SAN JOAQUIN VALLEY



CALIFORNIA'S FIFTH
CLIMATE CHANGE
ASSESSMENT

San Joaquin Valley Regional Report

A Regional Report for California's Fifth Climate Change Assessment

Coordinating Agency

CA Governor's Office of
Land Use and
Climate Innovation

About California's Fifth Climate Change Assessment

California's Climate Change Assessments are the state's scientific foundation for understanding future climate-related vulnerability across California's regions and systems. Senate Bill 1320 (Stern, 2020) requires the State to report the impacts and risks of climate change across California at least every five years, beginning with California's Fifth Climate Change Assessment (Fifth Assessment). Building on decades of climate research and previous Assessments, the Fifth Assessment presents new findings about California's climate future, with a dedicated focus on Tribal partnerships, public engagement, and communities most vulnerable to climate impacts.

The Fifth Assessment's research and tools are designed to fill knowledge gaps about California's climate future, inspire strategic climate actions, and shape planning, investments, and policies at the state, regional, and local scales. Guided by research priorities identified by state, Tribal, and local leaders, community representatives, and subject matter experts, its findings are designed to help illuminate potential climate futures, the challenges they may present, and the opportunities to build resilience through adaptation pathways.

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

Purpose of the Regional Reports

The Fifth Assessment Regional Reports bring together the latest climate science, community input, and adaptation opportunities to meet the needs of communities across nine California regions. These reports can inform regional and local vulnerability assessments, adaptation planning, and community resilience efforts. The Regional Reports include analyses of climate projections and impacts to natural systems, built systems, and social systems. They uplift case studies of adaptation solutions and highlight developments that have emerged since the Fourth Assessment was released in 2018. While climate impacts are felt across regional boundaries, the Regional Reports deepen our understanding of how climate change interacts with the unique communities, histories, waters, and landscapes across California.

Climate Modeling, Scenarios, & Time Periods

The Fifth Assessment Regional Reports consider the following climate models, greenhouse gas (GHG) emissions scenarios, and time periods:

- **CMIP6** (Coupled Model Intercomparison Project Phase 6) is the most recent version of a global collaboration that standardizes and combines the most advanced climate models to project how Earth's systems will react to our changing atmosphere. With CMIP6, we can see the most likely climate trends and the less likely, but still possible, extremes.
- **Greenhouse Gas Emissions Scenarios:** Current international climate models integrate two kinds of scenarios: Shared Socioeconomic Pathways (SSPs) and Representative Concentration Pathways (RCPs). The SSPs model how global society might evolve over the next century, including changes in population, policy, technology, and economic growth, while tracking the amount of heat trapped in the atmosphere. The RCPs correspond to GHG emissions and capture a quantifiable range of emissions and warming—how much do we expect the world will continue to emit, and the associated warming, throughout the century? Combined, these describe how global social conditions (e.g., population, technological, and economic growth) affect emission trajectories. This shift offers a more nuanced understanding of how our collective decisions today will shape the climate of tomorrow. The Fifth Assessment research primarily focuses on two RCP/SSP combinations:
- SSP 2–4.5 (i.e., utilizing the second SSP narrative and RCP 4.5) describes an intermediate scenario indicating improvements toward meeting mitigation commitments. This scenario shows carbon dioxide equivalent (CO_2e) emissions initially hover at current levels, then start to fall by mid-century.
- SSP 3–7.0 articulates a high emissions scenario and less optimistic pathway, assuming current emission levels continue throughout the year 2100. This scenario shows CO_2e emissions doubling by 2100.
- The Fifth Assessment also references a more aggressive emissions scenario (**SSP 5–8.5**), which describes a very high and unlikely emissions pathway that shows CO_2e emissions tripling by 2075. The Assessment includes this scenario as a reference tool for a worst-case emissions outcome for informational and planning purposes rather than a plausible climate change future.
- **Global Warming Levels** (GWLs) ask "What happens to California once the world reaches a certain level of warming?" The focus is on adapting to a change in the expected climate, such as a 2°C (3.6°F) increase. While these models identify a range of years when these thresholds might be reached, the emphasis is on the intensity of the impact rather than the calendar date. This is a different and complementary approach to the previously used *date-based approach*.
- **Downscaling with Localized Constructed Analogues (LOCA) and Weather Research and Forecasting (WRF):** To make global climate models (GCMs) useful for local planning, scientists use a technique called downscaling. While global models provide a *big picture* view of the planet, the Fifth Assessment uses the LOCA2 statistical and WRF dynamical downscaling techniques and a hybridized version of these techniques, LOCA2-Hybrid, to focus on California's particular climate future.
- **Time Periods:** The Fifth Assessment uses a 30-year timeframe for analyses, as shown in the table below, alongside historical projections to draw comparisons between current and future time periods.

Descriptive Term	Time Range
Historical	1981–2010
Mid-Century	2041–2070
Late-Century	2071–2100

CALIFORNIA'S FIFTH
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Map of California

Climate Change Assessment Regions

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Any references in this Assessment to the lingering and compounding effects of racism and discrimination are drawn from academic literature and are not factual findings of, or legal determinations by, the State of California or any agencies of the State, of prohibited discrimination in any particular instance. Similarly, any descriptions of potential future harms are not findings of or admissions by the State of California or any agencies of the State.

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Use of Artificial Intelligence (AI):

No AI was used to generate substantive content in the report. However, we acknowledge the use of AI tools in writing assistance and language refinement (e.g., Grammarly) for some sections of the report. In these cases, the resulting content was validated by the authors. Thus, authors take full responsibility for the correctness of the contents of this report.

Executive Summary

The San Joaquin Valley (SJV) is home to over 4.4 million residents, including dozens of Tribes and a diverse population shaped by multiple waves of migration. Its fertile soils and Mediterranean climate underpin a thriving agricultural economy that accounts for roughly half of California's agricultural production value, producing a majority of US-grown almonds, pistachios, and table grapes. However, intensive water use, dependence on imported water, and groundwater overdraft have made the region highly vulnerable to drought. Increasing water scarcity in the SJV has led to land subsidence and water shortages, with disproportionate impacts on Tribal, rural, and disadvantaged communities. Chronically hot summer temperatures and poor air quality pose health risks for residents of the Valley, particularly given the region's large outdoor labor force.

The SJV is warming rapidly—annual average temperatures have increased nearly 3°F (1.7°C) over the past half-century—with more frequent triple-digit temperatures and declining winter chill hours that threaten crop viability. Projections show an additional 3.5°F (1.9°C) warming by mid-century (2050) and up to 5.5°F (3°C) warming by late-century (2100), leading to more extreme heat, higher energy demand, and potential health risks. Disadvantaged communities are likely to experience severe health and economic impacts from such changes, due to greater exposure to extreme heat and lower access to resources (e.g., cooling). Furthermore, earlier snowmelt, more intense droughts, and rising evaporative demand (i.e., "atmospheric thirst", or how fast the atmosphere "wants" to evaporate water) may deepen water insecurity in the SJV. At the same time, increased likelihood of occasional, but extremely wet years and heavy precipitation events will heighten flood risk.

Water remains the unifying thread linking economic, social, and environmental futures in the SJV. Additional stressors to water resources from climate change pose great risks for the region's agriculture, which already faces water insecurity and warmer temperatures that affect crop viability. Coordinated efforts to enhance water storage, recharge aquifers, reduce water use, repurpose land, and optimize reservoir operations will be critical to balance water supply and demand under a warming climate. Strategic cropland repurposing and enhanced groundwater recharge efforts are potential opportunities for ensuring groundwater sustainability, creating economic opportunities, and restoring critical habitats, while also meeting the state's goals for ecosystem and rural community water resource improvement. Partnerships with local governments, Tribes, state agencies, non-governmental organizations (NGOs), and communities can help prioritize multi-benefit outcomes. In particular, partnerships with regional Tribes, whose stewardship practices emphasize water conservation and watershed-scale health, can strengthen these efforts, offering culturally appropriate strategies for supporting healthy water systems. Expanding climate-smart agriculture into the next generation of agricultural systems in the Valley can support continued prosperity of agriculture in the region. Clean energy development—particularly solar on retired farmland—offers opportunities for job creation and emissions reductions, but will require workforce transition support.

Building climate resilience in the SJV also means protecting public health and reducing long-standing inequities. Priority actions include implementing early warning systems, opening cooling centers, providing financial support for outdoor workers, and investing in urban greening to mitigate heat islands. Community-engaged planning is essential to ensure that adaptation strategies benefit the most vulnerable and do not worsen existing disparities.

