CALIFORNIA'S FOURTH
**CLIMATE CHANGE**
ASSESSMENT

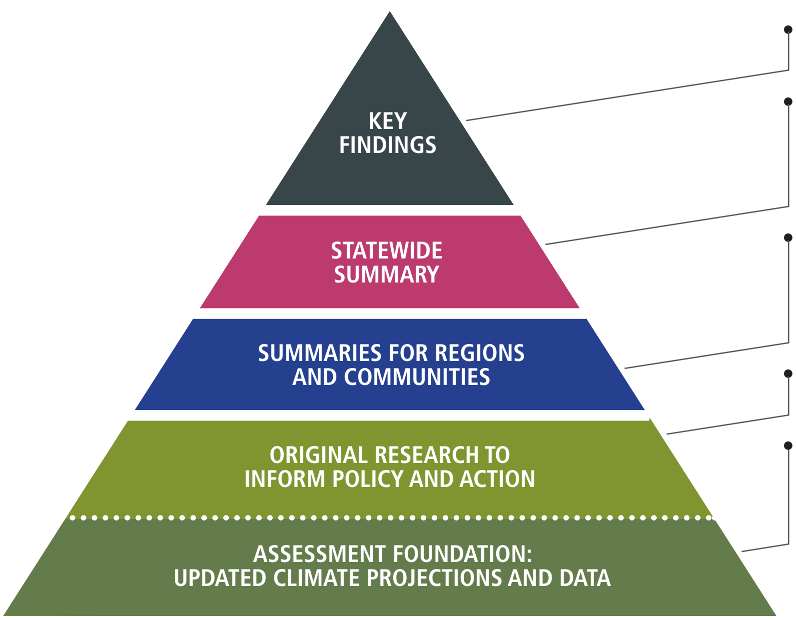

# San Joaquin Valley Region Report

Coordinating Agencies:

# Introduction to California's Fourth Climate Change Assessment

California is a global leader in using, investing in, and advancing research to set proactive climate change policy, and its Climate Change Assessments provide the scientific foundation for understanding climate-related vulnerability at the local scale and informing resilience actions. The Climate Change Assessments directly inform State policies, plans, programs, and guidance to promote effective and integrated action to safeguard California from climate change.

California's Fourth Climate Change Assessment (Fourth Assessment) advances actionable science that serves the growing needs of state and local-level decision-makers from a variety of sectors. This cutting-edge research initiative is comprised of a wide-ranging body of technical reports, including rigorous, comprehensive climate change scenarios at a scale suitable for illuminating regional vulnerabilities and localized adaptation strategies in California; datasets and tools that improve integration of observed and projected knowledge about climate change into decision-making; and recommendations and information to directly inform vulnerability assessments and adaptation strategies for California's energy sector, water resources and management, oceans and coasts, forests, wildfires, agriculture, biodiversity and habitat, and public health. In addition, these technical reports have been distilled into summary reports and a brochure, allowing the public and decision-makers to easily access relevant findings from the Fourth Assessment.




- A concise summary of the Fourth Assessment's most important findings and conclusions.
- An in-depth report on how California's people, built environment, and ecosystems will be impacted by climate change and how we can proactively adapt, based on the Fourth Assessment's findings.
- Reports summarizing Fourth Assessment findings to provide a state of the science for nine regions, the ocean and coast, tribal communities, and climate justice in California.
- Academic research that provides robust and detailed results on resilience and vulnerability to climate change.
- A shared foundation of updated climate change projections, data and ecosystem models developed for use by Assessment authors to permit cross-comparability of results and ensure the findings consider a robust range of future climate conditions. These data are available to the public via Cal-Adapt.org.

All research contributing to the Fourth Assessment was peer-reviewed to ensure scientific rigor as well as, where applicable, appropriate representation of the practitioners and stakeholders to whom each report applies.

For the full suite of Fourth Assessment research products, please visit: www.ClimateAssessment.ca.gov

## San Joaquin Valley Region


The San Joaquin Valley Region Summary Report will be part of a series of 12 assessments to support climate action by providing an overview of climate-related risks and adaptation strategies tailored to specific regions and themes. Produced as part of California's Fourth Climate Change Assessment as part of a pro bono initiative by leading climate experts, these summary reports translate the state of climate science into useful information for decision-makers and practitioners to catalyze action that will benefit regions, the ocean and coast, frontline communities, and tribal and indigenous communities.

The San Joaquin Valley Region Summary Report presents an overview of climate science, specific strategies to adapt to climate impacts, and key research gaps needed to spur additional progress on safeguarding the San Joaquin Valley Region from climate change.

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# Highlights and findings

The San Joaquin Valley is the southern portion of the Central Valley of California. It is surrounded by the Sierra Nevada on the East, the Southern Coastal Range on the West, and the Sacramento-San Joaquin Delta on the Northwest, spanning eight counties with 4.3 million inhabitants.

The socioeconomic and environmental conditions of the San Joaquin Valley are among the most precarious in California, with more than 55% of its population living in disadvantaged communities. Hundreds of thousands of people do not have water security, and most inhabitants suffer from chronic exposure to one of the nation's lowest air qualities. Heat stroke, valley fever, and conditions related to poor air and water quality are common illnesses and health hazards. The effects of the onset of climate change are exacerbating all these issues, and the lack of investment in fundamental infrastructure, such as access to drinking water, sewage, green areas, grocery stores, sidewalks, public electrification, education facilities, and health services, makes rural communities in the San Joaquin Valley some of the most vulnerable to climate change in the United States.

Ecosystems of the San Joaquin Valley are among the most degraded in California. Originally a humid region with ephemeral rivers and lakes, the San Joaquin Valley has lost 95% of its original wetlands. Most current agricultural practices compete with ecosystems for water access, and often the San Joaquin River runs nearly dry during the summer due to upstream diversions for beneficial uses.

Agriculture is the main economic activity of the San Joaquin Valley and is by far the most profitable agricultural region in the United States. Some of the most economically valuable commodities are threatened by some early climate change effects, including reduced chill hours, water scarcity, and extreme heat. Small farmers, including disadvantaged and minority farmers, are among the most impacted by climate extremes in part because of their limited resources to build the needed resilience. However, agriculture presents an outstanding opportunity to mitigate climate change by adapting agricultural practices.

Many of the climate mitigation opportunities facing the San Joaquin Valley are related to disadvantaged communities and agriculture. Investing in diversified land use strategies can provide new income opportunities that can decrease the economic risks that farmers may encounter under climate change. Many of the options to increase climate resilience in the San Joaquin Valley can be addressed with multi-benefit approaches that can benefit agriculture, ecosystems, communities, and cities. This report presents highlights of the potential climate change impacts in the San Joaquin Valley along with possible adaptation and mitigation strategies.

**Climate change is already affecting the San Joaquin Valley's communities and agriculture.**

- The San Joaquin Valley annual average maximum temperatures increased by 1 °F (0.6 °C) from 1950 to 2020, and it is projected to increase 4 °F to 5 °F (2.2 °C to 2.7 °C) by mid-century, and 5 °F to 8 °F (2.7 °C to 4.4 °C) by the end of the century. If emissions continue to rise at high rates (RCP 8.5), projections indicate that half of the San Joaquin Valley counties will have average annual maximum temperatures over 80 °F (26.7 °C) by the end of the century, which is more than an 8 °F increase compared to historical conditions.
- Snowpack in the Sierra Nevada has served as an essential water storage in the San Joaquin Valley, providing water during the drier season. However, snowpack is gradually decreasing at high elevations and is projected to become scant at lower elevations by the end of the century.

- As temperature increases, earlier snowmelt will shift peak flows by 2 to 4 months by the end of the century. This shift may reduce surface water storage, increasing the mismatch between when the water is available (winter-spring) and when most of the water is used (summer).
- Precipitation will likely be more intense, increasing the fraction of precipitation falling from November to March from 75% (current conditions) to 80% (by the end of the century). This translates into longer dry seasons with 20% less precipitation in average that may lead to increased groundwater pumping to compensate the diminished surface water supplies.
- Sea level rise increases flooding risk in Delta communities and San Joaquin County cities such as Stockton, threatening over 10,000 people. Over the past 100 years, sea level has risen 8 inches (20 cm), and it could rise 2 ft (74 cm) by mid-century and 3.5 ft (107 cm) by the end of the century.

**Climate change may accelerate deterioration of private property, canals, dams, roads, railways, and levees due to increasing land subsidence, droughts and associated overpumping, wildfires, and floods.**

- Changes in groundwater levels due to land subsidence (sinking ground levels resulting from water overextraction) may dramatically affect the region's infrastructure, including canals, roads, and railways. Levees protecting floodplains, cities, and farmlands will become more unstable due to prolonged droughts that promote water filtration through the soil, soil cracking, soil organic carbon decomposition, erosion, and land subsidence.
- Faster snowmelt may also threaten dam stability, leading to increasing risk of catastrophic dam failure. Earlier snowmelt will anticipate the peak flows to earlier than when agriculture needs them, signaling the currently inadequate water storage. Combined, the effects of snowmelt shifting may reduce the freshwater that returns and stays in the San Joaquin Valley due to the limited pumping and conveyance systems.
- Groundwater replacement for surface water losses may increase the pervasive groundwater overdraft, compromising water reserves to cope with future droughts. The Sustainable Groundwater Management Act (SGMA) enacted to prevent future overdraft is still in its early stages and some districts may not be able to fully implement sustainability plans by the 2040 time horizon.
- Higher salinity concentrations in soil and groundwater in the San Joaquin Valley may accelerate degradation of pumping equipment, which increases challenges for farmers, irrigation districts, utility companies, and wholesalers.
- More frequent wildfires threaten access to clean drinking water when fires affect urban supply watersheds and increase soil erosion that may move undesirable chemicals in the watershed. Wildfires can also damage the electrical system directly by burning transmission lines or indirectly by ionizing the air with smoke and ash, causing a system shutdown.

**The impacts of climate change are more pronounced in rural disadvantaged communities of the San Joaquin Valley than in the rest of California.**

- More than half of the population in the San Joaquin Valley live in disadvantaged communities, and many rural disadvantaged communities lack access to basic services such as safe, reliable, and affordable drinking water, sewage, and health care, making them some of the least resilient communities in California. Climate change is already disproportionately exacerbating their vulnerabilities, including water insecurity and extremely poor air quality.
- Multi-year climate extremes are becoming more frequent, such as the 2012 – 2016 drought when thousands of wells dried decreasing the already poor drinking water quality. In normal conditions, thousands of households

struggle purchasing bottled water, and that situation is exacerbated during droughts when some residents do not have any available water at all.

- Tribes are losing access to fundamental environmental resources due to overexploitation, land use change, and more frequent extreme climate events. Climate change will further reduce their access to cultural raw materials to fulfill their traditions and ways of life.
- Many families in the San Joaquin Valley rely on agriculture as their main source of income. Livelihood insecurity is increasing since agricultural productivity is threatened by more frequent extreme events such as droughts, floods, and more favorable conditions for some pests. Food insecurity and food deserts are common issues in frontline communities in the San Joaquin Valley.
- Education access is already negatively affected by reduced school attendance and difficulted study conditions because of environmental conditions such as flooding, high temperatures, poor drinking water quality, and air quality. These effects will likely increase with climate change.

**Human health and well-being of the general population will be impacted by climate change, including more heat-related deaths and illnesses, illnesses caused by poor water quality, and other issues caused by droughts, wildfire, and some agricultural activities.**

- Higher temperatures are increasing the risk of heat-stroke and other effects on vulnerable populations and outdoor workers. Valley fever cases are more common in the San Joaquin Valley than in the rest of California, and this poorly studied illness could be exacerbated by the intensified combination of wetter conditions that allow the fungus to reproduce, and dryer, windy periods that contribute to the spread of the spores from the soil into people's respiratory systems (dust storms). Current health services are insufficient, and climate change is increasing the necessity of emergency attention.
- Extreme heat days are projected to increase for all San Joaquin Valley counties from current 4 or 5 extreme heat days per year to about 18 to 28 days towards mid-century, and about 24 to 68 days towards the end-of-century.
- The COVID-19 crisis has been more impactful in disadvantaged communities in the San Joaquin Valley with chronic and extremely poor air quality, uncovering the rather lagging health services access for such communities. Chronic diseases, infectious diseases, and unsuitable air and water quality are being exacerbated by climate change.
- Intensifying climate change is likely to increase water quality issues that inequitably impact rural disadvantaged communities. Common chemicals across the San Joaquin Valley rural disadvantaged communities include arsenic, nitrate, 1,2,3-trichloropropane (1,2,3 TCP), chromium VI, and manganese. Pathogens (*E. coli*, *Giardia*, *Salmonella*) are also problematic in unincorporated communities and near some dairy farms.

**The intensive agricultural and urban footprints on the San Joaquin Valley are exacerbating the negative impacts of climate change, which may lead to ecological collapse because of the extensive habitat loss for native species and the establishment of invasive species.**

- Primary production will decrease with more frequent extreme temperatures, floods, and droughts, combined with land use change, affecting the production, transfer, and distribution of energy across trophic levels, and impacting ecosystem functions and services.
- Earlier and rapid snowmelt from warmer temperatures will change flow regime and water conditions, impacting spawning times, reproductive success, and habitat suitability for many species, including native endangered fish.

- Under climate change, natural wetlands may experience more prolonged periods of drought, disastrous floods, and increased water temperatures and evaporation rates. Combined with poor water management practices and competition with agriculture, climate change effects can lead to native population instability and to food scarcity for essential organisms such as overwintering birds and insects.
- Urban ecosystem species undergo the combining effects of climate changes and pollution from human expansion. Expanding impervious surfaces in cities will increase heat retention, leading to more prominent urban heat island effects. Land use change will increase human-animal disease transmission as urban areas overlap rural and wild environments.

**Agriculture climate vulnerabilities include fewer winter chill hours, shifts in water availability, and extreme heat. These threats have direct and indirect impacts such as changes in yield, crops water demand, increasing competition for water from other sectors, and reduced farm labor availability.**

- The agricultural sector in the San Joaquin Valley supports more than 200,000 jobs per year over 8 million acres (32,000 $km^2$), and it has successfully adapted to pests, changes in yield, and dry conditions by changing crop practices, land use, and water use decisions. Climate change will affect risk and resilience of the agriculture-dependent economy and employment. Additionally, the Sustainable Groundwater Management Act (SGMA) will have an important role on land and water use decisions, especially during droughts.
- Crop yields, especially tree orchards, are sensitive to changes in temperature and water stress. Changes in the seasonality are affecting the blooming of perennial crops, while the decreasing number of chill hours is affecting their quality and productivity.
- Crop water use will increase as higher temperatures increase vapor deficit and potential evapotranspiration. Higher carbon concentrations may partially offset this effect for some crops. More frequent droughts will increase the reliance on groundwater, but groundwater pumping regulations through the Sustainable Groundwater Management Act may limit such resource to drier years.
- Dairies and beef cattle will have less water available for irrigated feed crops as they compete with higher value crop commodities. Grazelands may move in elevation into the foothills but may be limited by land ownership. Rising temperatures and more intense and frequent heatwaves increase the cattle mortality risk.
- In the absence of target relief programs for small farmers, including most Hmong, Latino, and African American, the adaptation capacity of these groups will be hindered by climate change. Shallow wells, water restrictions, limited access to capital sources, and outdated technology and irrigation systems, threaten the economic feasibility of their diverse crops that are very important culturally and at the local level.

# Adaptation and mitigation strategies

**Infrastructure in the San Joaquin Valley merits adaptation and mitigation strategies that include improving flood management, replenishing aquifers, controlling land subsidence, and widely adopting zero-carbon technologies.**

- Investing in management of aquifer recharge projects to expand the current water storage capacity allows to capture the water generated by the more frequent extreme storms and by the more intense snowmelt.
- Reducing the impacts from major contributors to climate change in the San Joaquin Valley, such as fracking oil wells, natural gas peaker-plants, and the transportation sector, can improve air, water, and health quality while mitigating climate change. A planned transition (also known as "just transition") via regulation and stakeholder involvement will likely reduce the potential short-term socioeconomic inequity of this process.
- Replacing polluting sources with zero-carbon-emission technologies will promote new local infrastructure development and will align faster the energy sector with California policies.
- Energy security across the San Joaquin Valley can be increased by building new local energy grids for generation and storage, by making the current facilities and infrastructure more resilient, and by planning for extreme weather and disaster events (for example, heatwaves and wildfires).

**Inclusion of disadvantaged communities is an essential step to bring environmental justice to the San Joaquin Valley. Emergency management and health services require proper investments and adequate planning in underserved frontline communities.**

- Creation of buffer zones (physical separation areas) surrounding disadvantaged communities may help protect local aquifers and air quality. Buffers can be used for new economic activities with positive environmental and social externalities, including renewable energy, management of aquifer recharge, green corridors to preserve habitat, and nonpolluting industries. Sustainable land management in the buffers is important to avoid increasing environmental inequities.
- Programs to incentivize adoption of solar energy generation and storage in disadvantaged communities can provide energy security, and adequate policies can help keep employment opportunities within the communities without compromising the viability of agriculture.
- Funding for grassroot organizations to encourage local planning increases resilience of disadvantaged communities in emergencies and extreme weather events. Educational community outreach provides a foundation in efforts to understand local air and water quality issues. These programs can be more effective when targeted for both adults and children, and when they include advocacy and "citizen science" approaches. Funding scientific community-participatory research, especially in disadvantaged communities and tribes, furthers the usefulness of the research and better informs policy.
- Increasing the number of underrepresented minority researchers and promoting the hire of local scientists can contribute toward greater motivation to achieve solutions, more robust strategies, and more diverse perspectives.
- Developing transdisciplinary frameworks that include monitoring of ecological impacts of climate change and land use can serve to address some of the inequitable socioeconomic patterns in the San Joaquin Valley.

**The San Joaquin Valley ecosystems require more adequate planning and management to increase natural adaptation and mitigation to local and global climate changes. Climate change policies can be better informed by ecosystem research across biological scales (from cells to communities) to understand the system holistically.**

- Modernizing agricultural practices within an agroecosystems framework may increase agricultural yield, for example using natural predators for pests to reduce pesticide use. Holistic planned grazing to ensure land regeneration and plant populations will lead to more resilient agroecosystems.
- River ecosystems can benefit from enforcing management plans that include harvest management records for endangered, invasive, and ecologically and commercially beneficial freshwater species, and from funding for long-term monitoring research of springs, streams, and rivers using bioindicator responses to pollutants and habitat quality.
- Strategically removing or relocating some specific levees near riparian forests can help restore natural floodplains and mitigate the impacts of extreme climatic events, increasing habitat and resource availability, and quality for native species adapted to naturally variable conditions. When properly managed, wetlands can increase ecosystem resilience and mitigate some climate change impacts.
- Wildlife corridors and protected areas in urban environments can attenuate the frequency and intensity of human activity near sensitive ecosystems.

**Agricultural climate change mitigation can benefit from planned changes in crop decisions, optimized and equitable land use and water allocations, and the use of new technologies. To avoid furthering inequity, linkages between crop decisions and employment merit consideration and more research.**

- Adaptation to climate change may accelerate the existing trend towards more technical and data-driven agriculture. Public policies favoring more transparent data exchange can be beneficial for farmers.
- Climate strategies involving farmland may continue to require public program assistance to incentivize participation from the agricultural sector to mitigate climate change.
- In-farm managed aquifer recharge can bring opportunities to create multi-benefit projects, particularly during floods and droughts.
- Mitigation strategies in agriculture include the use of solar energy for in-farm operations (for example, for pumping and irrigation) and the use of renewable energies along the supply chain including transportation, food industry, and waste management.
- Agriculture can be used for natural habitat to increase ecosystem services and resilience to climate change, provided that some practices shift toward sustainable agriculture, including smart use of pesticides, improving soil health, and increasing soil carbon sequestration.
- Repurposing land and diversifying farmland income may bring new economic activity for farmers and communities, decreasing their economic risk, currently associated to extreme climate events in a globalized economy.

**The San Joaquin Valley has extensive land that can be strategically used for multi-benefit projects that create opportunities to mitigate climate change, and to bring socioeconomic development and environmental justice.**

- Promoting cleaner energy sources for heating and cooling, including industry, institutions and households, will reduce local greenhouse gas emissions and improve air quality in the San Joaquin Valley.
- Strategically repurposing farmland into other economic activities may help achieve groundwater sustainability, ameliorate the effects of surface water deficits, and maintain economic and social prosperity in the San Joaquin Valley.

# The San Joaquin Valley

For a present-day Californian who crosses the San Joaquin Valley it may be challenging to visualize how the Valley has changed in the last 200 years. Other regions of California, such as the Sierra Nevada to the east or the Southern Coastal Range to the west, have also changed, but they still preserve some of their timeless features. That is not the case of the San Joaquin Valley. In the 19th century, the San Joaquin Valley was the homeland of the Yokuts and Miwok, and it was covered by wetlands and ephemeral rivers. A large lake covered what today is part of Tulare, Kings, Fresno, and Kern counties. The Tulare Lake fluctuated in size every year due to varying weather conditions (from 110,000 acres to 470,000 acres, or between 450 $km^2$ and 1900 $km^2$); in a normal year, it would be larger than the city of Los Angeles. At present, the Tulare Lake no longer exists, and the San Joaquin Valley has lost about 95% of its original wetlands (Garone, 2011) (Figure 1).

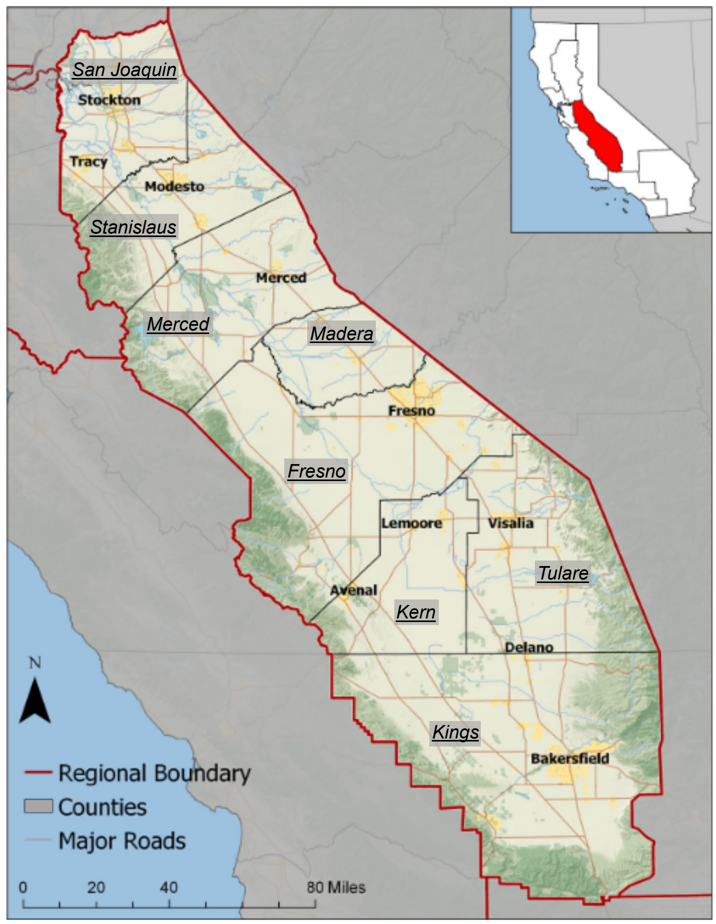
**FIGURE 1**

Wetlands of the Merced National Wildlife Refuge in February 2021. During the wet season (winter and spring), some of the few preserved wetlands are flooded with water, and millions of birds live in there or visit them. About 200 years ago, the wetlands of the San Joaquin Valley covered 20 times more area than at present. Photo by Angel S. Fernandez-Bou.

The San Joaquin Valley is split into two basins: San Joaquin River Basin in the north and the Tulare Lake Basin in the south, encompassing the counties of San Joaquin, Stanislaus, Merced, Madera, Fresno, Tulare, Kings, and Kern (Figure 2). The San Joaquin Valley is home to roughly 4.3 million people (Census Bureau, 2019), although many census tracts are identified as hard-to-count, leading to significant underestimates of the actual population, in particular, low-income families, African Americans, Latinos, Native Americans, and noncitizens (Latino Community Foundation, 2018). These groups are among the most affected populations by this underestimation, leaving them with less government investments and less political representation (Bohn et al., 2020). In the San Joaquin Valley, 55% of the population lives in 413 census tracts (out of 820) classified as disadvantaged, housing 2.2 million people (27% of the disadvantaged community residents of California) (OEHHA, 2017, 2018). With an average annual growth rate of 1.33%, the projected 2050 population in the San Joaquin Valley is 6.7 million.

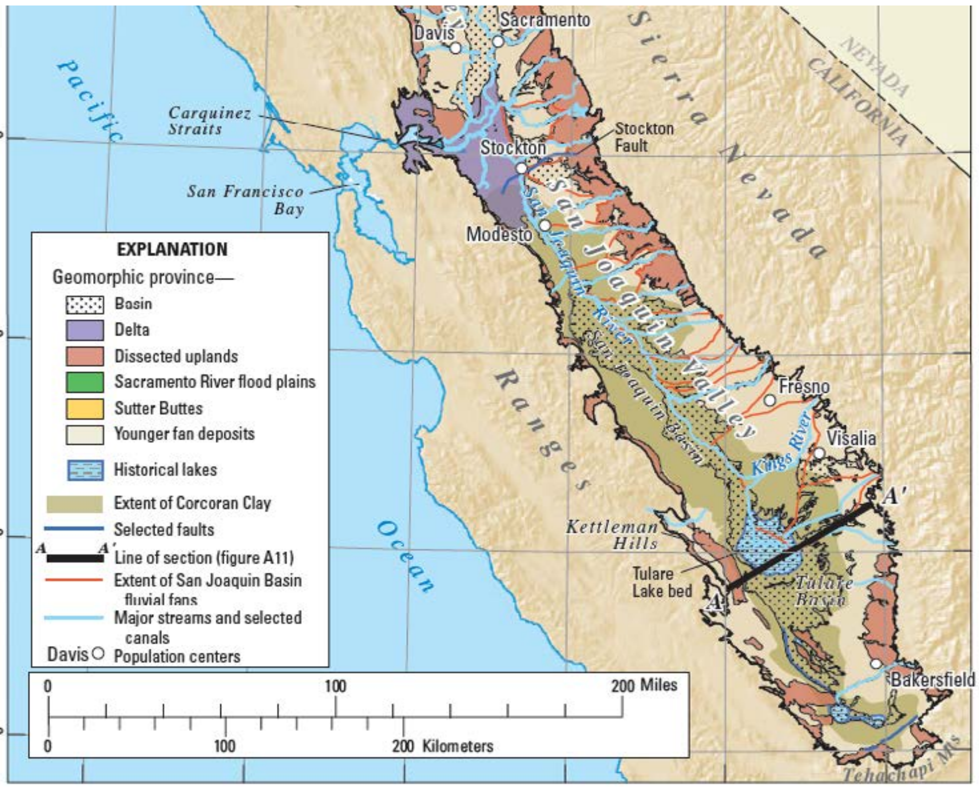
The San Joaquin River basin (15,800 square miles or 42,000 km$^2$) drains the San Joaquin River and its tributaries into the southern reaches of the Sacramento–San Joaquin Delta. The Tulare Lake basin (17,000 square miles or 44,000 km$^2$) is a closed (endorheic) basin with natural surface water contributions from the Kings, Kaweah, Tule, and Kern rivers. The San Joaquin Valley along with the entire Central Valley was created by the collision of the Pacific and North American Plates. The trough is bordered by three mountain ranges (Sierra Nevada, Diablo and Temblor, and the Tehachapi ranges) and is filled with continental sediments. Most sediments are fine-grained, such as clay and silt in fluvial and lacustrine environments. These compactable deposits contribute to the significant land subsidence (sinking soil due to water overextraction) in the San Joaquin Valley, and impermeable soil layers also interrupt groundwater deep percolation. The most notorious of these impermeable layers is the pervasive Corcoran Clay in the west side (Figure 3) (Galloway & Riley, 1999), a low-permeability layer that contributes to increasing soil salinity and it is associated to land subsidence.

