

vulnerable areas as displayed in Priority Sector 1, while being mindful not to let these upgrades increase property values and displace the people they are trying to protect.

Climate-resilient development can take on several different forms, so the County and local governments can decide on the paths that work best for them. This may take the form of sturdier structures like elevated buildings or barriers, or more flexible methods like low-impact development, which uses natural processes to manage stormwater (Zahmatkesh et al., 2014).

PRIORITY SECTOR 3: TRANSPORTATION INFRASTRUCTURE AND OPERATIONS

Transportation infrastructure and operations in San Bernardino County encompasses all modes of transportation, from rail to major highways to trails, sidewalks, and bike lanes, to airports, as well as stormwater infrastructure (e.g., culverts and road and storm drainage). These assets are often exposed to the elements and are subject to the impacts of climate change. In particular, heat, wildfire, flooding, mudslides, and winter weather have the potential to greatly impact the transportation system in San Bernardino County.

Heat has the potential to damage transportation infrastructure. High temperatures can lead to the expansion of pavements and joints in transportation infrastructure such as bridges, making them more susceptible to stress and damage. Extreme heat may also cause damage to other parts of transportation infrastructure, such as traffic signal controllers and sidewalks; for example, the city of Chino Hills has reported incidents of sidewalk panels popping up and asphalt warping at intersections.[11] Heat can also cause road buckling and bending and railway bending, which generally calls for repair and/or replacement that can be costly and time-consuming. In turn, maintenance activities during heat waves may be dangerous due to unsafe working conditions for employees working long hours outdoors (WSP, 2019). Airport runways are likely to experience road softening or buckling from high temperatures, which would affect planes' ability to take off and land. Additionally, crews cannot maintain airfields (e.g., by mowing) during high heat conditions, and so heat can affect the efficiency of air transportation.[12]

Wildfire can cause similar impacts by producing extreme heat locally. Wildfires can directly burn, damage or destroy transportation infrastructure, cause debris to block and/or damage assets, and can lead to transportation route shutdowns due to safety concerns and/or lack of access. Furthermore, wildfires produce smoke that affects visibility, which can be particularly disruptive airplane traffic (WSP, 2019). A number of critical transportation routes, including Interstates 10, 15 and 215, pass near high fire zones. A combination of drought and heat may lead to high tree mortality in the County's mountainous regions, increasing fire potential in these areas (WSP, 2019). The County has already faced damage to its transportation infrastructure from recent wildfires, such as the 2016 Blue Cut Fire that destroyed pieces of highway infrastructure off I-15 and Highway 138, and a 2017 brush fire that damaged the landscape and metal beam guard rail on Highway 91 (WSP, 2019). Given the difficulties associated with building new transportation infrastructure such as freeways, it is unlikely that there will be alternatives to a major freeway closure that does not result in substantial congestion. Because of these limitations, a number of sensitivities within the transportation sector (road signals and traffic control centers, evacuation routes, major roadways, railways, State and federal highways, and transit centers) received higher scores in the vulnerability assessment. San Bernardino International airport is the home of the U.S. Forest Service Tanker base for southern California and has prepared itself well for fires (U.S. Forest Service).

[11] Personal Communication: Chino Hills Public Works Department, April 18, 2019

[12] Personal Communication: San Bernardino County Department of Airports, April 22, 2019

Flooding has the potential to inundate roads, bridges, and rails, rendering them unsafe and impassable. Fast-moving water can damage or destroy transportation infrastructure via washouts or scour. Stormwater infrastructure could become overwhelmed in the event of intense precipitation, leading to debris and pollution directly entering bodies of water. Airports can be affected by flooding in several ways: standing water attracts birds, which can create bird hazards for aircraft. Debris flows can increase the need for repair and maintenance/cleanup of stormwater infrastructure.[13] San Bernardino County's transportation system has already experienced flooding damage in the past, such as in the 2010 and 2017 winter storms that overwhelmed culverts, flooded roadways, berms, slopes, and roadbeds, and resulted in erosion and washouts. The 2017 winter storms also resulted in heavy runoff on SR-38 that eventually led to the collapse of a retaining system and ongoing slope degradation (WSP, 2019). These extreme events are likely to occur more frequently under climate change.

Winter weather can bring about the same impacts as flooding. Atmospheric rivers conditions are projected to deliver nearly 40% more precipitation by the end of the 21st century under RCP 8.5. These storms could increase severe winter weather, including risk of extreme precipitation, wind and flooding in San Bernardino County (Espinoza et al., 2018).

Mudslides and landslides can be devastating on their own and have been shown to compound damage in the aftermath of a wildfire (Laris Karklis, 2018; Serna, 2018; Petersson, 2018). Bridges at vulnerable sites could be dislodged or damaged by mudslides and landslides. Such damage could result in severe structural and environmental damage as well as potential fatalities or prevent people from entering or exiting a particular area. Mudslides or landslides could deposit debris into culvert openings, clogging them and preventing water from smoothly flowing through, potentially overtopping the roadway surface. Mudslides and landslides may dislodge or deposit debris onto major roadways and render them unsafe or impassable, which may affect evacuation routes and emergency services. Existing infrastructure that is in the path of intense mudslides or landslides (e.g., following a fire) have very few protective options. Moreover, once a structure is affected by a mudslide or landslide, it often needs to be completely closed until it can be cleared, and integrity of both the structure and land can be confirmed. That is, partial use of the structure may not be feasible, and recovery may not be quick. Because of these limitations, a number of sensitivities within the transportation sector (bridges, road signals and traffic control centers, evacuation routes, railways, state and federal highways, transit centers, and transit service) received higher scores in the vulnerability assessment. However, airports are unlikely to be severely impacted by mudslides, as they are mostly located on flat ground away from slopes.

In some instances, wind is less of an issue. Incorporating extreme wind into building design standards is currently standard in California, as required by Chapter 16, Section 1609 of the California Building Code (CBSC, 2016). For transportation infrastructure, some types of transportation infrastructure require consideration of wind loads, as shown in California's High-Speed Train Project Design Criteria (California High-Speed Rail Authority, 2012), Caltrans Standard Specifications (Caltrans, 2018), and national standards on highway bridge superstructures (FHWA, 2015). Furthermore, the number of severe wind days in the County is largely projected to remain the same or decrease by 2050 (see the *Severe Weather and Wind* section above). The main impact of wind on general modes of transportation is causing delays by knocking trees, power lines, or other structures onto roads. Wind does have the potential to affect airports, as extreme winds can overturn or cause damage to planes and other airport equipment. Winds can also cause turbulence for planes taking off or landing at airports, and if winds are strong enough, pilots may choose not to take off or land. Similarly, air quality does not have much potential to impact transportation infrastructure.

Because of the critical nature of transportation infrastructure – most people depend on it to be maintained in adequate condition to go about their daily routines, and it is necessary for safe evacuations and emergency

[13] Personal communication, San Bernardino County Department of Airports, April 22, 2019

response in the case of a disaster – impacts to transportation infrastructure can have cascading impacts into other sectors. If routes are damaged or access is cut off, critical services such as healthcare, emergency response, and police have a reduced ability to carry out their necessary functions. People may not be able to commute to their workplaces, take children to childcare, go to school, or visit businesses. As the home for the U.S. Forest Service Tanker base for southern California San Bernardino International Airport plays a critical role in wildfire response, impacts to the airport have the potential to affect the ability of the Forest Service to successfully fight fires in the region.

PRIORITY SECTOR 4: ELECTRICITY RESOURCES AND RELIABILITY

Generally, the impacts to electricity resources and reliability from climate hazards can be split into two categories: stress on the system and physical damage to the system. Heat and drought stress the system, while wildfires, flooding, mudslides, and wind can cause physical damage.

Increased average and maximum air temperatures can lead to reduced service life of transformers and reduce the capacity rating of transformers and overhead lines. Such a decrease in service can create the need for investment in replacement and new capital. Increased heat can also lead to increased energy consumption for cooling, both from increased air conditioning use and from increased population in the summertime (for example, people who own second residences in Big Bear may stay over during the summer to escape the heat from lower elevations).[14] This increased usage can stress the electrical grid and may create the need for investments in transmission and distribution network improvements to handle a greater load. In addition, power plants may operate less efficienty during heat waves. Retrofits and modifications to operating procedures can offset capacity losses, and improved efficiency can help to reduce demand during heat waves. However, implementation may be an expensive and lengthy process, and the San Bernardino County communities have little or no operational control over the major commercial electricity grid. However, some communities do operate their own electric utilities, and so have control over these internal grids.

Drought can impact hydroelectric sources by decreasing water supply and creating demand conflicts for the limited available water. Loss from Colorado River will have to be made up from energy conservation or other electricity sources. Furthermore, power plants could be affected by drought if there is a lack of water available for steaming and cooling.

Damage to electrical infrastructure is a concern due to the remote nature of the county. Having disperse infrastructure can make redundancy and rapid repairs more difficult.

Wildfires could damage or destroy critical transmission/delivery wires, substations, and powerhouses, potentially causing power outages. Substations are usually surrounded by defensible space, and power lines too, though to a lesser extent. The areas facing greatest wildfire exposure include the mountain ranges to the north and east of the Inland Empire. State law requires utility companies to keep set distances between power lines and vegetation, depending on the line's voltage. These measures provide a reasonable degree of protection, but may not be sufficient for all blazes.

Transmission and delivery lines are often damaged by flooding, including by toppled trees and utility poles; solar panels are less commonly damaged. Redundancies in the transmission and distribution network should be able to meet some of the demand within the community, but it is unlikely that the region will be able to avoid power outages entirely in the event of a significant flood. Some strengthening of utility poles may be possible to make them more resilient to floods and flood-related debris. Power plants that become inundated with flood water may pose a serious risk, as dangerous substances may leak into the environment or affect workers. In addition,

[14] Personal Communication: Bear Valley Electric Service, March 28, 2019

serious damage to power plant assets and infrastructure can occur, causing electrical service problems (NRC 2018).

A major landslide or mudslide could cause significant damage to power infrastructure, as well as prevent access to the site. In such cases, a power plant may become inoperable. Energy transmission infrastructure at vulnerable sites may be dislodged or damaged by mudslides and landslides.

Extreme wind may knock down power lines, inhibiting energy transmission and creating lengthy disruptions as a maintenance crew will need to take time to safely put the lines back up. Creating redundancy and reinforcing the power grid can help avoid this impact. Subdividing the grid can contain the outage to a smaller population. However, these procedures may be somewhat costly. Wind power may benefit from wind events.

Across hazards, energy tranmission infrastructure received higher vulnerability scores in the vulnerability assessment. They both have the potential to be highly impacted by hazards such as heat, wildfire, and mudslides, and limited adaptive capacity to build resilience to these hazards without significant changes (e.g., being buried undergound).