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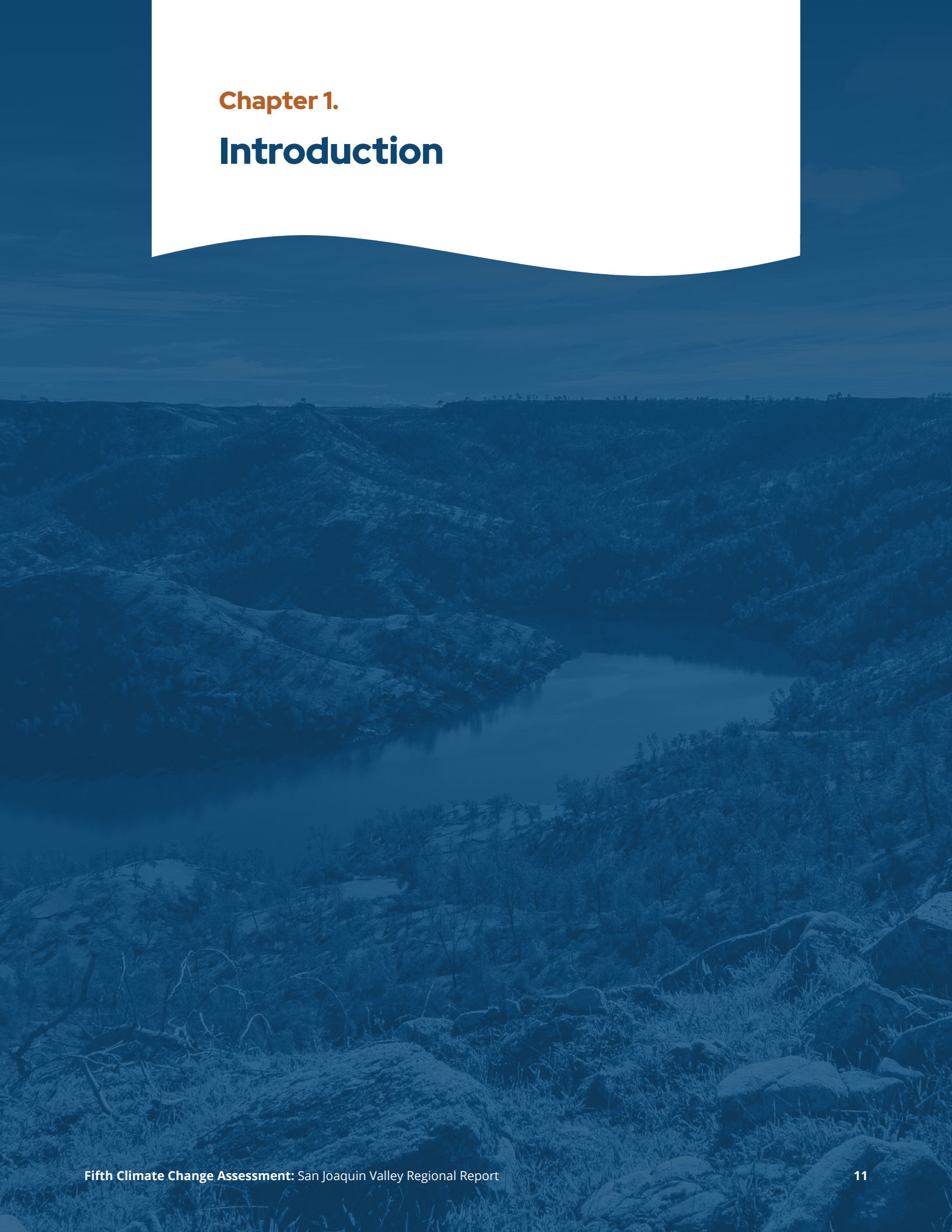
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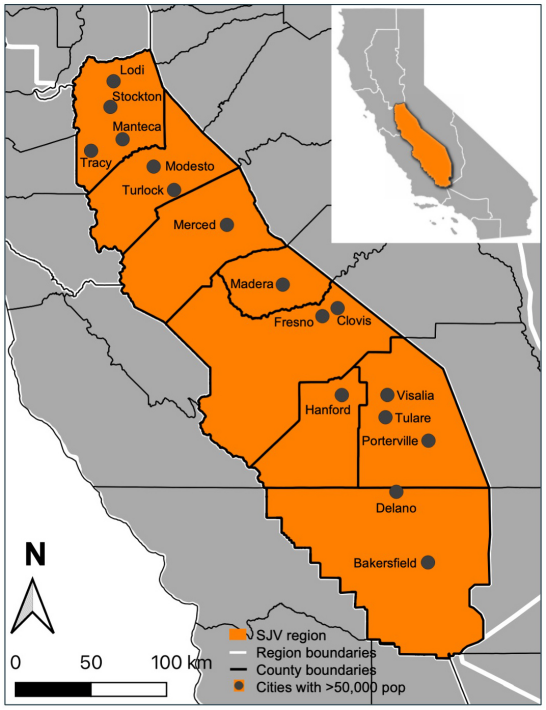
Chapter 1.

Introduction



The San Joaquin Valley (SJV) is the most distinctive agricultural region in California. Bounded by the Coastal Range in the west and the Sierra Nevada in the east, the region extends about 250 miles from the Sacramento–San Joaquin Delta in the north to the Transverse Ranges in the south, with two major transportation corridors along its length: Interstate 5 and Highway 99. Along these roadways, travelers see extensive cropland—largely almonds, pistachios, vines, and annual crops—as well as large dairies. At the same time, the SJV also represents one of California's most dramatically transformed landscapes, where diverse ecosystems (e.g., wetlands, grasslands, and riparian forests)—originally inhabited and stewarded by dozens of Native Tribes (e.g., Choynimni, Chunut, Kitanemuk, Miwok, Mono, Tachi, Tübatulabal, Tulamni, Yowlumne, Wukchumni, and Yokuts Peoples) for thousands of years—have been largely replaced by intensive agriculture, energy development, and urbanization.

The SJV has a Mediterranean climate characterized by sunny, hot, and dry summers and mild, wet winters. These climatic conditions, combined with the fertile alluvial soils deposited by the San Joaquin, Kings, Kaweah, Tule, and Kern rivers and their tributaries, have created the ideal environment for the region to become the most profitable agricultural area in the US (**Figure 1.1**). However, the expansion of high-water-use agriculture in the SJV over the past century has diminished groundwater reserves, contributing to land subsidence and water shortages for rural communities and some growers during recent droughts. Consequently, much of the SJV relies on ***critically overdrafted basins***, necessitating groundwater sustainability management to mitigate further economic, social, and environmental damage from declining groundwater levels.



Map of the San Joaquin Valley Region

Figure 1.1: *Map of the San Joaquin Valley region. County delineations and major cities are shown, the latter of which are cities with populations greater than 50,000 people.*

The SJV has undergone a massive social transformation over the past two centuries, shaped first by colonialism and later by federal policies. Spanish colonization subjected the Indigenous Peoples of the region to genocide, displacement, and forcibly converted them to Christianity (Ch. 3). Following the US acquisition of California after the Mexican–American War in 1846–1848, the passage of the Homestead Act and Reclamation Acts provided settlers with access to free or heavily subsidized land and water. Subsequent policies and water infrastructure began to provide water to SJV farms. Waves of migration have supplied the bulk of the region's agricultural labor force, including migrants of Mexican origin for the Bracero Program, farmers in the southern US Plains fleeing the Dust Bowl, and Hmong refugees following the Vietnam war (Ch. 5). The current socio-demographic context of the region is as diverse as the history of the region,

with numerous Tribes whose homelands and communities have been (and continue to be) rooted in the SJV since time immemorial, and with over 90% of farmworkers who are Latino, many of whom self-identify as undocumented (Ch. 5). As of 2024, the eight-county region had a population of 4.42 million and is among the few areas in the state to experience population growth over the last five years. However, existing social and environmental inequities have led to a majority of Valley residents living in disadvantaged communities.

Like most of California, many contemporary and future climate impacts in the SJV revolve around water. In the Valley, changes in the frequency, duration, and magnitude of drought exacerbate an already-depleted water supply, increasing dependence on groundwater (Ch. 2, 3) and leading to a competition between agriculture, energy, and communities. Furthermore, drought conditions and overdraft have contributed to heightened water insecurity and degraded water quality—particularly for those that rely on shallow wells—while significant interannual variability in water years can also lead to flooding (Ch. 4). Beyond water, climate change has amplified public health impacts in the region, including morbidity and mortality from extreme heat and poor air quality given the high portion of the Valley's labor force that work outdoors (Ch. 5).

This report synthesizes how climate change has affected, and will continue to affect, the SJV. It identifies unique sectors and communities who are most vulnerable to these impacts, and highlights case studies of successful adaptation and mitigation actions. Chapter 2 describes how the region's climate has already changed and how it is projected to change. Chapter 3 discusses the impacts of climate change on natural and working lands and waters, including the feedback between working lands and climate change. Chapter 4 describes climate impacts on the built systems of the region—including water infrastructure and energy—as well as how those systems in turn contribute to climate change. Chapter 5 then describes the impacts of climate change on social systems, including on the economy and public health, and how these impacts further exacerbate existing environmental and social injustices. Chapter 6 provides a summary of the key issues highlighted by each chapter and presents potential integrated solutions which could address several of the key, cross-cutting issues.

Given that many Tribal communities understand people and the natural world as inseparable, we have chosen to place the full, continuous narrative of Tribal communities, Indigenous Knowledges, and associated climate impacts in Chapter 3. In the remaining chapters, Indigenous Knowledges and experiences are briefly described, however, readers are directed back to Chapter 3 for a more complete discussion.

Natural lands, waters, built infrastructure, and society are tightly interconnected in the Valley. Because agriculture accounts for most of the region's land use and water, and many communities live within agricultural areas and are employed in the agricultural sector, water and agriculture are deeply connected as key climate-sensitive sectors that resonate across the SJV regional report. Similarly, communities are omnipresent throughout the report as they are both being impacted by climate change and positioned to adapt. The report provides illustrative examples of how local communities are already building resilience to climate stressors in the region. Without continued adaptation and mitigation efforts, ongoing climate change will likely contribute to chronic challenges; conversely, sharing successful, community-driven resilience strategies can help reduce future climate impacts across the SJV.

Chapter 2.

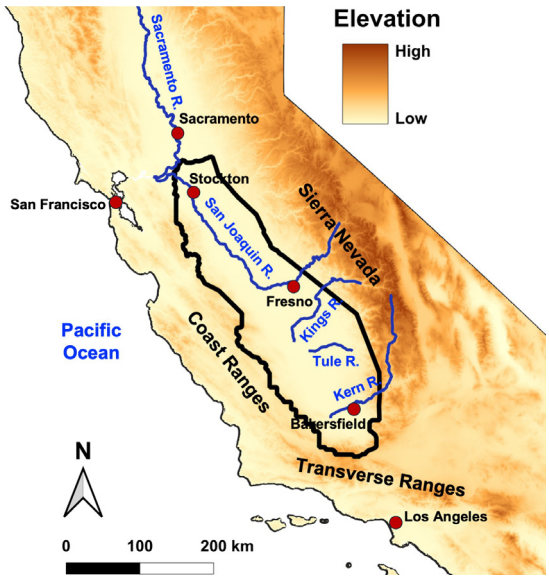
Climate Science: Historical & Projected Trends



Key Message

The San Joaquin Valley (SJV) has a Mediterranean climate with cool and wet winters and hot and dry summers. The region averages around 10 inches (254 mm) of precipitation annually, with substantial year-to-year variability in precipitation, though much of the region's water resources come from runoff from the adjacent Sierra Nevada. In recent decades, low precipitation and rising temperatures have strained water resources. Atmospheric rivers impact the region, often contributing to flooding and a fair portion of the hydroclimatic variability of the SJV. Poor air quality during the winter and summer also impacts the region, driven by both physiographic (i.e., the natural physical features and processes of the Earth's surface) and human-influenced factors. Like much of the rest of the state, country, and globe, the SJV has warmed over the past century. The region has warmed 2.9°F (1.6°C), with most of it since 1980, further exacerbating chronic summer heat. Climate projections suggest a continuation of recent trends with annual average temperatures warming 3.5°F (1.9°C) above late-20th century levels by the mid-21st century. With further increases in temperature and disruptive swings from wet to dry years projected, the region is likely to face more frequent heat waves, droughts, and floods.