**FIGURE 2.**




The San Joaquin Valley includes the San Joaquin River basin to the north and the Tulare Lake basin to the south, and it encompasses the counties of San Joaquin, Stanislaus, Merced, Madera, Fresno, Tulare, Kings, and Kern. More than half of the San Joaquin Valley population live in disadvantaged communities, and several major cities are usually in the top ten for the worst air quality in the United States.

**FIGURE 3.**



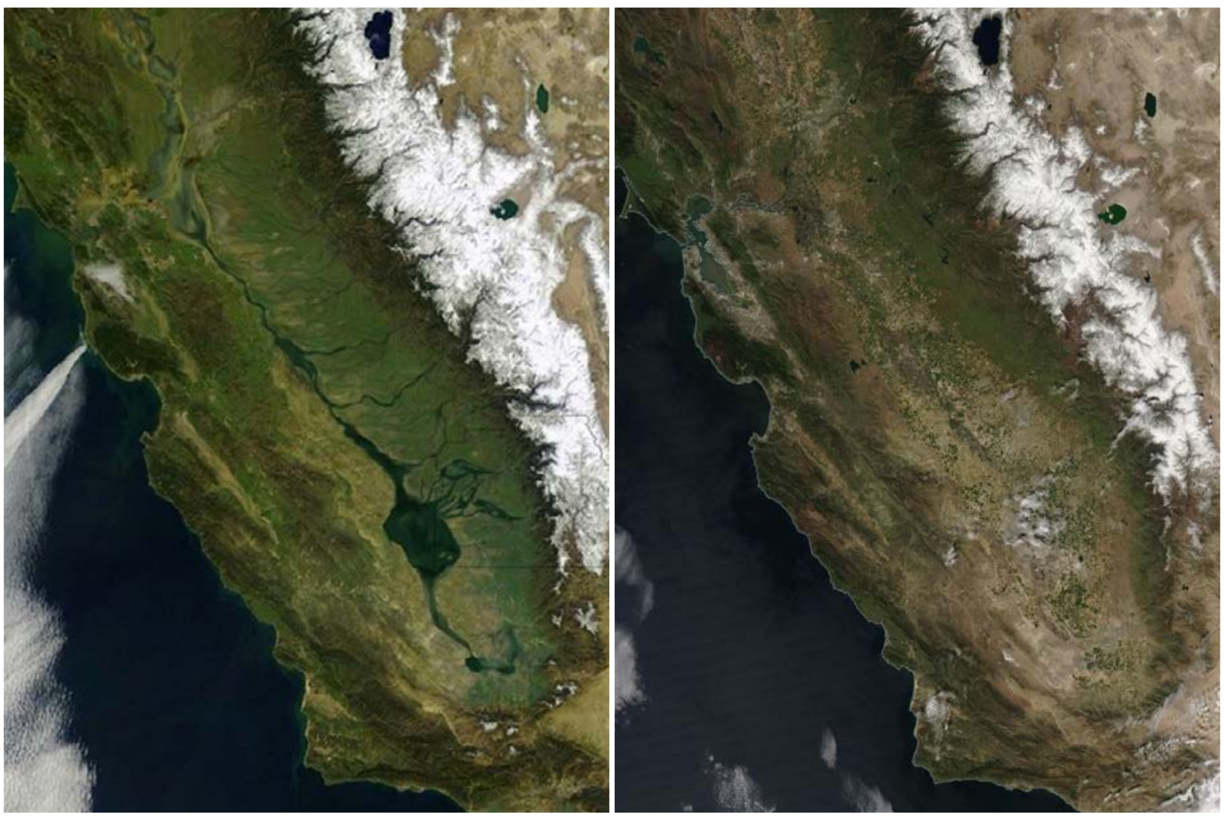

Cross section of the San Joaquin Valley in a USGS hydrological model report. The line of section crosses the now dried Tulare Lake and the Corcoran Clay. Source: USGS (Faunt, 2009)

Agriculture is the main economic activity of the San Joaquin Valley and also the largest water user in the region (89%) with the remainder used by cities (4%), managed wetlands (2%), and natural landscapes (4%) (Hanak et al., 2017). The San Joaquin Valley concentrates a great proportion of the US agricultural production with seven of its eight counties in the top 10 California agricultural counties by revenue (CDFA, 2020b). Kern and Fresno counties rank top two in agricultural value in the US with higher value commodities, such as almonds and pistachios, which are threatened by potential extreme climate effects including insufficient chill hours, water scarcity, and extreme heat.

The San Joaquin Valley's agricultural identity presents a unique opportunity for climate change adaptation and mitigation innovation by adopting new tools, using data technology, promoting renewable energy, and making land and water planning more robust. Agriculture has the capacity to champion multi-benefit projects, such as strategic land transitions, carbon sequestration and in-farm managed aquifer recharge, with co-equal benefits for ecosystems and disadvantaged communities.

While the San Joaquin Valley climate normally fluctuates yearly, anthropogenic activity is accelerating its rate of change. Climate is changing too fast for many species to adapt (Radchuk et al., 2019), and infrastructure and institutions are also surpassed (Persad et al., 2020). Physical and biological systems are being affected. Impacts on physical systems include higher temperatures, shifts in the peak flows due to early snowmelt (making water available earlier in winter related to water needs in summer), and sea level rise. Impacts in biological systems include forests affected by wildfires, negative agricultural impacts, and habitat loss for species unable to adapt to higher temperatures or that cannot find water and food where they used to be (Figure 4). Biological systems also include humans who are already experiencing more vector-borne diseases and more intense and frequent climate hazards that lead to illnesses and deaths. The compound effects of climate change and existing inequities exacerbate the negative impacts on the already vulnerable frontline communities of the San Joaquin Valley, which often lack resources to adapt and build the necessary resilience.

**FIGURE 4.**



The San Joaquin Valley of California with a simulation of how the Tulare Lake was in the year 1851 (left), and how it is at present (right; April 2021). In a wet year, the Tulare Lake basin would be connected with the Sacramento-San Joaquín Delta. Source: simulated image created by Mark Clack and published by Frank Jacobs (https://bigthink.com/strange-maps/557-the-first-satellite-map-of-california-1851). Satellite images by NASA, Landsat and Aqua MODIS.

# Climate Change in the San Joaquin Valley Region

The San Joaquin Valley region has the highest concentration of rural disadvantaged communities and the most stressed ecosystems of California, while also hosts the largest extension of irrigated agricultural land (Garone, 2011; Hanak et al., 2017; OEHHA, 2017). Climate change may impact the San Joaquin Valley disproportionally more than other regions of California.

Some of the most pressing inequities faced by disadvantaged communities are a higher exposure to environmental health threats and the lack of economic, educational, and recreational opportunities. San Joaquin Valley disadvantaged communities tend to be in areas more prone to hydroclimatic hazards, such as extreme heat, droughts, and floods; and due in part to systemic issues, they have fewer resources to plan and adapt for these conditions. As climate change exacerbates hydroclimatic hazards, California is at risk of perpetuating the history of inequity experienced in the San Joaquin Valley by creating more uneven access to resources and opportunities between wealthy and low-income communities.

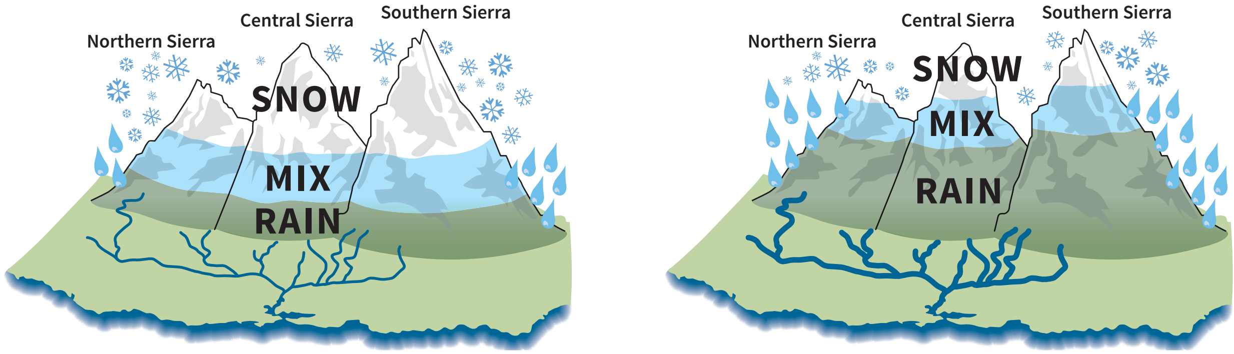
Climate vulnerability is a function of exposure to climate variations, the degree of sensitivity of a system, and the capacity of a system to adapt to changing climate conditions (IPCC, 2014). Better understanding and climate change planning is also vital for the San Joaquin Valley agriculture. The region hosts one of the most diverse crop production systems in the world, and climate change impacts will differ depending on the geographical location, water supply sources, water rights, and crop decisions. Small and minority farmers often experience less resilient conditions to face the various threats of climate change given their limited access to technology adoption and capital investments. Farmers have historically adapted to extreme climatic events such as droughts at the expense of groundwater overdraft. New regulation to protect groundwater from long-term depletion will at the same time bring challenges to maintain crops sustainably at the current pace.

## Current climate and future climate projections

Global Climate Models (GCMs) represent physical processes in the atmosphere, oceans, and land surface, and they are among the most advanced tools available for simulating global climate system responses to increasing greenhouse gas concentrations. GCMs are used to develop climate change projections for different scenarios known as Representative Concentration Pathways (RCP). Here we include model data for RCP 4.5 and 8.5, which respectively represent mitigation scenarios where global $CO_2$ emissions peak by 2040, and a business-as-usual scenario where $CO_2$ emissions continue to rise throughout the 21st century (van Vuuren et al., 2011). Such projections show:

- Higher temperatures
- Increasing potential evapotranspiration from plants and soils
- Longer and more severe droughts
- Declining snowpack (Figure 5)
- More intense precipitation events
- More frequent and extensive wildfires
- Sea level rise

FIGURE 5.




Climate Change considerations for Central Valley Flood Protection Plan 2017. Future conditions (right figure) will have less snow and more extreme rainfall and droughts than at present (left figure) (California Department of Water Resources 2017).

### HIGHER TEMPERATURES LEAD TO MORE EXTREME HOT DAYS AND NIGHTS

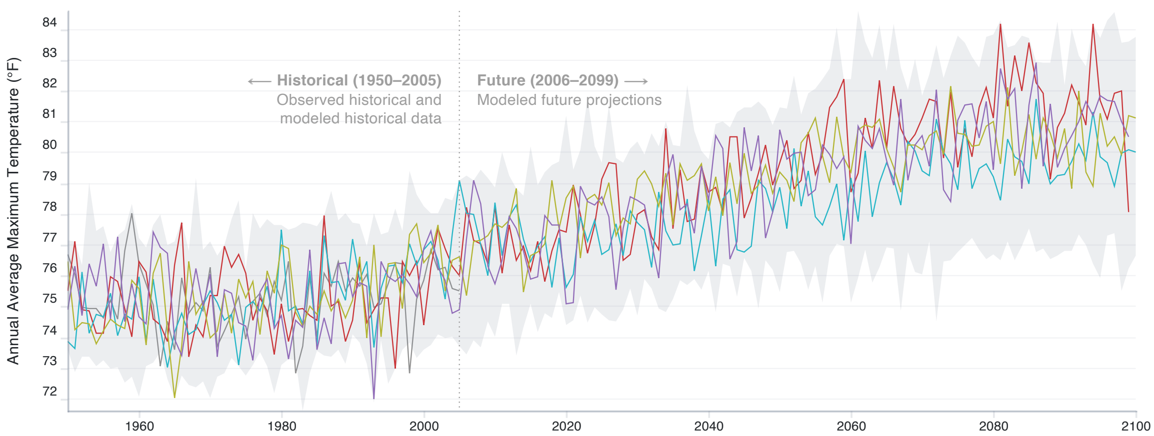
Climate change is already affecting the San Joaquin Valley communities and agriculture. With respect to historical data (1961-1990), the San Joaquin Valley annual average maximum temperatures increased by about 1 °F (0.5 °C) (Abatzoglou et al., 2009; WRCC, 2021), and they are projected to increase 4 °F to 5 °F (2.2 °C to 2.7 °C) by mid-century, and 5 °F to 8 °F (2.7 °C to 4.4 °C) by the end of the century depending on the actions we take to reduce heat-trapping gas emissions (Figure 6) (Cal-Adapt, 2019).

**FIGURE 6.**

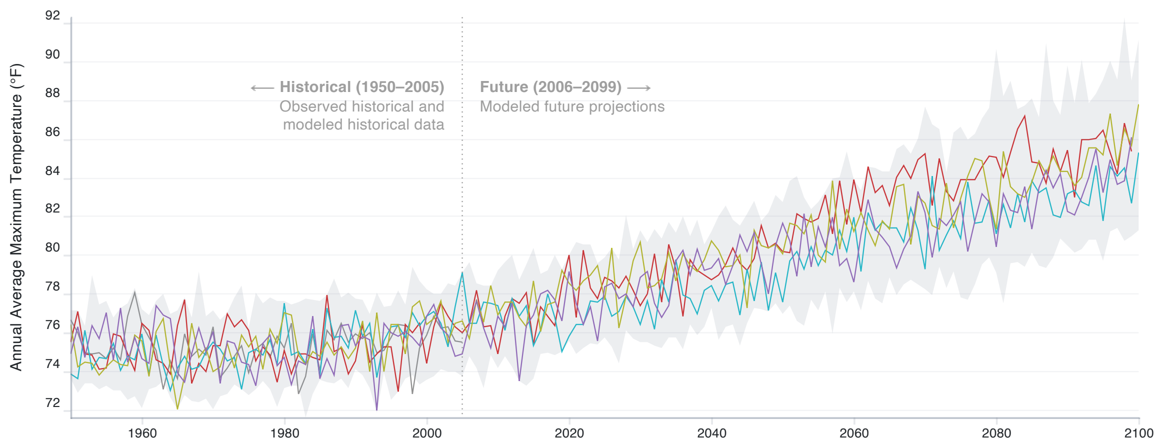
Modeled Variability (range of annual average values from all 32 LOCA downscaled climate models)

Observed (1950–2005) | HadGEM2-ES (Warm/Drier) | CNRM-CM5 (Cooler/Wetter) | CanESM2 (Average) | MIROC5 (Complement)

Data is shown for San Joaquin Valley Region under the RCP 4.5 scenario in which emissions peak around 2040, then decline.




Data is shown for San Joaquin Valley Region under the RCP 8.5 scenario in which emissions continue to rise strongly through 2050 and plateau around 2100.




Annual average maximum temperature in the San Joaquin Valley under two climate scenarios, estimated by four global circulation models. The San Joaquin Valley will likely see daily maximum temperatures increase between 5 °F (RCP 4.5) to 8 °F (RCP 8.5) (2.8 °C to 4.4 °C) by end-of-century. Source: Cal-Adapt 2018.

Table 1 shows a breakdown of the estimated potential changes in average maximum temperature for the eight San Joaquin Valley region counties. Projected average maximum temperatures changes range from 3.6 °F to 4.2 °F (2 °C to 2.3 °C) higher towards mid-century and from 4.7 °F to 5.4 °F (2.6 °C to 3 °C) by the end of the century under a medium emissions scenario (RCP 4.5). For a high emission scenario (RCP 8.5), the increment in projected average maximum temperature ranges from 4.6 °F to 5.2 °F (2.5 °C to 2.8 °C) higher towards mid-century and from 8.1 °F to 8.9 °F (4.5 °C to 4.9 °C) by the end of the century. If emissions continue to rise at high rates (RCP 8.5), half of the San Joaquin Valley counties will have projected average annual maximum temperatures in excess of 80 °F (26.7 °C) by the end of the century, which represents an increase of over 8 °F (4.4 °C) compared to historical conditions.

**TABLE 1.**

Annual average maximum temperatures in Fahrenheit degrees at the county level. Numbers in parentheses represent the change with respect to historical data. Source: Cal-Adapt 2018.

| | ANNUAL AVERAGE MAXIMUM TEMPERATURE °F | | | | |
|---|---|---|---|---|---|
| | | MID-CENTURY (2035-2064) | | END-CENTURY (2070-2099) | |
| COUNTY | HISTORICAL (1961-1990) | MEDIUM EMISSIONS (RCP 4.5) | HIGH EMISSIONS (RCP 8.5) | MEDIUM EMISSIONS (RCP 4.5) | HIGH EMISSIONS (RCP 8.5) |
| SAN JOAQUIN | 73.9 | 77.7 (+3.8) | 78.6 (+4.7) | 78.8 (+4.9) | 82.0 (+8.1) |
| STANISLAUS | 73.6 | 77.4 (+3.8) | 78.3 (+4.7) | 78.5 (+4.9) | 81.8 (+8.2) |
| MERCED | 74.7 | 78.7 (+4.0) | 79.6 (+4.9) | 79.8 (+5.1) | 83.2 (+8.5) |
| MADERA | 68.3 | 72.5 (+4.2) | 73.5 (+5.2) | 73.7 (+5.4) | 77.2 (+8.9) |
| FRESNO | 67.3 | 71.4 (+4.1) | 72.4 (+5.1) | 72.6 (+5.3) | 76.0 (+8.7) |
| KINGS | 76.7 | 80.3 (+3.6) | 81.3 (+4.6) | 81.4 (+4.7) | 84.8 (+8.1) |
| TULARE | 66.1 | 70.3 (+4.2) | 71.3 (+5.2) | 71.5 (+5.4) | 75.0 (+8.9) |
| KERN | 73.8 | 77.8 (+4.0) | 78.7 (+4.9) | 78.9 (+5.1) | 82.3 (+8.5) |

In a similar way, annual average minimum temperatures are projected to increase 3.2 °F to 4.6 °F (1.7 °C to 2.5 °C) by mid-century, and 4.7 °F to 8.2 °F (2.6 °C to 4.5 °C) by the end of the century depending on the actions we take to reduce heat-trapping gas emissions (Table 2) (Cal-Adapt, 2019).

**TABLE 2.**

Annual average minimum temperatures in Fahrenheit degrees at the county level. Numbers in parentheses represent the change with respect to historical data. Source: Cal-Adapt 2018.

| | ANNUAL AVERAGE MINIMUM TEMPERATURE °F | | | | |
|---|---|---|---|---|---|
| | | MID-CENTURY (2035-2064) | | END-CENTURY (2070-2099) | |
| COUNTY | HISTORICAL (1961-1990) | MEDIUM EMISSIONS (RCP 4.5) | HIGH EMISSIONS (RCP 8.5) | MEDIUM EMISSIONS (RCP 4.5) | HIGH EMISSIONS (RCP 8.5) |
| SAN JOAQUIN | 47.4 | 50.7 (+3.3) | 51.7 (+4.3) | 51.8 (+4.4) | 55.0 (+7.6) |
| STANISLAUS | 47.3 | 50.6 (+3.3) | 51.5 (+4.2) | 51.6 (+4.3) | 54.8 (+7.5) |
| MERCED | 47.3 | 50.7 (+3.4) | 51.6 (+4.3) | 51.7 (+4.4) | 55.0 (+7.7) |
| MADERA | 40.8 | 44.3 (+3.5) | 45.3 (+4.5) | 45.4 (+4.6) | 48.8 (+8.0) |
| FRESNO | 40.7 | 44.3 (+3.6) | 45.2 (+4.5) | 45.3 (+4.6) | 48.7 (+8.0) |
| KINGS | 48.9 | 52.1 (+3.2) | 53.0 (+4.1) | 53.1 (+4.2) | 56.4 (+7.5) |
| TULARE | 37.9 | 41.5 (+3.6) | 42.5 (+4.6) | 42.6 (+4.7) | 46.1 (+8.2) |
| KERN | 46.3 | 49.8 (+3.5) | 50.7 (+4.4) | 50.8 (+4.5) | 54.2 (+7.9) |

Extreme heat days occur when maximum temperatures are higher than 98% of the location-specific 1961-1990 daily maximum temperatures between April and October. Extreme heat days are projected to increase for all San Joaquin Valley counties from current 4 or 5 extreme heat days per year to about 18 to 28 days towards mid-century, and about 24 to 68 days towards the end-of-century (Table 3).

**TABLE 3.**

Extreme heat days at the county level, defined as days in which daily maximum temperature is above 101.6°F. Numbers in parentheses represent the change with respect to historical data. Source: Cal-Adapt 2018.

| | EXTREME HEAT DAYS (DAYS) | | | | |
|---|---|---|---|---|---|
| | | MID-CENTURY (2035-2064) | | END-CENTURY (2070-2099) | |
| COUNTY | HISTORICAL (1961-1990) | MEDIUM EMISSIONS (RCP 4.5) | HIGH EMISSIONS (RCP 8.5) | MEDIUM EMISSIONS (RCP 4.5) | HIGH EMISSIONS (RCP 8.5) |
| SAN JOAQUIN | 4 | 18 (+14) | 23 (+19) | 24 (+20) | 45 (+41) |
| STANISLAUS | 4 | 18 (+14) | 24 (+20) | 25 (+21) | 47 (+43) |
| MERCED | 4 | 22 (+18) | 29 (+25) | 30 (+26) | 56 (+52) |
| MADERA | 4 | 25 (+21) | 33 (+29) | 35 (+31) | 64 (+60) |
| FRESNO | 4 | 26 (+22) | 34 (+30) | 35 (+31) | 63 (+59) |
| KINGS | 5 | 22 (+17) | 29 (+24) | 30 (+25) | 57 (+52) |
| TULARE | 5 | 28 (+23) | 36 (+31) | 38 (+33) | 68 (+63) |
| KERN | 4 | 22 (+18) | 28 (+24) | 29 (+25) | 55 (+51) |

Warm nights between April and October are also projected to increase from historically (1961-1990) 3 to 5 nights to about 16 to 30 nights, and to 21 to 64 nights towards the end-of-century (Table 4). Warm nights may decrease sleep quality and time, leading to long-term health issues ranging from increased fatigue, bad mood, concentration issues, increased anxiety, and greater risk of traffic accidents (Ben Simon, Rossi, et al., 2020; Ben Simon, Vallat, et al., 2020). The issue largely affects low-income and disadvantaged communities lacking air conditioning or the economic means to pay higher energy bills (Sandoval & Toney, 2018). Impacts of warm nights multiplies when poor air quality prevents opening windows.

**TABLE 4.**

Average warm nights at the county level. Warm nights are defined as days which minimum temperatures are above 98% of minimum temperatures from 1961 to 1990. Numbers in parentheses represent the change with respect to historical data. Source: Cal-Adapt 2018.

| | WARM NIGHTS (DAYS) | | | | |
|---|---|---|---|---|---|
| | | MID-CENTURY (2035-2064) | | END-CENTURY (2070-2099) | |
| COUNTY | HISTORICAL (1961-1990) | MEDIUM EMISSIONS (RCP 4.5) | HIGH EMISSIONS (RCP 8.5) | MEDIUM EMISSIONS (RCP 4.5) | HIGH EMISSIONS (RCP 8.5) |
| SAN JOAQUIN | 4 | 19 (+15) | 26 (+22) | 27 (+23) | 60 (+56) |
| STANISLAUS | 5 | 20 (+15) | 27 (+22) | 28 (+23) | 58 (+53) |
| MERCED | 4 | 18 (+14) | 25 (+21) | 25 (+21) | 55 (+51) |
| MADERA | 4 | 22 (+18) | 30 (+26) | 31 (+27) | 64 (+60) |
| FRESNO | 4 | 21 (+17) | 28 (+24) | 29 (+25) | 59 (+25) |
| KINGS | 3 | 16 (+13) | 22 (+19) | 23 (+20) | 51 (+48) |
| TULARE | 4 | 21 (+17) | 28 (+24) | 29 (+25) | 60 (+56) |
| KERN | 3 | 16 (+13) | 22 (+19) | 22 (+19) | 48 (+45) |

## PRECIPITATION WILL TEND TO OCCUR IN EXTREME EVENTS INTENSIFYING FLOOD RISK, AND WARMER TEMPERATURES WILL DECREASE THE SNOWPACK, REDUCING WATER SUPPLY

Projections of changes in annual precipitation are characterized by more extremes and increasing variability. Extremely dry years will be 1.5 to 2 times more common, and wet extremes will be 3 times more than their historical frequency (Berg & Hall, 2015). Climate models yield larger 3-day flood magnitudes for the Southern Sierra Nevada by the end of the 21st century, increasing the magnitude of 5 year flood flows by 1.5 to 2 times (Das et al., 2013). Increases in the frequency of precipitation extremes will continue to exacerbate water management problems in the region, affecting the timing and magnitude of water supply and availability. Water scarcity exists in critical, dry, and below normal water year types, with 66% to 69% of the years projected as dry or critically dry by the end of the 21st century in the San Joaquin Valley (Null & Viers, 2013).

Current projections of annual average precipitation are similar to historical (1961-1990) conditions, suggesting the future volume of annual precipitation will be roughly the same (Table 5). However, that precipitation will increasingly fall as rain rather than snow, precipitation events will be more concentrated in the wet winter months (November to March), and there will be more year-to-year variability (Gershunov et al., 2019; Persad et al., 2020). Precipitation projections are complex because there are many variables and metrics relevant for water resources planning and management. Planning for the future requires consideration of the volume of water that precipitates on the state each year, and how climate change is modifying the patterns of when, where, and how precipitation occurs.