Finally, the ability of electrical systems to trigger climate hazards also has an impact on service and reliability. Transmission wires can create wildfires; extreme winds can knock down electricity poles and spread flames and live wires can create sparks if they encounter vegetation. To avoid having their equipment create these hazards, electricity providers may issue power outages on days with high wildfire risk (high wind and heat). While this action may mitigate wildfire risk, it also results in a temporary loss of electricity service. This can be especially critical for residents who rely on the grid to power life-support machines and other medical devices.

Nearly all sectors considered in this assessment rely on electricity services in some way, so impacts to the electrical system can have cascading impacts throughout the community. For example, healthcare services and people with disabilities or existing medical conditions who rely on electric devices may be severely impacted in life-threatening ways in the event that electrical service is interrupted. Communication services may not properly function, which can decrease a community's ability to respond to a disaster.

PRIORITY SECTOR 5: WATER RESOURCES AND RELIABILITY

Climate change is projected to affect San Bernardino County's water resources by altering the amount, timing, and type of precipitation. Projections indicate the County may experience an average annual increase in precipitation throughout the century; however, these increases are heavily weighted toward the winter, when precipitation will occur more often as rain rather than snow and create the potential for more extreme flooding than seen in the past. Flooding can limit access to water facilities, cause damage to facilities, and increase the turbidity of water that is being taken into the system.[15] Snowmelt in the Sierra Nevada Mountains is also projected to occur earlier in the year, causing springtime recharge to occur before it is most needed during the warmer and drier months of the year. Reduced snowpack also reduces water captured for storage in surface water bodies and aquifers for potable drinking water. As a result, the County will have less water available during spring and summer, which are also projected to become drier and warmer as a result of climate change.

These shifts in rainfall and streamflow timing can limit water supplies and hinder the County's ability to provide potable drinking water, recharge reservoirs, and produce hydroelectricity on their normal schedule. As temperatures in the County also increase, it will be crucial to continue providing adequate amounts of potable drinking water, particularly for more vulnerable populations such as the elderly. Local governments counteract

[15] Personal Communication: East Valley Water District, April 18, 2019

effects of drought by drawing more water from wells, but this makes water tables drop substantially, which can potentially result in land subsidence that permanently removes aquifer volume available for groundwater to recharge.[16] Drought may also be a larger concern for some communities; for example, because the City of Ontario imports most of their water from upstate, rather than sourcing groundwater, the effects of large-scale drought and decreased snowpack can have a significant effect on their water supply.[17]

Certain jurisdictions in San Bernardino County, such as Big Bear and Lake Arrowhead, also face unique challenges because they serve resorts and popular tourist destinations. Acute influx of tourists and also residents relocating to mountain communities to escape increasingly warmer temperatures elsewhere will add stress to these water utilities, which may struggle to adapt to significant changes in demand.[18]

San Bernardino County's topography creates challenges in delivering water to residents, and climate change may compound these issues. Large elevation gradients, such as for the East Valley Water District in Highland and the Lake Arrowhead Community Services District, requires a large amount of power to pressurize the system and distribute water across the area. Diminished electricity reliability from climate hazards such as heat, drought, and wildfire, could adversely impact the ability of water utilities to maintain water services. This problem is especially critical during wildfire conditions, which present conflicting utility needs. Electric utilities sometimes issue power outages on days with high wildfire risk (high wind and high heat conditions). Importantly, electric utilities conduct these service interruptions to prevent wildfires caused by their equipment, since severe winds can knock down electricity poles and spread flames and live wires can create sparks if they encounter vegetation. However, power is needed in the event that a fire does break out so that water can be pumped and used by firefighters. If electricity is not available to power the highly pressurized water system that firefighters need because the electric utility has shut down their power, the County may be unable to effectively combat wildfire risk.[19]

PRIORITY SECTOR 6: NATURAL RESOURCES

Natural resources represent a critical source of food, tourism, and cultural significance to San Bernardino County. The key natural resources focused on in this priority sector include agricultural operations and biological resources. Agriculture is vulnerable to region-wide hazards such as extreme heat and drought, both of which may reduce crop yield and quality, change the types of crops that are viable, increase the spread of pests and invasive species, and put stress on livestock, which can reduce the quality of their products or result in animal morbidity and mortality. Agriculture can also be vulnerable to wildfire if the farms are located in high-risk wildfire zones.

There already exist some federal initiatives to help protect agriculture against these hazards. Federal insurance programs, for example, can help reimburse farmers in San Bernardino for loss of important crops. However, these programs do not apply to ornamental nursery plants, and livestock insurance does not protect against unexpected decreases in dairy production that may arise due to extreme heat. The Federal Emergency Loan Program does provide aid to farmers who have suffered a 30% or more loss of crops or significant loss of livestock, and the Livestock Forage Disaster Program offers compensation to ranchers who suffered grazing losses due to drought.

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[16] Personal Communication: Chino Hills Department of Public Works, April 18, 2019

[17] Personal Communication: City of Ontario, May 15, 2019

[18] Personal Communication: Lake Arrowhead Community Services District, March 28, 2019

[19] Personal Communication: East Valley Water District, April 18, 2019

While these programs help compensate farmers after a climate event has occurred, they do not fix the problem of reduced crops and dairy products that result from climate hazards. To ensure that San Bernardino farms can continue to generate food, the County will need to invest in more proactive adaptation strategies.

Compared to agricultural resources, biological resources are quite variable, ranging from chaparral to riparian corridors to woodland. However, they mostly face risks from the same hazards as agriculture: extreme heat, drought, and wildfire. While San Bernardino County already experiences very hot days and much of the vegetation, such as chaparral and desert scrub, is heat-tolerant, other types of vegetation in the region are more heat-sensitive (such as Joshua trees and pinyon-juniper woodlands). Chronic extreme heat events can cause these sensitive species to migrate to other areas or die out as more heat-tolerant species move in.

Drought can create stress for water-reliant biological resources such as marshes and precipitation-sensitive habitats like conifer forests, pinyon-juniper woodlands and grasslands, especially since droughts are projected to become more intense and frequent in the region. Furthermore, drought may weaken trees by limiting their ability to produce resin, which leaves them defenseless against pests such as the bark beetle. Bark beetles can infiltrate weak trees, cutting off their moisture supply completely and leaving them to die. This in turn provides a large amount of dead fuel, which can increase wildfire risk, further endangering the surrounding vegetation.

Finally, an increase in wildfires can be devastating for biological resources that are not adapted to recovering quickly from being burned. Some biological resources have a cultural significance in the area, so ensuring their survival would be particularly critical; for example, Joshua trees are threatened by heat, drought, and invasive species, and have little ability to recover from wildfire. The loss of this species can have a significant impact on the identity of the region, potentially resulting in economic losses due to decreased tourism as well.

The diversity of biological resources makes it hard to pinpoint a one-size-fits-all strategy for climate adaptation. It is also harder to control the adaptive capacity of these resources. While San Bernardino County can install climate defenses or re-locate vulnerable sites to protect infrastructure, biological resources are often too vast and sensitive to development to implement these strategies. More land management-type techniques may be needed instead.

PRIORITY SECTOR 7: PLAN MAINTENANCE

San Bernardino County's current planning and emergency response documents represent an opportunity to integrate climate hazard vulnerability information and resilience planning into existing frameworks. The County already experiences the eight climate hazards mentioned to a certain degree, so its infrastructure, social systems, and residents are somewhat adapted to the current levels of these hazards. However, climate change may increase the frequency or severity of climate hazards in the future, requiring an update to emergency response processes and land use planning.

The planning and emergency documents below consider the impacts of climate change on the County:

- In the *San Bernardino County Multi-Jurisdictional Hazard Mitigation Plan (MJHMP)*, approved in 2017, Section 4 includes risk assessments of multiple climate hazards, including wildfire, flood, and drought (County of San Bernardino 2017). Section 4.8 focuses specifically on hazards due to climate change and how projections of these hazards may increase in the future.
- The County's *Emergency Operations Plan (EOP)*, revised in early 2018, also recognizes the increased occurrence of hazards due to climate change (County of San Bernardino, 2018a). The Plan's appendices include hazard profiles for wildfires, floods, drought, and climate change
- The *California Department of Public Health* conducted a report analyzing climate change and its impacts on public health in the County in 2017 and recommends strategies with both near-term and long-term actions to increase the resilience of communities (Maizlish et al., 2017).
- San Bernardino County's upcoming *County Policy Plan* recognizes the increased risk of natural hazards such as flooding and wildfire due to climate change in the Hazards Element section (County of San

Bernardino, 2018b). The recommended policies in the Hazards Element section include floodplain mapping, avoidance of new construction in high-risk areas, and adding resilient design to existing properties in high-risk areas. This Plan is still a draft and is not expected to be adopted until the second half of 2019; however, because it intends on guiding future decision-making for regional issues and services, the inclusion of climate adaptation can help the County prepare for future climate hazards.

In summary, the County currently considers climate change risks in both its planning and emergency response frameworks. Looking forward, there are opportunities to integrate updated climate change information to better prepare the County for climate hazards and formulate potential adaptation actions.

To address this, the County is currently producing a set of adaptation strategies that work to mitigate risks from climate hazards. However, climate projections and other metrics (such as populations and demographics) may still shift in the future, and the potential impacts from these hazards may change as well. Changing conditions require governments to be vigilant and flexible about implementing adaptation strategies.

The County can keep up with new information by creating a plan for updating climate-related documents. These updates can periodically incorporate the best available climate projections, data and best practices to evaluate climate hazard exposure in the County and prepare for potential adaptation actions. A specially designated department or team within the County can also serve as the primary overseer of these plans and make sure climate adaptation is integrated into other County processes, such as planning and emergency response.

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Technical Appendix Vulnerability Assessment

INTRODUCTION

San Bernardino County developed the report entitled **San Bernardino County Vulnerability Assessment** to evaluate the impact of climate hazards on County populations, assets and ecosystems under the influence of climate change through mid-century. The report includes a vulnerability assessment that identifies and ranks vulnerable assets; a separate document will include an overall resilience strategy to address vulnerability to climate change (see the forthcoming **San Bernardino County Resilience Strategy** report for potential adaptation strategies). This technical appendix provides background information on the data and methods used for this purpose and explains outcomes of the vulnerability assessment and resilience strategy process.