2.1 Current Climate Setting of SJV



Notable Geographic Features In and Adjacent to the San Joaquin Valley Region

Figure 2.1: *Notable geographic features in and adjacent to the San Joaquin Valley (SJV) region. The black polygon defines the bounds of the SJV in Central California. The three cities of Stockton, Fresno, and Bakersfield are highlighted to illustrate the general span of climate conditions along a north-south transect of the SJV.*

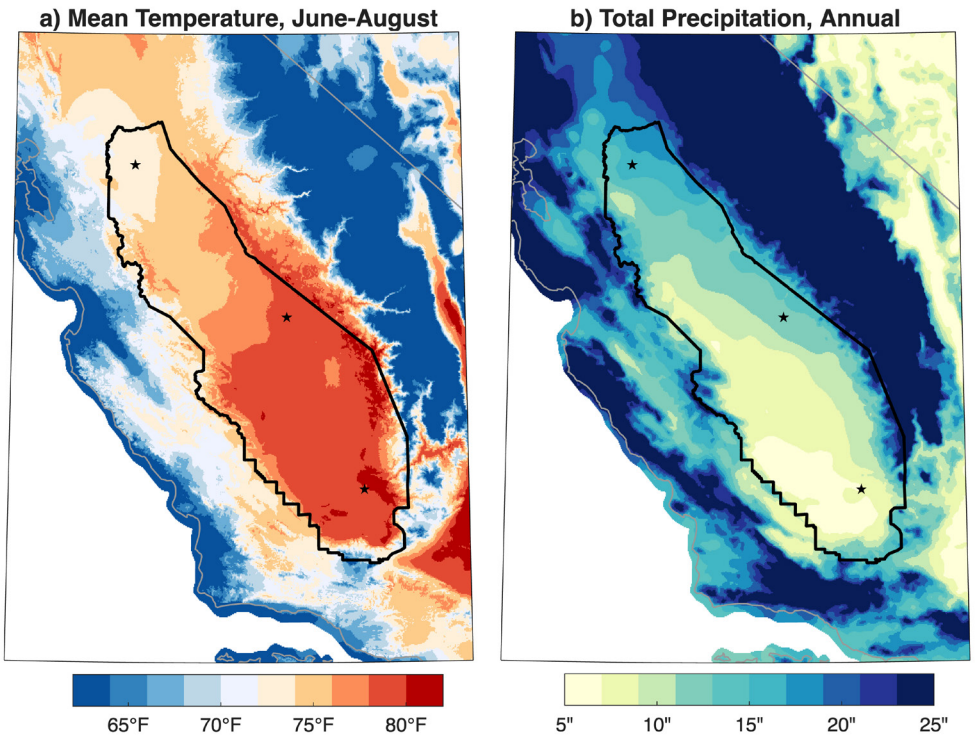
2.1.1 Geography & Topography

The San Joaquin Valley (SJV), comprising the southern half of the Central Valley, is a south-southeast to north-northwest oriented plain stretching about 250 miles from the Sacramento-San Joaquin Delta (the Delta) south to the Transverse Ranges (**Figure 2.1**). The SJV is about 50 miles wide with its western edge about 70 miles from the Pacific Ocean. Positioned between the Coast Ranges and the Sierra Nevada, the SJV experiences a more continental climate than coastal portions of the state and is semi-arid due to the ***rain shadow*** effect of the Coast Ranges. The Valley floor slightly rises in elevation from sea level at the Delta to approximately 600 feet adjacent to the Transverse Ranges of Southern California, and with higher elevations along the margins.

2.1.2 Temperature

Like much of California, the SJV experiences a hot-summer Mediterranean climate, with stronger seasonal temperature amplitudes than found in coastal areas of California. Summertime average high temperatures range

from 92°F (33.3°C) in Stockton to 97°F (36.1°C) in Bakersfield (**Table S1**)—among the highest temperatures for populated parts of the state (**Figure 2.2**). The northern SJV near Stockton is about 3.5°F (2°C) cooler than the southern SJV near Bakersfield, due to the combination of its higher latitude and from the cooling influence of the Delta breeze (Menne et al., 2012). Winters are cool with average high temperatures near 60°F (15.5°C) with limited differences in temperature across the region. Occasional periods of ***Tule fog*** during mid-winter dry spells can lead to much cooler daytime temperatures. Such episodes of Tule fog can benefit some fruit and nut crops that require a sufficient number of ***chill hours*** to break dormancy, although they lead to increased heating costs for residents due to persistent cool temperatures. From November 24–December 17, 2025, the region experienced a multi-week period with prolonged Tule fog coverage due to significant widespread rainfall in mid-November, followed by persistent high pressure over California in subsequent weeks. Local temperatures are also influenced by land cover variability. Minimum (i.e., nighttime) temperatures are warmer in urbanized areas due to the ***urban heat island*** effect, as well as in elevated areas along the valley edges, particularly during periods of light winds and stable air. Conversely, irrigated agricultural lands have cooler summer daytime temperatures than they would without irrigation. In this otherwise semi-arid Mediterranean climate, irrigation suppresses high daytime temperatures during the summer months (Lobell & Bonfils, 2008; Cook et al., 2015; Yang et al., 2017) due to increased water vapor that reduces the energy available for heating near-surface air. However, irrigation can increase heat stress at night due to increased humidity (Parajuli et al., 2024; Yu et al., 2025).



Maps of Recent Climate Averages for the San Joaquin Valley

Figure 2.2: Maps of recent climate averages for the San Joaquin Valley. *(a) Daily mean temperature from June–August in degrees Fahrenheit (°F), and (b) annual total precipitation during 1991–2020 in inches (“). Data source:* ***PRISM****. The black outline depicts the San Joaquin Valley region. The stars, from north to south, show the locations of Stockton, Fresno, and Bakersfield.*

The SJV experiences chronically hot temperatures, especially in areas that do not receive Delta breezes south of Stockton. During 1991–2020, Stockton experienced on average 19 days per year with maximum temperatures above 100°F (37.8°C), while Fresno and Bakersfield experienced an average of 35–40 days per year (Menne et al., 2012). Similarly, annual ***cooling degree days***—or the sum of daily means temperatures in excess of 65°F (18.3°C), which provides a proxy for energy for air conditioning—are higher in the southern SJV than near the Delta, with cooling degree days in Fresno and Bakersfield being 40% and 63% higher, respectively, than in Stockton (Menne et al., 2012). The all-time high temperature records for Fresno, Stockton, and Bakersfield have all been reached multiple times in recent years. Fresno reached 114°F (45.5°C) three different times since 2021, after having never exceeded 113°F (45°C) in official airport observations that started in 1948. Stockton and Bakersfield both tied their all-time records (115°F or 46.1°C) during a major heat wave in September 2022, which also produced 114°F (45.5°C) in Fresno.

The number of days below freezing varies geographically, with an average of 10–35 days per year across the SJV in recent decades (Menne et al., 2012). Below freezing temperatures are important from a human health and energy perspective (e.g., heating) but are less frequent in the urban core and more frequent in rural low-lying portions of the region. While extreme cold events in the SJV are infrequent, they can significantly affect cold-sensitive ***perennial crops*** such as citrus. Chill

hours, a metric relevant to agriculture, generally exceed 800 hours in much of the SJV, except for areas around the Valley rim and near Bakersfield.

2.1.3 Precipitation

Approximately 90% of the annual precipitation in the SJV falls between November and March, with negligible precipitation in the summer months. The region exhibits geographic differences in precipitation, ranging from 6 inches (152.4 mm) in the far southwestern end of the valley to 17 inches (431.8 mm) at the northern extent (Menne et al., 2012). There is also a west-east gradient in precipitation with more precipitation falling in the eastern side of the Valley, tied to the rain shadow effect of the Coast Ranges. However, the region experiences large interannual and decadal variability in precipitation as most precipitation occurs in a handful of extreme events (Dettinger et al., 2011). The semi-arid nature of the SJV and lack of precipitation during the warm season leads to the region's water resources being dependent on a combination of snowmelt runoff from the neighboring Sierra Nevada and groundwater.

2.1.4 Hydroclimate: Droughts and Floods

Water supply in the SJV primarily relies on snowmelt runoff from the Sierra Nevada, which has undergone significant changes in recent decades (see the Fifth Assessment's "Sierra Nevada Regional Report" for more). Thus, the region is highly reliant on an engineered water system which provides storage and conveyance for dry seasons and regions (Ch. 4). The SJV's semi-arid climate, characterized by persistently hot, sunny, and dry conditions during the warm season, leads to an elevated ***vapor pressure deficit*** which results in an ***evaporative demand*** that significantly exceeds the local water supply. The SJV's high evaporative demand, coupled with the region's substantial interannual variability in precipitation, leads to episodic droughts, though longer-term droughts are evident in the longer-term tree-ring record (Griffin & Anchukaitis, 2014). Drought has many definitions but is often articulated as periods where water demand exceeds water supply, acknowledging that these terms vary by water consumers (Redmond, 2004). However, the impacts of drought on managed water systems are often delayed due to the state's large surface reservoir capacity, which limits the effects of single dry years, and buffered by groundwater extraction. Consequently, realized drought impacts typically require consecutive dry years (McEvoy et al., 2012).

Precipitation on the valley floor contributes to certain sectors of water use (Ch. 3) and provides improved air quality, though also poses flood risks. Since much of the precipitation in the region falls in a handful of events, though these extreme precipitation events are crucial for replenishing water resources, they also pose significant hazards. In the SJV, ***atmospheric rivers*** and thunderstorms are the primary culprits, capable of producing intense rainfall and subsequent flooding.

2.1.5 Air Quality

The SJV is subject to air quality issues because surrounding mountain ranges trap both locally generated and remotely transported pollutants. Episodes of poor air quality commonly occur during summer and mid-winter dry spells (often coincident with Tule fog) due to the buildup

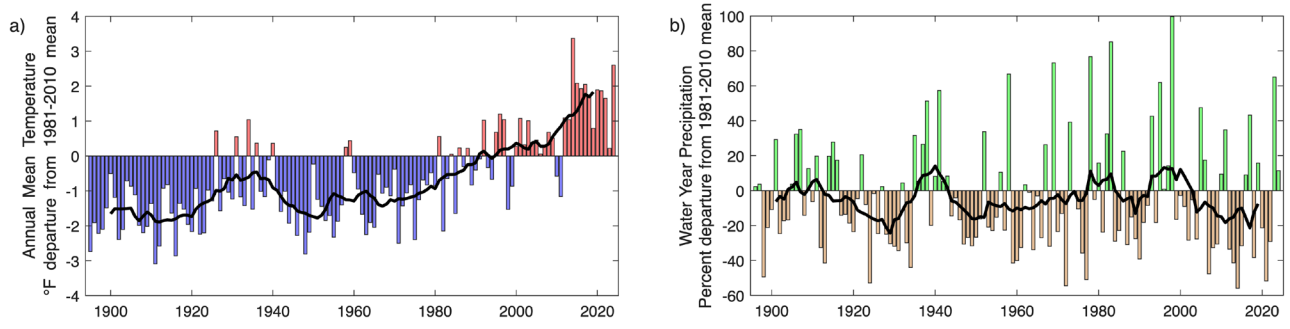
of pollutants during periods with weak winds and persistent atmospheric ***inversions***. This is particularly true in winter due to a shallow inversion layer that restricts the vertical mixing of air, leading to the accumulation of pollutants near the surface. Local emissions from agriculture and industry contribute significantly to ***ozone*** and fine particulate matter pollution, called ***PM2.5***. The region's location, downwind from major urban centers like Los Angeles and the Bay Area, adds transported pollutants. Additionally, wildfire smoke from the Sierra Nevada and other parts of California significantly impact the region's air quality, especially during summer and fall.