The San Joaquin Valley annual precipitation ranges from 8 inches to 20 inches (200 mm to 500 mm), showing the large year-to-year variability (Dettinger et al., 2011). Such variability depends on an atmospheric current known as an atmospheric river or the "Pineapple Express" that accumulates moisture from tropical regions in the Pacific and moves water vapor towards California. These atmospheric rivers bring about 20% to 50% of the state's precipitation (Dettinger et al., 2011; Gershunov et al., 2017; Lavers & Villarini, 2015). In California, atmospheric rivers vary in intensity; some are beneficial for water supply and replenish snowpack that naturally melts during the summer serving as water supply for people and agriculture, while others are responsible for destructive floods and landslides (NOAA, 2021). In California, projections of extreme precipitation are mostly due to changes in atmospheric river characteristics as warm air can hold more moisture. Atmospheric rivers are becoming a bigger contributor to total annual precipitation and extreme events (Gershunov et al., 2019; Payne et al., 2020).

**TABLE 5.**

Annual average precipitation at the county level. Numbers in parentheses represent the change with respect to historical data. Source: Cal-Adapt 2018.

| COUNTY | ANNUAL AVERAGE PRECIPITATION (INCHES) | | | | |
|---|---|---|---|---|---|
| | | MID-CENTURY (2035-2064) | | END-CENTURY (2070-2099) | |
| | HISTORICAL (1961-1990) | MEDIUM EMISSIONS (RCP 4.5) | HIGH EMISSIONS (RCP 8.5) | MEDIUM EMISSIONS (RCP 4.5) | HIGH EMISSIONS (RCP 8.5) |
| SAN JOAQUIN | 14.4 | 14.0 (-0.4) | 14.3 (-0.1) | 14.3 (-0.1) | 14.5 (+0.1) |
| STANISLAUS | 14.2 | 13.8 (-0.4) | 14.1 (-0.1) | 14.1 (-0.1) | 14.2 (0.0) |
| MERCED | 12.2 | 11.8 (-0.4) | 12.1 (-0.1) | 12.1 (-0.1) | 12.2 (0.0) |
| MADERA | 25.9 | 25.0 (-0.9) | 25.7 (-0.2) | 25.5 (-0.4) | 25.6 (-0.3) |
| FRESNO | 21.9 | 21.3 (-0.6) | 21.9 (0.0) | 21.7 (-0.2) | 21.9 (0.0) |
| KINGS | 8.3 | 8.0 (-0.3) | 8.2 (-0.1) | 8.1 (-0.2) | 8.2 (-0.1) |
| TULARE | 22.2 | 21.5 (-0.7) | 22.0 (-0.2) | 21.9 (-0.3) | 21.8 (-0.4) |
| KERN | 9.3 | 8.9 (-0.4) | 9.0 (-0.3) | 9.0 (-0.3) | 8.9 (-0.4) |

Other projections of relevant metrics for water resources planning and management include those related to precipitation type, snowpack, extreme events, narrowing wet season, water loss to atmosphere, and drastic swings between wet and dry years (Persad et al., 2020). For the San Joaquin Valley, changes for these variables show more than 50% decline on snowpack, 13% more precipitation coming in extreme events, more frequent very dry (+4% to 10%) and very wet years (+34% to 57%) towards the end of the century (Table 6). Projections also show sharp increases in precipitation variability or whiplash events (transition from a very wet period to a very dry or vice versa), potentially doubling in frequency towards the end of the century (Persad et al., 2020; Swain et al., 2018). Lastly, an average 6% increase in the fraction of precipitation falling from November to March is projected. Considering the small differences in projected annual average precipitation, there will be potential for longer dry seasons, requiring updated water planning.

**TABLE 6.**

Average percentage changes between current conditions (2006-2035) and end-of-century (2070-2099) for 11 hydroclimate metrics. Shading indicates inter-model agreement high (green or H: all models simulate same sign of change), medium (blue or M: at least one model simulates a change of opposite sign to, but smaller than, the model-mean change), or low (orange or L: at least one model simulates a change of the opposite sign to, and larger than, the model-mean change). Source (and more details): Persad et al. (2020).

| | END-CENTURY (2070-2099) | |
|---|---|---|
| | MEDIUM EMISSIONS (RCP 4.5) | HIGH EMISSIONS (RCP 8.5) |
| Total annual snowpack | -58% M | -84% H |
| Overall rain-on-snow risk | -54% M | -84% H |
| Rain-on-snow risk where and when snow remains | +4% L | +9% M |
| Fraction of annual precipitation falling as rain rather than snow | +1% H | +1% H |
| Fraction of annual precipitation falling on 5% most extreme days | +4% L | +13% M |
| Wettest 3-day period in a year | +4% L | +20% M |
| Fraction of annual precipitation falling from November to March | +1% L | +6% H |
| Total annual water loss from evaporation and transpiration | +1% M | +1% M |
| Frequency of very wet years | +34% L | +57% M |
| Frequency of very dry years | +4% L | +10% L |
| Frequency of swings between very wet and very dry years | +30% L | +124% L |

As temperatures increase, the Sierra Nevada will very likely receive more precipitation falling as rain and less as snow, reducing the state's snowpack to fill the San Joaquin Valley rim dams. Snowpack is essential for the San Joaquin Valley because it is a natural form of water storage that melts during the spring and fills reservoirs with water that later flows to agriculture. Snowpack is reducing gradually at high elevations and is projected to disappear at lower elevations by the end of the century. Then, reservoirs will fill sooner, and water will have to be released earlier in the spring before it is needed, leading to water supply shortages and lower reservoir storage (Cohen et al., 2020; Musselman et al., 2021). This earlier and less abundant snowmelt will likely impact agricultural supply making it more reliant on groundwater. As temperature increases, earlier snowmelt will shift peak flows by 2 to 4 months by the end of the century and increase risk of flood events (Huang et al., 2018). This shift may reduce surface water storage, increasing the mismatch between when the water is available (winter-spring) and when most of the water is used (summer).

## PROJECTIONS SHOW LONGER AND MORE SEVERE DROUGHTS THAT WILL DISPROPORTIONATELY AFFECT VULNERABLE COMMUNITIES AND AGRICULTURE, AND INCREASE SEVERITY OF WILDFIRES

Droughts can be defined in different ways: metrological, hydrological, agricultural, socioeconomic, and ecological droughts. A drought occurs when there is a lack of water to meet the needs of either human or environmental systems (Mann & Gleick, 2015; Mishra & Singh, 2010). As anthropogenic warming changes the climate, droughts in the San Joaquin Valley region are becoming more intense in both frequency and magnitude (Diffenbaugh et al., 2015; Stewart et al., 2020; A. P. Williams et al., 2015). Extreme droughts have damaged infrastructure in several ways including loss of canal capacity due to land subsidence (Mann & Gleick, 2015). This is also causing increased vulnerability of humans and ecosystems by reducing water security (Greene, 2021; Stewart et al., 2020).

Higher temperatures combined with wind events and delayed rains (longer dry seasons) have more-than-doubled the number of days with favorable conditions for wildfires since 1980, intensifying their extent and severity (Goss et al., 2020; Williams et al., 2015). The survival of drought tolerant trees decreases under severe and longer droughts, increasing tree mortality and creating conditions for more severe wildfires under a warming future (Crockett & Westerling, 2018). Under a medium emissions scenario, the area burned is projected to be about 12% larger annually on average by mid-century compared to historical conditions (Table 7). Wildfires deteriorate air quality and disproportionally impact human health in the San Joaquin Valley, which has more dramatic effects among vulnerable groups like farmworkers and rural disadvantaged communities.

**TABLE 7.**

San Joaquin Valley region projections of area burned by wildfires. Mean averages across four models (HadGEM2-ES, CNRM-CM5, CanESM2, MIROC5). More details in https://cal-adapt.org/.

| ANNUAL AVERAGE AREA BURNED (ACRES) | | | | |
|---|---|---|---|---|
| | MID-CENTURY (2035-2064) | | END-CENTURY (2070-2099) | |
| HISTORICAL (1961-1990) | MEDIUM EMISSIONS (RCP 4.5) | HIGH EMISSIONS (RCP 8.5) | MEDIUM EMISSIONS (RCP 4.5) | HIGH EMISSIONS (RCP 8.5) |
| 13,111 | 14,672 (+1,564) | 13,892 (+788) | 13,719 (+611) | 13,584 (+470) |

### SEA LEVEL RISE INCREASES FLOODING THREATS FOR COMMUNITIES AND AGRICULTURE IN THE SACRAMENTO-SAN JOAQUIN DELTA

The Sacramento-San Joaquin Delta (the Delta) is a National Heritage Area in the confluence of the Sacramento and San Joaquin Rivers before they reach the San Francisco Bay. It provides resources and habitat for birds and aquatic species (including the nearly extinct Delta smelt, that is an important bioindicator of the water resources health in California), it serves the local agriculture, and it is a barrier for sea water intrusion into the Sacramento and San Joaquin Rivers. The Delta region is also an important transfer point for water supplies from the North to Central and Southern California. Over a century ago, farmers and local stakeholders built a network of levees creating islands to drain the marsh. Today, most of the Delta islands are below the sea level due to land subsidence caused by the oxidation of the drier peatlands, and the surrounding levees protect them from flooding. Besides flooding, salinity (high concentrations of salt in water or soil) is another major concern as it turns water unsuitable for human consumption and agriculture, compromising Delta water exports through the State Water Project and the Central Valley Project. Sources of salinity include seawater coming into the Delta with the tides from the San Francisco Bay and agricultural and urban runoff from its two draining basins.

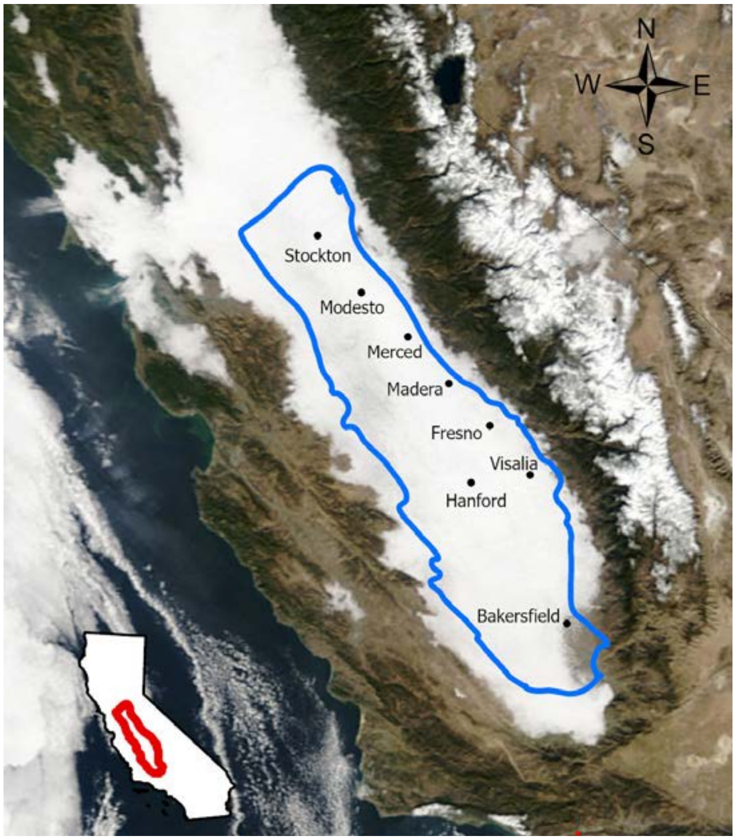
Sea level rise increases both the risk of flooding and unsustainable salinity. Sea level rise is also threatening over 10,000 people in Delta communities in San Joaquin County cities such as Stockton (Climate Central, 2016). Over the past 100 years, sea level has risen 8 inches (20 cm), and it could rise 2 feet (74 cm) by mid-century and 3.5 ft (107 cm) by the end of the century (Delta Stewardship Council, 2020). Sea level rise is also compromising the structural integrity of the levees, leading to an even greater flood risk for communities.

Salinity barriers (temporary rock structures installed in 1977, 2015, and 2021) will be more difficult to maintain, and preventing freshwater from being contaminated with salt will be increasingly difficult. A way to prevent sea water intrusion in the Delta is increasing Delta outflow requirements by reducing some diversions from upstream users in the Sacramento and San Joaquin basins. Such actions could reduce water availability for agriculture and cities, but they can reduce salinity intrusion. Sea level rise may also threaten public health if flooding and rising groundwater levels damage underground sewer pipes and systems, leading to toxic waste seeping into fresh groundwater aquifers and getting onto streets and homes (LAO, 2020).

### TULE FOG FREQUENCY IS DECLINING AND LIKELY IMPACTING AGRICULTURE

The Tule fog is a thick fog that covers the whole Central Valley, and it is a unique phenomenon that is uncommon at this scale (Figure 7). It was named after the Tulare Lake, a freshwater lake in the southern region of the San Joaquin Valley dried a century ago by human intervention. The Tule fog forms after a heavy rain when radiating heat combined with a cool night causes moisture to condense around microscopic, aerated particles. The Tule fog is known for causing weather-related vehicle accidents, hampering aviation, and even triggering closing schools. At the same time, the Tule fog plays a positive role in agriculture, as prolonged periods of dense fog help attain dormancy requirements of fruit and nut trees. Fog frequency has decreased about 75% since 1980, with high correlation with decreased air pollution, as cleaner air has fewer particles for the droplets to form. Combined with other climate change effects, this can negatively affect the profitability of tree nuts and orchards in the San Joaquin Valley (Duginski, 2020; Gray et al., 2019).

**FIGURE 7.**




Tule fog covering the Central Valley of California. The perimeter of the San Joaquin Valley is depicted with a blue solid line, and the seats of each county are indicated with a black dot (from north to south, Stockton, Modesto, Merced, Madera, Fresno, Visalia, Hanford, and Bakersfield). Fog at this scale is a unique phenomenon in the Central Valley, and crops such as vineyards rely on this air moisture for wine quality. Source: adapted from NASA earth observatory (Terra, MODIS) (Schmaltz, 2005), December 16, 2005.

## Climate change impact on water resources

Drought-related climate vulnerability greatly impacts disadvantaged communities and agriculture in the San Joaquin Valley as the sensitivity and exposure to changing climate conditions outpaces the ability of the system to adapt. Reduced water availability for irrigated agriculture is expected due to increasing applied water demands as evapotranspiration rates increase because of higher temperatures (Pathak et al., 2018). Higher evapotranspiration on high elevations (Sierra Nevada) may reduce runoff (Jepsen et al., 2018). In addition, large-scale irrigation in the San Joaquin Valley with water imported from other basins causes more water to leave the basin through evapotranspiration than what comes as precipitation (twice as much in most of the basin) (Szilagyi & Jozsa, 2018). As droughts continue to affect the San Joaquin Valley in increasing frequency and intensity, the demand for groundwater for agriculture will increase while groundwater availability decreases, worsening the multidimensional issues faced by disadvantaged communities relying on wells for domestic water uses. The 2012-2016 drought exacerbated a pre-existing water crisis as groundwater became about 80% of the supply in the San Joaquin Valley. The 2012-2016 drought marked the three driest consecutive years in California's history and was associated with greater extremes in temperature and precipitation than any drought in the prior century (Crockett & Westerling, 2018). Farms responded by pumping large amounts of groundwater out of the San Joaquin Valley basin, increasing overdraft of critically stressed aquifers, increasing land subsidence, and impacting private wells and (mainly rural disadvantaged) communities that depend on local wells for water supply (Castillo, 2016; Howitt et al., 2015) (Figure 8). Rural disadvantaged communities had to rely on bottled water, interim tanks, and filling buckets and barrels from neighboring communities (Greene, 2021). This highlights the disparity that rural disadvantaged communities experience and emphasizes the need for environmental equity and justice policies.

Adequate regulation for groundwater sustainability (see *Case Study 5. Sustainable Groundwater Management Act and Agriculture*) brings opportunities to reduce some of these inequities and reach groundwater sustainability. Most rural disadvantaged communities rely solely on groundwater for their water supply. Groundwater is currently in a perpetual state of overdraft, its physical storage capacity is reducing due to land subsidence, and its management to serve conjunctive (surface and groundwater) uses in the future is becoming more difficult. Increasing water scarcity and more rigorous regulations will require improved water accounting for management and an overall reduction in groundwater overdraft. The implementation of water regulatory policies and the precarity of some infrastructures may constrain water management adaptation strategies. Changes in policy, behavior, and technology will be needed to adequately sustain water resources in the San Joaquin Valley.

### IMPACTS ON REGIONAL WATER QUALITY

Intensifying climate change is likely to degrade water quality and reduce its availability (Barnett et al., 2008). The San Joaquin Valley already suffers from serious water quality issues that inequitably impact rural disadvantaged communities (Figure 8 and Figure 9). Unlike climate change research in relation to droughts, snowpack, and extreme events, water quality effects remain largely unexplored (Michalak, 2016). Yet there are indirect effects such as reduced water quality in source waters after wildfires, algae bloom due to higher temperatures, and increased concentration of contaminants as water is reduced in surface and groundwater reservoirs, among other effects. Research suggests that water quality has seasonal variations, with higher pollutant concentrations during dry periods and improved water quality during wet periods (Dokou et al., 2016).

### Water quality in rural unincorporated and disadvantaged communities

Hundreds of thousands of San Joaquin Valley residents do not have access to safe drinking water and rely on bottled water. In some cases, they recur to boiling water which can kill bacteria and other pathogens but will increase the concentration of harmful chemicals. Common chemicals across the San Joaquin Valley rural disadvantaged communities include arsenic, nitrate, 1,2,3-trichloropropane (1,2,3-TCP), chromium VI, bacteria, and high concentrations of sediments. Some of these chronic water quality issues can be solved at the household level by installing reverse osmosis systems with ultraviolet light or similar in-situ treatment to purify and disinfect water. Other concerns revealed by interviews with disadvantaged community stakeholders of the San Joaquin Valley include distress from children's lack of access to safe drinking water in schools, not having sufficient income to afford bottled water, and uncertainty about the impacts of water in their health (Fernandez-Bou, Ortiz-Partida, Dobbin, et al., 2021; Flores-Landeros et al., 2021).

#### *Arsenic*

Arsenic is a chemical element naturally found in rocks and soil, but aquifer overpumping has increased its concentration in the San Joaquin Valley groundwater (R. Smith et al., 2018). Arsenic in drinking water has been linked to an increased risk of cancer, heart diseases, and diabetes (Singh & Stern, 2017; Yoshida et al., 2004). A recent study found that arsenic concentrations are decreasing in many domestic wells (while increasing in others), but those with decreasing trends are showing correlation with higher concentration of nitrate (Haugen et al., 2021). Many cities and communities in the San Joaquin Valley have arsenic levels beyond the maximum contaminant level (MCL) such as the community of Tranquility (Fresno County) and the city of Arvin (Kern County) whose arsenic levels in wells are more than three times the maximum contaminant level (see Table 8). Poor planning and systemic injustice have led to inadequate policies regarding arsenic management. For example, the rural disadvantaged community of Lanare (Fresno County) received a $1.3 million water plant to treat arsenic in their water that was disconnected after a few months because the community could not afford its maintenance (Ores, 2019).

#### *Nitrate*

Nitrate in groundwater remains as one of the state's greatest contaminants (Rosenstock et al., 2014). For over half a century, nitrate from agricultural fertilizer use and animal waste have infiltrated into San Joaquin Valley's aquifers (Fujii et al., 1995). Climate change may increase nitrate concentration due to droughts, and nitrate concentrations will likely increase for decades (Harter et al., 2012). Too much nitrate impairs drinking water quality and can pose a threat to human health and has been linked to cancer, birth defects, blue baby syndrome, and other adverse health effects (Ward et al., 2018). The California Department of Public Health (CDPH) has set a maximum contaminant level for nitrate in drinking water at 45 milligrams per liter as nitrate (Table 8). Managed aquifer recharge may help reduce nitrate concentrations in shallow wells near recharge sites (Castaldo et al., 2021).

#### *1,2,3-Trichloropropane (1,2,3-TCP)*

1,2,3-TCP is a human-made chemical that was used for decades in agriculture. 1,2,3-TCP infiltrated into the ground and, even though its use was banned in 1979, it has continued moving slowly into groundwater. 1,2,3-TCP has been shown to increase the risk of cancer and birth defects (Burow et al., 2019). In many communities it is present at levels more than twice the maximum contaminant level. For example, since 2018, it has been detected at five times or more the maximum contaminant level in more than 200 municipal wells, including in Manteca and Lodi (San Joaquin County), in Hughson and Ceres (Stanislaus County), in Atwater and Livingston (Merced County), in Kerman and Parlier (Fresno County), in Tulare and Visalia (Tulare County), in Wasco and Shafter (Kern County). More research is needed to assess how concentrations of 1,2,3-TCP in groundwater may be directly affected by climate change. Indirect effects such as reducing surface water availability and increasing dependance on groundwater will likely maintain the presence 1,2,3-TCP in private and municipal wells.

### *Chromium VI*

Chromium VI or Cr(VI) is a chemical whose presence in the San Joaquin Valley has both human and natural causes. Drinking Cr(VI) contaminated water may increase risk of stomach cancer and reproductive harm, and it can cause allergic skin rashes in some people (A. H. Smith & Steinmaus, 2009). While chromium VI can occur naturally in groundwater, industrial activities—such as metal plating, leather tanning, and others—can lead to elevated concentrations of this chemical (Hausladen et al., 2018). Los Banos is an example of a community with more than three times the (currently unenforceable) maximum contaminant level. Like with arsenic (and other heavy metals), long-term monitoring and more research are need to better understand direct relations between climate extremes such as droughts and floods and Cr(VI) concentrations in groundwater. Studies developed in other regions show increased concentration of Cr(VI) as water in aquifers and streamflow decrease in climate change-related dry periods (Dokou et al., 2016).

**TABLE 8.**

Maximum contaminant levels (MCL) of most common contaminants in the San Joaquin Valley. The term maximum contaminant level refers to a standard concentration set by the EPA for the quality of drinking water. MCLs are established to keep public water systems safe by enforcing the legal limits on concentrations of certain substances in drinking water. Notes: μg = microgram, L=liter. The MCL for chromium VI is no longer enforceable for legal reasons related to the economic feasibility of implementing such MCL, but the amount represents a meaningful number for assessing the toxicity of the chemical.

| CONTAMINANT | MAXIMUM CONTAMINANT LEVEL |
|---|---|
| 1,2,3-TCP | 0.005 μg/L |
| Nitrate | 45 mg/L |
| Arsenic | 10 μg/L |
| Chromium VI | 10 μg/L |

### *Bacteria*

Microscopic organisms such as *Salmonella*, *Escherichia coli* (*E. coli*), and the parasite *Giardia* are often associated to proximity to septic tanks and cattle operations. Health adverse effects from such micro-organisms are diverse, including nausea, vomiting, diarrhea, and fever. Emptying septic tanks in backyards can further contaminate groundwater, and poorly managed waste disposal and proximity to dairy and cattle industries can have such impact too. Aging and underfunded infrastructure is an underlying reason for bacterial contamination, mainly in communities with unmaintained sewage systems or without them (London et al., 2018). As climate change keeps adding pressure to our water infrastructure (Persad et al., 2020), this situation is likely to aggravate.

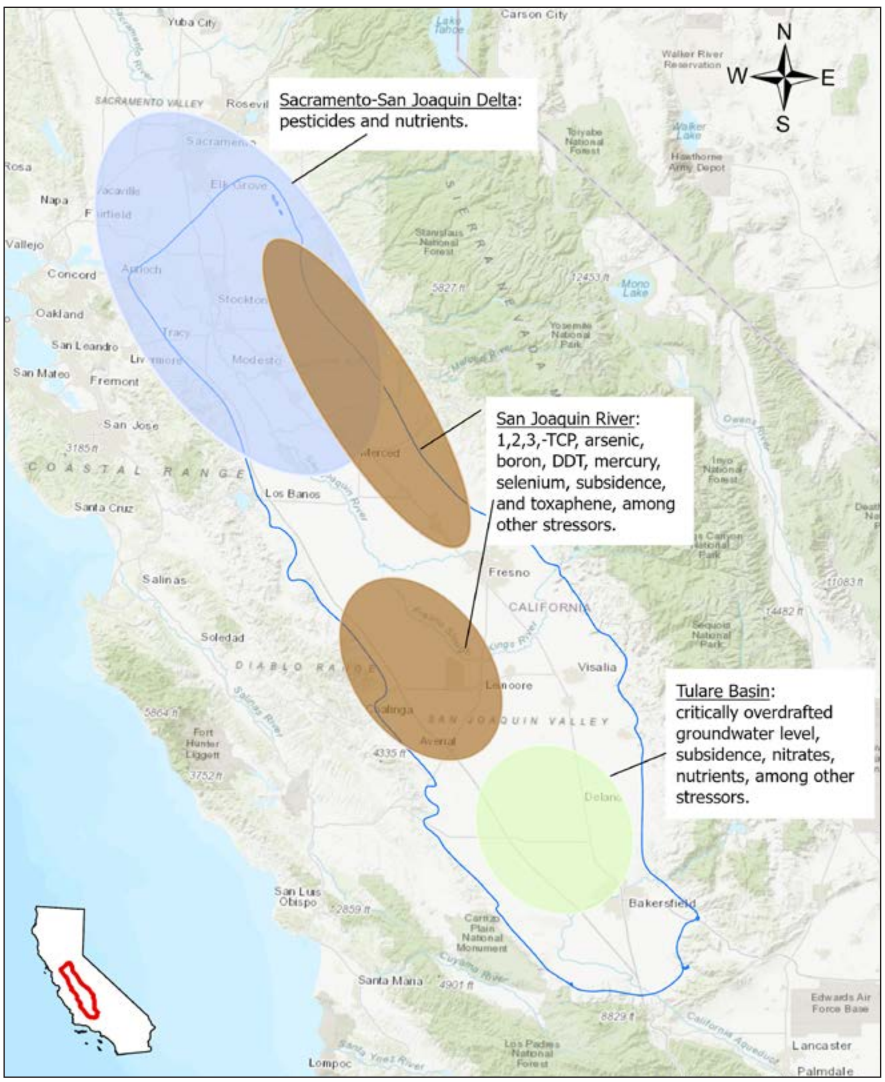
**FIGURE 8.**

Water in two homes in the city of San Joaquín, Fresno County, CA, in November 2019. Groundwater overdraft due to climate change-induced droughts depletes aquifers, and small communities with shallow wells pump water with high concentration of sediments and pollutants. Photos from community members, provided by Jose Ornelas.

### Salinity

Climate change indirectly causes salinity increase by reducing water supplies and by increasing water consumptive use to adapt to climate change (Corwin, 2021). Adaptation strategies like drip irrigation also reduce the flushing out of the soil salts, besides decreasing groundwater recharge (Zheng et al., 2009). Other impacts from salinity in agriculture are presented in the *Climate Change Impacts on the San Joaquin Valley Agriculture* section and on *Case study 1. Desalination in the Panoche Water and Drainage District*.

**FIGURE 9.**




Localized soil and water quality problems in the San Joaquin Valley. The Sacramento-San Joaquin Delta subregion suffers from pesticides and nutrients in the water. The lower and upper San Joaquin River subregion has excessive levels of 1,2,3-TCP, arsenic, boron, DDT, mercury, selenium, and toxaphene, besides suffering from soil subsidence. The Tulare Basin has excessive nitrate and nutrients, besides soil subsidence and critically overdrafted groundwater levels. Adapted from Figure 2.7 from Hanak et al. (2011).