Key Terms

This Vulnerability Assessment uses several key terms that are defined in accordance with the California Natural Resource Agency's 2009 *California Adaptation Planning Guide.* The following list provides definitions for these terms:

- **Hazard** – climate changes that pose a risk to a community
- **Exposure** – the degree to which a community or asset will experience a climate hazard
- **Sensitivity** – a structure, function, or population that could be affected by climate change
- **Adaptive Capacity** – the ability of a system to respond to climate change, moderate potential damages, take advantage of opportunities, and cope with the consequences
- **Vulnerability** – the degree to which a system is exposed to, susceptible to, and unable to cope with the adverse effects of climate change
- **Impact** – an effect of climate change on the structure or function of a system
- **Adaptation Strategy** – an action taken to protect an asset or community from climate change impacts
- **Resilience Strategy** – a set of methods and measures to enhance a system's ability to withstand and respond to climate change

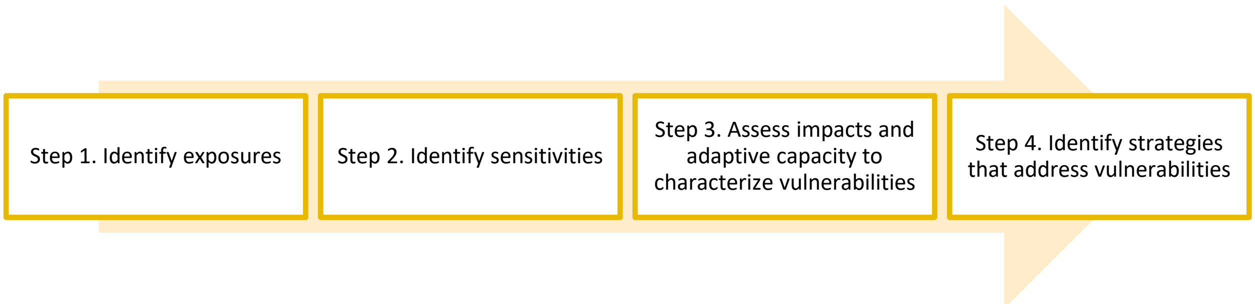
VULNERABILITY ASSESSMENT PROCESS

The vulnerability assessment relies on the latest climate projections and datasets, scholarly research, and government reports. These sources help identify how climate change may increase the frequency and severity of climate hazards and how hazards could impact sensitivity areas, such as transportation infrastructure, disadvantages communities and natural resources. The assessment considered climate exposure, impacts, and adaptive capacity to assign a total vulnerability score for each sensitivity, allowing the County to determine which of its assets are most at risk to climate change. The process addresses the following questions:

- What climate effects (known as *hazards* – see **Table A-1** for a list of hazards assessed) could change in the planning area as a result of climate change?
- What assets or populations in San Bernardino County (known as *sensitivities* – see **Table A-2** for a list of sensitivities assessed) could be affected by the hazards?
- How would hazards affect assets or populations (known as *impacts*), and how are those assets and populations currently prepared to deal with such impacts (known as *adaptive capacity*)?
- What topics should adaptation strategies address (which sensitivities are the most *vulnerable*)?

Figure A-1 summarizes the four-part process to answer these questions in sequence.

Figure A-1: The Vulnerability Assessment and Resilience Strategy Process



This Technical Appendix follows the four-part process identified in **Figure A-1**. The following sections lay out, in order, the data sources and methodology behind the exposure analysis; the justification behind identifying sensitivities; the data sources and methodology behind the impact and adaptive capacity assessment to understand vulnerability sectors in the County; and brief methods on how San Bernardino County outlines adaptation strategies in the separate San Bernardino County Resilience Strategy report.

DATA SOURCES AND METHODOLOGY

EXPOSURE

To prepare the Vulnerability Assessment, San Bernardino County evaluated exposure to eight climate hazards that could increase in frequency and severity due to climate change. Specifically, San Bernardino County identified extreme heat, wildfire, drought, flooding, air quality human health, and ecological hazards, extreme wind, severe weather and landslides as the most impactful climate related hazards to consider. This section provides an overview of the data sources and methods used to evaluate how these hazards will change in San Bernardino County as a result of climate change. **Table A-1** lists the climate hazards assessed in the exposure analysis along with their corresponding data sources.

Table A-1: Climate Hazards Considered in the Vulnerability Assessment

Climate Hazard	Data Sources
Extreme Heat	Cal-Adapt, California 4th Climate Change Assessment and scientific literature
Wildfire	Cal-Adapt, California 4th Climate Change Assessment and scientific literature
Drought	California 4th Climate Change Assessment and scientific literature
Flooding	FEMA flood maps, California 4th Climate Change Assessment and scientific literature
Air Quality, Human Health, and Ecological Hazards	California 4th Climate Change Assessment and scientific literature
Extreme Wind	Cal-Adapt, California 4th Climate Change Assessment and scientific literature
Severe Weather	California 4th Climate Change Assessment and scientific literature
Landslides	California 4th Climate Change Assessment, California Geological Survey and scientific literature

Data Sources

The **San Bernardino County Vulnerability Assessment** evaluated how climate change may increase the frequency and severity of climate hazards using two principle data types. First, projections for extreme heat, wildfire and extreme wind were collected from the web-based tool Cal-Adapt (CEC 2019); these data sets allowed for a spatial analysis of where changes would be greatest/least throughout the County. Second, the County used summary reports and research prepared for California's Fourth Climate Change Assessment and the Fourth National Climate Assessment to provide general information on all climate hazards considered.

In terms of timeframes, the County emphasized the mid-century, rather than end-of-century, timeframe because it better aligns with the planning time horizon of most agencies. In particular, the mid-century timeframe was used for all Cal-Adapt projections. Looking at the end-of-century timeframe (sometimes referred to as 2100) does generate more dramatic estimated changes in climate; however, there is greater uncertainty not only in climate changes but also in demographics, land use, and technology, so it is more difficult to estimate vulnerabilities and impacts that far into the future. Moreover, since the end of century is far outside of most agencies' planning horizon, discussing potential impacts that far in the future can sometimes shut down adaptation planning discussions with stakeholders as it is seen as too far away to be actionable.

Nevertheless, San Bernardino County does consider end-of-century projections where appropriate to illustrate high-end climate change and potential long-term impacts. Ultimately, the **San Bernardino County Vulnerability Assessment** main report includes both mid-century and end-of-century projections to provide users with a range of possible climate futures.

Climate hazards including extreme heat, wildfire and extreme wind were evaluated quantitatively and spatially using climate projections from the web-based tool Cal-Adapt (CEC 2019). Cal-Adapt allows users to identify projected changes in temperature, precipitation, wildfire, snowpack and sea level rise in specific geographic locations throughout the state (e.g.,

Figure A-2). Cal-Adapt routinely incorporates the latest climate projections and currently uses the Coupled Model Intercomparison Project (CMIP 5) multi-model daily climate set generated for the 2013 Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report. Climate projections are statistically downscaled using the LOCA method to a 1/16° (~6km) resolution grid[1], which allows for a detailed spatial analysis of these hazards and their future change across San Bernardino County (Pierce and Cayan 2014). The methodology section describes the spatial analysis using Cal-Adapt climate projections in more detail.

Because Cal-Adapt does not have projections for all climate hazards, San Bernardino County used additional data sources to characterize expected changes to drought, flooding, air quality, human health and ecological hazards, severe weather and landslides. These additional sources represent the latest state-of-the-art climate literature and projections, and include California's Fourth Climate Change Assessment, the Fourth National Climate Assessment and Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps. Severe weather and extreme wind were evaluated separately but discussed in combination in the main report to provide a more cohesive view of how severe events may change in the face of climate change.

As part of California's effort to advance climate change research and policy, the State completed its Fourth Climate Change Assessment to provide a foundation for understanding climate vulnerability and resilience. San Bernardino County draws on results and research cited in the Inland Deserts (Hopkins 2018) and Los Angeles (Hall, Berg and Reich 2018) regional reports of the Fourth Assessment to characterize future increases in the frequency and magnitude of drought, severe weather, air quality and human health hazards and landslides.

The assessment also used current FEMA flood maps to estimate areas potentially exposed to future flooding in the 100-year and 500-year flood zones. While FEMA maps do not explicitly represent increases in future flooding, the flood zones indicate which areas are most likely to flood first, or more frequently, as the climate changes. Therefore, they are an imperfect but reasonable proxy for future flood exposure.

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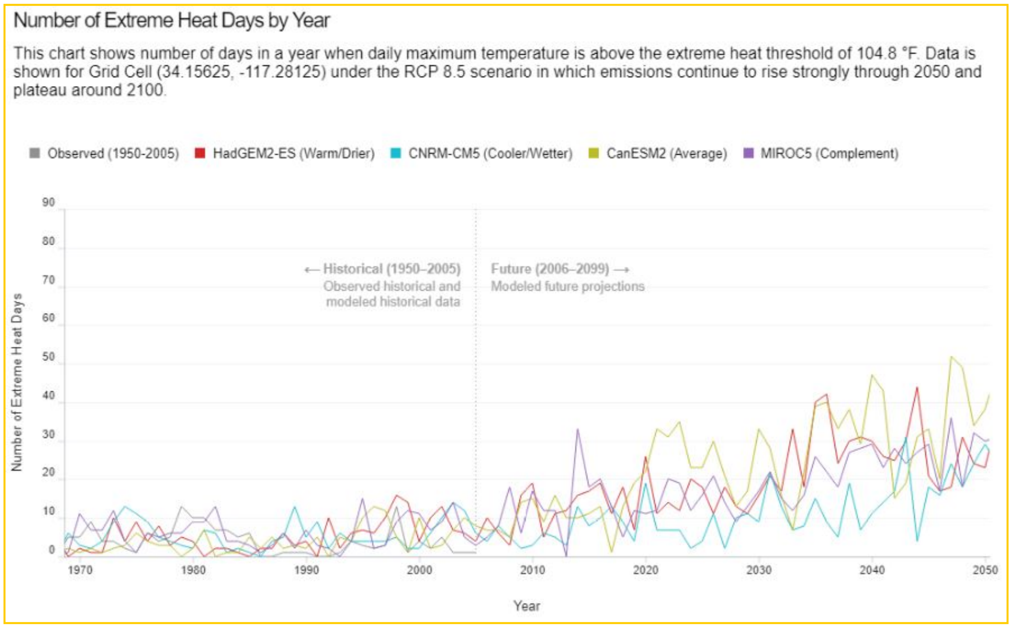
[1] Cal-Adapt LOCA Downscaled Climate Projections are prepared by the Scripps Institution of Oceanography.

Figure A-2: Cal-Adapt Output Showing Number of Extreme Heat Days per Year in the City of San Bernardino



Source: California Energy Commission (CEC) 2019

Methodology

<u>Climate Projections and Uncertainty</u>

For the hazards for which exposure was quantitatively assessed using data from Cal-Adapt, San Bernardino County made two key assumptions: (1) the representative concentration pathways (RCP) referred to as 8.5 was the appropriate one to use, and (2) the four priority Global Climate Models (GCMs) recommended by the State of California were appropriate for this report.

RCPs approximate different trajectories of future GHG concentrations. RCPs were developed for the 2013 IPCC Fifth Assessment Report, and the different RCP trajectories represent different combinations of economic, technological, policy and demographic futures (IPCC 2013). For this report, San Bernardino County used RCP 8.5[2], which assumes a continuation of business-as-usual emissions and GHG concentrations throughout the 21^{st} century. Alternative RCPs assume GHG concentrations peak or decline by mid-century, which would require near-term mitigation efforts exceeding current capabilities.