2.2 Observed Changes in San Joaquin Valley's Climate

2.2.1 Temperature

Over the past century, the SJV has experienced a general warming trend, consistent with the broader changes observed across California, largely due to ***anthropogenic climate change*** (e.g., Diffenbaugh et al., 2015). Mean annual temperature in the region has warmed by 2.9°F (1.6°C) during 1895–2024, with most of the warming occurring since 1980 (**Figure 2.3a**). Nine of the 10 warmest years on record have occurred since 2014. Warming is seen for all seasons and most multi-decade periods, with the most significant increases seen for minimum (nighttime) temperatures, particularly in the summer months (**Table S2; Figure S1**). Urban areas have experienced a more rapid increase in minimum temperatures due to the urban heat island effect. For example, Fresno airport has seen a more pronounced warming trend for minimum temperatures than adjacent rural areas (Kim & Christy, 2022). Conversely, warming has been more limited for daytime highs due to the widespread increases in irrigation over the 20th century (Lobell & Bonfils, 2008). Average high temperatures during summer in the SJV have risen less compared to other regions in the state over the past century (Cordero et al., 2011). However, limited recent changes in irrigation extent alongside broader warming trends have allowed for increased summer maximum temperatures over the past four decades (**Figure S1**).

The observed warming in the SJV has pronounced impacts on human health and energy demand. Increased multi-day extremely warm nights are evident across the region (Gershunov et al., 2009). Pronounced increases in nighttime temperatures pose a risk to human health as people are unable to cool down at night, and subsequently increases energy demands (e.g., 60% increase in ***cooling degree days*** in Fresno during 1948–2024). The combination of extremely hot days and warm nights places considerable strain on the human body, particularly impacting the outdoor labor force, which includes a disproportionate number of farmworkers (Knowlton et al., 2009; Ch. 5). The odds of such heat extremes have been significantly enhanced due to human-caused climate change (Mera et al., 2015).



Time Series of Temperature and Precipitation for the San Joaquin Valley Region

Figure 2.3: *Time series of temperature and precipitation for the San Joaquin Valley region. (a) Mean annual temperature from* ***nClimgrid*** *(Durre et al., 2022) for the SJV reported as anomalies and (b) water year precipitation anomalies, from the 1981–2010 period. The black line shows the 11–year centered moving average.*

Additionally, the region has experienced a decline in winter chill hours, with important implications for agriculture and the timing of crop development (Baldhochi, 2008; Parker et al., 2022). Over the past four decades, much of the SJV has recorded a reduction of chill hours by 160–400 hours. This trend compounds with a decline in the frequency of Tule fog, which can further reduce the number of chill hours as Tule fog suppresses winter daytime high temperatures (Baldocchi & Waller, 2014). Studies suggest that the decline in Tule fog frequency is likely linked to a decline in agricultural and industrial pollutants that provide a base for fog droplets to gather on (Gray et al., 2019).

2.2.2 Precipitation

Unlike the pronounced increases in temperature, changes in annual precipitation in the SJV show little significant change over time (**Figure 2.3**). Trends from 1980–2024 are negative, with annual total precipitation declining by approximately 15% (0.4 inch per decade), including a 60% decline in autumn precipitation (**Figure S1c**). However, given the significant interannual variability in annual and seasonal precipitation, these trends are not statistically significant, except for autumn precipitation (Luković et al., 2021). These changes are likely due to a combination of natural variability (Lehner et al., 2018) and ***anthropogenic*** airborne particle, or aerosol, emissions (Kuo et al., 2023). There has also been an increase in interannual variability in water-year precipitation in the SJV similar to that seen in the rest of California (Luković et al., 2021; Swain et al., 2025), although most of the increase occurred during the 20th century. Finally, although more extreme precipitation events are projected for the future in California, there is no detected change in such precipitation extremes in the region to date (Williams et al., 2024). However, temperatures during atmospheric river events and other heavy precipitation events have warmed (Gonzales et al., 2019; Abatzoglou et al., 2022), affecting how much precipitation falls as rain versus as snow in the adjacent Sierra Nevada and, consequently, water resources in the SJV.

2.2.3 Hydroclimate: Droughts and Floods

Pervasive warming trends have increased the frequency of hot and dry conditions in the SJV, leading to more frequent and intense drought (Diffenbaugh et al., 2015; Williams et al., 2015). In the Sierra Nevada, warming has shifted more precipitation from snow to rain (Lynn et al., 2020), reduced spring snowpack, lead to earlier snowmelt runoff, and reduced summer soil moisture (Lynn et al., 2020; Shukla et al., 2015; Mote et al., 2018). To date, such changes have been most pronounced at mid-elevations of the Sierra Nevada near the rain-snow transition (Mote et al., 2018).

Compounding these trends, regional evaporative demand has increased over the past four decades, widening the water deficit and making drought recovery more challenging (Albano et al., 2022; Williams & Abatzoglou, 2025; Williams et al., 2024). The drought conditions of 2012–2015 in the SJV were particularly severe, representing the driest period in 1,200 years based on tree-ring records (Griffin & Anchukaitis, 2014). High evaporative demand due to human-caused climate change has intensified extreme multi-year droughts (such as the 2012–2015 drought) and the longer-term ***megadrought*** since the turn of the millennium (Williams et al., 2015, 2020).

By contrast, most studies show no significant trends in the frequency or magnitude of flood events in the SJV in recent decades (Kemter et al., 2023; Slater & Villarini, 2016). These changes somewhat mirror the lack of change in precipitation extremes for the region. However, other processes such as drier soils tied to increased evaporative demand and reduced snowpack in the Sierra may partially act to buffer increased flood risks with increased precipitation (Sharma et al., 2018). Nonetheless, widespread flooding during 2023 points to both the impacts of flooding in the Valley and their connection to meteorological drivers.

2.2.4 Air Quality

The air quality in the SJV has generally improved over the past five decades, with a decline in the number of days per year that exceed the federal air quality standard for ozone and PM2.5 (San Joaquin Valley Air Pollution Control District, 2022). These changes largely reflect policy and technology changes, including the implementation of stricter air quality regulations and reduction in agricultural waste burning. There has also been a steady decline in nitrogen oxides —which are a precursor to ozone and PM2.5—from urban sources over the past decade (Wang et al., 2023), though there have been limited changes in nitrogen oxides from agricultural lands. The decline in winter PM2.5 may also be due to the weakening of Tule fog since the 1980s (Baldocchi & Waller, 2014; Gray et al., 2019), as prolonged episodes of Tule fog allow for PM2.5 to build up in the Valley. However, extreme poor air quality episodes in the summer and fall tied to wildfires have countered the policy-driven improvements in air quality (Burke et al., 2023). The culprit—increased burned area in the adjacent Sierra Nevada—has been partially attributed to climate change (Williams et al., 2019), highlighting its role in degrading regional air quality.

2.3 San Joaquin Valley Future Climate

Box 2.1: *Climate Modeling and Future Scenarios*

Models aid decision-making by helping people understand and predict systems. Weather forecasts, for example, employ observations and numerical models, and are routinely shown to provide substantial benefits by mitigating hazard impacts and providing economic value. Global ***climate models*** (GCMs), developed by scientific agencies around the world, simulate the climate system's response to various factors from volcanic eruptions to El Niño to changes in greenhouse gas concentrations. GCMs simulate the physics, chemistry, and biology of the atmosphere, land, and oceans and their interactions with one another, and are intricately complex. Unlike in some scientific fields where replicate experiments can be performed in a lab, such experiments cannot be done with the Earth. Modeling provides a virtual laboratory that allows scientists to conduct experiments to enhance scientific understanding and inform policies and adaptation solutions.

The sixth Coupled Model Intercomparison Project (CMIP6) was a coordinated effort by more than 49 modeling groups (and 100 models) to perform the same experiments with each group's GCMs. The benefit of using a collection, or ensemble, of models is to capture commonalities and uncertainties in the climate responses. Some climate models show a larger response to increased carbon dioxide concentrations than others, while some models depict different changes in regional precipitation responses to a warming climate. Rather than trying to project a single future scenario, these models provide a probabilistic view of the future that ultimately can be a better guide for adaptation planning. Advancements in models aside, model output is at very coarse spatial resolution—with grid sizes of approximately 100 km or larger—making it not directly usable for applications and impact modeling. To overcome spatial limitations, post-processing efforts to downscale climate model output to local scales (e.g., 3 km) include various dynamical and statistical ***downscaling*** methods (e.g., Rahimi et al., 2025). Regional climate projection summaries presented in this report use the ***LOCA2-hybrid*** approach that leverages output from a limited set of dynamically downscaled climate models with statistical downscaling methods that are more computationally efficient (Pierce et al., 2025).

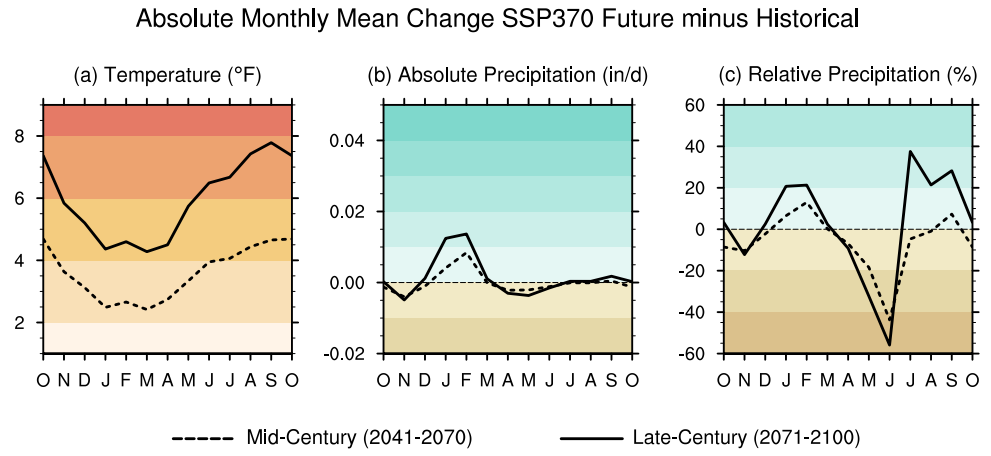
Greenhouse gas concentrations, predominantly driven by ***anthropogenic*** activities such as the burning of fossil fuels and deforestation, have been steadily increasing since the start of the Industrial Revolution. These gases, primarily carbon dioxide (CO2) and methane, trap heat in the Earth's atmosphere, leading to an enhanced greenhouse effect. This increase in trapped heat causes an imbalance in the Earth's energy budget, resulting in a net increase in ***radiative forcing***. Radiative forcing, measured in watts per square meter (W/m^2), quantifies the change in how much energy is entering versus leaving the atmosphere due to these greenhouse gases relative to pre-industrial levels (prior to 1850). This provides one approach for contextualizing the socioeconomic pathways that are used to drive climate modeling experiments.