## CASE STUDY 1. Desalination in the Panoche Water and Drainage District

Agricultural districts in the San Joaquin Valley face chronic water shortages and growing salt contamination. Excess salinity from agricultural irrigation return flows has been the focus of regulatory agencies for decades, initiated by detrimental environmental impacts to wildlife after the completion of the Central Valley Project (Wichelns & Oster, 2006). Droughts and increasing water scarcity due to climate change, combined with comprehensive actions promoted in the Central Valley Salinity Alternatives for Long-Term Sustainability initiative (CV-SALTS), have pointed toward closed loop hydrological systems as a means for climate change adaptation to maintaining agricultural productivity in a water stressed region (information available on www.cvsalinity.org). Closed loop hydrology looks to reduce environmental flows by creating an internal cycling of water which reduces salt leaching by treating run-off water for reapplication.

The Panoche Water and Drainage District is located in an overdrafted basin west of Firebaugh, in Fresno County. Excessive groundwater pumping to compensate for water scarcity has increased selenium concentrations. The district has been experimenting with alternative treatment options for selenium-contaminated drainage water with two reverse osmosis systems and one solar thermal system. Briny irrigation drainage water is collected and used on drought and salt tolerant crops. Then, the highly saline drainage is captured and treated at the plant. Treated water may be reused to irrigate crops while the concentrated sludge, classified as hazardous waste, must be disposed of in a special landfill (Grossi, 2015).

An additional desalination experiment using reverse osmosis developed by University of California Los Angeles researchers has also been implemented at the site. The demonstration-scale field lab can desalinate and purify as much as 27,000 gallons (102 $m^3$) of contaminated agricultural runoff and groundwater per day (Kisliuk, 2014). The District has also financed a $1 million solar thermal desalination plant with state funds. The demonstration plant, operated by Water FX, uses a solar thermal receiver to desalinate the water at a lower cost than traditional desalination. During the pilot project in 2013, the plant produced 14,000 gallons of purified water a day (Woody, 2014). Surface water inflows are blended with treated water and applied to salt tolerant crops (for example, pistachios or Jose tall wheatgrass which is a fodder for dairy cows). It is foreseeable that other irrigators will need to consider technologies, such as small-scale distributed brackish water desalination, in concert with cropping changes to adapt to the combination of increasing water scarcity and water quantity and quality regulation.

## Climate change impacts to San Joaquin Valley water infrastructure

Projected increases in storm intensity and duration, and changes in the timing of runoff due to increased rainfall pose additional stress on the flood control infrastructure of the San Joaquin Valley. Recent flood risk infrastructure incidents in the Central Valley include the Oroville Dam erosion in the Sacramento Valley in 2017 due to intense precipitation (Vahedifard et al., 2017), and an evacuation notice issued at Moccasin Reservoir (built in 1930) in the San Joaquin Valley after heavy rains almost lead to system failure (Cabanatuan & Alexander, 2018).

Urban areas have been designed to satisfy relatively constant per capita human demands for water, energy, and transportation services. These services, including the infrastructure built to deliver them, must remain reliable under perturbations and stress caused by climate extremes. Climate change can directly and indirectly degrade infrastructure by increasing exposure to high-stress events that infrastructure must withstand, such as land subsidence or exceeding design operation load for extended periods.

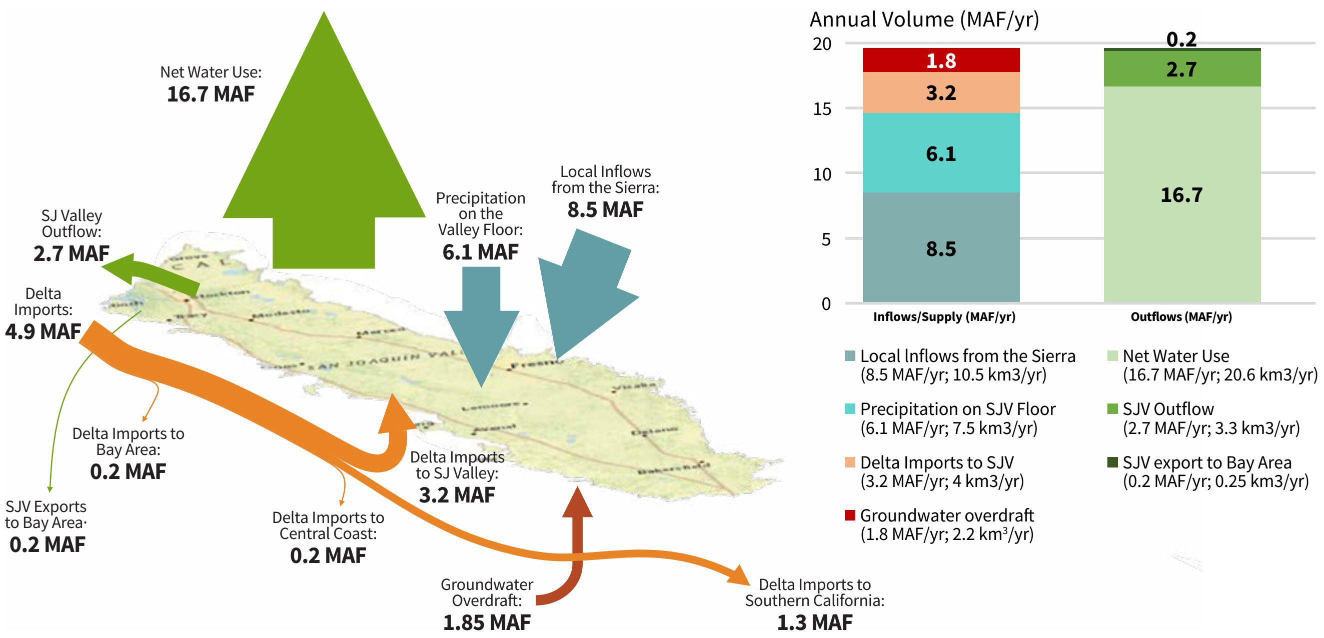
While climate change effects on water, power, and transportation are to a certain extent generalizable across geographic regions, the San Joaquin Valley has some characteristics that differentiate it from the rest of California. These include higher maximum temperatures, larger water demands, and declining groundwater levels.

### WATER SYSTEMS

The San Joaquin Valley has a unique hydrologic context. The region has thirteen major reservoirs that provide surface water storage, although groundwater storage is about 25 times more (Escriva-Bou, 2019). In other regions and countries, groundwater has traditionally been an emergency water storage to cope with droughts. However, in the San Joaquin Valley, groundwater storage has been depleted at an average rate of 1.5 million acre-feet per year (1.85 $km^3$/yr) since 1962, and this rate doubled during the 2012-2016 drought (Hanak et al., 2017). If surface water availability remains the same or declines, the rate at which aquifer systems are depleted is likely to increase. Overextraction of groundwater has degraded groundwater quality (R. Smith et al., 2018), has created land subsidence impacting infrastructure (Jeanne et al., 2019; Levy et al., 2020), and has dried private and community wells (Greene, 2021), among other impacts. The water rights in the state's major river basins are overallocated, with the greatest degree of appropriation observed in the San Joaquin Rivers and its tributaries (Grantham & Viers, 2014).

Figure 10 presents the water balance in the San Joaquin Valley from 1988 to 2017. Water sources in the San Joaquin Valley mainly come from local watersheds and water from net precipitation on the valley floor (70%). Direct diversions from the Delta represent about 6% and water imported from other regions is 19%. The remaining 11% comes from groundwater overdraft (Escriva-Bou, 2019). These inflows and imports are highly variable depending on annual precipitation, making water storage essential to adapting to water scarcity. The region receives water imports from Northern California through the Delta, conveyed using local, state, and federal infrastructure, managed by a diverse set of agencies, and delivered under a variety of water rights and contracts, with joint water management and water trading across the combined regions. Water leaves the San Joaquin Valley through consumptive water use from evapotranspiration (which remains comparatively constant from year to year), outflows to the Delta, exports from the San Joaquin River tributaries to Bay Area water users, and exports of imported water that enters the San Joaquin Valley. Some Delta imports that enter the region through the Central Valley Project and State Water Project pumps are then delivered to the San Francisco Bay Area, the Central Coast, and Southern California (Hanak et al., 2017).

**FIGURE 10.**




Average water balance in the San Joaquin Valley, 1988-2017. Inputs include local inflows from the Sierra (8.5 million acre-feet per year or 10.5 km$^3$ per year), precipitation on the San Joaquin Valley floors (6.1 million acre-feet per year or 7.5 km$^3$ per year), Delta imports (3.2 million acre-feet per year or 4 km$^3$ per year), and groundwater overdraft (1.8 million acre-feet per year or 2.2 km$^3$ per year). Outflows include net water use (16.7 million acre-feet per year or 20.6 km$^3$ per year), San Joaquin Valley outflow (2.7 million acre-feet per year or 3.3 km$^3$ per year), and San Joaquin Valley exports to the Bay Area (0.2 million acre-feet per year or 0.25 km$^3$ per year). Source: Escriva-Bou (2019) and adapted.

### Projected Urban Water Demand in the San Joaquin Valley

The San Joaquin Valley urban water demand is about 700 thousand acre-feet per year (863 million m$^3$ per year), and it is projected to increase from 52% to 131% by 2050 compared to 2006 baselines (DWR, 2013). The projections of water demand depend on climate change, population growth, and per-capita water use.

### Water treatment pre-use and post-use

Warmer temperatures linked to climate change will worsen algal blooms in reservoirs used to store urban water supplies. During droughts, there will also be less water to dilute algal toxins. This increases the need for water treatment before it is suitable for human use and could lead to water reliability challenges. Severe precipitation events can cause runoff entering streams and eventually reservoirs to have higher turbidity, also requiring more filtration before human use (RMC Water and Environment, 2013).

Wildfires pose a threat to urban water supplies if they burn within watersheds drawn on for water supplies. For example, the 2015 Rough Fire burned within the Kings River watershed, on which Fresno relies for urban water supplies (Fresno city, 2016). Forests that have been burned by severe wildfire have a reduced ability to retain rainfall and chemicals such as nitrate, dissolved organic carbon, and certain metals. Subsequent precipitation events can trigger erosion and wash these unwanted chemicals, in addition to ash and other debris, into streams (Writer & Murphy, 2012). These contaminants take time and resources to clean out from water supply reserves.

Severe precipitation events may threaten to overwhelm the infrastructure built to convey and treat wastewater and stormwater. If stormwater infrastructure is overwhelmed, localized flooding may occur in cities. If wastewater treatment plants are overwhelmed with inflows, these may be forced to discharge untreated or partially treated water causing water quality issues and public health problems. Conversely, during extended droughts, wastewater treatment plants may receive a reduced quantity of inflows but with increased pollutant concentrations, leading to cost inefficiencies in the treatment process (Tran et al., 2017).

### Water supply and delivery

The Sustainable Groundwater Management Act (SGMA) establishes a framework for sustainable management of groundwater in California. SGMA requires the establishment of Groundwater Sustainability Agencies (GSAs), each of which is required to have a Groundwater Sustainability Plan (GSP). Depending on the state of each groundwater basin, GSPs detail how each GSA will achieve sustainability by year 2040 to 2042 (roughly twenty years after GSPs have been filed with the California Department of Water Resources). This has a significant impact on groundwater supplies that were previously nearly unregulated. Given GSP implementation is in its early years, the efficacy of this regulation on the San Joaquin Valley water supplies during drought remains uncertain.

The San Joaquin Valley water supply may be negatively affected by climate change in multiple ways. Temperature increases will promote earlier water release from reservoirs and less water availability for summer and drought periods (snowpack retreat to higher altitudes and more rapid snowpack melting), and they will lead to larger freshwater amounts delivered to the Delta during peak flows (more frequent severe storms can overwhelm the pumping and conveying capacity to send water back to the San Joaquin Valley) (DWR, 2017). Continued groundwater extraction (due to drier conditions) will threaten the canal network due to land subsidence, impacting the San Joaquin Valley water supplies. In addition, structural deterioration of the earthen levees (due to droughts and land subsidence) will promote water loses, soil cracking, soil organic carbon decomposition, and erosion (Vahedifard et al., 2015).

### Groundwater banking and recharge

Groundwater basins can provide large storage capacity for groundwater banking in the San Joaquin Valley. Runoff from high magnitude winter storms is not legally allocated and provides a source of surface water for groundwater banking. While high magnitude flows reach the outlet of the San Joaquin River about half of the years, they occur later in the growing season, limiting the utilization of flood flows for on-farm recharge as the onset of the growing season shifts towards earlier dates (Kocis & Dahlke, 2017). Although there is high recharge potential in the San Joaquin Valley, there are limitations related to water conveyance and lack of local supplies.

## ENERGY SYSTEMS

California energy systems play an essential role in reaching a zero-carbon future (Senate Bill 100, 2018). In most of the United States, energy comes from non-renewable fossil fuels, and power plants alone contributed 27% of the total greenhouse gas emissions from 2018 (EPA, 2021). Replacing non-renewable fossil fuel power plants with cleaner energy sources will represent a significant reduction of greenhouse gases. However, the transition to clean energy is susceptible to extreme weather events linked to climate change. In addition to climate change, economic globalization and the uncertain future of fossil fuels have added new opportunities to the electric sector, such as sustainability, energy efficiency, mitigation of greenhouse gas emissions, and improved accessibility of energy services (Jakstas, 2020).

### Electric Power System

The electric system that serves the San Joaquin Valley is vulnerable to climate change due to its impact on the energy supply and energy usage. Some climate change-driven environmental conditions that diminish the available energy resource are plumes from wildfires that cast shades on solar arrays and droughts that limit hydropower generation. During August, 2020, California experienced statewide extreme heat with temperatures 10 °F to 20 °F (5.6 °C to 11.1 °C) above normal (CAISO, 2021). California (and the entire West of the United States) faced one of its worst heat waves since 1985 affecting 32 million California residents. These weather events, paired with an increase in electricity demand, caused a cascade effect forcing the California Independent System Operator (CAISO) to initiate rotating electricity outages which disconnected 812,600 users across the California territory (see related *Case Study 2. Air Conditioning and Energy Demand*).

The region's electricity infrastructure is threatened by climate change impacts to electricity generation and transmission in other regions since California imports one quarter of its electricity (EIA, 2020). The transmission of electricity to the San Joaquin Valley communities is vulnerable to extreme climate events. Unexpected outages from transmission line failures, earthquakes, or wildfires increase the risk of short circuiting and ignition causing wildfires. Thermal expansion of the lines also could cause them to droop and get in contact with fuels, igniting them. In a drier, more wildfire-prone future, wildfires may cause more frequent and severe damage to poles carrying transmission lines (Davis & Clemmer, 2014). Smoke and ash from fires can ionize the air and create an electrical path, causing system shutdown (Davis & Clemmer, 2014; Hasanbeigi et al., 2012; Ward, 2013). During stronger storms with higher winds, power lines could be at risk from falling or from treefalls impacting them (Troccoli et al., 2014).

### Natural gas infrastructure

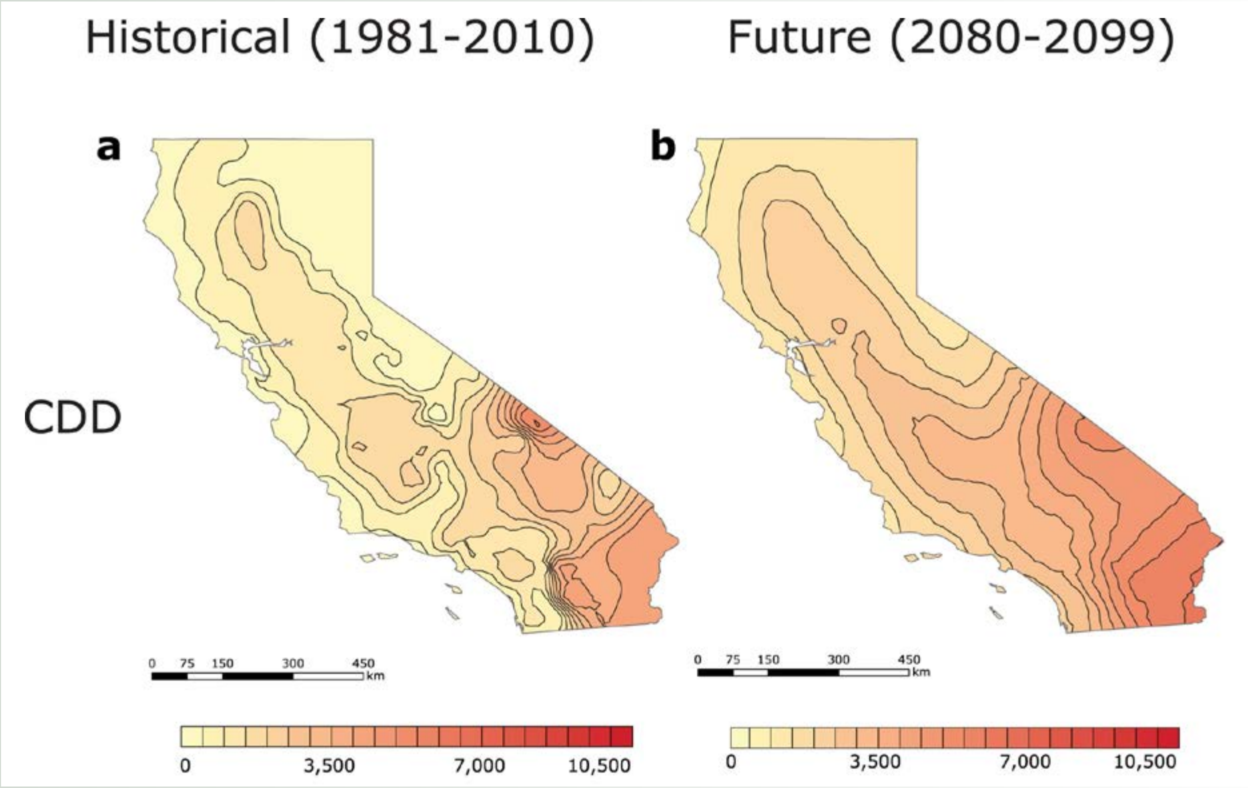
Under climate change, natural gas infrastructure is vulnerable to flooding, which can result in fractures, corrosion, and loss of structural integrity due to erosion and scouring. A study modeling the Sacramento-San Joaquin Delta found that a near 100-year storm could inundate 77 miles out of 3,421 miles (124 km out of 5,506 km) of natural gas pipelines in the Bay-Delta Region, and that a near-100 year storm combined with 0.5 m of sea level rise would inundate 139 miles (224 km) of pipes (Radke & Biging, 2017). Some of this flooding could impact natural gas supplies to Stockton and surrounding communities.

## CASE STUDY 2. Air Conditioning and Energy Demand

Residents of the San Joaquin valley pay 14% more for energy than the average in California due to the hotter summer and colder winters (Jones et al., 2017), and air conditioning is a major component of energy demand. The number of cooling degree-days is projected to increase due to climate change (Figure 11). A cooling degree-day is every degree (1 °F = 0.56 °C) that the daily mean temperature is above 65 °F, and it is a predictive metric for air conditioning demand. For example, if the mean temperature is 85 °F one day, that day has 20 degree-days.

The San Joaquin Valley is expected to experience an increase in cumulative cooling degree-days, and maintain its higher cooling costs compared with most other parts of California (Petri & Caldeira, 2015). The increase in summertime air conditioning demand is a risk to electricity reliability, which can be decreased by installing local grids for energy generation and storage. The loss of energy to homes and critical facilities such as hospitals during heat waves has major public health and safety implications.

**FIGURE 11.**




Annual cumulative cooling degree-days (CDD) in California for a historical period (1981-2010, left) versus a future projection (2080-2099, right). Source: Petri & Caldeira (2015)

## TRANSPORTATION SYSTEMS

Transportation infrastructure is physically exposed to climate conditions and is vulnerable to extreme weather events. The California Department of Transportation (Caltrans) reports the expected regional climate change impacts to California's transportation infrastructure. The northern San Joaquin Valley (San Joaquin, Stanislaus, and Merced Counties) are part of Caltrans District 10, and the southern San Joaquin Valley (Fresno, Madera, Tulare, and Kings Counties, and most of Kern County) are part of Caltrans District 6. The regional reports issued by Districts 6 (Southern San Joaquin Valley) (CALTRANS, 2018) and 10 (Northern San Joaquin Valley) (CALTRANS, 2019) share coverage of several threats to transportation infrastructure posed by climate change:

1. **Temperature:** Paved roads, rail tracks, and bridge joint seals could be vulnerable to deformation and buckling under sustained high temperatures. Pavement design parameters such as the choice of pavement binder may need to be adjusted based on shifting climate conditions. Infrastructure with longer lifespans (for example, 50 years for bridges) will require consideration of conditions based on longer-term projections.

2. **Precipitation:** Paved roads, rail tracks, and bridges could be scoured and eroded by flooding or major precipitation events. Caltrans is particularly concerned about the risk to the state's highway system from larger, more frequent storm events under a more extreme precipitation regime. For example, floods and heavy rain could wash away unconsolidated material and cause obstruction of roads and rail tracks. If soil moisture rises or falls too much in response to floods or droughts, the roadbed foundations for paved roads and bridges could be undermined. While simulations show that the San Joaquin Valley will likely experience a modest (5%) increase in 100-year storm precipitation depth (Scripps Institute of Oceanography), that precipitation will occur in fewer events.

3. **Wildfire:** The predominantly urban and agricultural nature of the San Joaquin Valley limits the direct risk of wildfires to the region's transportation infrastructure. Concerns for the forested portions of the San Joaquin Valley include increased erosion from soils that are burned and lack forest cover leading to road overwashing and damage, and damaged or clogged culverts due to landslides of debris from burned ground.

Additionally, sea level rise and increased storm surge pose a threat to the low-lying portions of the northern San Joaquin Valley located within the Sacramento-San Joaquin Delta. For example, a three-dimensional hydrodynamic model, 3Di, estimates that under a high-end sea level rise scenario of 4.62 feet, a 100-year storm event would result in 10.5 miles of San Joaquin County highways being vulnerable to flooding (CALTRANS, 2019)

## Adaptation and mitigation strategies

The San Joaquin Valley is already experiencing some of the impacts driven by climate change in California. However, it is still possible to avoid the worst impacts with adequate adaptation and mitigation strategies. These strategies vary according to the sector and scale. For example, rural areas need different strategies than urban areas, and sustainable agriculture can help mitigate pressures exerted by California cities (see *Adaptation and mitigation strategies in the Climate Change Impacts on the San Joaquin Valley Agriculture*). The more that it is done soon to reduce emissions of heat-trapping gasses going into the atmosphere, the less negative climate change impacts the San Joaquin Valley will experience in the future.

Replacing carbon dioxide and pollution sources with clean, zero-carbon-emission technologies will prevent the effects of excessive greenhouse gases in the atmosphere, will promote new local infrastructure development, and will faster align the energy sector with California climate policies. In addition, reducing or eliminating the impacts from major contributors to climate change in the San Joaquin Valley, such as fracking oil wells, natural gas peaker-plants, and the transportation sector, can improve air quality, water quality, and health while mitigating climate change. Planning a just transition away from these major climate change contributors via regulation and stakeholder involvement will likely reduce social, economic, and environmental inequities in the process.

At the state level, some adaptation strategies to cope with changing availability of water resources are related to protecting forests and increasing forest management to reduce risk of wildfire. Recovering flood plains to enable better water distribution across the land can help reduce flood risk and improve groundwater recharge. Management of aquifer recharge projects are the most promising way to expand the current water storage, allowing water to be safely captured from the more frequent extreme storms and the more intense snow melting. Soil storage is at least one order of magnitude larger than surface storage, and dams may not be able to hold all the water released during peak flows and extreme events. Adequate soil storage will also reduce the impacts of droughts and can contribute to preventing land subsidence.

Other strategies include changing the operation of current water infrastructure based on the best available science. This includes changing timing and volume of reservoir releases to cope with future streamflow changes and to better mimic natural streamflow patterns to protect and recover aquatic and riverine ecosystems. More information about adaptation strategies can be found at the Governor's Office of Planning & Research (available on https://resilientca.org/apg/).

Energy security across the San Joaquin Valley can be increased by building new local energy grids for generation and storage, including solar energy infrastructure, making the current facilities and infrastructure more resilient, and planning for extreme weather and disaster events (for example, heatwaves and wildfires).

Using the best available science to inform the mitigation and adaptation strategies is essential for success. Including stakeholders who are affected by climate change, especially frontline communities, small and medium farmers, and the environment, can help develop better policies at the local level, leading to more robust solutions in the longer term and a more resilient San Joaquin Valley.

# Climate Change Impacts on San Joaquin Valley Ecosystems

Ecosystems of the San Joaquin Valley are among the most degraded and impacted by human development in California. The region was a fertile and humid land with ephemeral rivers and lakes more than one century ago, but agriculture, flood planning, and cities have taken over the San Joaquin Valley, losing 95% of the original wetlands (Garone, 2011). Climate change threatens ecosystem functions and services (Shaw et al., 2011), and its compounding effects along with human impacts make the San Joaquin Valley one of the most climate-vulnerable regions in California. The San Joaquin River (3rd longest in California) and the Kern River (10th longest) often run nearly or totally dry for several months during the lower-flow season due to numerous upstream diversions for beneficial use (Figure 12). The Tulare Lake basin surface flows from the Sierras were dried by dams and diversions about one century ago (Negrini et al., 2006). The vast conversion of wetlands and grasslands into farms and cities, coupled with the continuous alteration of aquatic ecosystems from damming, diking, and dredging, has created habitats that are marginalized, fragmented, and highly invaded by non-native species, bringing new challenging stressors for biophysical processes. In addition to phenological and environmental shifts, impacts from climate change will prevent such degraded ecosystems to fully fulfill important biophysical processes that provide essential ecosystem functions and services on which humans depend (Webb et al., 2017).

**FIGURE 12.**

Kern River dry crossing Bakersfield in the fall of 2021, and canal full of water (left side of the image). The Kern River is the 10th longest river in California, but in Bakersfield it is normally dry during the summer and fall months. Photo by Peter Szera.

Ecosystems degradation reduces carrying capacity by decreasing species persistence and overall biodiversity, and it may trigger ecological collapse in the San Joaquin Valley (Pecl et al., 2017; Webb et al., 2017). Surrounding forests are usually stressed by drought and pest-induced mortality, increased fire frequency and severity, and shifts in the hydrological cycle (Hurteau et al., 2014; Thorne et al., 2018). Grasslands may be vulnerable to changing fire frequency and extent, phenological shifts, pests, and biotic homogenization (Finch, 2012). Wetlands, many of which are already artificially maintained by management for waterfowl, will be subject to increasing water scarcity and diminished water quality. Freshwater ecosystems will continue to suffer from current water management activities, but they will be stressed by prolonged periods of drought, disastrous floods, and increased water temperatures (Moyle et al., 2013).