To quantify changes in extreme heat, wildfire and extreme wind events through mid-century, San Bernardino County followed the recommendations in the Fourth California Climate Change Assessment and used the four GCMs that best represent the range of future climate outcomes in the state. These GCMs include:

- HadGEM2-ES (representing a Warm/Dry future climate)
- CNRM-CM5 (Cool/Wet)
- CanESM2 (Average)
- MIROC5 (Complimentary)

[2] RCP 8.5 denotes a global radiative forcing of 8.5 W/m^2 by the year 2100.

Whereas GCM datasets usually have a very coarse spatial resolution (~1°), Cal-Adapt shares projections in a statistically downscaled format (1/16°), which better approximates the climate in southern California and provides more confident projections (Pierce et al. 2014). This report investigates how climate conditions and hazards change between the recent baseline time period and mid-century. For this report, the baseline is calculated as the average of the 30-year period between 1976 – 2005, which represents the Cal-Adapt's standard baseline, and mid-century represents the 30-year period around 2050, or 2036 – 2065.

When obtaining wildfire projections from Cal-Adapt (Westerling 2018), San Bernardino County assumed business-as-usual land use and population changes through mid-century. These variables help determine the frequency and size of wildfires in the County in addition to climate hazards such as temperature and precipitation.

While GCMs often predict similar climate trends through mid-century (i.e., models agree that temperatures will increase steadily), the magnitude of change can differ between models. These differences result from slight differences in the resolution and internal dynamics approximating climate processes in each model. To address this, California compared output from each GCM against historical climate observations to determine which models best capture regional climate. California's four priority models were chosen from the group of models that performed best and represent the smallest selection of models that captures the mean and range of all possible future climate scenarios. As a result, the projections used in this report confidently capture the uncertainty in mid-century climate within San Bernardino County.

Understanding the Difference Between Weather and Climate

A common misconception is that weather and climate are synonymous. In fact, the two terms refer to very different phenomena. "Weather" refers to the short-term state of the atmosphere. In contrast, "climate" refers to the long-term average of weather and reflects the mean and range of weather at a particular geographic location. Whereas weather changes on timescales ranging from minutes to weeks, climate changes over the course of many years. It is important to understand that you can have year-to-year variation in weather that is different from a longer-term trend.

San Bernardino County will always experience year-to-year differences in weather conditions. Even while temperatures are expected to climb steadily through mid-century, there may be anomalously cool or warm years along the way due to significant natural variability. For example, annual temperature and precipitation in Southern California vary strongly with El Niño and La Niña conditions in the tropical Pacific Ocean. For this reason, this report uses an average of the years 2036 through 2065 to represent climate in the mid-Century timeframe.

Exposure Maps

The report used ArcGIS software to map extreme heat, wildfire, flooding and landslide hazards across San Bernardino County. These maps provide important visual aids and spatial datasets to identify and prioritize vulnerable assets. Where possible, the report performed spatial correlations between exposures and county assets and sensitivity areas, such as civic offices, critical infrastructure and population characteristics. For example, maps of extreme heat and social vulnerability identify disadvantaged communities most at risk of heat exposure. Similarly, wildfire maps identify roads and infrastructure proximal to increasing wildfire exposure through mid-century.

San Bernardino did not develop exposure maps for drought, severe weather, air quality and human health hazards, and landslides because, as noted above, projection data were not available for those hazards. Instead, changes in those hazards are discussed more qualitatively in the *Climate Change in the County* section of the main report.

SENSITIVITY

Sensitivities are the structures, populations, or other assets that could be affected by climate change. As the second step in the vulnerability assessment process, this section identifies sensitivities that are potentially vulnerable to climate change.

The Western Riverside Council of Governments (WRCOG)'s Climate Action Plan (CAP) provides an initial list of structure and demographic sensitivities to consider. These lists of sensitivities have been expanded upon and refined to reflect the specific populations and areas of special focus for San Bernardino County. The sensitivity categories used for this analysis are described in **Figure A-3**.

Figure A-3: Types of Sensitivities

Populations	• A group of people that share a demographic trait • *Examples:* Individuals 65 years and older, ethnic communities
Infrastructure	• Major public structures or networks that serve a critical purpose • *Examples:* Bridges, energy transmission infrastructure, railways
Buildings	• Individual buildings that serve specific purposes • *Examples:* Government offices, healthcare facilities, residences
Economic Resources	• Industries that bring economic activity to San Bernardino County • *Examples:* Business centers, industrial sites, winter and water recreation
Biological Resources	• A distinct type of habitat that supports specific plants and animals • *Examples:* Riparian areas, chaparral, desert scrub
Services	• Public services for San Bernardino County • *Examples:* Communication services, natural gas service, transit service

This vulnerability assessment focused on understanding the impacts to and adaptive capacity of sensitivities in the sectors described above: populations (23 sensitivities), infrastructure (19 sensitivities), buildings (14 sensitivities), economic resources (14 sensitivities), biological resources (10 sensitivities), and services (12 sensitivities). This high volume of sensitivities was considered in order to better understand possible nuances in vulnerabilities within sectors and to help identify specific areas for building resilience. The full list of sensitivities analyzed is shown in **Table A-2**.

Table A-2: Sensitivities Considered in the Vulnerability Assessment

Populations	Infrastructure	Buildings	Economic Resources	Biological Resources	Services
• Children • Cost-burdened households	• Airports • Bridges • Communication facilities	• Community facilities • Government offices	• Agricultural operations • Business centers	• Chaparral and coastal scrub	• Communication services • Electrical services

Populations	Infrastructure	Buildings	Economic Resources	Biological Resources	Services
• Homeless persons • Households in poverty • Households overpaying for housing • Incarcerated persons • Individuals living on single access roads • Individuals with disabilities • Individuals with existing medical conditions • Individuals without access to lifelines • Linguistically isolated persons • Low income households • Native American persons • Outdoor workers • Overcrowded households • Persons in mobile homes • Renters • Seasonal residents and migrant workers • Senior citizens • Senior citizens living alone • Students • Undocumented persons • Pregnant and nursing women	• Culverts and Arizona crossings • Dams • Energy transmission infrastructure • Evacuation routes • Flood control infrastructure • Major roadways • Power plants • Railways • Sidewalks and bike lanes • Single access roads • State and federal highways • Trails • Transit centers • Waste and wastewater infrastructure • Road and storm drainage • Road signals and traffic control centers	• Health care facilities • Military installations • Old homes • Parks and open space • Public safety buildings • Public Works corporation yards • Schools • Adult residential care facilities • Child care centers • Foster homes • Public housing • Senior care centers	• Campsites • Colleges and universities • Historic buildings and sites • Hotels and lodging • Major industrial sites • Movie and television filming • Renewable energy potential • Retail centers • State and federal protected land • Warehouses and logistic centers • Water recreation • Winter recreation	• Conifer forests • Deciduous forest and woodlands • Desert scrub • Grasslands • Joshua trees • Lakes and waterways • Marshes and seasonal wetlands • Pinyon-juniper woodlands • Riparian corridors	• Emergency response • Freight and shipping • Government administration services • Health services • Natural gas service • Public safety services • Transit service • Wastewater delivery service • Water delivery service • Emergency notification

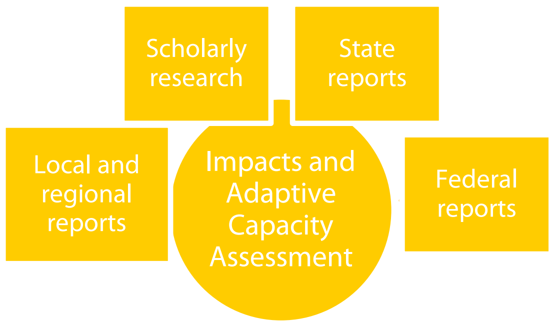
IMPACT AND ADAPTIVE CAPACITY

Vulnerability, for the purposes of this analysis, is defined as susceptibility to harm or change. San Bernardino County used two different metrics to determine the vulnerability of a sensitivity to climate hazards: impacts and adaptive capacity. "Impact" describes the harm or damage (or lack thereof) a sensitivity might experience due to climate hazards. "Adaptive capacity" refers to a sensitivity's ability to prepare for, withstand, or recover from the hazard. This section provides an overview of the data sources and methods used to evaluate impacts and adaptive capacities of the assessed sensitivities to the eight climate hazards. This section also describes how San Bernardino County defined socially vulnerable populations and accounted for their specific needs when evaluating impacts and adaptive capacities.

Data Sources

Figure A-4 identifies the sources used to assess impacts and adaptive capacities in **San Bernardino County Vulnerability Assessment** and this Technical Appendix. The sources are discussed following the figure.

Figure A-4: Vulnerability Assessment Data Sources



Local and Regional Reports

Where available, San Bernardino County obtained and reviewed local general plan safety elements, emergency operation plans, local hazard mitigation plans, and climate change adaptation plans for jurisdictions in the County. The plans were used to identify existing planning framework conditions and information about local hazard conditions. These plans included:

- San Bernardino Associated Governments (SANBAG) Long-Range Transit Plan (SANBAG 2010)
- City of San Bernardino 2016 Hazard Mitigation Plan Update (City of San Bernardino 2016)
- San Bernardino County Transportation Authority (SBCTA) County-Wide Transportation Plan (SBCTA 2015)
- SBCTA Short-Range Transportation Plan (SBCTA 2016)
- San Bernardino County Multi-Jurisdictional Hazard Mitigation Plan (San Bernardino County 2017)
- Emergency Operations Plan (San Bernardino County Fire and Office of Emergency Services 2018)
- County Policy Plan (San Bernardino County 2018)

State Reports

San Bernardino County referred to California's Fourth Climate Change Assessment (CEC and CNRA 2018) for California-specific information on climate impacts. The Fourth Assessment provides statewide, regional, and technical reports covering topics ranging from climate projections to impacts on specific sectors. In this vulnerability assessment, the County looked at the Inland Deserts and Los Angeles regional reports, which represented the areas covered by San Bernardino County.

San Bernardino County also looked to state design criteria, such as the California High-Speed Train Project Design Criteria (California High-Speed Rail Authority 2012a), to understand whether or not climate impacts are already included in such standards.

Federal Reports

San Bernardino County looked at the Fourth National Climate Assessment (USGCRP 2018), which describes climate change impacts, risks, and adaptation strategies in the United States. On a more granular level, references such as the U.S. Forest Service describes the role San Bernardino International Airport plays in fire response in southern California (US Forest Service n.d.), and the U.S. DOE describes the vulnerabilities of Native Americans' energy systems to climate change (US Department of Energy 2015).

Scholarly Research

This vulnerability assessment relies heavily on peer-reviewed research to estimate the impacts of climate change on the various types of populations, structures, and functions in the County. It is important to note that most scholarly research on topics related to this vulnerability assessment is international, national, or statewide in scope and focus. San Bernardino County has made its best effort to only use research that studies conditions comparable to those experienced in the County. These include a report on the impacts of climate change on older Americans (Gamble, et al. 2013) and another on the impacts of climate change, particularly drought, on Native Americans (Gautam, Chief and Smith 2013). For a complete list of resources used to complete this vulnerability assessment, see the citations list at the end of this document.