Here, we adopt the ***Shared Socioeconomic Pathways (SSPs)*** convention used by the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. SSPs are scenarios used in GCM experiments to explore how different future societal developments might influence greenhouse gas emissions and therefore climate change. They provide narratives describing potential trajectories of socioeconomic factors such as population growth, economic development, technological advancements, and policy decisions that directly influence radiative forcing changes by 2100. Each SSP represents a distinct set of challenges for climate change mitigation and adaptation, ranging from sustainable, equitable development (SSP1) to a middle of the road scenario that follows historical patterns (SSP2) to scenarios that focus on nationalism and fragmentation (SSP3) to fossil-fueled development (SSP5). By incorporating these socioeconomic narratives into climate models, researchers can assess a wider range of potential climate futures and evaluate the effectiveness of various mitigation and adaptation strategies under different societal contexts.

We focus primarily on two pathways: (i) SSP2–4.5, which results in 4.5 W/m^2 of energy trapped (above preindustrial) through changes in greenhouse gases and aerosols by 2100, with global mean temperatures warming by 3.6–5.4°F (2–3°C) above preindustrial levels, and (ii) SSP3–7.0, which results in 7.0 W/m^2 of energy trapped through changes in greenhouse gases and aerosols by 2100 and a global mean temperature rise of 5.3–7.2°F (3–4°C) above preindustrial levels. Notably, SSP3–7.0 has substantially higher aerosol emissions than other SSPs due to lenient air quality policies that contribute to complex impacts in terms of regional precipitation and temperature impacts (Shiogama et al., 2020). Other pathways include both more aggressive emission scenarios (SSP5–8.5) and rapid mitigation scenarios (SSP1–1.9); we place less emphasis on those pathways here as they are considered less plausible at present given the trajectory of global energy systems (Hausfather & Peters, 2020). Note that this slightly differs from pathways used in the Fourth Assessment, which considered pathways analogous to SSP2–4.5 and SSP5–8.5.

2.3.1 Temperature

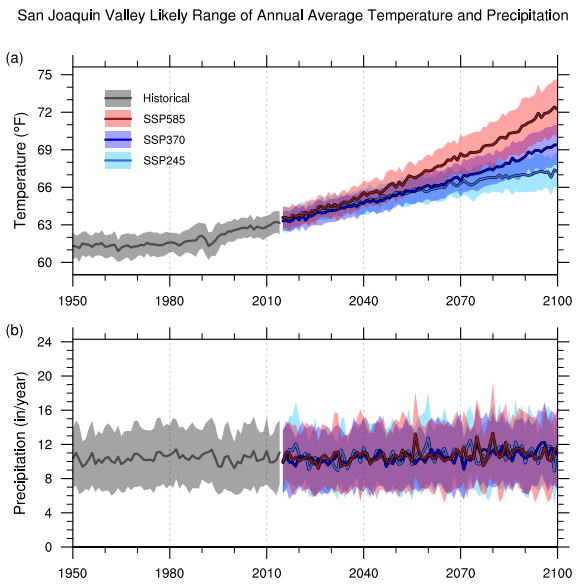
The annual mean temperature in the SJV is projected to increase by approximately 3.5°F (1.9°C) by mid-century (2041–2070) relative to the historical period (1981–2010) and between 4.5–5.5°F (2.5–3.1°C) by the late-century under the moderate (SSP2–4.5) and high (SSP3–7.0) emissions scenarios, respectively (**Figure 2.4, 2.5a; Table S3**). By mid-century, mean temperature is projected to warm more in summer and fall than during winter and spring, with similar seasonal patterns by the end of the century (**Figure 2.4**). While there is some variability in the projected warming across climate models, all models indicate significant warming across all seasons (**Figure S2**). Models with an equilibrium climate sensitivity above 4.5°C (8.1°F) (how much the Earth's surface is projected to warm in response to a doubling of atmospheric CO_2) show slightly higher rates of warming—+0.8°F (+0.4°C) averaged across models for SSP2–4.5 and SSP3–7.0 experiments—by the end of the century than other models.



Projected Monthly Change in Temperature and Precipitation

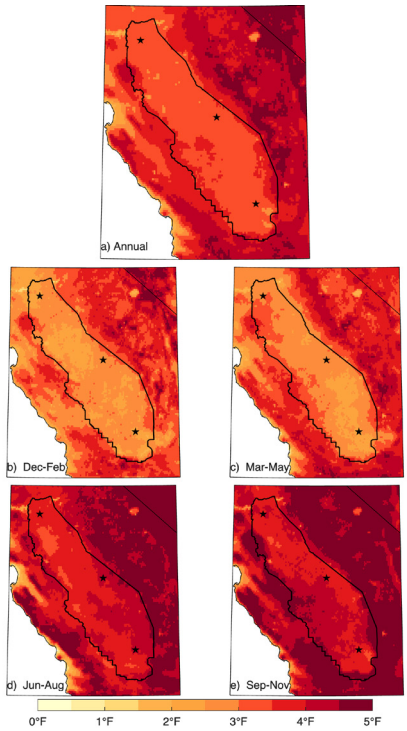
Figure 2.4: *Projected changes in seasonal temperature and precipitation. Projected changes in monthly (a) temperature (°F), (b) precipitation (in/day), and (c) relative precipitation (% of 1981–2010) for the SJV region relative to the historical (1981–2010) period. Results are shown for both mid-century (2041–2070, dashed) and late century (2071–2100, solid). Results are shown for the multi-model mean using SSP3–7.0. Credit: Paul Ulrich (UCD/LBNL).*

Projected warming is largely homogeneous across the Valley (**Figure 2.6; Figure S3–S5**). However, it is worth noting that downscaled climate models show less pronounced warming in the SJV compared to the adjacent Sierra Nevada and Central Coast Ranges—potentially due to amplified warming in those locations due to land-surface feedbacks (e.g., decreased soil moisture and snow) and elevational dependent warming. The models show similar rates of warming for both maximum and minimum temperatures, except in spring, where they show greater warming for maximum temperatures by mid-century (**Figure S3–S4**). Factors such as increased urban development, changes in agricultural practices, and the extent of irrigated lands in the Valley—all of which are uncertain and not incorporated in the modeling effort—will have additional impacts on finer-scale temperature changes beyond those shown here.



San Joaquin Valley Likely Range of Annual Average Temperature and Precipitation

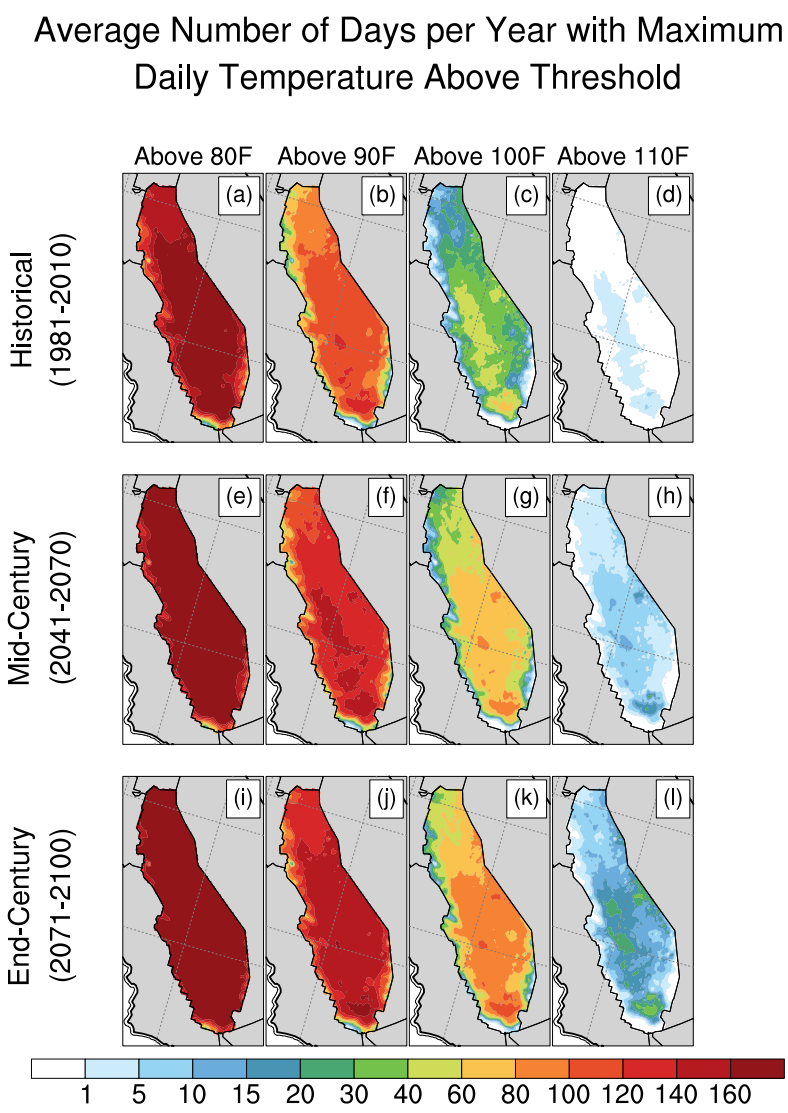
Figure 2.5: *Modeled changes in temperature and precipitation for the San Joaquin Valley through 2100. (a) Mean annual temperature and (b) precipitation likely range estimated by **LOCA2** downscaled global climate models over the historical period (1950–2014; gray) and future periods (2015–2100) under three climate scenarios: SSP2–4.5 (cyan), SSP3–7.0 (blue), and SSP5–8.5 (red). Credit: Paul Ullrich (UCD/LLNL).*



Projected Annual and Seasonal Change in Temperature

Figure 2.6: *Projected temperature change for the San Joaquin Valley. Projected change in mean temperature for (a) annual, (b) December–February, (c) March–May, (d) June–August, and (e) September–November for the mid-century (2041–2070) relative to historical (1981–2010) averages. Results shown are the multi-model median for the first ensemble member from 15 models for SSP2–4.5. The black outline shows the SJV Region.*

Projected changes in the number of hot days (temperatures ≥ 100°F [37.8°C]) and other temperature extremes in the SJV are projected to rise (**Figure 2.7; Figure S6; Table S3**) with longer duration heat waves (**Figure S7**). Periods of elevated heat indices (a combination of air temperature and humidity) have the potential to significantly impact the outdoor labor force in the region (Licker et al., 2022). Agriculture is likewise likely to be adversely affected as the number of very hot days (e.g., > 113°F [45°C]) increases, potentially impacting crops such as pistachio (Parker et al., 2021; Parker et al., 2025). In addition, models project about a 20% decline in winter chill accumulation by mid-century across the SJV that may affect chill-dependent crops (Parker et al., 2025).