The San Joaquin Valley landscape is largely dominated by agriculture, leaving little area for native flora and fauna. Some remaining habitats for wildlife are protected by the Federal Endangered Species Act and the California Endangered Species Act. The state also has developed a State Wildlife Action Plan (CDFW 2015) to increase habitat and populations of listed species. However, the surface area of wildlife refuges is insufficient, and the region is dealing with novel ecosystems in rivers, with mixtures of native and non-native species in highly altered environments (Moyle et al., 2013).

## Terrestrial Ecosystems

Climate change projections predict higher air temperatures and a drier landscape in the San Joaquin Valley. Water scarcity will shape habitats and will be the determining factor for survival of many species, especially for those that rely on water resources throughout their life cycle. While higher atmospheric $CO_2$ concentrations will increase photosynthesis by improving water use efficiency, climate change will increase evapotranspiration at higher rates, leading to more water demand (Lovejoy, 2006). In the long-term, climate change will decrease California crop yields unless greenhouse gas emissions are impeded (Lee et al., 2011), or farming practices are adapted by adjusting crop types, irrigation, land use, and agronomic practices (Jackson et al., 2011; Suddick et al., 2010).

Climate change has agitated the evolution of many species and impacts the selection and inheritance of traits. Drought and other factors associated with climate change are particularly strong selective influences in arid regions. Shortened growing seasons in terrestrial ecosystems caused by drought lead to the earlier onset of flowering, and this flowering time is heritable (Franks et al., 2007). This has a major impact on migratory animals and pollinators (Kudo & Cooper, 2019).

### EFFECTS OF CLIMATE CHANGE ON SOILS

Any alteration in climate patterns can dramatically influence agricultural areas, particularly as they relate to soil. Arid regions such as the San Joaquin Valley are especially vulnerable to increases in soil salinity that can be favored by climate change conditions, for example by saltwater intrusion and in areas with shallower water tables (Corwin, 2021). Higher temperatures and $CO_2$ concentrations will heighten symptoms of drought including less soil moisture, snowpack, and streamflow (Lund et al., 2018). Continuous pesticide application will significantly reduce soil enzyme activity, which is an important indicator of soil health (Hussain et al., 2009). However, wetland restoration can create favorable conditions for carbon storage in soils: water depth, temperature, and pH are lower in areas with emerging vegetation, as opposed to submerged vegetation (Miller & Fujii, 2010).

#### GRASSLANDS AND RANGELANDS

Grasslands are found mostly around protected wetlands in the San Joaquin Valley, but rangelands also provide habitat for species adapted to grasslands. High meteorological variability linked to climate change conditions may affect productivity of plants growing in grasslands (Craine et al., 2012). However, the timing of extreme temperature and precipitation events plays a role in determining the extent to which production will be affected. Low productivity in plants results in food scarcity for herbivores living in these habitats, which affects animals in higher trophic levels. Thus, decreased plant production may drive declining animal populations (Huntly, 1991). Droughts reduce resource availability directly and drive population declines indirectly, adding declines associated with habitat loss (Butt et al., 2015).

Species found in rangelands and grasslands that burrow in the ground for shelter include endangered species such as the giant kangaroo rat (*Dipodomys ingens*) and the blunt-nosed leopard lizard (*Gambelia sila*), and vulnerable species such as the San Joaquin kit fox (*Vulpes macrotis*) and the burrowing owl (*Athene cunicularia*). Climate change is likely to increase the frequency of floods as a result from increased frequency and intensity of extreme precipitation events (Dettinger, 2011), and as higher temperatures drive earlier snowmelt and more precipitation falling as rain in the Sierra Nevada (Dettinger et al., 2004). Animals that burrow for shelter are susceptible to these floods as they may be caught in their burrows during the event and drown, although more research is needed to understand how floods would impact populations of these and other listed species.

Grasslands and rangelands are also at risk of agricultural and urban development, which is important for the flora and fauna that depend on these habitats and because these areas have the potential to be carbon sinks (Byrd et al., 2015).

### Freshwater Ecosystems

Climate change is increasing water temperature, which decreases the concentration of dissolved oxygen available and increases toxicity of pollutants (Ficke et al., 2007). North American freshwater environments are some of the most susceptible to climate change (Abell et al., 2000), and dramatic shifts in the Sacramento-San Joaquin Delta are apparent. California fish are especially vulnerable to climate change impacts, and the ability of native fish to adapt and recover from drought has changed (Mount et al., 2017). Changes in temperature, flows, and turbidity are impacting spawning times, reproductive success, and habitat suitability of native fish. The gross primary production of the freshwater ecosystems in the San Joaquin Valley is experiencing a rotation between warmer, less productive periods and cooler periods of high productivity. This suggests that there will be an overall decline in freshwater productivity associated with climate change (Rykaczewski & Dunne, 2010).

#### STILL WATER ECOSYSTEMS: WETLANDS AND RIPARIAN AREAS

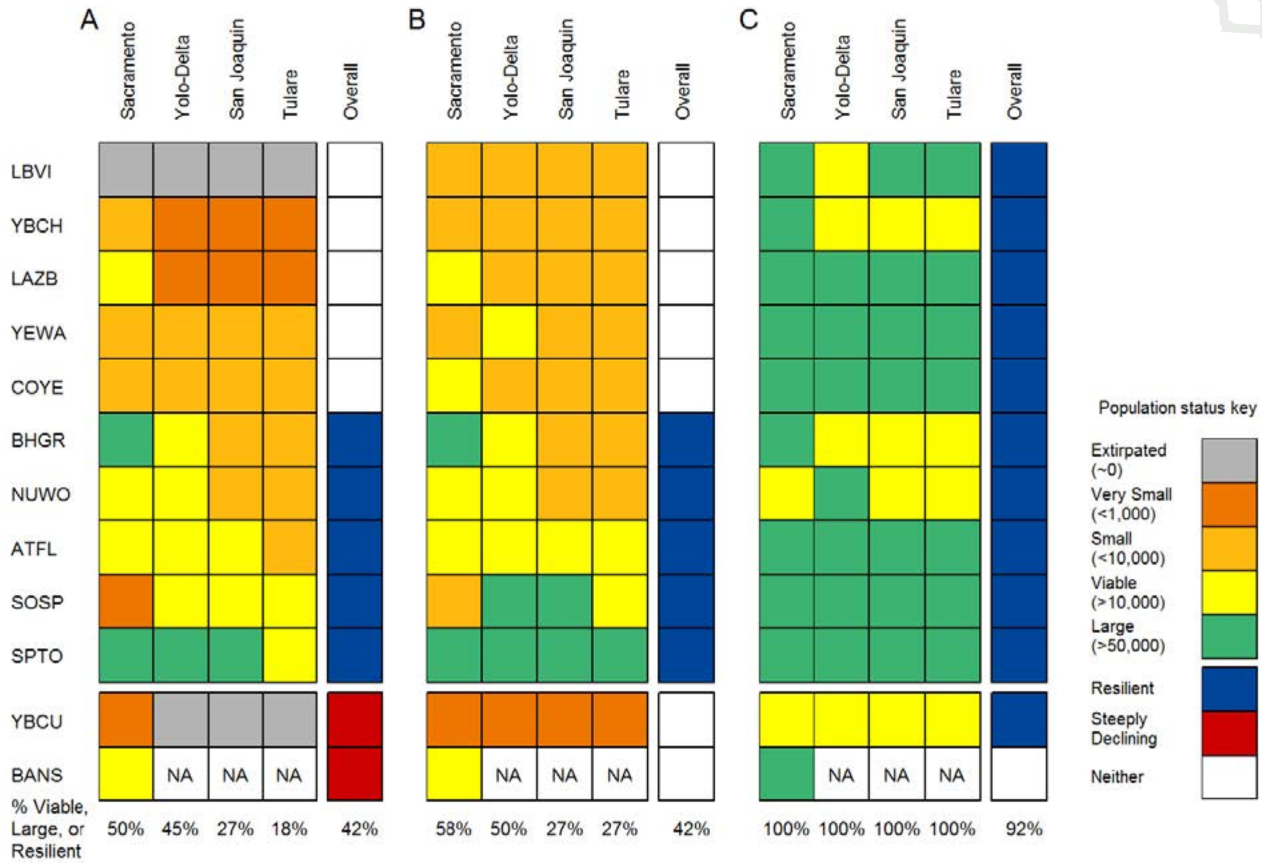
Wetlands and riparian areas in the San Joaquin Valley are largely degraded or have been completely developed for agriculture or urban use, and nearly 95% of wetlands have been permanently lost (Central Valley Joint Venture, 2006; Garone, 2011). Climate change is increasing evapotranspiration and drought frequency, affecting still water ecosystems that provide essential habitat for different local species and are necessary for migratory birds of the Pacific flyway (Reynolds et al., 2017).

Climate change projections predict that bird assemblages will change dramatically across California. Conservation efforts focusing on biodiversity will need to consider the potential for dramatically different communities and the potential impacts of those changes on ecosystem functions (Stralberg et al., 2009). Despite dramatic habitat loss, the Central Valley still hosts the highest concentration of overwintering waterfowl in the world. However, future droughts may lead to insufficient flooding and a decrease in food availability for waterfowl (Petrie et al., 2016), with potential declines in populations of overwintering birds. Waterfowl depend on flooded field crops like rice for habitat, and water programs that affect water usage for agriculture also affect bird habitat availability.

Riparian forests and vegetation areas around rivers and streams have also been lost to human development. Riparian forests are habitat for many different species as they are often cooler than the surrounding areas and serve as thermal refugia for animals during times of high heat (Seavy et al., 2009). Protecting and expanding riparian forests has the potential to mitigate climate change impacts. Levees to prevent natural flooding are affecting still water ecosystems, and proper ecosystem restoration may require moving levees or removing them entirely. Restoration of natural floodplains has the potential to increase ecological resilience to climate change and to lessen the impact of the flooding that is predicted in the future. Overall, floodplain restoration can lessen the impact of flood events as levees tend to increase flood stage and flow velocity (Gergel et al., 2002).

Management and proper restoration in the future will be crucial to the survival and health of these systems. In their natural state, riparian areas are resilient to climate change and have a high capacity for adaptation (Capon et al., 2013). Plants and animals in these systems have evolved to be resilient to highly variable conditions, including drought and temperature fluctuations, resulting in native plants and animals with the ability to adapt to rapidly changing conditions. Improper restoration may negatively impact the ability of these systems to adapt to climate change. Wetland habitats are being actively restored and managed. Proper restoration and management have the potential to boost bird populations (Figure 13), and thereby mitigate climate change impacts that would result in the loss of bird species. Restoration efforts can focus on wetlands that will support large populations of focal species (Dybala et al., 2017) and near rural disadvantaged communities with water insecurity.

**FIGURE 13.**




Evaluation of each regional focal species population for (A) current population status; (B) projected population status if short-term (10-year) habitat and density objectives are achieved; and (C) long-term (100-year) population objectives. Species codes (listed on the far left edge) are derived from common names; all are focal waterfowl species (Dybala et al., 2017). LBVI: Least Bell's Vireo; YBCH: Yellow-breasted Chat; LAZB: Lazuli Bunting; YEWA: Yellow Warbler; COYE: Common Yellowthroat; BHGR: Black-headed Grosbeak; NUWO: Nuttall's Woodpecker; ATFL: Ash-throated Flycatcher; SOSP: Song Sparrow; SPTO: Spotted Towhee; YBCU: Yellow-breasted Cuckoo; BANS: Bank Swallow.

### FLOWING WATER ECOSYSTEMS: SPRINGS, STREAMS, AND RIVERS

Warming associated to climate change in the San Joaquin Valley rivers is contributing to local species extinction and is facilitating the colonization by invading species (Cloern et al., 2011). Biodiversity decreases can result in a loss of higher consumers, which would cascade and affect the entire food web, affecting ecosystem stability. Biodiversity has direct benefits on water use (drinking water, domestic purposes, agriculture, and industry) and fisheries (fish consumption and economic value) (Cardinale et al., 2012). Negative climate change impacts are especially magnified for native fish, freshwater fish, and stream-dependent fish (Table 9). By contrast, alien fish species will thrive in altered aquatic conditions because they have less restricted environmental tolerances.

**TABLE 9.**

Impacts of climate change and management of San Joaquin Valley endangered fish. Climate change is changing freshwater availability and quality, and it is increasing sea water intrusion. Water scarcity poses a fundamental threat to fish and other animals, and changes in water quality can displace native species and facilitate the survival of invasive species. Correct management practices can mitigate and reverse the effect of climate change.

| SPECIES | IMPLICATIONS AND IMPACTS | RECOMMENDED MANAGEMENT |
|---|---|---|
| **WHITE STURGEON**<br>• (*Acipenser transmontanus*)<br>• Largest North American fish<br>• Prolific and of economic value in the 19th century<br>• Currently hardly present in the San Joaquin River<br>• Sensitive to many pollutants | • Warmer water decreases spawning potential and reproductive success, impairs ovarian development, and increases disease susceptibility.<br>• Seasonal shifts in precipitation and increased flood frequency may displace juvenile fish into estuarine areas before they are fully capable of surviving in brackish water. | • Limiting captures, harvest management with detailed fishing record, habitat improvement, hatchery use, and improved monitoring of non-point source pollution (Olswang, 2017). |
| **SACRAMENTO PERCH**<br>• (*Archoplites interruptus*)<br>• Not present in the San Joaquin River anymore<br>• Only present in a few Delta ponds | • Decreased water levels have led to temperature and alkalinity increases, reducing adequate perch habitat. Warmer water temperatures are linked to disease susceptibility. | • Conservation strategies must include management of genetic variability, implementing floodplain ponds, rearing facilities, reintroduction to suitable habitats, and monitoring all extant populations (Crain & Moyle, 2011). |
| **DELTA SMELT**<br>• (*Hypomesus transpacificus*)<br>• Indicator of Delta ecosystem health<br>• No longer found in the San Joaquin River<br>• Rare in the Delta (present only when moved there by water conveyance) | • Climate change will shift low salinity zones and increase water temperatures. Artificial alteration of freshwater flows to accommodate humans will impact habitat suitability for the Delta Smelt, especially during droughts. | • Controlling water exports and environmental flows in the Delta to maintain natural salinity and temperature. Regulating pesticide use. |
| **CALIFORNIA CHINOOK SALMON**<br>• (*Oncorhynchus tshawytscha*)<br>• All Chinook salmon varieties are state and/or federally threatened and are of high or critical concern as of 2017 (Moyle et al., 2017). | • Increased temperature, more variable upwelling, reduction and variability in precipitation, reduced snowfall and snowpack leading to lower baseflows, and increased river water temperatures will alter salmon's life cycle (Lindley et al., 2007). | • Keeping enough flow to maintain natural temperature cues may help the salmon to succeed in their reproductive cycle. |
| **RIFFLE SCULPIN**<br>• (*Cottus gulosus*)<br>• Cold-water obligate, increasingly rare | • Higher temperatures, lower dissolved oxygen levels, and more intermittent flows threat the necessary habitat for survival of the riffle sculpin in the San Joaquin Valley. | • Identification and conservation of cold-water refuges. More genetic studies to understand the different populations. |
| **CALIFORNIA ROACH**<br>• (*Hesperoleucus symmetricus*)<br>• Restricted in distribution, dependent on small, intermittent streams | • California roaches are susceptible to harsh environmental conditions, since they have restricted distribution dependent on small, intermittent streams. Increasing temperatures and larger peak flows impact negatively this native species. | • Each tributary in the Delta has its own distinct population, and monitoring those populations is important to ensure their health. Identification and reintroduction into suitable habitats could help in the conservation of this species. |

## Adaptation and mitigation strategies

Each habitat has its unique needs and problems that require efficient and effective management and conservation practices to maintain their native functional biodiversity. Current environmental policies are likely to create conflicting demands on species, habitats, and ecosystem processes. Climate change impacts are likely to reduce ecosystem services in this region unless there is direct intervention to protect highly functional ecosystems, restore ecosystem processes in key locations (for example, floodplains), and develop ecosystem-compatible human activities. With proper restoration and management, ecosystems in the San Joaquin Valley can increase resilience to climate change. Scientifically rigorous and supported conservation efforts prove crucial to the continued persistence of San Joaquin Valley species.

The San Joaquin Valley has insufficient wildlife refuges to support adequate species survival (Borders et al., 2011), and just a third of those refuges are managed. With so little habitat remaining, species living in these areas are especially sensitive to perturbations caused by climate change. Retiring agricultural lands strategically and reverting them to their native habitat can benefit ecosystems and farmers. When properly managed, wetlands can increase ecosystem resilience and mitigate some climate change impacts. For example, wetlands can be used for carbon sequestration, can store groundwater, and can help mitigate extreme weather events (ASWM, 2016).

Increasing resilience of the San Joaquin Valley ecosystems will likely increase natural adaptation to local and global climatic changes. Understanding the contribution of each ecosystem at the ecological and evolutionary level and across biological scales can help develop new, better climate change adaptation and mitigation strategies.

Better monitoring of the ecosystem's quality and functionality will lead to better planning for adaptation and mitigation strategies. Conducting ecological studies will address the direct effects of climate change on diverse species and the indirect effects on species and community interactions.

Adapting agricultural practices under an ecological frame may increase agricultural produce quality and revenue. Using natural predators for pests to reduce pesticide use, and holistic planned grazing to ensure land regeneration and plant populations will lead to more resilient ecosystems. Partnerships with agriculture can bring opportunities such as promoting green areas, wildlife corridors and refuges, and environmental buffers.

Strategically removing or relocating levees near riparian forests will help restore natural floodplains and mitigate the impacts of extreme climatic events, improving habitat and resource availability for native species adapted to naturally variable conditions. River ecosystems will benefit from enforcing management plans that include detailed harvest management records for endangered, invasive, and beneficial fish species. Funding long-term monitoring research using bioindicator responses to pollutants and habitat quality can help to better understand springs, streams, and rivers ecosystems.

Urban expansion exacerbates the effects of climate change, driving ecological and evolutionary changes in ecosystems. Mitigation strategies may include implementing urban buffer zones, creating green corridors, and abandoning roads to attenuate the frequency and intensity of human activity near sensory danger zones.

Promoting the hire of local researchers, resource managers, policymakers, advocates, and other professions from underrepresented minorities can contribute toward greater motivation to achieve solutions, more robust strategies, and more diverse perspectives. Conducting ecological and evolutionary studies under transdisciplinary frameworks that include monitoring of ecological impacts of climate change and land use can serve as well to address some of the inequitable socioeconomic patterns in the San Joaquin Valley. Using citizen science to monitor and maintain ecosystems can increase engagement of the population to protect the environment from the effects of climate change.

# Climate Change Impacts on the San Joaquin Valley Agriculture

## History of Agriculture in the San Joaquin Valley

The San Joaquin Valley is California's largest agricultural region and an important contributor to the food supply in the United States. Agriculture (farms and food industry) accounts for 25% of the Central Valley revenue, 16% of local employment, and 89% of annual net water use (Hanak et al., 2017). While the San Joaquin Valley has been cultivated by settlers for more than a century, agricultural production grew dramatically after the implementation of the Central Valley Project and the State Water Project (of which 30% of water is used for irrigation). Those large projects allowed the creation of much more irrigated farmland, converting wetlands and wildlife areas to agriculture. During the 2012-2016 drought, the total irrigated area in the San Joaquin Valley, was more than 5 million acres (more than 20,000 $km^2$), and open space and rangelands covered additional 3 million acres (12,000 $km^2$) (Hanak et al., 2019). The extensive area of grasslands and forage crops provides low-cost feed for dairy and beef production cattle. The state of California ranks first in milk production in the country (CDFA, 2020a), and the San Joaquin Valley has shown an expansion in the last decade to become the main dairy region in the state (Hanak et al., 2017). The history of the San Joaquin Valley, its economy, and its communities, have been traditionally linked to water and agriculture. The expansion of agriculture in the San Joaquin Valley because of more irrigation means employment opportunities for many immigrants (see *Case Study 3. Expansion of perennial tree crops in the San Joaquin Valley*, example from Kern County). However, farmworkers have fewer rights than most other professions, and rural unincorporated communities have been underserved since more than a century ago (Fernandez-Bou, Ortiz-Partida, Dobbin, et al., 2021). Assembly Bill 1066 (2016) is set to protect farmworkers and equate their rights by 2022 (see *Human Dimensions of Climate Change in the San Joaquin Valley*).

## Climate Change Impacts on Agriculture

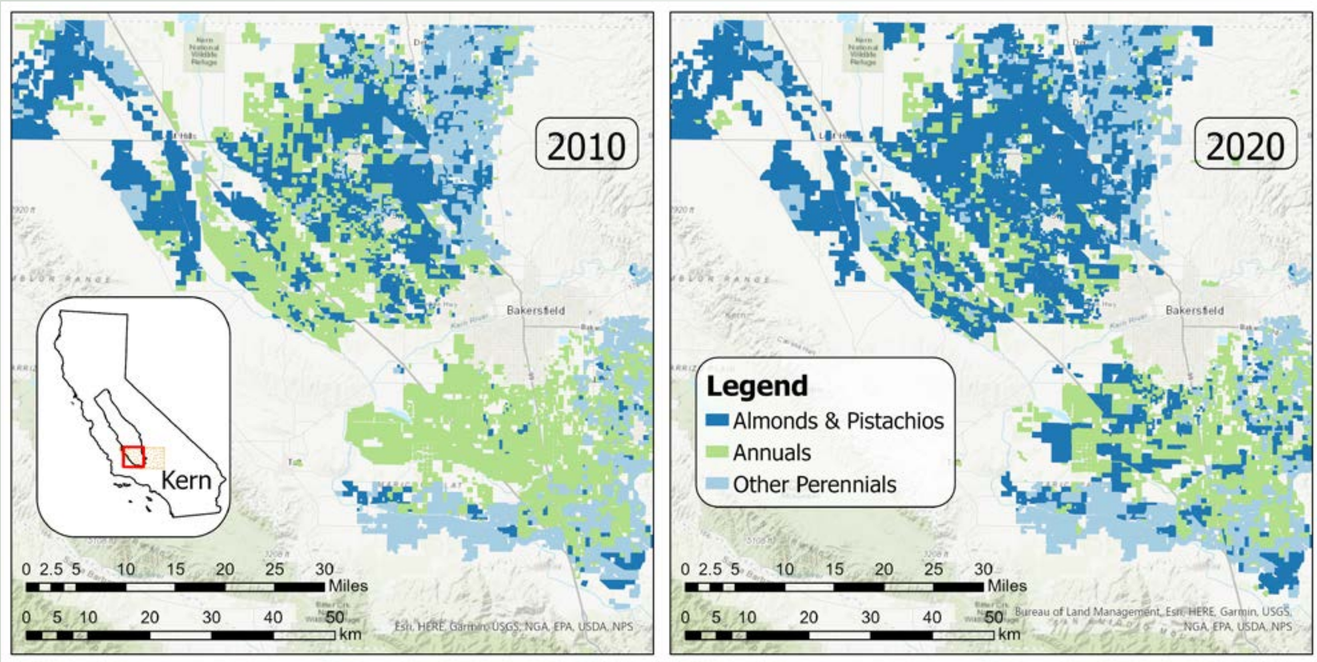
Climate change may deteriorate agronomic and environmental conditions to agricultural production, and it may impede maintaining some historically grown crops in the future. Direct impacts such as water shortage, a decrease in chill hours, and an increase in extreme heat waves, coupled with indirect impacts such as greater prevalence of crop pests and water scarcity, are expected to limit agricultural suitability for various crops. These impacts may also interact with commodity markets, labor force dynamics, and regulatory policies (including water allocation policies). Altogether, continuing agricultural productivity at the current growth levels is unlikely. Changes in gross crop revenues will occur along with changes in land use and water availability from surface or groundwater sources. Under the hydrologic scenarios predicted with the main global circulation models used for California (CanESM2, CNRMCM5, HadGEM2, and MIROC5 models), gross crop revenues are expected to decline roughly 3% (Medellín-Azuara et al., 2018). In addition, increases in the water requirement for dairy-related crops could affect the California dairy industry, resulting in a 22% long-term decline in quantity demanded.

Higher temperatures will decrease the snowpack and raise the snowline, decreasing one of the most important surface water reserves for agriculture, population, and ecosystems (see *Current climate and future climate projections*). Projections of dry and warm climate mostly point to declines in crop yields, increasing costs and ultimately decreasing crop profitability. Temperature changes will also affect environmental conditions for agriculture, such as changes in pollination, the spread of pests, and other stressors in crops. Adapting to climate change may require repurposing agricultural land, improvement of current technologies and automation, and increase sustainability in the use of agricultural inputs.

## CASE STUDY 3. Expansion of perennial tree crops in the San Joaquin Valley, example from Kern County

Kern is one of the most important counties in the United States in agricultural production value. Historically, farmers have made land use and crop decisions to adapt to water and economic conditions. The San Joaquin Valley produces many different commodities, including alfalfa, corn, grapes, tomatoes, vegetables and non-tree fruits, and citrus. However, the specialization towards higher-profit perennial tree crops has increased, particularly for almonds and pistachios, and other high-quality crops such as cotton have almost disappeared (Figure 14). In the San Joaquin Valley, the ratio of perennial crop area to total cropland has changed from 30% in 1990 to over 60% in 2019. This specialization has also positively impacted the food processing industry, employment, and economy of the region. The current crop mosaic and its trends present some challenges for coping with future climate conditions and droughts. Almond water demand is about 4 acre-feet per year and rather inflexible as almond trees do not tolerate water stress and soil salinity well. Other perennial tree crops also have high establishment cost and high variable costs, which increases the risk for farmers to experience water shortages (Mall & Herman, 2019), reductions in productivity, price volatility, and increasing cost.

### FIGURE 14.




Cropland use change in Kern County in 2010 (left) and in 2020 (right). The land area of almonds and pistachios increased by 51% from 267,000 acres to 403,000 acres (from 108,000 hectares to 163,000 hectares), while the land area of annual crops decreased by 27% from 497,000 acres to 365,000 acres (from 201,000 acres to 148,000 acres) and the land area of the rest of the crops decreased by 7% from 203,000 acres to 189,000 acres (from 82,000 hectares to 77,000 hectares). Source: adapted from HYPERLINK "http://www.kernag.com/gis/gis-data.asp" www.kernag.com/gis/gis-data.asp.

## Physical Effects

### CHILL HOURS

Chill hours (hours below 45 °F or 7 °C) are required for many of the most valuable orchards of the San Joaquin Valley to break dormancy during the winter, to synchronize blooming, to facilitate pollination, and to produce standard quality and quantity of the crops (see *Case Study 4. Insufficient chill hours for pistachios*).