Social Vulnerability Index

San Bernardino County experiences both physical and social exposure to climate change and associated hazards. In order to account for "social vulnerability," or the susceptibility of populations to climate hazards and their ability to prepare for, respond to and recover from climate stresses (Cooley, et al. 2012), San Bernardino County adopted a social vulnerability index (SoVI) recently released as part of the 2018 California State Hazard Mitigation Plan by the California Governor's Office of Emergency Services (California Governor's Office of Emergency Services 2018). This SoVI was incorporated into the 4th California Climate Change Assessment (Roos 2018). As a result, the County uses this indicator to follow best practices and evaluate the cumulative influence of socio-economic and demographic characteristics on hazard exposure.

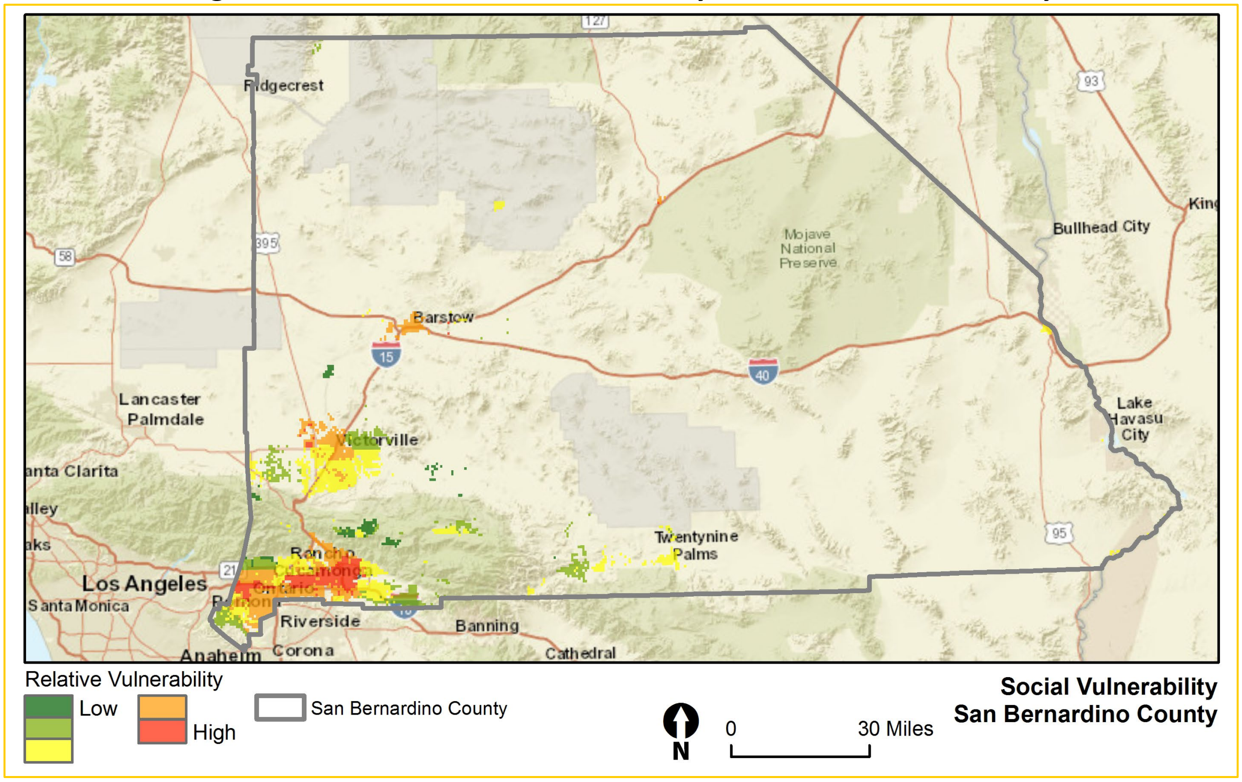
The social vulnerability index represents a weighted value for the following indicators,

- Poverty/Income (0.190)
- Disabilities (0.126)
- Food Access (0.105)
- Education (0.093)
- Linguistic Isolation (0.090)
- Vehicle Availability (0.087)
- Age (0.072)
- Minority Status (0.071)
- Long-term Care Facility Residents (0.069)
- Housing Tenure (0.054)
- Gender (0.043)

Higher SoVI values shown in red correspond to higher social vulnerability in San Bernardino County (**Figure A-5**). Indicator variables were collected for each ZIP Code Tabulation Area (ZCTA) in San Bernardino County (California Governor's Office of Emergency Services 2018). Indicator weights used to calculate SoVI are shown within parenthesis in the list above. The resulting SoVI was interpolated to a 1-km resolution grid and grid cells with populations less than 75 were not included in the final map by Cal-OES.

Other sources can use slightly different indicators and influences to create maps of social vulnerability, each with different strengths and weaknesses. In addition, subjective decisions are necessary to help determine indicator weights, which can influence the final calculation. To address this, Cal-OES performed an uncertainty analysis whereby thousands of alternative weighting schemes were considered. This analysis revealed a relatively small average change (~10%), providing confidence in the existing SoVI model (California Governor's Office of Emergency Services 2018).

Figure A-5: Relative Social Vulnerability in San Bernardino County



Source: California Energy Commission (CEC) 2019

Methodology

This vulnerability assessment evaluates both primary and secondary impacts. Primary impacts are those caused directly by hazards, such as an extreme weather event that damages infrastructure. Secondary impacts are not caused directly by hazards; they occur as a result of a direct impact (e.g., warmer temperatures make conditions more favorable for mosquitoes, resulting in greater risk of mosquito-transmitted diseases). To determine the vulnerability of each sensitivity for each hazard, it is necessary to identify two characteristics: How is the sensitivity *impacted* by the hazard, and what *adaptive capacity* does the sensitivity have to the hazard?

Impact

The impact assessment methods in this vulnerability assessment use a combination of qualitative and quantitative information to determine the severity of each impact. For infrastructure components or functions/services, this evaluation includes the following:

- What is the value of the structure or function, including its assessed value and intangible importance to the community (e.g., contributions to overall quality of life)?

- Does the structure or function benefit only select members of the community, or is it used by most or all residents?
- How substantial must damage be to the structure or function from the hazard in question, before the structure or function ceases to provide the level of service that community members require or expect?
- If the structure or function can no longer provide adequate service, how easy is it to restore service?
- If the structure or function can no longer provide service, is there a risk of mortality or morbidity?
- Is the structure(s) that provide(s) the service located in an area currently at risk from the hazard in question? If not, what is the likelihood that the area will be at risk from the hazard in question as climate change occurs?

A similar set of questions was used to evaluate impacts to populations, including the following:

- What sort of hardships would be felt by the population as a result of the hazard? Would it result in a decrease in quality of life or threaten to damage and/or destroy property?
- Is there a risk of mortality or morbidity to the population as a result of the hazard?
- How many people are affected by the hazard? Is it a relatively small group within the community, or is it most or all of the residents?
- In the event that hardships occur, how long would the population be affected? Would hardships diminish in severity over time or remain at the same level of severity during the course of the impact?

Each sensitivity was given a score from I0 (minimal impact) to I4 (severe impact) for each hazard.

Table A-3 reports how each score was qualitatively determined.

Table A-3: Impact Scoring Matrix

Impact Score	Summary (Structure, Public Health, Transportation)	Summary (Human and Biological Communities)
I0	Impacts are minimal. There are no service disruptions that community members are aware of.	All impacts are minimal. Community members may not notice effects.
I1	Performance or services may be somewhat degraded on occasion.	Community members notice minor impacts. There may be mild disruptions to some behaviors or actions.
I2	The asset is likely to experience chronic stress, limiting the ability to reliably function. Effectiveness may be entirely disrupted on occasion.	There is a marked decline in overall quality of life. Reductions to health, public safety, and/or community viability are likely.
I3	The asset may only function in a limited way. It may frequently or always be unable to meet community needs.	There is a substantial drop in the well-being of the affected communities. Current lifestyles/habitat may no longer be viable.
I4	The ability of the asset to provide beneficial service is destroyed.	There is a severe risk of injury or death in human populations and of major habitat shifts or degradation for biological communities.

Adaptive Capacity

This vulnerability assessment evaluates the adaptive capacity of each sensitivity to each hazard. Adaptive capacity is the ability of the sensitivity to respond to impacts using existing resources. While the process for assessing impact includes a combination of qualitative and quantitative data, the adaptive capacity assessment is primarily a qualitative effort. The adaptive capacity evaluation for structures and functions includes the following considerations:

- Are there existing policies, plans, or programs in place or being considered to guide the response?
- Do the owners or operators of the asset have the financial means to respond to impacts?
- Would recovery be voluntary (i.e., does the owner/operator have the ability to choose if and to what degree recovery occurs)?
- Are there alternatives to the asset that the community can rely on while service is being restored? Do these alternatives adequately meet the community's needs?
- Are there any significant or insurmountable barriers to a response? Does the response require solutions that are technologically and/or politically infeasible?

A similar set of questions was used to evaluate the adaptive capacity of populations, including:

- Are there any existing/planned policies or programs to assist individuals with the response? Do community members have easy access to such services or are there difficulties associated with receiving assistance?
- Does the population have the financial means to respond to the impact? How complete would the response be?
- Does the population have the agency to implement a response, or is adaptation of their surroundings dependent on other parties?
- What alternatives exist to reduce or eliminate the hardships caused by the hazard?
- Do other barriers exist to the response, including technological capabilities and/or political will?

Each sensitivity associated with each hazard was also given an adaptive capacity score from AC0 (no adaptive capacity) to AC4 (high adaptive capacity). **Table A-4** reports how each score was qualitatively determined. Note that while for impacts, a lower score is preferable, a higher score is better for adaptive capacity.

Table A-4: Adaptive Capacity Scoring Matrix

Impact Score	Summary
AC4	Assets and populations can adapt with little or no effort. Overall quality of life may improve as a result.
AC3	Adaptive solutions are feasible for most or all sensitivities. Some sensitivities may face limited challenges.
AC2	Threats can be reduced or mitigated, but solutions are only feasible for some sensitivities. Many assets and populations are likely to face substantive difficulties in adapting.
AC1	Adaptive solutions are expensive and/or technologically difficult, but feasible. Approach may require politically unpopular actions or widespread lifestyle changes.
AC0	No method of adapting is currently feasible, although solutions may be possible in the future.

VULNERABILITY

The combination of each sensitivity's impact score and adaptive capacity score results in a vulnerability score, ranging from V0 (low) to V5 (high). A low impact score and high adaptive capacity score results in a low vulnerability score, while the opposite results in a higher vulnerability score. **Table A-5** illustrates how a sensitivity's impact score and adaptive capacity score combine to create a vulnerability score.