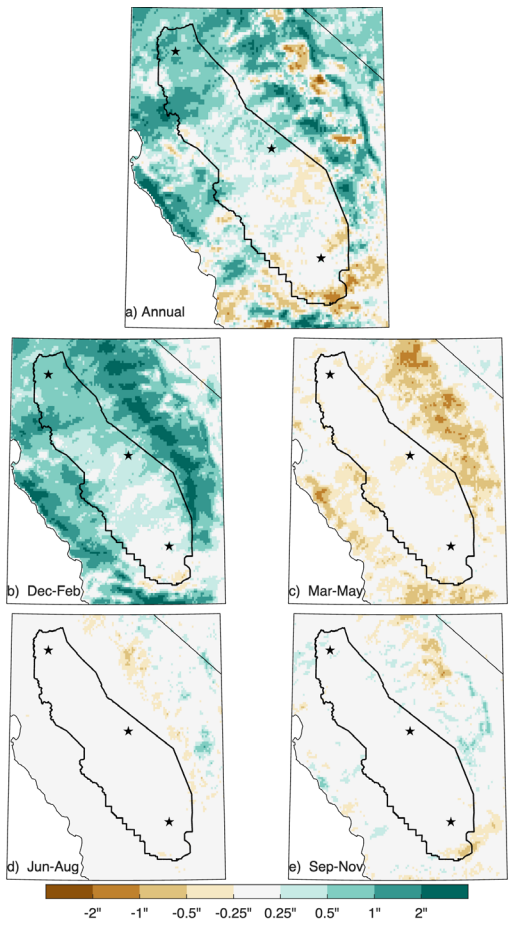


Average Number of Days per Year with Maximum Daily Temperature Above Threshold

Figure 2.7: *Map of the number of days each year where daily maximum temperatures exceed one of four different temperature thresholds (80°F, 90°F, 100°F, and 110°F) for (a-d) historical (1981–2010), (e-h) mid-century (2041–2070), and (i-l) late-century (2071–2100) under the SSP3–7.0 scenario. Results show the multi-model mean change. Credit: Paul Ullrich (UCD/LLNL).*

2.3.2 Precipitation

Projections indicate limited overall change in annual precipitation totals for the SJV. The mid-century annual mean change is negligible, with ample model-to-model variability in projected changes (**Figure 2.5b; Figure S2b**). Notably, changes in precipitation are also small relative to interannual precipitation variability of the region. This ambiguity largely mirrors results from previous model generations (Petrova et al., 2024; He, 2022). The models show a bit more agreement on increased winter precipitation (**Figure 2.4b; Figure S2b; Figure 2.8**), albeit with declines in spring and early autumn precipitation. Spatially, changes in precipitation show a bit more agreement of increased winter precipitation in the northern half of the Valley than the southern half (**Figure 2.8**). The models also tend to show a higher increase in winter precipitation along the western edge of the Valley, in the lee of the Coast Range, due to a weakening of the rain shadow effect (Koszuta et al., 2023).



Projected Annual and Seasonal Change in Precipitation

Figure 2.8: *Projected precipitation change for the San Joaquin Valley. Projected change in total precipitation for (a) annual, (b) December–February, (c) March–May, (d) June–August, and (e) September–November for the mid-century (2041–2070) relative to historical (1981–2010) averages. Results shown are the multi-model median for the first ensemble member from 15 models for SSP2–4.5. The black outline shows the SJV Region.*

2.3.3 Hydroclimate: Floods and Droughts

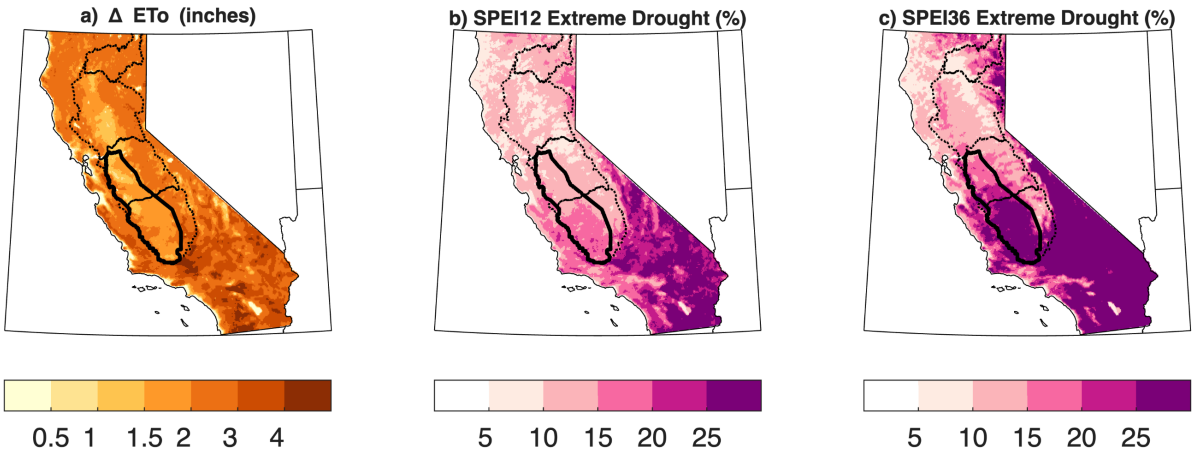
The Valley faces a future of low-probability, high-impact climate extremes that could challenge its resilience. The region is already vulnerable to *whiplash* events, or swings between extremely wet and extremely dry seasons or years, that are projected to increase across the region (Swain et al., 2018; Swain et al., 2025; Persad et al., 2020). This poses risks to the region from both drought, such as the 2012–2016 and 2020–2022 droughts, and floods, such as those that impacted communities like Planada in 2023.

Although projected changes in precipitation are uncertain for the region, changes in precipitation phase (e.g., shift from snow to rain) in headwaters regions of the SJV and warming-driven increases in evaporative demand are likely to lead to increased water scarcity. Continued warming will result in declines in snowpack in the Sierra Nevada at higher elevations, a large decline in average April 1 snow water equivalent, and an increased risk of not only years with little to no snow in early April (Siirila-Woodburn et al., 2021; Norris et al., 2025; Greenspan et al., 2025) but also sequential years with very low snowpack (Marshall et al., 2019). Extreme snow years, like 2023, are already exceptionally rare and are projected to become even less frequent (Marshall et al., 2024), although very wet years in terms of total precipitation and winter runoff from the Sierra may increase (**Figure S8**), thus placing greater emphasis on storage to compensate for summer demands. Shifts in hydroclimate in the Sierra due to warming are ultimately projected to result in earlier streamflow timing and less streamflow during the warm season (He et al., 2021), and more frequent *critical* water year types for the SJV that triggered reduced agricultural water deliveries (He, 2022).

The loss of water storage in spring snowpack will magnify existing disparities in seasonal supply and demand in the SJV, including for agricultural water use (Qin et al., 2020), absent shifts in water consumption or storage. Projected increases in temperature will lead to significant increases in evaporative demand (ETo; **Figure 2.9a**) across California (McEvoy et al., 2020; Abatzoglou et al., 2025; Gamelin et al., 2022), contributing to increased summer drought. Absent changes in cropping practices, this will contribute to an increase in water resources demand given warming-driven increased irrigation requirements. Likewise, chronic increases in evaporative demand will facilitate a shift toward a more arid climate in the region.

Most studies suggest significant increases in the likelihood of extreme multi-year droughts with climate change, similar to the 2012–2015 drought (Cook et al., 2021; McEvoy et al., 2020). Projected changes in 12- and 36-month ***Standardized Precipitation-Evapotranspiration Index (SPEI)*** show increased likelihood of severe drought in the SJV, particularly in the southern half of the region. From a water-supply perspective, increased likelihood of severe drought is also shown in the headwaters of the San Joaquin and Tulare watersheds (**Figure 2.9**). Projected changes in drought risk vary across different definitions of drought. The projected increase in drought risk is primarily due to rising evaporative demand. For example, the Standardized Precipitation Index (SPI), a drought index based solely on precipitation, shows limited change in drought risk and large disagreement on changes in risk across models and scenarios (**Figure S9–S10**). By contrast, SPEI, a drought index which incorporates precipitation and evaporative demand, shows more obvious increases in drought risk (**Figure S9**), thus emphasizing the role of enhanced evaporative demand in future drought projections. The more widely used ***Palmer Drought Severity Index (PDSI)*** that accounts for both precipitation and evaporative demand also shows increased drought probability under future climates similar to that of SPEI (**Figure S9**).

Widespread warming and increased drought frequency will lead to a marked increase in concurrent heat waves and droughts. Compound drought and heat waves not only favor large fire occurrences across much of the state that impact air quality in the Valley, but also increase water demand for agriculture.



Projected Changes in Evaporative Demand and Odds of Extreme Drought

Figure 2.9: *Projected changes in evaporative demand and odds of extreme drought. Multi-model mean change in (a) annual reference evapotranspiration for a grass crop (ETo), and the likelihood of extreme drought realized through (b) 12-month Standardized Precipitation-Evapotranspiration Index (SPEI), and (c) 36-month SPEI for mid-century (2041–2070) under SSP2–4.5. ETo was calculated using the Penman-Monteith approach accounting for the influence of rising carbon dioxide concentrations on stomatal closure (Yang et al., 2019). Extreme drought was defined as the 5th percentile for historical conditions based on the period 1951–2000. The thick black outline shows the SJV Region, while the dashed light outlines depict hydrologic basins in the San Joaquin, Tulare, and Sacramento River basins that collectively are water sources for the SJV. The multi-model mean is limited to seven climate models that had the requisite variables for calculating ETo (ACCESS-CM2, EC-Earth3, EC-Earth3-Veg, GFDL-ESM4, INM-CM5-0, MPI-ESM1-2-HR, and MRI-ESM2-0).*

Climate projections also suggest an increased risk of years with very high amounts of precipitation (Berg & Hall, 2015; Swain et al., 2018) and an intensification of cool-season precipitation (Pendergrass et al., 2017), especially during El Niño years (Allen & Anderson, 2018). Similarly, despite observations not showing significant changes to date (Williams et al., 2024), models project increases in the frequency of heavy rainfall events (He, 2022). Frequency of rare extremes, such as the magnitude of 50-year return events, could increase by 10–30% by the end of the century (Pierce et al., 2023; **Figure 2.10**). Such changes largely reflect a warming climate that increases the moisture holding capacity of the air (Swain et al., 2025). In the SJV, such changes largely manifest due to a projected increase in atmospheric river magnitude and their growing contribution to annual precipitation (Gershunov et al., 2019; Rhoades et al., 2020; Rhoades et al., 2026), thus placing more importance on these events in driving annual precipitation and subsequent economic impacts (Corringham et al., 2022). Exceptionally rare chronic extreme rainfall events, such as those responsible for the historic 1861–1862 Great Flood that inundated large swaths of the SJV, are projected to become increasingly likely with warming (Huang & Swain, 2022).

The southern and central Sierra Nevada are projected to experience more precipitation falling as rain instead of snow leading to reduced snowpack, earlier snowmelt runoff, and a greater frequency of snow droughts (Siirila-Woodburn et al., 2021; Marshall et al., 2019; Beltran-Pena et al., 2025). Significant rain-on-snow events that have historically driven riverine flooding, such as the long-duration 1862 Great Flood and shorter-duration 1997 New Years flood, are projected to become wetter with more precipitation falling as rain versus snow in the headwaters, yielding more runoff through mid-century (Rhoades et al., 2024). Continued warming paradoxically yields a reduction in rain-on-snow flood hazards emanating from the Sierra despite increased precipitation intensity due to the widespread reduction in Sierra snowpack.