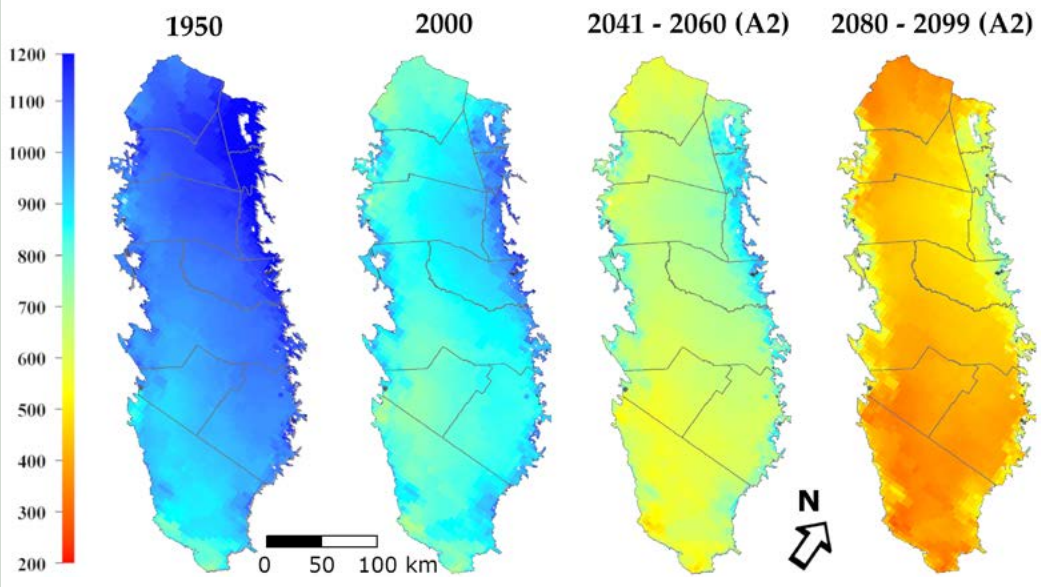
Climate change is decreasing the number of chill hours for crops, resulting in reduced tree yields, particularly affecting cultivars that require more chill hours, such as pistachios and walnuts, and decreasing locations suitable for cultivars. Walnuts are expected to decline in acreage most, since they are among the crops that require the highest number of chill hours per season in the San Joaquin Valley (Elloumi et al., 2013; Pathak et al., 2018).

### CASE STUDY 4. Insufficient chill hours for pistachios

Pistachios represent more than two billion dollars for the economy of the San Joaquín Valley and can endure higher water and soil salinity conditions than almonds. However, pistachios need from 800 to 1,000 chill hours per year (Kallsen, 2017). Many pistachio orchards located in southern San Joaquin Valley in saline soils may not reach enough chill hours to guarantee adequate productivity, and pistachios may need to shift north to regions where temperatures are cooler. Current pistachio farmlands may lose most of their profitability since they may not be used for other perennials such as almonds that need fewer chill hours but are more sensitive to saline soils (Figure 15).

Potential adaptation strategies include finding new pistachio varieties that require fewer chill hours, retiring land to save water, creating wildlife habitat, and planning aquifer recharge projects.

**FIGURE 15.**




Chill hours in the San Joaquin Valley of California in four time periods. While in 1950 the number of chill hours was enough for pistachios, in 2000 it was close to the threshold, and future climate projections show that pistachios may not be feasible in the San Joaquin Valley anymore. Adapted from Luedeling et al. (2009).

### HEAT EVENTS

Physical pressures by more frequent heat waves and wildfires in the San Joaquin Valley impact farmworkers and farm operations. Crop yield response to higher temperatures vary, but most crops experience decrease in photosynthesis, in pollen production, and in viability, and they undergo an increase in seed abortion (with fewer and lighter grains) (Siebert & Ewert, 2014). Heat waves are main concerns in San Joaquin Valley vulnerable communities without access to air conditioning, and they affect directly farmworkers and livestock operations (see *Case Study 2. Air Conditioning and Energy Demand*). Estimated heat load costs in California dairies have been over $118 million per year (St-Pierre et al., 2003). Farmworkers suffer and die from heat stress at much larger rates than any other industry (Jackson & Rosenberg, 2010; Luginbuhl et al., 2008). Future climate scenarios predicting more frequent heat waves highlight the need to better manage occupational heat stress in agricultural activities.

### INCREASED INTENSITY AND FREQUENCY OF DROUGHTS AND FLOODS

Projected increases in storm intensity and duration, as well as changes in the timing of runoff due to a larger part of the precipitation falling as rain and less falling as snow, will likely put additional stress on the San Joaquin Valley flood control infrastructure and will affect crops directly. Both floods and droughts can result in regional losses of crops and property, and they can stress the statewide water supply and flood systems (see *Climate change impacts to San Joaquin Valley water infrastructure*).

Regulatory pressures may lead to improve the water efficiency of irrigation systems by mid-century (Joyce et al., 2009). However, decreasing surface runoff and percolation may reduce groundwater recharge and the flushing of accumulated salts (Grafton et al., 2018). Irrigation efficiency programs to cope with extreme climate may benefit from a more holistic water accounting to avoid the unintended effects of decreased aquifer recharge and increased consumptive use.

### TULE FOG

The Tule fog is a unique phenomenon that can cover the whole Central Valley of California when certain temperatures and other atmospheric conditions occur after a rainfall event (see *Tule fog frequency is declining and likely impacting agriculture and air quality*). The fog has a relevant role to achieve the necessary dormancy that some fruit and nut trees require to improve their quality and production. However, the Tule fog frequency is decreasing due to climate change and to decreased particulate matter in the air. This reduction may impact the profitability of some orchards in the San Joaquin Valley (Duginski, 2020; Gray et al., 2019).

### $CO_2$ CONCENTRATIONS

Increasing $CO_2$ concentrations may have several effects on crop growth and development, affecting biological nitrogen fixation, photosynthesis, water use efficiency, and yield production. While projections show that $CO_2$ increases may also increase some crop yields (Cai et al., 2016), experiments in open-air field conditions indicate that $CO_2$ fertilization is not likely to offset projected losses due to higher temperature and lower soil moisture (Berntsen et al., 2006; Ewert et al., 2015; Long et al., 2006).

## Biological effects

Besides direct physiological effects of climate change, other indirect effects can affect agriculture, including biological pressures on crops. Insects and arachnids constantly undergo selective pressures from human activities (for example, chemical, noise, and light pollution) and adapt faster to climate change conditions by altering their behavioral patterns. This adaptability can have implications on ecosystem services such as pollination, and it can increase pest resistance because of low predation from natural predators sensitive to pollutants and species displacement due to habitat loss from increased land homogeneity.

### POLLINATION

In California, about half of the crops depend on pollinators, and the surface area of these pollinator-depending crops is increasing (Klein et al., 2007; Rader et al., 2013). Some specialty crops of the San Joaquin Valley that depend on pollinators include tomatoes, peppers, melon, squash, cotton, and almonds. Conservation and management of natural areas is key to keeping ecosystems fit for pollinators. Climate change effects on temperature, precipitation, and the increasing frequency of extreme events such as droughts can affect pollinators and their habitat. Those climate change-driven impacts include shifts in species spatial range, alterations in phenology and physiology, modifications in species interactions, and changes in diversity and resources (Laws et al., 2019).

Some on-farm strategies for adaptation to climate-related pollination stressors can include crop diversification, combined use of managed bees and native pollinators (integrated crop pollination), plant hedgerows, flower strips, polyculture to attract pollinators, and provision of nesting sites for native pollinators (CDFA & Agriculture, 2013).

The trend toward perennial tree crops increases the demand for pollinators which are mostly imported from other states in the country. During February when almonds are flowering, almost 90% of the beehives of the country are shipped to the Central Valley. Climate change-driven disasters such as wildfires and hurricanes in other regions of the country can affect beekeeping practices and the supply of hives to California.

### PEST SPREAD AND SURVIVAL

In the same way that a regional climate can shift in a direction less hospitable for a crop, regional climates can shift in a direction that is more hospitable for pathogens and pests (Elad & Pertot, 2014; Ziska et al., 2011). During the 2010's, droughts, insects, and disease have converged to cause widespread loss of mixed-conifer forests of the Sierra Nevada (Crockett & Westerling, 2018; Preisler et al., 2017). More generally, the expansion of pest species has larger negative impacts when warmer climate trends occur at higher latitudes (north and south) and at higher elevations (Parmesan, 2006). One of the mechanisms responsible of the pest success is the increased insect overwinter survival due to milder winter temperatures. Warmer temperatures also lead to additional insect reproduction (Bale et al., 2002).

The effect of elevated $CO_2$ concentrations on pest-crop interactions is mostly uncertain, as increased $CO_2$ concentrations can both increase and decrease the effectiveness of plant pest defenses or pest activity (CDFA & Agriculture, 2013).

Climatic pressures may necessitate the adoption of multiple pest control strategies, combining biological controls (predators) with chemical controls (pesticide), and crop cultivar choice into an integrated pest management system. When coupled with climate models, these interactions can be used to project future viability and variability of pests in the San Joaquin Valley. Higher temperatures will lead to an increase in insect reproduction for a variety of agricultural pests (Luedeling et al., 2011; Trumble & Butler, 2009; Ziter et al., 2012). For example, nut crops will suffer an increased impact from the navel orangeworm due to increasing temperatures that will favor a larger number of generations of this insect pest (Pathak et al., 2021). The impact of non-insect plant pathogens such as the microorganism responsible for root rot (Phytophthora cinnamomi) will be regulated by interactions with temperature and precipitation, in which warmer winters can improve pathogen survival rates, but drier conditions can limit its range of growth (Thompson et al., 2014).

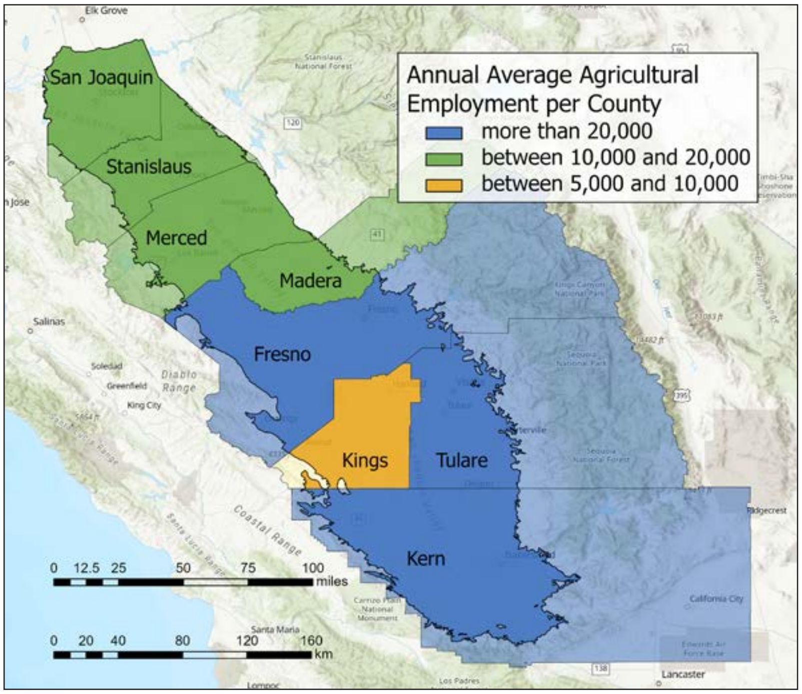
## Economic and Employment Effects

The total value of production in the San Joaquin Valley was $36 billion in 2019, which represents 72% of the total agricultural production value of California. The San Joaquin Valley alone generates more agricultural revenue than any other state of the United States, and more than the whole production of such countries as Canada, Germany, or Peru (CDFA, 2020b). The leading counties in value of production are Fresno and Kern, which also rank as the most important in the Country. The increasing trend of agricultural production is correlated with the expansion of almonds observed in past years. During 2014 and 2015, the driest years of the past drought, there was an estimate of $1.8 billion in losses due to fallow land, dairies and beef cattle, and increased pumping costs (Lund et al., 2018). Considering the spillover effects in the economy, total economic losses become $2.7 billion and 21,000 jobs. This trend is expected to increase under climate change-induced long, dry periods, and additional groundwater regulations may limit surface water replacement during droughts (Hanak et al., 2019) (see *Case Study 5. Sustainable Groundwater Management Act and Agriculture*). If the crops do not receive all the necessary water to maximize their production (known as stress irrigation) because of water scarcity, some additional costs may occur. However, some crops benefit in quality when they are stress irrigated (for example, olive trees and wine vineyards). Altogether, crop irrigation might be disincentivized by the increasing cost and the potential unavailability of water.

Agriculture in the San Joaquin Valley is the main source of employment (Figure 16) with an average of 204,000 workers in the last ten years (EDD, 2019). Kern, Tulare, and Fresno counties are the three main agricultural employers that mainly hire from labor contractors and crew leaders (Martin et al., 2017). The average annual wage of a farmworker is $43,613 in 2020. From all the population employed in agriculture, 45% of the farmworkers had more than one farm job in 2016 (Martin et al., 2019). Climate change may affect employment as frequency of extreme events increases, particularly droughts that promote land retirement and induce changes in crop decisions (see *Case Study 5. Sustainable Groundwater Management Act and Agriculture*). Changes in cropping patterns with climate change will have effects on labor demand for agriculture. Most valuable commodities including fruits, nuts, and vegetables concentrate roughly 85% of the labor and gross revenues in crop agriculture (Medellin-Azuara et al., 2015). Thus, employment effects from these shifts remain largely uncertain.

Nevertheless, employment impacts will affect mainly rural disadvantaged communities whose population depend directly on seasonal agricultural jobs with low wages, and the unemployment insurance rate has an average of 19% of the laid-off workers in 2016 (Martin et al., 2019). Other climate change effects that directly affect the health of farmworkers are the exposure to heat waves, high temperatures, and poor air quality (aggravated during wildfires) (Shonkoff et al., 2011). Hindered access to health insurance and the increase of health risks due to climate change also increase the inequity gap.

**FIGURE 16.**




Map of the San Joaquin Valley agricultural employment in 2019. Fresno, Tulare, and Kern (blue) have more than 20,000 agricultural employees; San Joaquin, Stanislaus, Merced, and Madera have between 10,000 and 20,000 agricultural employees; Kings has between 5,000 and 10,000 agricultural employees. The San Joaquin Valley is presented with darker colors. Source: adapted from data available at https://www.labormarketinfo.edd.ca.gov/data/ca-agriculture.html

## CASE STUDY 5. Sustainable Groundwater Management Act and Agriculture

The 2014 Sustainable Groundwater Management Act (SGMA) was in part a response to the effects of the 2012-2016 drought on California's groundwater resources. About 40% of the water used in California is groundwater, and aquifer overexploitation has been a major issue in the state for decades (Chappelle et al., 2017). By some estimates, historical overdraft in the San Joaquin Valley is 1.8 million acre-feet per year (2.22 $km^3$) in net use (Hanak et al. 2019). SGMA intends to achieve sustainable groundwater exploitation that prevents undesirable results that include lowering groundwater levels, reduction of storage, seawater intrusion, degraded water quality, land subsidence, and surface water depletion. The 2012-2016 drought exacerbated the longstanding groundwater overdraft and resulted in additional 5 million acre-feet (6.2 $km^3$) of increased pumping by some estimates (Howitt et al., 2015). SGMA requires that by 2040-2042 all groundwater basins achieve balance in recharge and extractions. Groundwater Sustainability Agencies (GSAs) are responsible for developing and implementing Groundwater Sustainability Plans (GSPs) so that sustainability is achieved by 2040-2042. The implications of SGMA in unsustainable agricultural practices may require that more than 535,000 acres of agricultural land (2,165 $km^2$) go out of production to address groundwater overdraft in the state (see *Strategic Agricultural Land Use Transitions*) (Hanak et al., 2019). These land-use changes could have mixed socioeconomic impacts on already vulnerable communities and small-scale farmers: land out of production impacts employment and farm gross revenues, yet sustainable groundwater levels may reduce the average economic costs on small farmers and disadvantaged communities with shallow wells during droughts. Repurposing agricultural land into multi-benefit projects can compensate the socioeconomic impacts of retiring agricultural land if it is strategically done (Fernandez-Bou, Ortiz-Partida, Classen-Rodriguez, et al., 2021). Despite the potential costs, SGMA presents an opportunity to reach groundwater sustainability and reduce inequities in the San Joaquin Valley.

## Adaptation and mitigation strategies

Agriculture has the potential to mitigate climate change by modernizing practices, including reducing the application of synthetic fertilizer, promoting land and soil conservation, and investing in solar electrification, and these implementations can benefit from economic incentives (Garnache et al., 2017). Ecosystem services in agriculture, particularly soil and above ground carbon sequestration, can be part of greenhouse gases mitigation strategies, especially for perennial tree crops (Williams et al., 2020) given the area devoted for these crops and their larger aboveground biomass. Old tree biomass may be transformed into biochar, which is an effective strategy to transform organic waste into chemical resistant black carbon to be sequestered in carbon for the long-term (Lehmann et al., 2006). However, it is essential to use adequate technologies to avoid emitting toxic particulate matter from poorly done pyrolysis. Additionally, range lands have opportunities to promote management of carbon sequestration (Byrd et al., 2015) since they are less prone to wildfires than forests and they are a common land use in the San Joaquin Valley.

Climate change adaptation to declining chill hours must depend on projections rather than historical records. Adaptation strategies to insufficient chill hours include breeding low-chill cultivars; defoliating trees after harvest to artificially induce dormancy, enabling temperate fruits in warm, dry regions (Luedeling, 2012); microclimate manipulation to enhance chill accumulation by shading during dormancy (Campoy et al., 2011); overhead irrigation to enhance chill accumulation by cooling off buds during the hottest days of the year (Erez, 1995).

Heat advisories that are currently issued to inform outdoor physical activity could also be integrated into farm heat protection systems. Space and heat abatement strategies may require modification in many California dry lot dairies. This may manifest as additional capital costs and operational costs (Tresoldi et al., 2017). Alternative livestock management systems may also enhance adaptation to extreme heat, such as agroforestry in pasture lands for shade, genetic selection, or modification of feeding strategies (Renaudeau et al., 2012; Rojas-Downing et al., 2017).

Adaptive responses to changing water supply include improvements in irrigation efficiency, adoption of new technologies, and shifts to less water-intensive and higher-value crops. While flood events pose a hazard for crops and property in certain areas, they can provide benefits through managed aquifer recharge (see *Case Study 6. Agricultural Managed Aquifer Recharge (Ag-MAR)*). This form of conjunctive use operation may reduce water shortages in dry years. Improvements in weather forecasts can help farmers and managers locate areas for managed aquifer recharge and can improve reservoir operations to allow for strategic capture of high-magnitude events. Groundwater recharge locations also add capacity to existing flood control infrastructure (Kocis & Dahlke, 2017).

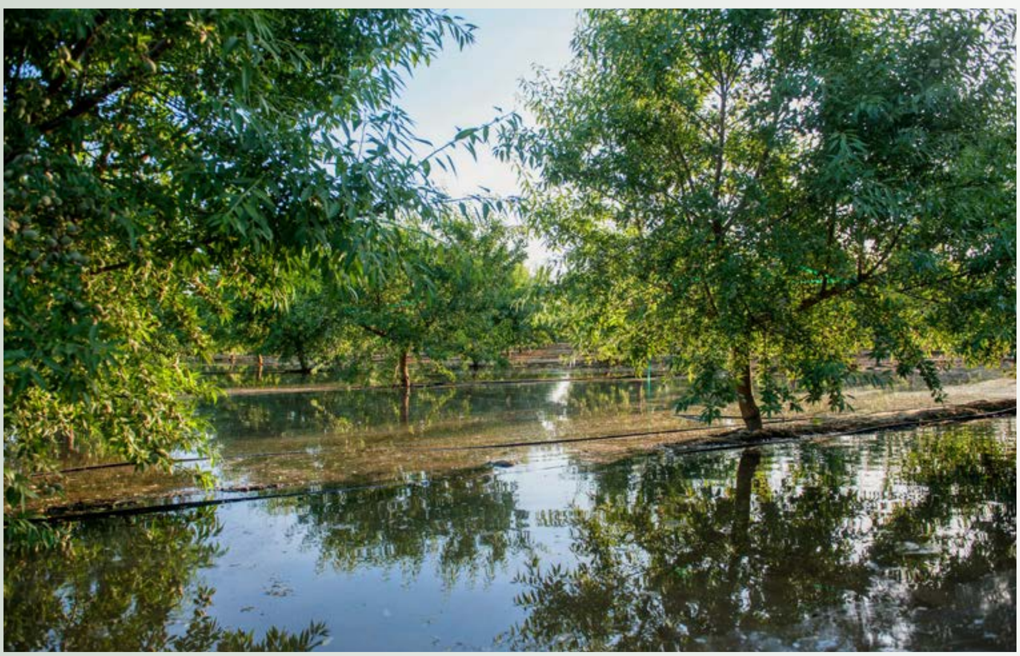
Farmers change their decisions to minimize climate change risk, and policymakers can support the strategies through economic incentives. These strategies need to account for multiple uncertainties related to climate change, water supply, and impacts on yields in the San Joaquin Valley (see *Case Study 7. Future for annual crops, perennial orchards, and livestock*). In-farm adaptation depends on the farmers' capacity and perception of risk to climate change (Byerly et al., 2018; Haden et al., 2012; Niles et al., 2013; Wagner & Niles, 2020).

## CASE STUDY 6. Agricultural Managed Aquifer Recharge (Ag-MAR)

Ag-MAR projects (Figure 17) manage excess surface water by directing it to agricultural fields to recharge underlying groundwater aquifers for later use (for example, during droughts). A few considerations for implementing Ag-MAR methods are regional soil properties, economic costs, water laws and permits, surface water availability, conveyance infrastructure, groundwater quality, and crop saturation tolerance (Dahlke, LaHue, et al., 2018). An on-farm flood capture study conducted on 1,000 acres of Terranova Ranch located in western Fresno County that grows tomatoes, alfalfa, wine grapes, and pistachios showed these crops were able to tolerate flooding and showed no significant yield penalties, especially for pistachios and alfalfa (Bachand et al., 2016; Dahlke, Brown, et al., 2018).

Flood flows, over 3,000 acre-feet (3.7 million $m^3$) of water, were diverted to the 1,000-acre (405 ha) study region from the Kings River – two weeks in January and then from April to early July. The study also found that at sustained infiltration rates of 2.5 inches per day (63 mm per day), 10-acres (4.1 ha) are needed to capture 1 cubic-foot per second (CFS) or 62.5 acre-feet per month (28.3 liter per second or 77,100 $m^3$ per month) of excess surface water. These findings highlight the potential for on-farm capture of excess surface water, especially during flooding, which have multiple benefits such as water for crop demands, direct recharge of aquifers, and flood risk management.

**FIGURE 17.**



Management of aquifer recharge project implemented in an almond orchard in Fresno County, especially during wet water years. Credit: Paolo Vescia and Sustainable Conservation (https://suscon.org/project/groundwater-recharge).

## crops, perennial orchards, and livestock

**CROPS**

| CHALLENGES | CLIMATE CHANGE PRESSURES | PROMISING ADAPTATIONS |
|---|---|---|
| • Hardening of demand through shifts from annual crops to perennial tree fruit and nuts (Mall & Herman, 2019).<br>• Severe and chronic groundwater dependence and overdraft.<br>• Challenges exercising demand management through fallowing due to reliance on voluntary, profit driven programs (Howitt et al., 2015).<br>• Labor shortages, particularly for harvesting labor intensive crops.<br>• Natural pollinator shortages.<br>• Soil degradation. | • Increasing uncertainty in water availability and in snow-driven hydrologic processes.<br>• Increases in evapotranspiration.<br>• Sensitivity to temperature and $CO_2$ concentrations for biomass addition (Pathak et al., 2018).<br>• Reduction in chill hours, particularly in tree fruits and nuts (Luedeling et al., 2009).<br>• Reduction in Delta exports to maintain salinity line.<br>• Fallowing is voluntary and poorly coordinated.<br>• Occupational hazards from heat stress (Jackson & Rosenberg, 2010).<br>• Changing pest and disease vectors. | • Groundwater banking and flood managed aquifer recharge may provide storage for interannual shifts in groundwater levels.<br>• Low chill-dependent strains, irrigation for cooling, defoliation practices (Luedeling, 2012).<br>• Fallowing and other demand management strategies coordinated or mandated through Groundwater Sustainability Agencies.<br>• Carbon sequestration market can reduce greenhouse gases emissions, free up water demand, and support small and minority farmers if it is correctly planned.<br>• Crop diversification can help support pollinator populations. |

**DAIRY**

| CHALLENGES | CLIMATE CHANGE PRESSURES | PROMISING ADAPTATIONS |
|---|---|---|
| • High concentration of cows.<br>• Smell near rural communities.<br>• High methane emissions.<br>• Nitrate contamination.<br>• Economic and logistic barriers to importing high moisture feeds; requires local feed production.<br>• Shifting crop portfolio towards high value perennials drives competition for land and water.<br>• High relative costs of feed as an input to production system. | • Relationship with crop production for supporting dairies passes challenges onto the dairy industry; competition for land and water resources will continue to increase as climate change exacerbates current resource challenges.<br>• Heat increases and air quality impacts from wildfires may reduce dairy yield and more cows may perish from heatstroke. | • Shifts towards less resource-demanding feed crops.<br>• Exercising options for importing low-moisture feed across state and national borders.<br>• Overhead water-cooling systems and genetic selection can combat heat stress (Tresoldi et al., 2017). |

**BEEF**

| CHALLENGES | CLIMATE CHANGE PRESSURES | PROMISING ADAPTATIONS |
|---|---|---|
| • Shifting to other states with cheap and abundant grazing land (Polansek, 2014).<br>• Environmental justice issues in locating feedlots, which are highly polluting for air and water (Chamanara et al., 2021). | • Growing wildfire frequency and intensity may threaten grazing land. | • Capitalization on expanding grazeland to combat land competition.<br>• Shifting snowline under climate change may make more rangeland available for grazing cattle (Medellín-Azuara et al., 2018). |

### "CLIMATE-SMART" AGRICULTURE

"Climate-smart" agriculture is a term introduced by the Food and Agriculture Organization of the United Nations to describe agricultural techniques which sustainably increase agricultural productivity, are resilient to the impacts of climate change, and contribute to climate change mitigation where possible. This framework is feasible in California as an adaptation and mitigation strategy (Medellín-Azuara et al., 2018). A variety of programs exist to support the resilience of California agriculture under different future climatic, economic, or regulatory scenarios. The regional USDA climate hubs work to connect climate research to agricultural producers, creating opportunities for the co-production of knowledge, tools, and products. For example, the Southwest Regional Climate Hub sponsored an assessment of "Climate Change Vulnerability and Adaptation and Mitigation Strategies" that examined regional issues for specialty crops, livestock systems, and forest systems among others (Kerr et al., 2016). The State Water Efficiency Enhancement Program (SWEEP) from the California Department of Food and Agriculture is one approach for encouraging climate-smart adaptations, by providing financial assistance for the implementation of more efficient irrigation systems that can save water and reduce greenhouse gas emissions. Long-term agricultural experiments, such as the Century Experiment at the Russell Ranch Sustainable Agriculture Facility (RRSAF) currently test crop systems and management practices, and their relation to resource use and soil health (Wolf et al., 2017). Conservation agriculture may also improve farm operation resilience by increasing soil water storage (by retaining soil organic matter) or decreasing the labor and fuel costs of tilling operations (Mitchell et al., 2016).