Table A-5: Vulnerability Scoring Matrix

		Impact Score				
		I0	**I1**	**I2**	**I3**	**I4**
Adaptive Capacity Score	**AC0**	V2	V3	V4	V5	V5
	AC1	V1	V2	V3	V4	V5
	AC2	V1	V1	V2	V3	V4
	AC3	V0	V1	V1	V2	V3
	AC4	V0	V0	V0	V1	V2

VULNERABILITY ASSESSMENT OUTCOMES

This section provides information about sensitivities that had a score of V3 or higher. The sensitivities are sorted by hazard, category, and by vulnerability score. Each subsection begins with a brief overview of vulnerability for the respective hazard. Each subsection includes a brief overview statement summarizing each hazard and its associated exposure. However, the main report of the **San Bernardino County Vulnerability Assessment** provides a more detailed view of each climate hazard and their projected changes in the County.

Sensitivities are sorted into six categories: populations, infrastructure, buildings, economic resources, biological resources, and services. **Figure A-6** identifies icons used for each category.

Figure A-6: Sensitivity Categories

Overall, the most vulnerable sensitivities are disadvantaged populations, particularly those who are highly exposed to climate hazards (such as seasonal residents and migrant workers, outdoor workers, and homeless persons), those who are highly sensitive to climate hazards (such as senior citizens living alone and individuals with disabilities or medical conditions), and those with low adaptive capacity to climate hazards (such as incarcerated persons). These populations consistently have the highest vulnerability scores across multiple hazards. Low-income populations are also highly vulnerable to multiple climate hazards.

Out of infrastructure and services, climate hazards pose greater threats to the electricity, transportation, and emergency response sectors. Climate hazards that create the most vulnerabilities include wildfires, flooding, and mudslides, while drought and air quality issues are less pressing. However, chronic stresses like drought and extreme heat pose risks to biological resources in San Bernardino County, particularly pinyon-juniper woodlands and Joshua trees.

EXTREME HEAT

For this assessment, San Bernardino County defined extreme heat days as those with temperatures hotter than 95% of daily maximum temperatures in the baseline time period. The County looked at the time period of 1976 to 2005, and determined the temperature threshold at which, in an average year, only 18 days (5% of the year) were hotter than that threshold. Then, looking toward the future time period of 2036 through 2065, the County projected how many additional days would fall above this threshold. The exact threshold varies by geographic area, but ranges from 75 to 113°F, with an average of 103°F across the entire county.

The greatest threat posed by extreme heat is health impacts caused by higher temperatures, which can be particularly problematic for children and older individuals, individuals who work outside, homeless persons, individuals with existing medical conditions, and those who lack access to effective cooling in their homes or workplaces. Some types of infrastructure, particularly electricity transmission and delivery wires, may be less efficient and more vulnerable to disruptions as a result of very high temperatures. Water and wastewater infrastructure may experience decreased base water flow, and alternative water sources may be difficult to find. This can also affect water recreation in the area. Extreme heat can also increase water loss in plants and animals, which may put stress on the county's biological communities and agricultural operations.

Vulnerability Score	Sensitivity	Impact Score	Adaptive Capacity Score
	Populations		
V5	Outdoor workers	I3	AC0
V5	Seasonal residents and migrant workers	I3	AC0
V4	Homeless persons	I3	AC1
V4	Individuals with existing medical conditions	I3	AC1
V4	Senior citizens living alone	I3	AC1
V3	Children	I2	AC1
V3	Cost-burdened households	I2	AC1
V3	Households in poverty	I2	AC1
V3	Households overpaying for housing	I2	AC1

Vulnerability Score	Sensitivity	Impact Score	Adaptive Capacity Score
V3	Incarcerated persons	I2	AC1
V3	Individuals with disabilities	I2	AC1
V3	Individuals without access to lifelines	I2	AC1
V3	Low income households	I2	AC1
V3	Native American Persons	I2	AC1
V3	Overcrowded households	I2	AC1
V3	Persons in mobile homes	I2	AC1
V3	Senior citizens	I3	AC2
Infrastructure			
V3	Energy transmission infrastructure	I2	AC1
V3	Waste and wastewater infrastructure	I2	AC1
Economic Resources			
V4	Agricultural operations	I3	AC1
V3	Water recreation	I1	AC0
Biological Resources			
V3	Joshua trees	I3	AC2
V3	Pinyon-juniper woodlands	I3	AC2

WILDFIRE

The anticipated effects of climate change include warmer temperatures and a decline in precipitation levels, which are projected to lead to an increase in the number of wildfires due to drier vegetation and atmospheric conditions more favorable to fire. Parts of San Bernardino County already experience elevated fire risks, primarily in the forested mountain regions. The risk of wildfires in the County is projected to increase moderately; by 2050, annual burned area is projected to increase up to 25 to 60 hectares per 36 km^2 in some locations. The greatest increases are projected to occur in communities neighboring the Santa Bernardino and San Gabriel mountains.

In addition to the direct risk to people, property, and biological communities from the flames, wildfires can also result in a number of indirect risks. Smoke can cause or exacerbate respiratory problems for sensitive individuals, and the fine particles in smoke can damage machinery. Without vegetation to help hold the ground together, recently burned areas may also be at greater risk from landslides.

Vulnerability Score	Sensitivity	Impact Score	Adaptive Capacity Score
Populations			
V5	Seasonal residents and migrant workers	I3	AC0
V4	Cost-burdened households	I3	AC1
V4	Homeless persons	I3	AC1
V4	Households in poverty	I3	AC1
V4	Households overpaying for housing	I3	AC1
V4	Incarcerated persons	I3	AC1
V4	Individuals with disabilities	I3	AC1
V4	Individuals with existing medical conditions	I3	AC1
V4	Individuals without access to lifelines	I2	AC0
V4	Low income households	I3	AC1
V4	Native American persons	I3	AC1
V4	Outdoor workers	I2	AC0
V4	Overcrowded households	I3	AC1
V4	Persons in mobile homes	I3	AC1
V4	Senior citizens	I3	AC1
V4	Senior citizens living alone	I3	AC1
V3	Individuals living on single access roads	I2	AC1
V3	Renters	I2	AC1
V3	Students	I2	AC1
V3	Pregnant and nursing women	I3	AC2
Infrastructure			
V4	Energy transmission infrastructure	I4	AC1
V4	Power plants	I3	AC1

Vulnerability Score	Sensitivity	Impact Score	Adaptive Capacity Score
V4	Road signals and traffic control centers	I3	AC3
V3	Dams	I2	AC4
V3	Evacuation routes	I2	AC2
V3	Major roadways	I2	AC3
V3	Railways	I2	AC2
V3	State and federal highways	I2	AC3
V3	Transit centers	I2	AC3
V3	Waste and wastewater infrastructure	I3	AC1
Buildings			
V3	Health care facilities	I3	AC2
V3	Old homes	I2	AC2
V3	Parks and open space	I2	AC2
Economic Resources			
V3	Renewable energy potential	I2	AC2
Biological Resources			
V4	Joshua trees	I3	AC3
V4	Pinyon-juniper woodlands	I3	AC4
V3	Riparian corridors	I2	AC1
Services			
V3	Communication services	I3	AC4
V3	Electrical services	I4	AC3

DROUGHT

Water used in San Bernardino County is imported from the Sierra Nevada (through the State Water Project), the Rocky Mountains (through the Colorado River, delivered to the region by the Metropolitan Water District of Southern California), and from local groundwater and surface water bodies. Climate change is expected to cause a decrease in precipitation in many parts of California, resulting in less local water to replenish groundwater supplies and less water in the Sierra Nevada to be delivered through the State Water Project. Warmer temperatures are also likely to increase the melting of snowpack in the Sierra Nevada and the Rocky Mountains and cause increased evaporation from reservoirs and aqueducts, decreasing the amount of water available during summer and early autumn. Some evidence suggests that severe water shortages, such as the recent statewide drought, may become more frequent as climate change exacerbates conditions that result in such droughts, although more research is needed.

Most impacts from droughts are expected to be on biological resources. Pinyon-juniper woodlands are likely to experience dieback and tree mortality as drought stress weakens pinyon trees and makes them a target for bark beetles. Drought can also increase the flammability of trees, which elevates wildfire risk. Drought may impact species composition in conifer forests and grasslands. Joshua trees rely on periodic heavy rainfall for survival, and wetlands and marshes require adequate water supply to maintain their ecosystem characteristics. Agriculture may be forced to scale back operations if enough water is not available, causing financial difficulties for individuals in this industry and supporting businesses. In communities that lack sufficient water supplies (particularly those more dependent on groundwater), individuals may be forced to buy retail water at significantly elevated rates, causing economic hardships for those of limited financial means; this happened in some communities in the San Joaquin Valley as a result of the recent drought. Those who are also particularly exposed to drought conditions without readily available solutions (e.g., homeless persons, incarcerated persons, and those working outside) are also vulnerable.

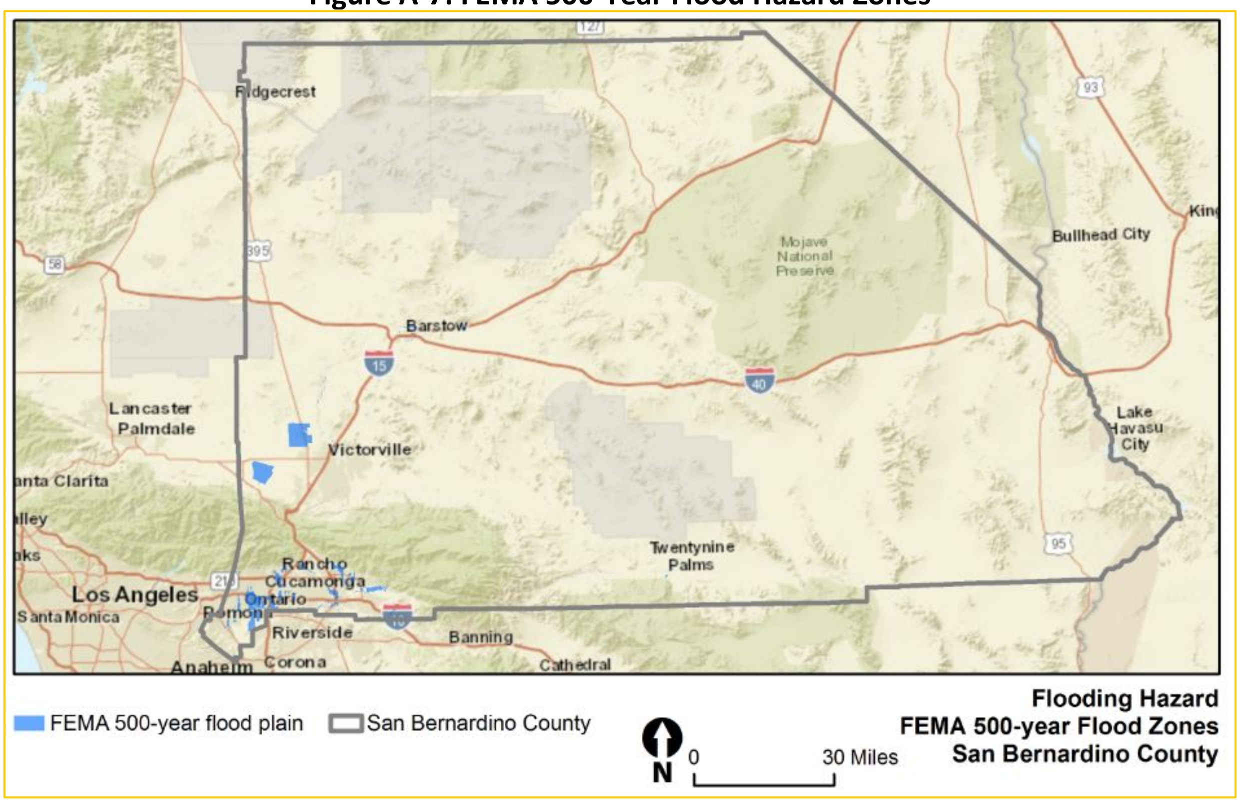
Vulnerability Score	Sensitivity	Impact Score	Adaptive Capacity Score
Populations			
V3	Homeless persons	I2	AC1
V3	Incarcerated persons	I2	AC1
V3	Outdoor workers	I2	AC1
V3	Seasonal residents and migrant workers	I2	AC1
Buildings			
V3	Parks and open space	I3	AC2
Economic Resources			
V3	Agricultural operations	I3	AC2
Biological Resources			
V5	Pinyon-juniper woodlands	I4	AC1
V4	Conifer forests	I4	AC2
V4	Grasslands	I3	AC1