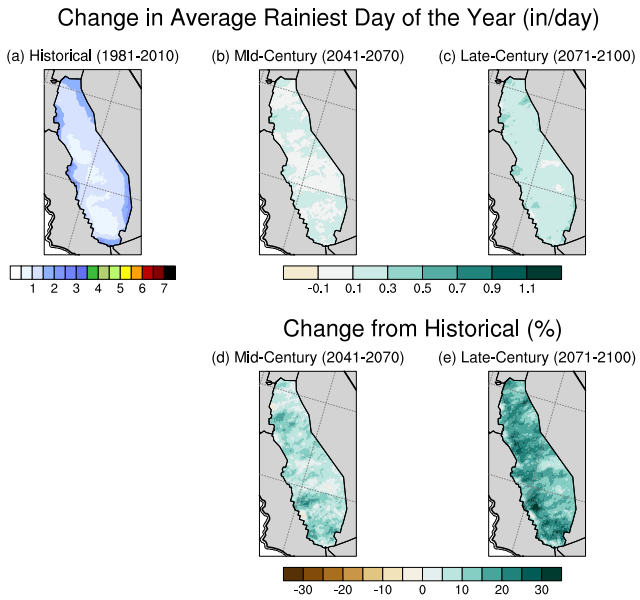


Figure 2.10: *Projected changes in the wettest days of the year. Map of annual average maximum daily precipitation per year (in/day) for (a) historical (1981–2010) and projected changes for (b) mid-century (2041–2070) and (c) late-century (2071–2100) for the SSP3–7.0 scenario. Panels (d, e) show relative changes expressed as a percent of 1981–2010 averages. Results are shown for the multi-model average. Credit: Paul Ullrich (UCD/LLNL).*

2.3.4 Air Quality

Technological and policy changes, such as the transition toward electric vehicles and the phase out of agricultural burning (SB 705 [2003]), are likely to alleviate some of the sources of air pollution that plague the SJV in the coming decades. Yet, other stressors such as increased wildfire smoke from fires in surrounding regions will likely shape the trajectories of regional air quality (Ford et al., 2018). Fire weather is projected to increase during the summer and fall across the broader region (Goss et al., 2020), leading to an earlier start to the fire season (Madakumbura et al., 2025) and facilitating increased fire activity (e.g., Turco et al., 2023) absent significant changes in fire and land management policies. These wildfires not only directly emit PM2.5, leading to hazardous air quality levels, but also contribute to the formation of ozone, further exacerbating air pollution problems (Burke et al., 2023). Dust storms pose another significant health threat to the Valley due to the coarser particles, as well as the potential for dust storms, to be a catalyst to Valley Fever. There has been limited research on how climate change in isolation (e.g., drier soils) or in tandem with other land use changes may alter the frequency of dust events. Acute air quality episodes brought about through widespread wildfires or dust storms can have adverse effects on human health and disproportionately impact vulnerable communities.

2.3.5 Sea Level Rise

Stockton and surrounding areas face significant threats from sea-level rise due to its low elevation and proximity to the Delta. For example, many blocks in western Stockton are projected to be inundated with water levels three feet above high tide that result from a combination of 1–2 foot (30.5–61 cm) sea level rise, riverine flooding, and tidal forces (Climate Central, 2025). More involved modeling exercises suggest significant increases in the risk of inundation between Lathrop and west Stockton by mid-century (**Figure S11**; Delta Stewardship Council, 2021). This poses substantial risks to infrastructure, housing, and the overall well-being of the community. Adaptation strategies such as building seawalls and levees, raising the elevation of structures, and implementing managed retreat are crucial to mitigate the impacts of sea-level rise and protect the communities and infrastructure from future flooding events.

Chapter 3.

Natural and Working Lands & Waters

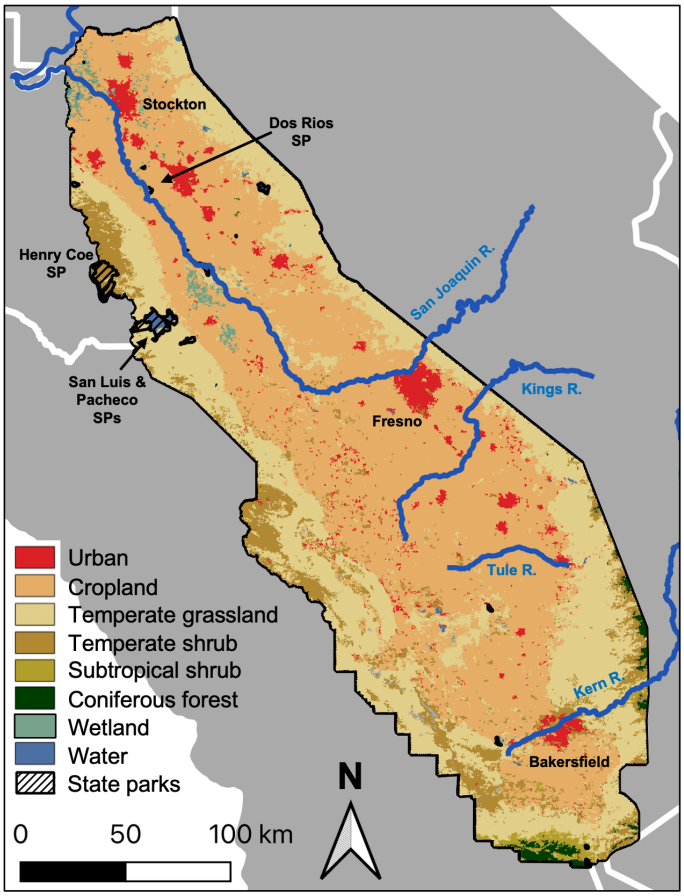


Key Message

Natural and working lands and waters are intertwined in the San Joaquin Valley (SJV). Climate change is disrupting the state's natural water storage and increasing demand, further compounding the region's chronic groundwater challenges. These changes in water resources directly impact the viability of agriculture in the SJV, which is additionally impacted by changes in heat stress and in the frequency of extreme weather events like floods and droughts. Climate change also threatens ecosystems and biodiversity by altering water availability and quality, disproportionately impacting the health, economies, and cultural practices of Indigenous Peoples. These climate-induced changes are compounding problems stemming from past and existing practices: the natural and working lands of this region have undergone a dramatic transformation over the past 170 years, shaped by the state's legacy of mistreatment of and violence against California's Indigenous communities, unsustainable land use practices, and insufficient public investment. This chapter explores how climate change affects the SJV's natural and working lands and waters in conjunction with this history. Despite current challenges, the SJV has the opportunity to lead transformational changes, such as strategic cropland repurposing, climate-smart agriculture, and managed aquifer recharge, which collectively address water security, agricultural sustainability, habitat restoration, and community resilience.

3.1 Historical Context

The SJV has undergone one of the most dramatic landscape transformations in North America. The SJV's pre-colonial landscape was dominated by vast wetlands, riparian forests, grasslands, oak woodlands, and the Tulare Lake (originally known as Pa'ashi)—once the largest freshwater lake west of the Mississippi River. This diverse ecosystem supported hundreds of Indigenous communities for thousands of years who developed sophisticated sustainable land management practices, including cultural burning, selective harvesting, and water management systems. The arrival of European settlers



Natural and Working Lands and Waters in the San Joaquin Valley

Figure 3.1: *Map of the San Joaquin Valley's natural and working lands and waters. Dominant land cover types are shown, with state parks overlaid with hatching stripes.*

led to profound and irreversible changes, including the transition to commercial agriculture and away from Indigenous land management systems that had increased the resilience of the region to extreme flood and droughts (Gilio-Whitaker, 2019). As a result, the Valley lost 95% of its original wetlands and riparian habitat through drainage projects, dam construction, agricultural conversion, and urban development. This transformation eliminated critical habitat for migratory birds and other native species and disrupted the livelihoods of thousands of Indigenous Peoples.

Today, the vast majority of land in the SJV is used for agriculture (**Figure 3.1**). It is the most profitable agricultural region in the US (USDA NASS, 2023), offering substantial agricultural-related employment to the region (Ch. 5). A majority of today's global almond and pistachio production originates in the Valley, with many other high-value specialty crops prominently grown in the region. However, in many places throughout the region, the water demands of these and other crops have outstripped the water supply, leading the region to heavily rely on runoff from the Sierra Nevada, water imports from northern California, and groundwater pumping (Escriva-Bou et al., 2023). The development of these profitable agricultural landscapes has come at the cost of habitat loss and unsustainable groundwater use that has led to extreme land subsidence, thousands of dry wells (Perrone & Jasechko, 2017), and poor air and water quality from agricultural practices.

3.2 Water Resources

3.2.1 Context for Water Resources in the SJV

In the SJV, water supply and demand are seasonally out of phase (Ch. 2). Regional water demands are met through groundwater and spring snowmelt from the Sierra Nevada mountains, with runoff providing the majority of surface water through an extensive network of dams, aqueducts, and canals (e.g., ***Central Valley Project*** and ***State Water Project***, Ch. 4). In the past several decades, runoff has declined and shifted to occur earlier in the year due to climate change (Ch. 2). Groundwater serves as the primary water source during droughts and in places without access to surface water (Hanak et al., 2019). However, groundwater has been overdrafted, with widespread declines in aquifer levels over the past half-century due to land-use changes, punctuated by recent droughts exacerbated by climate change (Liu et al., 2022; Chandanpurkar et al., 2025), leading to land subsidence and the permanent loss of groundwater storage capacity (Smith et al., 2017).

The reduction in water supply has affected the agricultural sector through increased water costs (including energy costs for pumping), impacts of subsidence on infrastructure, and declining land values (Hanak et al., 2023). Water access limitations are also carried by communities and small farms that depend solely on groundwater (Ch. 4, 5), with water access disparities being particularly acute in the southwestern portion of the Valley—a region dominated by large-, mainly industrial-, scale farms.

These pressures on agriculture and communities prompted the State of California to adopt policies that incentivize water conservation, as exemplified by the passage of the ***Sustainable Groundwater Management Act (SGMA)*** in 2014. As a response to the fact that nearly all basins in the Valley are critically overdrafted, SGMA is legislation aimed to achieve groundwater sustainability in California in at-risk groundwater basins across the state (**Box 3.1**).