### LOGISTICS, TRANSPORTATION, AND ELECTRIFICATION OF MACHINERY

Yield improvement and labor efficiency are among the many motivations driving the trend toward increasingly automated and data-driven agricultural practices. Among these improvements, there are opportunities for reducing carbon emissions, both to meet global targets and to improve local environmental conditions, which help mitigate some of the environmental health pressures from climate change.

In a 2020 summary of carbon emission trends by the California Air Resources Board, agricultural operations were identified as accounting for 8% of 2018 greenhouse gases emissions in California (ARB, 2020). Of this 8%, 75% of the greenhouse gas emissions were related to livestock and manure management, and the remaining 25% was related to crop production activities, including fuel combustion for on-farm purposes. The electrification of farm machinery including tractors and pumps may contribute to greenhouse gases reductions as well, especially if located near energy generation or other supporting infrastructure. Heating and cooling of warehouses and production operations may also take advantage of renewable energy sources, and production activities can be timed to take advantage of surplus energy generation from renewable energy sources.

Regulatory changes related to the state's carbon-neutrality goals may present a challenge for small transportation companies unless the planning is well done. An example of a well-planned regulation is the 2020 Advanced Clean Trucks regulation, which establishes variable targets for zero-emission vehicles (ZEV) in commercial truck sales with a goal of 60% zero-emission vehicles sales for some truck classes by 2045.

## FARM-SCALE NON-TRANSPORTATION EMISSIONS

Certain conservation methods in agriculture bring savings in both resource use and carbon emissions. While compost operations are a source of methane emissions (much less if aerobic conditions are promoted during the composting process), compost applications can enhance soil carbon sequestration for many years after initial application. However, the effectiveness of carbon sequestration may decrease in warmer climate scenarios (Silver et al., 2018). Increases in soil organic carbon due to compost amendments also produce hydrologic benefits and increase water-retention in soils.

"Carbon farming" refers to agricultural techniques that improve atmospheric $CO_2$ removal and conversion to biomass or soil organic matter. Carbon farming plans can be incorporated into carbon markets, producing economic benefits to the grower while allowing the state to meet emission goals (Flint et al., 2018).

# Human Dimensions of Climate Change in the San Joaquin Valley

The San Joaquin Valley has some of the lowest environmental quality and socioeconomic conditions statewide (OEHHA, 2017). The region hosts a much higher proportion of disadvantaged communities than the rest of California, as 55% of the population in the San Joaquin Valley lives in 413 census tracts classified as disadvantaged. Poverty, unemployment, and health and environmental burdens are common traits of the San Joaquin Valley disadvantaged communities. Rural disadvantaged communities often do not have some fundamental infrastructure, such as access to safe drinking water, sewage, green areas, grocery stores, sidewalks, public electrification, education facilities, and health services. This lack of essential services and public infrastructure makes these communities more vulnerable to climate change (Fernandez-Bou, Ortiz-Partida, Classen-Rodriguez, et al., 2021). Hundreds of thousands of people do not have water security, and most inhabitants suffer from chronic exposure to one of the nation's poorest air qualities. Heat stroke, valley fever, and conditions related to poor air and water quality are common illnesses and health hazards in the San Joaquin Valley. The region relies on agriculture as its main economic driver while hosting some of the fastest growing cities in California. Many households in vulnerable communities depend almost exclusively on agricultural employment as their main source of income. However, some agricultural practices compromise air and water quality of surrounding rural communities.

Extreme climate-related effects are already exacerbating the outstanding public and environmental health issues in the San Joaquin Valley, increasing temperature-related deaths and illness, drought and flood-related spread of disease, and worsening air quality. Climate change is likely to disrupt urban water supplies, induce energy shortages, and compromise transportation services in urban centers (Díaz et al., 2017). Heat stress on roads, bridges, and transmission lines will likely become chronic, degrading infrastructure more quickly and making it more vulnerable to failure from extreme events. These extreme events, such as torrential rainfall that overwhelms storm drains and wastewater treatment facilities, are likely to increase in frequency (Huang et al., 2018; Williams et al., 2019) (see *Climate change impacts to San Joaquin Valley water infrastructure*). For both chronic stress and acute events, loss of function in infrastructure will have indirect impacts on communities through disruption of health and safety of residents, as well as increasing the financial burden on governments and supporting utilities. Even without direct failure of infrastructure, changes to supporting ecosystem services in response to climate warming are likely to reduce the reliability and quality of water resources. For example, increased fire severity in forested watersheds will result in higher sediment delivery to streams, which in turn limits the longevity of receiving reservoirs and increases the operational cost of water treatment facilities. These environmental and infrastructural stresses will further pressure San Joaquin Valley communities, which are already exposed to higher public and environmental health hazards compared to the rest of California. Disadvantaged community members will be less able to cope with additional stresses from direct impacts of climate change, such as exposure to extreme heat events, and from indirect impacts, such as increased financial cost from cooling demands.

This section provides an overview of the San Joaquin Valley communities and human dimensions of climate change impacts, including some of the current and future impacts of climate extremes on human health and security.

## San Joaquin Valley and Climate Justice

The Climate Justice framework identifies disadvantaged communities as "frontline communities" that result from legacies of racism, injustice, and disinvestment (Eissinger, 2017; OEHHA, 2018; Pannu, 2012). Climate Justice demands leadership to ensure that the most vulnerable communities are not disproportionately affected by climate change impacts (Climate Justice Working Group, 2017). The Environmental Protection Agency identifies socially vulnerable groups to climate extremes such as low income, minorities, with no high school diploma, and over 65 years of age (EPA, 2021). The recommendations of the Climate Justice Working Group for the 2018 California's Climate Change Adaptation Strategy call for greater inclusion of vulnerable communities in planning and implementing processes (CNRA, 2018). The climate crisis and current injustice in the San Joaquin Valley is intensifying the compound effects of the critical environmental and socioeconomic issues experienced by the majority of residents.

Communities in the San Joaquin Valley have experienced water inequities for decades. An attempt to reduce such inequities was the California's Human Right to Water bill, enacted in 2012 (Assembly Bill 685). It established that "…every human being has the right to safe, clean, affordable, and accessible water adequate for human consumption, cooking, and sanitary purposes." In order to define and assess the status of water security and other vulnerabilities, the California's Office of Environmental Health Hazard Assessment (OEHHA) developed an analytical tool that uses 20 indicators. Three of those indicators are directly related to water quality, accessibility, and affordability to measure and score water systems throughout California (Balazs et al., 2021).

Despite AB 685, there are about one million people without reliable access to safe drinking water in the state (The Poynter Institute, 2019), and about 100,000 of them live in disadvantaged communities of the San Joaquin Valley (London et al., 2018). The COVID-19 pandemic brought to light more inequities, as people lost their jobs and sources of income, and farmworkers had to risk their health to continue working as essential workers without adequate personal protection equipment (Vela, 2021). Those who rely on bottled water for everyday use faced difficulties to access it since there was greater demand by people without such necessity at the start of the pandemic. With many people unable to work, debts on water utility bills grew, particularly in lower-income Black and Brown communities (Vaughan, 2021; Walton, 2021).

## San Joaquin Valley Community Characteristics

### REGIONAL DEMOGRAPHICS

The San Joaquin Valley has a population of around 4.3 million, with some of the fastest growing counties and an overall population density of 248.8 people per square mile as of 2009 (96 people per $km^2$), but it varies from 71.7 people per square mile in Madera County to 487.4 people per square mile in San Joaquin County. As a largely agricultural area, agricultural employment represents about 16% of all employment, which is a much larger proportion compared with the 2% that it represents for the whole state of California (Jones et al., 2017). While agriculture is a major economic force in the region, oil and gas extraction, transportation, and health services are other major employers. Although agriculture revenues continue to grow, farm labor compensation has remained low for many years and 24% of the population in the San Joaquin Valley is living below the federal poverty line compared to 16% of the rest of California (Avalos, 2010; Hanak et al., 2017; Jones et al., 2017). The unemployment rate in the San Joaquin Valley is at least three percentage points greater than the rest of California (historical employment data available at https://data.edd.ca.gov/). Many migrant workers lacking formal education or career preparation are drawn by low-income and agricultural employment opportunities in the San Joaquin Valley. Consequently, the Latino population is much higher in the San Joaquin Valley at 51% compared to 38% for the state as a whole.

### Urban Communities

There are 62 cities in the San Joaquin Valley, including Fresno, Bakersfield, and Modesto. The urban population reached 3.5 million in 2010, accounting for 89% of the total population (United States Census Bureau). Urban communities in the San Joaquin Valley have large and growing populations that are vulnerable to climate change impacts. For example, urban heat island effects will become more severe with projected increasing temperature in the San Joaquin Valley, especially in areas with less tree canopy and larger areas of impervious surfaces (for example, asphalt, pavement, or concrete). Urban infrastructures are vulnerable to disruptions, especially in many cities with aging infrastructures in need of renovation (see *Case Study 8. City of Madera*). Disabled, socially isolated, homeless, and those who lack access to cooling facilities are more vulnerable (Ganesh & Smith, 2018).

### CASE STUDY 8. City of Madera

Hundreds of California cities and counties have adopted Climate Action Plans (CAPs), which detail climate change adaptation and mitigation efforts in support of the State's greenhouse gas reduction targets. For example, the City of Madera adopted its CAP in September 2015. The CAP calls for changes to Madera's General Plan, including increasing groundwater recharge, encouraging water conservation and use of reclaimed water, adding climate change impacts to utility master plans and service delivery plans, and prohibiting developments that do not compensate for added demands on public infrastructure and services.

### RURAL COMMUNITIES

Around 96% of the land in the San Joaquin Valley is rural (see *Case Study 9. Disadvantaged and minority farmers lack resources and access to information about new regulations*), while only about 11% of the population lives in rural areas (United States Census Bureau). Many residents in rural communities in the San Joaquin Valley are low-income and Latino who work in the agriculture sector and often live in unincorporated disadvantaged communities (Flegel et al., 2013; London et al., 2018). Agricultural workers in the San Joaquin Valley have the worst health conditions compared with other labor groups due to prolonged exposure to intense heat which is projected to increase. Smoke from wildfires is another major risk exacerbated by climate change that also negatively impacts air quality. Limited communication and transportation infrastructure in rural areas create problems for emergency response systems. In addition, rural populations have limited access to health care facilities.

## CASE STUDY 9. Disadvantaged and minority farmers lack resources and access to information about new regulations

California's labor-intensive and seasonal agricultural sector (Martin, 2002) relies on about 450,000 workers, and the vast majority are Latinos (data available on www.edd.ca.gov). While farmworkers have more income in California than in other states, they face poor health (Alderete et al., 2000; Xiao et al., 2013), economic hardship (Pulgar et al., 2016), and poor air and drinking water quality (London et al., 2018).

Few Latino farmworkers are able to purchase or lease land to start their own farm. Latinos own about 3% of the farms in the United States (USDA, 2017) and there are 14,000 Latino farmers in California (UC ANR, 2019). One of the challenges that Latino small-scale farmers face is keeping up with large-scale operations that implement mechanization and land consolidation, which makes it difficult for small-scale farmers to acquire land and capital (Danish, 2019). Conversations and interviews with Latino, small-scale, and other minority farmers in the San Joaquin Valley reveal another critical issue that involves inequity in dissemination of information (both in language availability and media distribution) regarding new regulations that impact their farming operations.

The Sustainable Groundwater Management Act (SGMA) of 2014 highlights the need to address the knowledge equity gap that has persisted in the state for decades. Groundwater Sustainability Agencies (GSAs) are tasked with making decisions on water use, water prices, and land-use transitions with the aim to address groundwater overdraft (see *Case Study 5. Sustainable Groundwater Management Act and Agriculture*), all of which impact the future and livelihood of small- and large-scale agricultural production. GSAs consist of interested parties and require members to sign up for email notifications or post meeting notices online, which may limit the reach to Latino and small-scale farmers who may have limited access to broadband, or prefer in-person or mail-in methods for receiving information. Much of the information related to SGMA and other land-use policies in the state are not available for monolingual populations that make up the region, like Spanish and Hmong. Recently, the Department of Water Resources began providing GSAs with written translation in various languages (water.ca.gov/Programs/Groundwater-Management/Assistance-and-Engagement), and they have created two short videos (in Spanish: youtu.be/A4jNAgS_yXQ and in English: youtu.be/JpvTslYuS4Y) describing groundwater. Scientists have also started developing resources to better inform underserved communities (for example, CaliWaterAg has resources available in English, Spanish, and Hmong https://www.youtube.com/channel/UCym_U7oaloj9dW9EM7s5NQw). However, underrepresented stakeholders can benefit if state agencies and local GSAs provide translation services available during in-person meetings and dedicated phone numbers for monolingual speakers (for example, Spanish and Hmong).

### TRIBAL COMMUNITIES

The San Joaquin Valley is home to several cultural communities: Northern Valley Yokuts, Southern Valley Yokuts, Foothill Yokuts, Tubatulabals, Kitanemuk, Western Mono, and Miwok. Currently, there are ten federally recognized tribes and at least eleven federally non-recognized tribal nations (some tribes are seeking federal acknowledgment) with an estimated population of 3,833 inhabitants in 2016 according to the United States Census Bureau (Table 10 and Figure 18).

**TABLE 10.**

Tribes of the San Joaquin Valley region

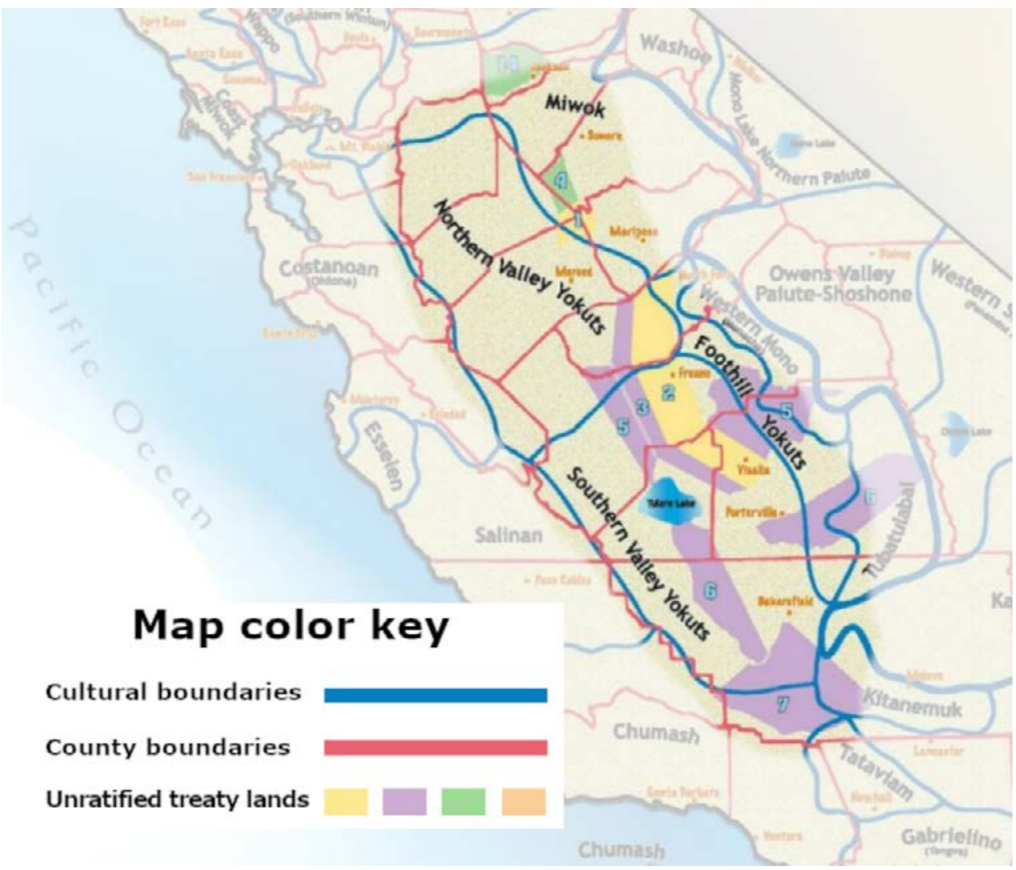
| FEDERALLY RECOGNIZED TRIBE | COUNTY | MEMBERS | LAND TRUST |
|---|---|---|---|
| Tule River Reservation | Tulare | 1,800 | ~48,000 acres |
| Table Mountain Rancheria | Fresno | 34 | 61 acres |
| Big Sandy Rancheria of Western Mono Indians | Fresno | * | 280 acres |
| Cold Springs Rancheria of Mono Indians | Fresno | 184 | 155 acres |
| Picayune Rancheria of Chukansi Indians | Fresno | 1200 | Some land restored |
| Dunlap Band of Mono Indians | Fresno | * | * |
| North Fork Rancheria of Mono Indians | Madera | 2,000 | 80 acres |
| Santa Rosa Rancheria | Kings | 200 | 170 acres |
| Tejon Indian Tribe | Kern | 1,111 | * |
| California Miwok Tribe | San Joaquin | * | * |

| FEDERALLY NON-RECOGNIZED TRIBE | COUNTY | MEMBERS | LAND TRUST |
|---|---|---|---|
| Strathmore Rancheria | Tulare | * | * |
| Squaw Valley Rancheria | Fresno | * | * |
| Dumna Wo-Wah Tribal Government | Fresno | * | * |
| Kings River Choinumni Farm Tribe | Fresno | * | * |
| Traditional Choinumni Tribe | Fresno | * | * |
| Wuksachi Indian Tribe | Fresno | * | * |
| Millerton Rancheria of the Dumna Tribe | Kings | * | * |
| Tubatulabals of Kern Valley | Kern | * | * |
| Chumash Council of Bakersfield | Kern | * | * |
| Kern Valley Indian Community | Kern | 1,200 | * |
| Kitanemuk & Yowlumne Tejon Indians | Kern | * | * |

Source: Native American Heritage Commission http://nahc.ca.gov/ and TKFA tularelakebasin.com/alliance/tulare-kern-dac-involvement/dac-education-and-engagement-page/tkfa-tribal-engagement/. Some tribes may be missing, and status may have changed. *data unavailable.

Tribes in the San Joaquin Valley are vulnerable to climate change impacts because of historical displacement, loss of territory, and restricted access to resources (see *Case Study 11. San Joaquin Valley Tribal lands and climate change*). Many tribes seek federal acknowledgement in order to claim land and resources held in trust by the federal government (see *Case Study 10. Water Rights and Tule River Indian Reservation*). Some federally recognized tribes have established casinos to provide essential services such as housing and employment. However, the criteria used to identify vulnerable groups can overlook tribes, leading to exclusion in state policy, planning, and support for some tribes more at risk to climate change impacts.

**FIGURE 18.**




Indian cultural areas and unratified treaty lands in the San Joaquin Valley. The San Joaquin Valley is the ancestral land of the Yokuts and Miwok peoples. Source: adapted from https://calindianhistory.org/california-unratified-treaties-map

## CASE STUDY 10. Water Rights and Tule River Indian Reservation

The Tule River Reservation has been located in the foothills of the Southern Sierra Nevada since 1873 after being forcibly relocated from productive valley land bisected by the main tributary of the Tule River. The tribe lost this land due to fraudulent means and was moved to its current location in mountainous, arid land inhospitable to agriculture (NARF, 2013). The reservation relies on surface water of the South Fork of the Tule River and groundwater, but lacks reliable water access, especially as the frequency and intensity of drought increases with climate change. In dry periods, tribal members must haul water from the river to their homes. The tribe also requires reliable water access to support its firefighting efforts in this region susceptible to wildfire. Without secure water rights or water access, the tribe cannot thrive as a growing community (https://tulerivertribe-nsn.gov/).

The lack of government initiatives to restore adequate land and water resources has caused severe economic injury. Under the Winters Doctrine, the Tule River Tribe claimed their federally reserved water right and damages of 512 million dollars against the U.S government. Winters rights supersede non-Indian water rights in priority and cannot be forfeited for non-use (Sanchez et al., 2020). In 2007, after nine years of litigation, the settlement agreement issued 5,828 acre-feet per year (7.2 million $m^3$ per year) of water and the US government responsibility to pay for the development and construction of a reservoir, conveyance, and a water treatment facility (NARF, 2013).

## CASE STUDY 11. San Joaquin Valley Tribal lands and climate change

The Indian tribes of San Joaquin Valley, along with other California tribes, lost most of their ancestral lands due to the United States Senate's refusal to ratify treaties in 1852 that the US Senate itself had already authorized. These treaties allotted the tribes large tracts of land for permanent occupation. The land treaties encompassed much of current day Southern San Joaquin Valley area (Figure 18). Since the US Senate had authorized the treaties, many tribal members relocated to these new lands. When the US Senate refused to ratify the treaties and subsequent lawsuits disfavored the tribal side, many tribal members were left homeless, starving, and hunted by militia and vigilante groups. They were indentured, enslaved, kidnapped, and killed (Johnston-Dodds & Burton, 2002). The malfeasance and genocide of the California Indians reduced their population by 85% between 1850 and 1890 (Goldberg & Duane, 2002).

Knowledge about the unratified treaties was withheld from the American public until 1905 causing a large public outcry. In response, the US government established small reservations or Rancherias for landless Indians. In the 1950's, the Rancheria Act passed by the California government sought, without consent, to sever federal support by terminating most Rancherias causing further economic hardship. In the San Joaquin Valley, the displacement and impoverishment of Indians has led the tribes to seek out restoration of Rancheria land rights and to seek federal recognition to regain sovereignty and property rights. Without federal recognition, tribes have limited access to government support and aid. In the San Joaquin Valley, there are nine Rancherias and one reservation: all federally recognized tribes. There are at least 11 federally unrecognized tribes. Many of these tribal lands are small and have limited land resources (most under a few hundred acres). To offset this limitation, some tribes established casinos to generate revenue in the hope of improving their living conditions. An exception is the Tule River Reservation that has several thousand acres but continues to be severely disadvantaged and lacks access to reliable water resources.

**CASE STUDY 11.** ***continued***

Climate change has added another layer to the difficulties of tribes by contributing to the decline of the San Joaquin Valley native ecology, reducing tribes' access their ancestral cultural and natural resources (for example, wild fish for consumption and reeds used for basket weaving) (Anderson, 2013).

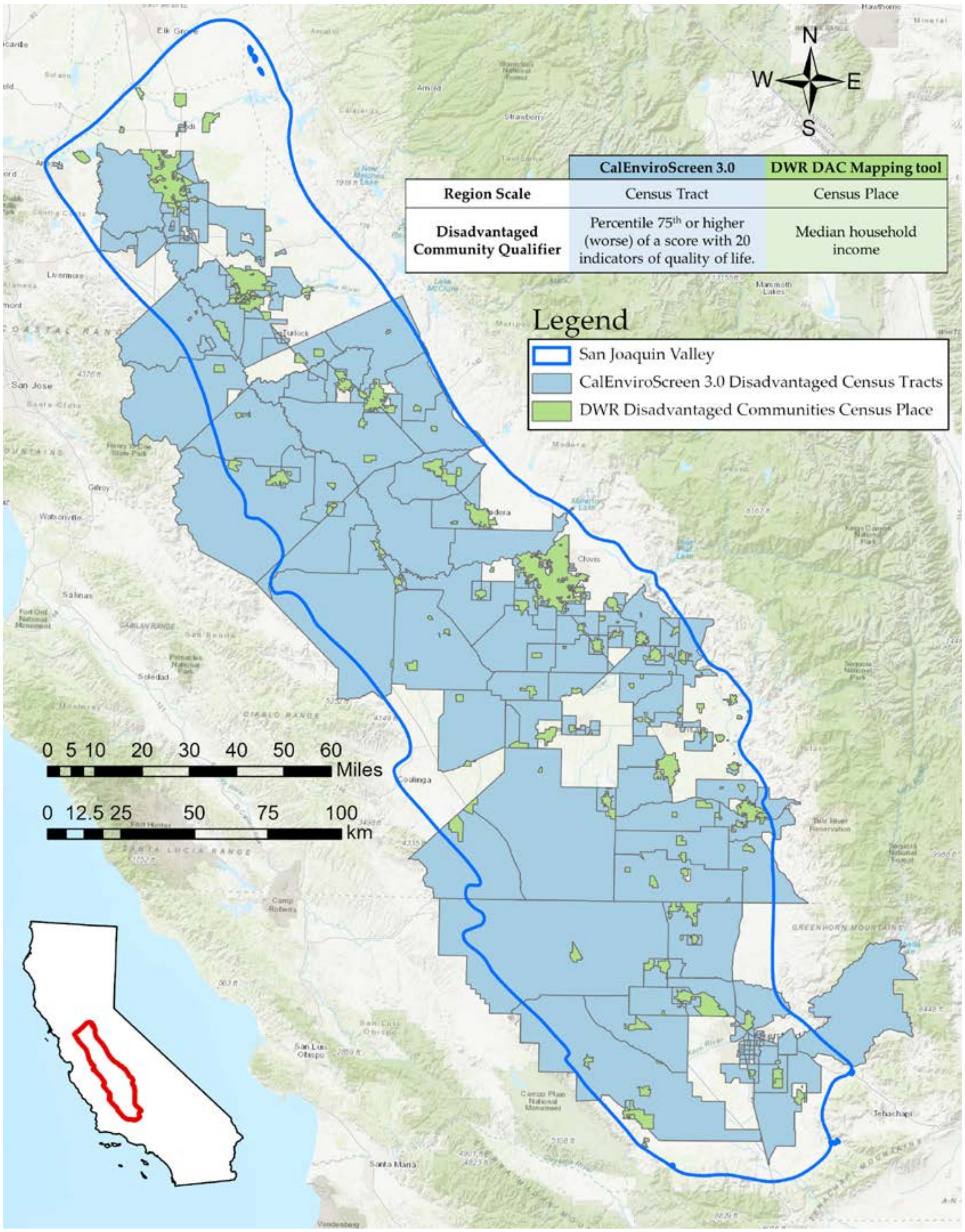
Mapping tools used to determine vulnerability to climate change and target areas for aid are not adequate in accounting for the complexity of the tribal lands. San Joaquin Valley Rancherias do not appear on the mapping tools as disadvantaged communities. There are inconsistencies in data used by the different tools that determine vulnerability status causing these tribes and tribal lands to be overlooked. For example, The Tule River Reservation is not indicated as a vulnerable population according to the spatial data used for climate change investments (https://webmaps.arb.ca.gov/PriorityPopulations), yet it is indicated as severely disadvantaged according to the disadvantaged communities mapping tool of the California Department of Water Resources. Additionally, the tribes and tribal lands are rarely referred to by name in documentation regarding groups vulnerable to climate change impacts. Inclusion of tribal communities in plans would improve prospects for climate change mitigation in San Joaquin Valley communities.