Vulnerability Score	Sensitivity	Impact Score	Adaptive Capacity Score
V4	Marshes and seasonal wetlands	I4	AC2
V3	Joshua trees	I3	AC2

FLOODING

Climate change is expected to cause a decrease in precipitation in many parts of California, including San Bernardino County, but there is also evidence that it may strengthen certain atmospheric mechanisms which are responsible for delivering storm systems to the state. Some studies indicate that extremely wet seasons (those with a 4% chance of occurring) may double in frequency by mid-century. Although overall precipitation is expected to decline, the increased frequency and intensity of these storms can create an increased risk of flooding. There is no specific information on how much flood risk may increase due to climate change, but it is reasonable to assume that flood events will be more frequent in already flood-prone areas and that the size of flood-prone areas will expand. In addition to 100-year floodplain maps, FEMA provides areal extents associated with 500-year flood hazards in San Bernardino County (**Figure A-7**). Flood hazard maps show that flooding is most common in low-lying areas and river systems throughout the County. The 500-year flood zone also inundates sections of the cities of Ontario and San Bernardino in the southwest corner of the county.

Figure A-7: FEMA 500-Year Flood Hazard Zones



Source: FEMA Flood Map Service Center

The primary threat from flooding is damage to structures and individuals posed by the floodwaters. Indirectly, floods can have impacts to social and emotional health by limiting the ability to travel. Health risks can also occur after floodwaters recede, including respiratory conditions caused by mold and increased threats of diseases from vectors that rely on stagnant water, such as mosquitoes.

Vulnerability Score	Sensitivity	Impact Score	Adaptive Capacity Score
Populations			
V4	Homeless persons	I3	AC1
V4	Incarcerated persons	I3	AC1
V4	Individuals with disabilities	I3	AC1
V4	Senior citizens living alone	I3	AC1
V3	Cost-burdened households	I2	AC1
V3	Households in poverty	I2	AC1
V3	Households overpaying for housing	I2	AC1
V3	Individuals with existing medical conditions	I3	AC2
V3	Individuals without access to lifelines	I3	AC2
V3	Low income households	I2	AC1
V3	Overcrowded households	I2	AC1
V3	Persons in mobile homes	I2	AC1
V3	Seasonal residents and migrant workers	I2	AC1
V3	Senior citizens	I3	AC2
Infrastructure			
V3	Power plants	I3	AC2
Buildings			
V4	Senior care centers	I3	AC1
V3	Old homes	I2	AC1
V3	Adult residential care facilities	I2	AC1
V3	Foster homes	I2	AC1

Vulnerability Score	Sensitivity	Impact Score	Adaptive Capacity Score
V3	Public housing	I2	AC1

EXTREME WIND

For this study, San Bernardino County defined severe wind days as those exceeding the 95th percentile of daily maximum wind speeds over the baseline time period. Most of San Bernardino County is projected to see a modest reduction in severe wind through mid-century. The largest reductions (5 to 4 days per year) are projected to be in the interior and eastern sections of the county. In contrast, low-lying areas east of Victorville could see small increases.

The primary threat from extreme wind is to populations who may not have access to shelter or transportation for retreat, such as homeless persons and seasonal workers, and those for whom evacuation poses difficulties, such as incarcerated persons, individuals with disabilities and/or existing medical conditions, and senior citizens living alone. Extreme wind may result in bridge failure if the wind exceeds design standards and can cause electrical outages by knocking down or damaging above-ground power lines.

Vulnerability Score	Sensitivity	Impact Score	Adaptive Capacity Score
	Populations		
V4	Homeless persons	I3	AC1
V4	Incarcerated persons	I3	AC1
V3	Individuals with disabilities	I3	AC2
V3	Individuals with existing medical conditions	I3	AC2
V3	Seasonal residents and migrant workers	I2	AC1
V3	Senior citizens living alone	I3	AC2
	Infrastructure		
V3	Bridges	I3	AC2
	Services		
V3	Electrical services	I2	AC1

SEVERE WEATHER

Severe weather includes extreme events like rain or snowstorms, wind, thunderstorms, and hail. Rain and snowstorms often form from atmospheric rivers, or narrow parts of the atmosphere that carry large amounts of water vapor which turn into precipitation over land. Storms generated from atmospheric rivers can provide half of California's annual precipitation. Due to climate change, these atmospheric rivers may become longer, wider, and carry more water vapor and therefore cause more precipitation by mid-century. This precipitation is also more likely to fall as rain rather than snow due to coincident rising temperatures. Climate projections surrounding thunderstorms and hail are more uncertain, but these events are still likely to persist throughout the century.

The combination of extreme precipitation, wind, thunderstorms, and hail poses many safety hazards to the County. Flash flooding may become more common in the future, inundating structures and endangering populations that live in high-risk zones. Flooding may also increase risk of mudslides if heavy precipitation occurs along recently burned areas. Extreme wind, hail, and thunderstorms can damage buildings and critical infrastructure. Disadvantaged populations are especially vulnerable to displacement if their home is destroyed by these effects of severe weather.

Vulnerability Score	Sensitivity	Impact Score	Adaptive Capacity Score
Populations			
V4	Homeless persons	I3	AC1
V4	Incarcerated persons	I3	AC1
V4	Individuals with disabilities	I3	AC1
V4	Individuals with existing medical conditions	I3	AC1
V4	Seasonal residents and migrant workers	I2	AC0
V4	Senior citizens living alone	I3	AC1
V3	Cost-burdened households	I2	AC1
V3	Households in poverty	I2	AC1
V3	Households overpaying for housing	I2	AC1
V3	Low income households	I2	AC1
V3	Outdoor workers	I1	AC0
V3	Overcrowded households	I2	AC1
V3	Persons in mobile homes	I2	AC1
V3	Senior citizens	I3	AC2

Vulnerability Score	Sensitivity	Impact Score	Adaptive Capacity Score
Infrastructure			
V4	Power plants	I3	AC1
Buildings			
V4	Senior care centers	I3	AC1
V3	Health care facilities	I2	AC1
V3	Adult residential care facilities	I2	AC1
V3	Public housing	I2	AC1

AIR QUALITY, HUMAN HEALTH AND ECOLOGICAL HAZARDS

Climate changes such as increasing air temperature and wildfire frequency spur a range of associated human health risks in San Bernardino County. For example, San Bernardino will very likely experience more than seven additional days with unhealthy ozone levels per year by mid-century (Shen et al. 2016), because local ozone production accelerates at high temperatures. Increased ozone levels are linked to a multitude of health hazards, including aggravation of lung diseases such as asthma, emphysema and chronic bronchitis.

Climate change may allow pathogens and pests to proliferate in San Bernardino County. For example, projected air temperature increases and greater winter precipitation could support larger numbers of mosquitos. As a result, pests may expand their geographical range within San Bernardino County or more frequently migrate into the county. Simultaneously, people may become more at risk of heat stroke and hypothermia due to warmer temperatures and longer duration heat waves.

Climate hazards can also cause proliferation of other pests that eat away at the ecological health of the County. For example, California's recent drought weakened trees so that they were more vulnerable to bark beetles, which can infest trees, use their moisture, and leave them to die.

Vulnerable populations face the greatest threats from these hazards. Homeless persons may not have access to shelter or medical services to protect themselves. Children, individuals with disabilities and/or existing medical conditions, and senior citizens living alone may experience respiratory problems if exposed to poor air quality and may also experience barriers to evacuation. People working outdoors, including seasonal residents and migrant workers, may have no choice but to experience exposure to poor air quality.

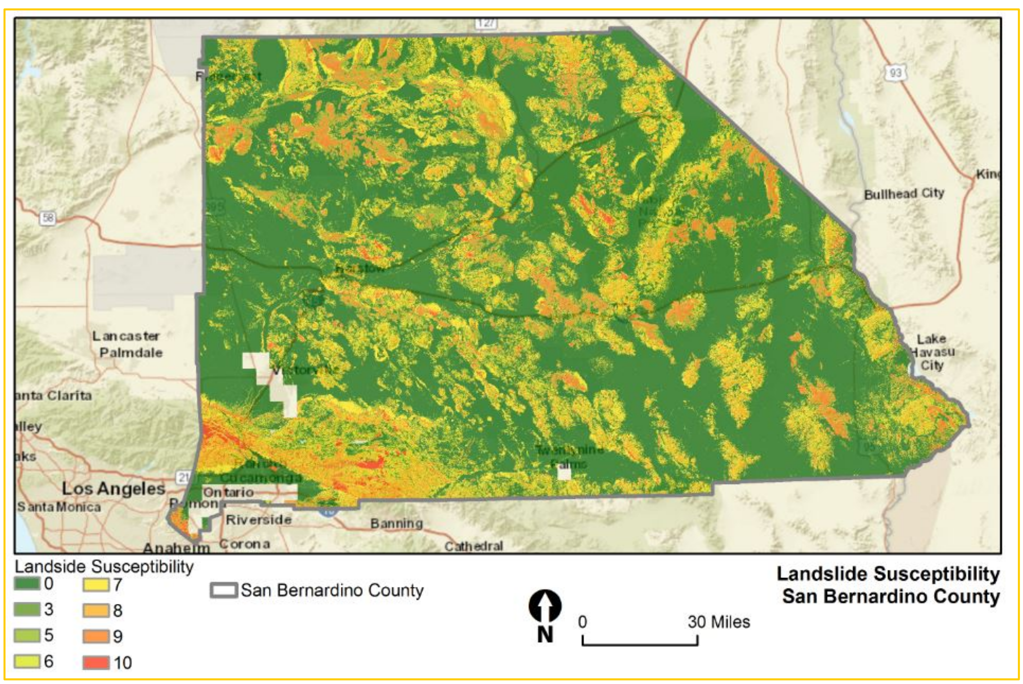
Vulnerability Score	Sensitivity	Impact Score	Adaptive Capacity Score
Populations			
V4	Homeless persons	I2	AC1
V3	Children	I3	AC2

Vulnerability Score	Sensitivity	Impact Score	Adaptive Capacity Score
V3	Individuals with disabilities	I2	AC1
V3	Individuals with existing medical conditions	I2	AC1
V3	Outdoor workers	I2	AC1
V3	Seasonal residents and migrant workers	I2	AC1
V3	Senior citizens living alone	I2	AC1

MUDSLIDES AND LANDSLIDES

Geologic factors like earthquakes may cause mud and landslides, but climatic factors such as wildfires and precipitation can also lead to mudslide-inducing conditions. When wildfires burn vegetation on a hillside, the soil loses stability, and a heavy rainfall can saturate the soil and move it in a mass down the slope. Because both wildfires and extreme precipitation are projected to increase in the future, mudslides may also occur more often. Due to the multiple factors that go into a mudslide, it is hard to predict specific locations where they may occur more often. **Figure A-8** shows the relative likelihood of deep-seated landslides across San Bernardino County based on local rock strength and steepness of slope. The dataset was developed by the California Geologic Society (Willis, Perez and Gutierrez 2011). The steep terrain and wildfire risk within the San Bernardino, San Gabriel, and San Jacinto mountains make these areas highly susceptible to landslides, as well as highly critical due to the dense populations and infrastructure sited there.

Figure A-8: Deep-Seated Landslide Susceptibility



Source: California Energy Commission (CEC) 2019

Mud and landslides can cause severe damage to infrastructure and buildings by dislodging or depositing debris onto them. This can be particularly dangerous for critical infrastructure such as bridges, electrical and emergency services, roads, and other buildings or infrastructure needed to protect public safety. Damage that results from mud and landslides can be very costly and may take a long time to repair, and structures exposed to these events may not have much adaptive capacity to protect against them.

Vulnerability Score	Sensitivity	Impact Score	Adaptive Capacity Score
Populations			
V4	Homeless persons	I3	AC1
V4	Incarcerated persons	I3	AC1
V4	Senior citizens living alone	I3	AC1
V3	Cost-burdened households	I2	AC1
V3	Households in poverty	I2	AC1
V3	Households overpaying for housing	I2	AC1
V3	Individuals living on single access roads	I2	AC1
V3	Individuals with disabilities	I3	AC2
V3	Individuals with existing medical conditions	I3	AC2
V3	Individuals without access to lifelines	I2	AC1
V3	Low income households	I2	AC1
V3	Native American persons	I2	AC1
V3	Overcrowded households	I2	AC1
V3	Persons in mobile homes	I2	AC1
V3	Seasonal residents and migrant workers	I2	AC1
V3	Senior citizens	I3	AC2
Infrastructure			
V4	Bridges	I3	AC1
V4	Energy transmission infrastructure	I3	AC1
V3	Communication facilities	I2	AC1

Vulnerability Score	Sensitivity	Impact Score	Adaptive Capacity Score
V3	Dams	I2	AC1
V3	Evacuation routes	I2	AC1
V3	Power plants	I2	AC1
V3	Railways	I2	AC1
V3	State and federal highways	I2	AC1
V3	Transit centers	I2	AC1
V3	Road signals and traffic control centers	I2	AC1
Buildings			
V3	Community facilities	I2	AC1
V3	Government offices	I2	AC1
V3	Health care facilities	I2	AC1
V3	Military installations	I2	AC1
V3	Old homes	I2	AC1
V3	Public safety buildings	I2	AC1
V3	Public Works corporation yards	I2	AC1
V3	Schools	I2	AC1
V3	Adult residential care facilities	I2	AC1
V3	Child care centers	I2	AC1
V3	Foster homes	I2	AC1
V3	Public housing	I2	AC1
V3	Senior care centers	I2	AC1
Economic Resources			
V3	Historic buildings and sites	I3	AC2
V3	Major industrial sites	I3	AC2

Vulnerability Score	Sensitivity	Impact Score	Adaptive Capacity Score
Services			
V4	Communication services	I3	AC1
V4	Electrical services	I3	AC1
V3	Emergency response	I2	AC1
V3	Freight and shipping	I2	AC1
V3	Natural gas service	I2	AC1
V3	Public safety services	I2	AC1
V3	Transit service	I2	AC1
V3	Emergency notification	I2	AC1

PRIORITY VULNERABILITY SECTORS AND LOOKING TOWARDS RESILIENCE

The matrices above list sensitivities with high vulnerability scores. Because many vulnerability indicators are often interrelated and overlapping, San Bernardino County reviewed these highest scoring sensitivities and identified emerging themes. These themes are expressed as priority sectors in **San Bernardino County Vulnerability Assessment**.

San Bernardino County also reviewed existing adaptation plans and state guidance, as well as knowledge from climate adaptation experts, to develop a list of best practices to address and increase adaptative capacity for each priority sector. These documents include official statewide reports like the California Fourth Climate Change Assessment and literature such as the Canadian Council of Ministers of the Environment's report on climate resilient natural infrastructure. The list was reviewed and edited to generate a suite of adaptation strategies provided in the separate **San Bernardino County Resilience Strategy report**. Each strategy is intended to respond to a priority vulnerability sector and are tailored to directly address sensitivities with high vulnerability scores.

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GLOSSARY OF TERMS

Adaptation – Adjustments in natural or human systems in response to actual or expected climate changes or their effects which minimize harm or take advantage of beneficial opportunities (CNRA 2009a).

Adaptive Capacity – The ability of a system to respond to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, and to cope with the consequences (CNRA 2009a).

Adaptation Strategy – An action taken to protect an asset or community from climate change impacts.

Arizona Crossing – A type of road crossing, also known as a ford, that allows a small waterway to pass over the roadbed. Arizona crossings are common in desert environments, where waterways usually do not contain enough water to affect traffic.

Atmospheric River – An atmospheric river is a narrow section of the atmosphere that transports large amounts of water vapor, which often turns into precipitation when the atmospheric river travels over land (NOAA 2015).

Climate – The long-term average of meteorological conditions (temperature, precipitation, wind, etc.) at a particular location or over a broader area (IPCC 2013).

Climate Change – Any long-term change in average climate conditions in a place or region, whether due to natural causes or as a result of human activity (CNRA 2009a).

Climate Variability – Variations in the mean state of the climate and other statistics (such as standard deviations or the occurrence of extremes) on all temporal and spatial scales beyond that of individual weather events (CNRA 2009a).

Cooling Center – A designated public facility, often air-conditioned, where people may go for relief during periods of extreme heat.

Culvert – A tunnel carrying water under a road or railroad.

Energy Conservation – Saving energy by reducing or going without an energy-using service, such as turning off a light when leaving the room or unplugging an appliance that is not in use (Lawrence Berkeley National Laboratory 2014).

Energy Efficiency – Saving energy by using less energy to provide the same or better service, such as replacing a washing machine with a model that washes clothes as effectively as the previous device but requires less energy (Lawrence Berkeley National Laboratory 2014).

Evapotranspiration – The sum of water lost through evaporation off of surfaces, and water lost through the pores of a plant as part of its normal respiratory cycle (a process called transpiration) (U.S. Geologic Survey 2014).

Exposure – The degree to which a community or asset will experience a climate hazard.

Hazard – The climate changes that a community will likely experience based on available data (CalEMA and CNRA 2012).

Heat wave – There is no single quantitative definition of a heat wave. The Cal-Adapt online tool defines a heat wave as a period of 4 consecutive extreme heat days or warm nights when the daily maximum/minimum temperature is above an extreme heat threshold (>98th historical percentile based on historical data from 1961-1990 and between April and October) (CEC 2019).

Hydroperiod – The seasonal pattern of the water level in a particular environment (U.S. Forest Service n.d.)

Impact – An effect of climate change on the structure or function of a system (CNRA 2009a).

Mitigation – In hazard mitigation planning, mitigation means "sustained action taken to reduce or eliminate the long-term risk to human life and property from natural, human-caused, and technological hazards and their effects. Note that this emphasis on long-term risk distinguishes mitigation from actions geared primarily to emergency preparedness and short-term recovery" (California Governor's Office of Emergency Services 2018).

Renewable Energy – Energy sources that restore themselves over short periods of time and do not diminish. In California, this includes solar, wind, geothermal, biomass, and limited types of hydroelectric generation (California Public Resources Code n.d.).

Resilience – The ability of a community, natural resource, or system to anticipate, absorb, accommodate, or recover from the effects of a potentially hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions (IPCC 2007).

Resilience Strategy – A set of methods and measures to enhance a system's ability to withstand and respond to climate change

Resource Conservation – Reducing the use of a resource (water, electricity, fuel, etc.) by reducing the use of services or devices that require the resource; in short, doing less with less (U.S. EPA 2013) (Lawrence Berkeley National Laboratory 2014).

Resource Efficiency – Reducing the use of a resource (water, electricity, fuel, etc.) by using less of the resource to provide the same service; in short, doing the same or more with less (U.S. EPA 2013) (Lawrence Berkeley National Laboratory 2014).

Risk – The possibility of interaction of physically defined hazards with the exposed systems. Risk is commonly considered to be the combination of the likelihood of an event and its consequences—i.e., risk equals the probability of climate change impact occurring multiplied by the consequences a given system may experience (CNRA 2009a).

Sensitivity – A structure, function, or population that could be affected by climate change (CalEMA and CNRA 2012).

Snowpack – A seasonal accumulation of slow-melting snow. In California, the snowpack acts as a reservoir to provide water during drier months (IPCC 2007).

Sustainability – A process in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspiration; sustainability integrates the political, social, economic, and environmental (IPCC 2007). A more common and concise definition of sustainability is a system that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development 1987).

System – A human population or ecosystem; or a group of natural resources, species, infrastructure, or other assets (CNRA 2009a).

Urban Heat Island – A phenomenon in which developed areas are warmer than rural zones due to the prevalence of impermeable, dry, and heat-absorbing surfaces (such as asphalt and concrete) in urban areas (Akbari 2005).

Urban-Wildland Interface – The transition area between wild areas and the urban/developed zone.

Vulnerability – A susceptibility to harm or change. More specifically, the degree to which a system is exposed to, susceptible to, and unable to cope with the adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, as well as of non-climatic characteristics of the system, including its adaptive capacity (CNRA 2009a).

Water Conservation – Saving water by reducing the use of services that require water, such as replacing a lawn with plants that require little or no irrigation (U.S. EPA 2013).

Water Efficiency – Saving water by using less water to provide the same or better service, such as a faucet with a model that satisfies the same needs as the previous faucet but requires less water (U.S. EPA 2013).

Weather – The meteorological conditions (temperature, precipitation, wind, etc.) at a specific location and moment (IPCC 2013).