## Disadvantaged Communities in San Joaquin Valley

Communities in the San Joaquin Valley experience the greatest degree of environmental injustice in California, ranking highest in the state for pollution burden and vulnerability (Figure 19) (OEHHA, 2017). Income, access to education, and health are important indicators for healthy communities and social equity. High poverty and lower education rates are obstacles for San Joaquin Valley residents who are attempting to deal with the changing environment. Vulnerable populations in the San Joaquin Valley include low-income individuals, some Latino and African American communities, immigrants with lower levels of education and English proficiency, indigenous people, children, pregnant women, the elderly, workers in vulnerable occupations, the disabled, and those with health issues. Vulnerable populations and disadvantaged communities will suffer disproportionally more from the impacts of climate change since they have less capacity to adapt (Ortiz-Partida et al., 2020).

The San Joaquin Valley has a long history of social oppression that began with the displacement and extermination of the local Indian tribes, followed by the racialized annexation and underinvestment of unincorporated areas populated by African Americans and lower income people (London et al., 2018). Their unincorporated status denied them municipal services and political representation that persists to this day (Flegel et al., 2013; Flores-Landeros et al., 2021). The San Joaquin Valley has the greatest number of rural disadvantaged unincorporated communities, which are predominantly Latino, migrant workers, and lower income people (Flegel et al., 2013; London et al., 2018).

**FIGURE 19.**




Map of disadvantaged communities according to CalEnviroScreen 3.0 and to the California Department of Water Resources. The methodologies and the scale are different, yielding different results. CalEnviroScreen 3.0 is an index with 20 indicators of socioeconomic and environmental conditions of the population at the census tract level (https://oehha.ca.gov/calenviroscreen/report/calenviroscreen-30). The Department of Water Resources uses only median household income less than 80% of the median household income in California as the indicator to classify a community as disadvantaged, but the methodology is used at the census place level (https://gis.water.ca.gov/app/dacs/), which is more appropriate to identify for small rural communities (Fernandez-Bou, Ortiz-Partida, Classen-Rodriguez, et al., 2021).

### IDENTIFYING DISADVANTAGED COMMUNITY NEEDS

While policymakers are trying to identify disadvantaged communities to target more funds for aid and development, the nuances of their locally specific needs have not been correctly addressed so far, leaving disadvantaged communities underserved (Dobbin, 2020, 2021; Fernandez-Bou et al., 2021). Interviews with San Joaquin Valley community members and allies that focus on their views regarding resource access, climate change impacts on their community, and representation indicate that there is a mismatch between policy solutions and community members' needs (Fernandez-Bou, Ortiz-Partida, Dobbin, et al., 2021; Flores-Landeros et al., 2021). Disadvantaged communities are also underrepresented by the media in essential topics such as access to water security (Bernacchi et al., 2020; Fernandez-Bou, Ortiz-Partida, Dobbin, et al., 2021). Including communities' perspectives on specific needs is essential in the process of identifying effective solutions (Fernandez-Bou, Ortiz-Partida, Classen-Rodriguez, et al., 2021; Fernandez-Bou, Ortiz-Partida, Dobbin, et al., 2021). Some of the primary concerns of disadvantaged communities are water issues such as quality, quantity, and the high cost of bottled water (Ortiz-Partida et al., 2020). Flooding is also another important concern that is a result of inadequate infrastructure such as drainage, sidewalks, and sewage. Air quality, pesticide drift, low wages, and lack of political representation and access to healthy foods are other common concerns (Fernandez-Bou, Ortiz-Partida, Dobbin, et al., 2021; Flores-Landeros et al., 2021; Ortiz-Partida et al., 2020) (see *Case Study 12. Community of resilience: The Committee for a Better Arvin*). Many of these concerns are exacerbated by climate change and affect disadvantaged communities' resiliency and ability to adapt (Fernandez-Bou, Ortiz-Partida, Classen-Rodriguez, et al., 2021).

## Human dimensions of water resources

### DRINKING WATER INSECURITY AND GROUNDWATER SUSTAINABILITY

About 95% of drinking water in the San Joaquin Valley is supplied from groundwater. The intensive groundwater use in the San Joaquin Valley has severely limited water access for communities dependent on small water systems and private shallow wells located in rural unincorporated areas that are predominantly Latino communities (London et al., 2018). Drinking water wells in vulnerable communities are seriously threatened by deepening water tables and degraded quality as droughts increase in frequency and intensity. The 2012 to 2016 drought left hundreds of wells dry and others with excessively high nitrate and arsenic levels (Feinstein et al., 2017) (see *Case Study 13. Contaminated drinking water in disadvantaged communities*). The Sustainable Groundwater Management Act (SGMA) was enacted to bring groundwater pumping to more sustainable levels. However, recent analyses find that the groundwater sustainability plans (GSPs) created by the groundwater sustainability agencies (GSAs) do not address drinking water needs (Dobbin, 2020). Under the current GSPs goals for the San Joaquin Valley, threshold levels will result in 4,000 to 12,000 dry wells causing 46,000 to 127,000 residents to lose all or part of their drinking water access (Water Foundation, 2020). Groundwater wells that are most threatened are disproportionately located in Latino communities where documented and undocumented residents are the most vulnerable to water insecurity (Balazs et al., 2011; Jepson & Vandewalle, 2016). The lack of reliable drinking water has forced many communities to rely on bottled water which for low-income households is an economic burden (Fernandez-Bou, Ortiz-Partida, Dobbin, et al., 2021; Flores-Landeros et al., 2021).

### LIVELIHOOD SECURITY AND EXPANDING GREEN ECONOMIES

The dwindling water supply threatens the future of the agricultural industry and employment in the San Joaquin Valley. Changes in groundwater regulations may lead to water conservation agricultural practices, such as cultivating less water-intensive crops and decreasing cultivated areas. The San Joaquin Valley reduced roughly half a million acres (about 200,000 ha) of irrigated acreage during the drought in 2014 (Hanak et al., 2017). The San Joaquin Valley's reliance on agriculture is far greater than the rest of the state providing 25% of revenues and 16% of the employment in comparison to just 5% revenues and 2% employment for the rest of California (Hanak et al., 2017). The region's high vulnerability to drought, along with regulations now limiting groundwater extraction, increases the uncertainty for the future livelihoods of farmers, farmworkers, and other agriculture-related employment, which is compounded by a less developed and less diversified non-agricultural economy. The San Joaquin Valley has lower educational attainment with only 16% of the population with a bachelor's degree, compared to 31% for the rest of California. Education attainment also influences lifetime earnings. In the San Joaquin Valley, the median household income in 2019 was 25% lower than in the whole state ($58,308 compared to $78,105). In addition to a low education attainment, many Latino farmworkers are linguistically isolated, presenting obstacles in obtaining job security.

In a region with an already high unemployment rate, focused policy and action can better prepare the region to face potential agriculture-related employment losses. Certain climate policies incorporate programs that diversify the region's economy with renewable energy jobs, and the Greenhouse Gas Reduction Fund (GGRF) supported initiatives such as the high-speed rail system among other strategies contributing thousands of new jobs. Continued support of these programs improves economic benefits and employment security prospects (Jones et al., 2017). However, it is unclear who is receiving these new jobs and if these new jobs are benefiting disadvantaged communities. Although the reports indicate apprenticeship programs that are inclusive of ethnic minorities, particularly Latino, more research is needed to assess whether such programs result in more equitable and long-term employment with middle-class earnings for vulnerable communities (Luke et al., 2017).

### FLOOD RISK AND HUMAN SECURITY

The Central Valley has one of the greatest risks of residual flooding in the U.S. according to the Central Valley Flood Protection Plan (DWR, 2017). Climate change is contributing to this threat with more rain and less snow. Catastrophic floods are a potential hazard to inhabitants and employment, and they pose an economic burden to rebuild stranded infrastructure and homes. Flooding also threatens the agriculture-based economy and national and international food supplies. The San Joaquin Valley needs improvements to its levee system to prevent major impacts from floods. Better weather forecasting and evacuation planning are the primary strategies in the event of a catastrophic flood (Hanak et al., 2019). The devastation of a major flood can be even greater for rural communities that are located farther away from basic emergency services, and their population may not be as informed on emergency response in part due to language barriers. Annual flooding events in the San Joaquin Valley often affect more disadvantaged communities because of the lack of basic infrastructure, such as storm drains and sidewalks. For example, in some low-income communities, children regularly arrive at school with water-soaked shoes and socks on rainy days, presenting an additional barrier to learning and academic success (Fernandez-Bou, Ortiz-Partida, Dobbin, et al., 2021).

An increase in violent crime is an often-overlooked potential indirect impact of climate change. California's highest rate of violent crime in 2019 was in the San Joaquin Valley, with 556 violent incidents per 100,000 residents (Lofstrom

& Martin, 2021). Economic inequality is linked to violent crime, and the San Joaquin Valley already has higher unemployment and lower average earnings than the rest of the state. The potential for greater incidence of violent crime as a result of climate change-induced economic disparities requires further investigation. Gender inequality is another consideration in preparing for human security and climate change impacts. Research shows that women and girls are at greater risk of violence in the aftermath of natural disasters as well as poverty-induced domestic violence (Demetriades & Esplen, 2010).

### CASE STUDY 12. Community of resilience: The Committee for a Better Arvin

The San Joaquin Valley demonstrates that with adversity comes resistance. Community-based groups are working to challenge unfair practices and bring justice to disadvantaged communities. For example, in 2018 the city of Arvin, an agricultural community of 21,000 inhabitants of which 90% are Latino, opposed the new oil and gas development located next to households (see www.caleja.org). The oil industry pollution deteriorates the air and water quality, and it utilizes valuable and scarce water resources. Arvin has some of the worst air quality in the San Joaquin Valley region and some of the highest pollution scores (OEHHA, 2017). The Committee for a Better Arvin sued the Arvin city council for approving four new oil and gas wells ignoring community leader efforts to develop an ordinance to protect the health of local communities from oil and gas development. By using the California Environmental Quality Act (CEQA) to substantiate their claims, the Committee for a Better Arvin pushed through the new ordinance which mandates that all new drilling must have 300 ft setback from all residential areas and 600 ft from sensitive sites such as parks, schools, and hospitals (City of Arvin, Ordinance 451, 2018).

### CASE STUDY 13. Contaminated drinking water in disadvantaged communities

Matheny Tract is a census-designated place located in Tulare County and formed by 300 households. Matheny is classified as a disadvantaged community (DAC) by CalEnviroScreen 3.0, scoring an 85% Pollution Burden and a 94% relative burden for drinking water. These burdens on drinking water are primarily attributed to the high levels of arsenic that makes the water unsafe for drinking, cooking, and bathing. Matheny residents experience skin rashes due to the arsenic in their bathing water, and even after being fully connected to the city of Tulare's water system in 2016, they still rely on bottled water for drinking and cooking. This connection was made possible by the signing of SB 88 by Governor Brown encouraging the delivery of drinking water to disadvantaged communities from larger water supply systems. However, connecting to the Tulare water system took several years of legal dispute because of the former Tulare city government's refusal to do so until the courts decided in favor of Matheny.

## San Joaquin Valley Public Health

The San Joaquin Valley presents California and the nation with a remarkable context for assessing the human toll of climate change. Experiences in the San Joaquin Valley exemplify the social and environmental determinants of racial, ethnic, and social class health inequalities.

Climate change impacts - including rising temperatures, more extreme weather, rising sea levels, and increasing carbon dioxide levels - together with other natural and social health stressors, affect a wide range of health outcomes (Crimmins et al., 2016). Disadvantaged communities (55% of the San Joaquin Valley population) will experience higher health risks than in other parts of California due to their more limited access to health services (including mental health). Additionally, the compounding and inter-connected nature of many of climate change and anthropogenic impacts (for example, extreme heat, poor air quality, and COVID-19) will exacerbate the health conditions of these communities. This section examines temperature-related deaths and illnesses; air quality and wildfires; the relationship between extreme events (for example, flood and drought) and diseases; food safety, nutrition, and distribution; and mental health.

### TEMPERATURE-RELATED DEATHS AND ILLNESSES

Extreme heat is one of the main health concerns in the San Joaquin Valley, and climate change is exacerbating extreme temperatures with warmer summers and falls. Extreme heat days are projected to increase across the region from the current 5 per year to up to 68 days per year by the end of the century. Heat affects the respiratory, the nervous, and the cardiovascular system, and it can cause heat stroke and dehydration. The number of warm nights is also projected to increase from the current 5 per year to up to 64 nights per year by the end of the century. Warm nights are linked to poorer sleeping quality, which increases fatigue, anxiety, and the risk of traffic accidents (Ben Simon, Rossi, et al., 2020; Ben Simon, Vallat, et al., 2020). Heat problems disproportionately affect farmworkers and disadvantaged communities that lack the means to pay for air conditioning. Currently, farm work is the occupation most affected by heat and heat-related deaths are about 20 times higher than in any other industry (Jackson & Rosenberg, 2010; Luginbuhl et al., 2008).

### IMPACTS OF AIR QUALITY, DUST, AND WILDFIRES

The air quality in the San Joaquin Valley is already among the worst in the nation and has repeatedly failed to meet federal health standards for both ozone and particulate pollution (data available on https://www.lung.org/research/sota/city-rankings/most-polluted-cities). This is a result of the San Joaquin Valley's topography, which traps air pollution from automobiles, oil and gas production, agricultural operations, and wildfires. Children, elderly, low-income populations and those with asthma, lung cancer, heart disease, and diabetes are the most vulnerable to this threat. Table 11 shows the number of people at risk due to poor air quality. The worse 12 metropolitan regions of the United States include more than 60% of the population of the San Joaquin Valley (see *Case Study 14. Successful health-related policies in the San Joaquin Valley*).

**TABLE 11.**

People at risk in the 3 most polluted United States metropolitan areas by year-round particulate pollution, annual PM2.5, in 2021. The three most polluted areas in the United States are in the San Joaquin Valley, corresponding to most of the population of the counties of Kern, Fresno, Madera, Kings, and Tulare (more than 60% of the San Joaquin Valley's population). "CV" stands for cardiovascular disease. Source: www.lung.org.

| 2021 Rank | Metropolitan Statistical Areas | Population | Under 18 | 65 and Over | Pediatric Asthma | Adult Asthma | COPD | Lung Cancer | CV Disease | People of Color | Poverty | Ever Smoked |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Bakersfield, CA | 900,202 | 259,087 | 101,155 | 19,014 | 49,933 | 25,961 | 354 | 37,512 | 604,487 | 164,817 | 206,478 |
| 2 | Fresno-Madera-Hanford, CA | 1,309,368 | 366,345 | 164,036 | 26,885 | 73,602 | 39,304 | 514 | 57,381 | 923,184 | 249,022 | 306,174 |
| 3 | Visalia, CA | 466,195 | 142,106 | 54,291 | 10,429 | 25,274 | 13,357 | 183 | 19,425 | 337,240 | 86,940 | 104,895 |

Warming and greater precipitation extremes are increasing wildfires in California (Crockett & Westerling, 2018). Wildfires pose immediate threats to residents living in fire-prone areas, including burns and smoke inhalation, as well as secondary impacts to people further away from traveling smoke, such as asthma and respiratory irritation. Changes in wildfire and weather patterns could increase pollutants such as ozone, carbon monoxide, and particulate matter, which further negatively impact air quality.

The dry, dusty conditions associated with drought can lead to infectious disease and vector-borne diseases like *Coccidioidomycosis* (Valley Fever) in the San Joaquin Valley. Between 2009 and 2012, the annual rate of *Coccidioidomycosis* in California increased by 67.7%, from 6.5 per 100,000 people to 10.9 per 100,000 people. The San Joaquin Valley is the region with the greatest occurrence of *Coccidioidomycosis* in California.

The conditions caused by climatic extremes also create breeding grounds for mosquitoes and a potential increase in mosquito-borne diseases, such as West Nile Virus (WNV) (Zelezny et al., 2015).

## CASE STUDY 14. Successful health-related policies in the San Joaquin Valley

The initiative "Tune in and Tune up" was created by the San Joaquin Valley Air Pollution Control District to reduce emissions from highly polluting vehicles that contribute to poor air quality. The program provides residents with free emission tests and vouchers for emission-related repairs. Since 2005, tens of thousands of residents of disadvantaged communities have benefited from the proceedings of this program. Thanks to this program, vehicle emissions in the San Joaquin Valley are decreasing. Tune in and Tune Up is a model of balancing efficiency and equity.

Other policies that can benefit public health and environmental justice include (1) ensuring health coverage regardless of immigration status; (2) addressing the shortage of medical resources in the San Joaquin Region; (3) providing access to safe drinking water, nutritious food and affordable housing to disadvantaged communities; and (4) providing job creation and workforce training for disadvantaged communities.

#### WATER QUALITY AND HEALTH

Contaminated water from agriculture has been well documented in disadvantaged communities of the San Joaquin Valley (Balazs et al., 2011, 2012), and climate change will intensify water quality issues (Barnett et al., 2008). The San Joaquin Valley has some of the most contaminated aquifers in the country, which is an especially acute problem given the high reliance on groundwater. Many small community systems serving high percentages of Latinos deliver water with high nitrate levels (Balazs et al., 2011), and the problem is likely to worsen (Harter et al., 2012; London et al., 2018). Water systems serving predominantly socio-economically disadvantaged communities in the San Joaquin Valley have higher odds of incurring an arsenic maximum contaminant level violation compared to water systems serving communities of higher socio-economic status (Balazs et al., 2012).

In the San Joaquin Valley, hundreds of thousands of residents lack access to safe drinking water and rely on bottled water representing an economic burden for many (Fernandez-Bou, Ortiz-Partida, Dobbin, et al., 2021; Flores-Landeros et al., 2021). Common pollutants across the San Joaquin Valley include nitrate, arsenic, 1,2,3-TCP, chromium VI, and bacteria (see *Impacts on regional water quality*).

#### MENTAL HEALTH

The experience of going through extreme weather events can lead to mental health issues, including disorders and aggressive behaviors, with more severe consequences for disadvantaged communities (Fritze et al., 2008). Another profound impact of climate change is solastalgia, which is a sense of loss of identity often associated with place-based occupations such as farming and fishing (Ganesh & Smith, 2018). California farmworkers already experience a high risk of psychiatric disorders (Alderete et al., 2000; Greene, 2018) that will likely increase under climate change conditions. Populations such as indigenous communities, low-income groups, women, children, older adults, individuals with disabilities, and those living in high-risk areas are also more vulnerable to the mental health impacts of climate change.

## Adaptation and mitigation strategies

Including disadvantaged communities in an effective way in decision making processes and policy initiatives is an essential step to bring environmental justice to the San Joaquin Valley (Fernandez-Bou, Ortiz-Partida, Classen-Rodriguez, et al., 2021). It is also necessary to facilitate community participation by addressing any obstacles (for example, removing language barriers or providing more flexible meeting hours)

Funding for grassroot organizations and local initiatives to foster local planning and educational community outreach increases resilience of disadvantaged communities. Outreach can increase community awareness to local air and water quality, and it leads to better preparedness for emergencies and extreme weather events. Community based advocacy and education programs could target adults and children, including vulnerable groups such as women with young children, the elderly, and minority groups. Funding combined with scientific and community-participatory research, especially with disadvantaged and tribal communities, furthers the usefulness of research and policy. Also, increasing underrepresented minorities in scientific research and climate-related fields will bring broader perspectives of the San Joaquin Valley.

Emergency management and health services require continuous funding and more inclusive planning in the San Joaquin Valley. Local concerns must be properly addressed, including extreme heat, valley fever, and other health hazards experienced in disadvantaged communities.

Creation of buffer zones for environmental protection surrounding disadvantaged communities may help bring environmental justice, and the buffers can be used for new economic activities with positive environmental and social externalities. These can include programs to incentivize the adoption of solar energy generation and storage in disadvantaged communities, management of aquifer recharge to improve water security, green corridors to preserve habitat, and nonpolluting industries.

# Opportunities for Climate Change Adaptation and Mitigation in the San Joaquin Valley

## Strategic Agricultural Land Use Transitions

Increasing water scarcity and overreliance on groundwater resources, especially during drought periods, are driving changes in the way California is managing water use and demands. The Sustainable Groundwater Management Act (see *Case Study 5. Sustainable Groundwater Management Act and Agriculture*) has implications on agricultural land use and irrigation pumping. Fallowing agricultural land can lead to increased soil erosion and dust issues if agricultural practices are not modernized, which may lead to health impacts on already negatively affected rural communities. Collaborative approaches including policymakers, academia, disadvantaged community members, farmers, industry, and environmental organizations may effectively transition land to alternative uses that increase water security while improving socioeconomic conditions for communities and agriculture.

Strategic land repurposing is an alternative land use management plan that gives retired agricultural land a new value (Environmental Defense Fund, 2021). Strategic land repurposing could help improve air quality, reduce net water use, and at least partially offset loss of revenue and jobs due to climate extremes and competing water. Some alternative land uses could offer multiple benefits together with agriculture to encompass economic, environmental, and societal benefits. Some examples of land repurposing options that have been considered to address water scarcity and groundwater overdraft issues in the state are habitat restoration (Butterfield et al., 2017; Lortie et al., 2018), managed aquifer recharge (Ghasemizade et al., 2019; O'Geen et al., 2015), renewable energy (Butterfield et al., 2013), carbon sequestration (for example, cover crops, grazing), and switching to less water-intensive crops. Implementing habitat restoration or species conservation at the farm level by crossing structures and conservation easements can mitigate the habitat-related climate pressures on California fauna. Managed aquifer recharge is gaining momentum in the San Joaquin Valley both as a land repurposing strategy, and as a systemwide resilience building. The FloodMAR initiative championed by the Department of Water Resources and other partners has conducted pilot studies in the Merced River Basin (Marr & Arrate, 2020). Academic studies document gains from implementing the approach in alfalfa and almond farms (Ma et al., 2021). This "climate-wise connectivity" is an emerging field of conservation science, focused on creating and maintaining landscapes that facilitate species movements required for future climate-driven range shifts (Keeley et al., 2018). Hence, agricultural land-use transitions aimed to minimize unwarranted tradeoffs and colocation conflicts for the environment, economy, and surrounding disadvantaged communities are more likely to move forward.

Land repurposing options may also provide solutions to other health and environmental issues in the San Joaquin Valley, like poor air and water quality in already burdened rural communities. Some studies have demonstrated the potential of multi-benefit land use combinations, like promoting biodiversity and groundwater recharge (Bourque et al., 2019). Water regulations provide the opportunity to find land-use solutions that help address the environmental issues that burden disadvantaged communities in the San Joaquin Valley (for example, poor air and water quality). For example, transitioning to land use that facilitates groundwater recharge near disadvantaged communities can improve water security prospects since many communities rely on shallow wells for their water needs (Mayzelle et al., 2015). Some land repurposing options can help California address its zero carbon emission goals by 2045 (Senate Bill 100, 2018). When considering the higher rates of greenhouse gases emissions from urban lands versus agricultural lands, limiting conversion of farming and grazing land to suburbs presents one of the greatest opportunities for agriculture to contribute to California's climate goals (Byrnes et al., 2017). The conversion of agricultural lands to urban requires support for urban densification and vertical construction. There are several state programs that recognize this challenge. The Sustainable Agricultural Lands Conservation (SALC) Program provides funding for purchasing conservation easements of farmland at risk of suburban sprawl development, ultimately avoiding the increase in greenhouse gases emissions associated with automobile emissions (Strategic Growth Council, 2015).

## Renewable energies and agriculture in the San Joaquin Valley

The benefits offered by solar power and flexibility in capacity size have been increasingly recognized by California farmers, especially under water scarcity and the Sustainable Groundwater Management Act. Some farmers have embraced this technology, investing in small-scale to large solar energy systems, including solar irrigation systems. For example, a Tulare County farmer with a 1,400-acre wheat farm converted about one-fifth to solar. The decision to convert part of the farm to solar was due in part to the costly water prices in the region and the solar lease deal that pays ten times more than wheat on a per acre basis (Kasler, 2019). Another example is a grape farmer in Edison, Kern County, who installed solar panels to power the main production and cold storage facility with the added financial incentives pushing for this land-use change (Boyles, 2012). The economic incentives of dedicating part of the farmland to solar energy generation so far indicate it is a promising land repurposing option that might enhance non-farm income.

## Carbon sequestration and negative-emissions agriculture

Methane emissions from ruminant animals in livestock operations account for the large majority of greenhouse gases emissions from California's agriculture section (ARB, 2020). When considered within the carbon cycle, ruminant animals are a component of an existing natural cycle, where they mobilize carbon that otherwise could be mobilized by natural microbial decay processes for biomass. However, methane is a gas with 30 times more global warming potential in 100 years than carbon dioxide (US EPA). Addition of fossil-derived fertilizers to this system can move the system to produce net emissions. However, a variety of technology options can move these agricultural systems to be net sinks of carbon.

Agroecology and regenerative agricultural techniques can meet multiple objectives of carbon sequestration, biodiversity preservation, and system resilience. A 2016 research editorial identified soil erosion, soil tillage, use of fertilizers, and anerobic runoff among the main mechanisms of net carbon emissions from animal agriculture. Such operations can provide services of carbon sequestration, water filtration, ecosystem stability, and biodiversity among other benefits (Teague et al., 2016). Diversification is an important element of livestock agroecology, and these practices incorporate human and social values within the context of sustainable development (FAO, 2018b, 2018a). Additionally, new technologies have recently been explored from the effects of feedstock supplements on ruminant methane production to soil inoculants and carbon sequestration credits (Ahmed et al., 2018; Giles, 2021; Roque et al., 2021). As researchers, states, and commercial interests turn attention toward different tools to meet climate goals, agricultural innovations may achieve a dual purpose of meeting food and environmental security needs.

# Conclusions

The San Joaquin Valley experiences one of the most challenging environmental and socioeconomic conditions in California: millions of residents have water insecurity and the worst air quality in the United States; the ecosystems are the most degraded in the state; and the main economic engine, agriculture, is continuously at risk to maintain its productivity due to water scarcity. Climate change is aggravating these conditions and threatening the already diminished quality of life and economic livelihood of the San Joaquin Valley.

However, the San Joaquin Valley presents many climate mitigation opportunities that, if well planned, can benefit disadvantaged communities, socioeconomic and environmental conditions, and agriculture.

Environmental justice requires multi-benefit projects that prioritize disadvantaged communities and involve several stakeholders. One promising adaptation opportunity that can bring environmental justice and new economic development to frontline communities is repurposing land surrounding rural disadvantaged communities into green areas, aquifer recharge projects, wildlife corridors, cleaner industry, solar panels, and other clean socioeconomic opportunities. This approach has the potential of creating wealth for the communities, for all the involved stakeholders, and for the State.

Alternative and simultaneous farmland uses can decrease the economic challenges that farmers would face under climate change. For example, incorporating solar energy can bring a new income source while maintaining farming operations.

Carbon sequestration and land management such as wildlife areas can bring new opportunities for the San Joaquin Valley, while benefiting the whole state, including helping mitigate climate change.

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