Box 3.1: *Sustainable Groundwater Management Act & Multibenefit Land Repurposing Program*

The California Sustainable Groundwater Management Act (SGMA, Water Code §§ 10720–10737.8) legally requires reductions in water use, aimed at ensuring groundwater sustainability, water access for rural communities, and sufficient water for environmental flows. Specifically, SGMA requires that groundwater basins achieve balance between recharge and extractions by 2042 (2040 for overdrafted basins). This poses significant challenges to some agricultural operations, which may result in repurposing some of this land for less water-intensive uses. Farmers may modify their agricultural operations, transitioning some croplands to dryland agriculture or rangelands, or they may use the opportunity to repurpose cropland into non-agricultural uses that enhance local economies and bring climate resilience (Fernandez-Bou et al., 2023). Groundwater Sustainability Agencies are also implementing pumping fees and allocation plans that will reduce irrigated cropland.

To address these challenges, the California Department of Conservation created the ***Multibenefit Land Repurposing Program (MLRP)***, which provides incentives for transitioning agricultural land to uses that reduce groundwater reliance while delivering essential benefits to ecosystems and communities. The program's objective is to achieve multiple benefits, including water savings, habitat restoration that supports biodiversity and climate resilience, and economic opportunities that strengthen rural economies. By requiring that all projects deliver community, environmental, and water benefits in tandem, MLRP supports the transition to groundwater sustainability as a pathway to broader regional prosperity (Nuñez-Bolaño et al., 2025; Penny et al., 2025).

3.2.2 Direct Climate Impacts on Water Resources

Climate change has altered the water cycle in the SJV through multiple interconnected pathways (**Figure 3.2**). The most significant change is the observed and projected reduction in spring snowpack in the adjacent Sierra Nevada, with earlier runoff timing and lower summer surface water supply. This shift fundamentally alters the timing of water availability, with more water flowing during winter storms and less water available during the summer growing season when agricultural demand peaks (Ch. 2). The changes in snowpack and runoff, coupled with increased ***evaporative demand***, increases the intensity of drought in the region (Williams et al., 2015, 2020) and strains water resources (e.g., Liu et al., 2022; Williams & Abatzoglou, 2025).

Conversely, climate change may also favor an increase in wet years and extreme precipitation events, as well as increased precipitation variability and hydroclimate whiplash (Ch. 2). Both short-term and interannual precipitation extremes pose risks to infrastructure and communities in areas that are susceptible to flooding. Changes in short-duration extreme precipitation events are affecting stormwater management (see **Box 3.2**) while the potential for recurring flooding in the Tulare Lake basin presents challenges for communities, agriculture, and ecosystems. This increased variability challenges water management systems that are designed for more predictable patterns (Zamora-Reyes et al., 2022; Ch. 4).

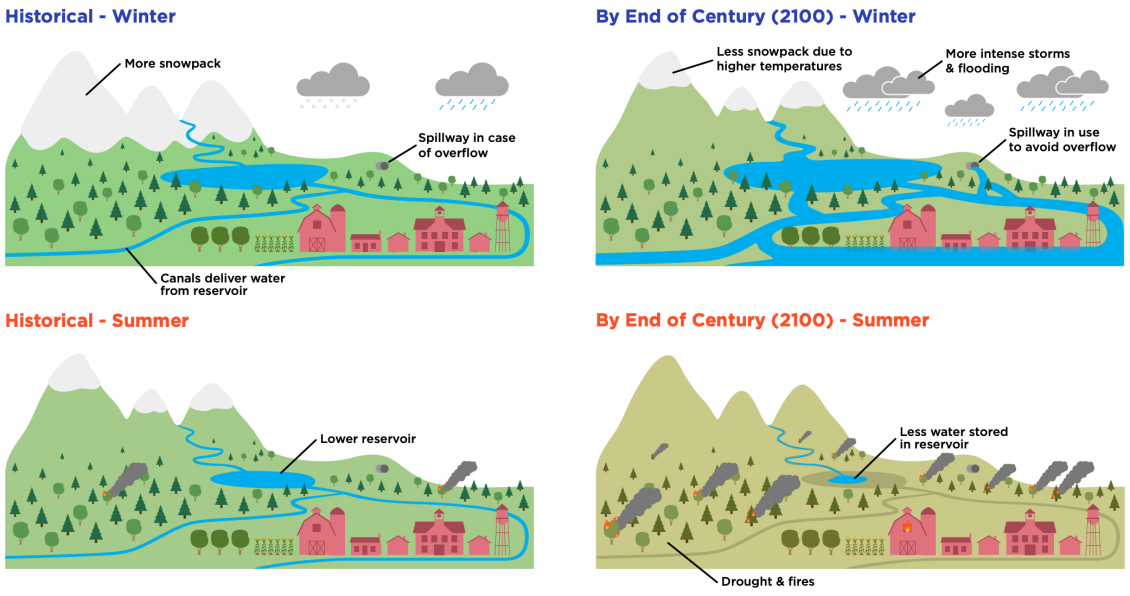


Illustration of Expected Climate Impacts on California Water Supplies

Figure 3.2: *Expected climate change impacts on California water supplies by the end of the century. On the left side, historical conditions for winter and summer show how the climate used to be in California in the past. On the right side, the figure shows what it will look like by the end of the century under projected climate change, under a* ***business-as-usual*** *scenario. Figure credit: Nicholas Iannaco/UCS in Ortiz-Partida et al. (2020).*

Box 3.2: *Fairmead Stormwater Basin*

The Fairmead Groundwater Resilience Project proposes to transform a 17.3-acre water-intensive almond orchard into an integrated stormwater management system in Fairmead, a ***disadvantaged community*** in Madera County. Several community-based organizations and the County of Madera hosted six community workshops to ensure that resident priorities guided the project design. The project serves as a model for collaborative land repurposing that prioritizes community voices and delivers environmental and economic benefits.

The project features a habitat-friendly stormwater basin with native vegetation, a community walking path, and ecological restoration areas with cover crops and pollinator habitats. The project saves 37.6 acre-feet of groundwater annually and is expected to infiltrate 47–72 acre-feet for aquifer recharge, thereby supporting water sustainability efforts. Additionally, the basin serves as flood projection for adjacent communities and infrastructure.

3.2.3 Water Quality Concerns

The SJV has significant water quality issues, particularly due to nitrate contamination from agricultural fertilizers. Intensive livestock operations are the main sources of nitrate pollution for local aquifers, followed by fields irrigated with manure from livestock operations (van der Schans et al., 2009). Synthetic fertilizers applied to agricultural crops also contribute to nitrate pollution, with over half of the nitrogen applied as fertilizer leaching into groundwater (Harter et al., 2012),

creating long-term contamination that affects rural disadvantaged communities as well as Tribal practitioners whose traditional gathering areas and plant materials are vulnerable to groundwater contamination.

Climate change exacerbates these problems. During droughts, declining groundwater levels concentrate dissolved pollutants, leading to poor water quality. In addition, groundwater depletion can mobilize heavy metals—including arsenic, uranium, and chromium—that were previously otherwise stable in aquifer sediments (Hausladen et al., 2018; Smith et al., 2018; Lopez et al., 2021). Moreover, drip irrigation, which has expanded in an effort to reduce ***applied water*** in response to drought and climate change, has unintentionally increased soil salinity (Ward & Pulido-Velazquez, 2008; Mall & Herman, 2019; Pérez-Blanco et al., 2021), reduced groundwater recharge, and, where high-value ***perennials*** have been planted, reduced the flexibility to manage water resources for agriculture during drought (Grafton et al., 2018; Medellín-Azuara et al., 2024).

Additional risks to water quality in the SJV come from sea level rise near the Delta from sea water intrusion (Ch. 2). Intrusion-affected groundwater, with even small amounts of sea water, is unsuitable for drinking (Jasechko et al., 2020) and can increase soil salinity when used for irrigation (Medellín-Azuara et al., 2014; Stone & Chaudhry, 2025).

Finally, increased wildfire in the adjacent Sierra Nevada threatens downstream water quality in the SJV. High-severity wildfires enable increased erosion and sediment into terminal dams that are the surface water supply for the SJV that can persist for a decade post-fire (Paul et al., 2022). Very high sediment loads and post-fire debris flows can reduce reservoir storage capacity, constraining the ability to meet downstream demands (Dow et al., 2024), and degrade water quality, raising treatment costs.

3.3 Agriculture

Climate change is transforming agricultural systems in the Valley through multiple, interconnected pathways that affect physical and biological processes, rural economies, and social well-being. These changes have and will continue to impact agricultural operations, crop productivity, water resources, skilled labor availability, and ecosystem services that agriculture depends upon.

3.3.1 Context for Agriculture in the SJV

Prior to colonization, the combination of fertile soils, warm and dry growing seasons, and seemingly abundant water resources provided an environment well-suited for the hunter-gatherer societies of Indigenous Peoples (see *Section 3.5 Indigenous Knowledges and Natural Systems* for further context). The expansion of large-scale farming damaged wetlands and riparian habitats, which were sources of essential traditional foods like roots, greens, native fish (e.g., salmon), and acorns, as well as medicinal plants, thus impacting Tribal food sovereignty.

These same environmental conditions fostered the development of the SJV as a global agricultural powerhouse, with agricultural development following distinct phases reflecting changing economic conditions and water availability. In the 1850s–early 1900s, wheat and hay were the main crops and about 5% of California farmland was irrigated (Olmstead & Rhode, 2017).

During the 20th century, significant expansion of irrigated croplands occurred through major water infrastructure projects and advanced groundwater extraction technologies. The rise of water-intensive tree crops like almonds and pistachios, as well as the geographic concentration of California dairies in the SJV during the early 21st century, further shaped agricultural lands (Barrowman et al., 2025). Improvements in agricultural infrastructure, market prices, and incentives for water efficiency allowed a transition from ***annual crops*** to ***perennial crops*** in recent decades, particularly tree nuts and fruits (e.g., Geisseler & Horwath, 2016; **Figure 3.3**). This shift toward perennial crops, while profitable, also requires irrigation regardless of water availability (e.g., during droughts). This increasing water demand led the state to incentivize irrigation efficiency. However, instead of conserving more water, the incentivized technologies, such as drip irrigation, enabled the cultivation of previously marginal areas and decreased the return flows to groundwater from flood irrigation (Grafton et al., 2018).

The SJV accounts for roughly 5.7% of the US agricultural economic production and more than half of California's total agricultural production, which was valued at $40 billion in 2024 (USDA NASS, 2025). The Valley is the leader in many high-value specialty crops, including almonds, pistachios, grapes, tomatoes, citrus, as well as dairy. The Valley is also responsible for about half of the state's agricultural jobs (CA Employment Development Department, 2025) and a sizable portion of the region's employment and economy is directly tied to the agricultural sector (Escriva-Bou et al., 2023), accounting for 16.4% of the SJV gross domestic product (US BEA, 2024). Thus, the regional economic reliance on agriculture makes the SJV particularly vulnerable to climate-related economic disruptions that can affect entire rural communities (Ch. 5).



Table Grape Harvest in Kern County

Figure 3.3: *Harvest of table grapes at a Kern County vineyard. The San Joaquin Valley grows both table and wine grapes, but accounts for a vast majority of the table grapes grown in the US. Credit: DWR, 2014.*

3.3.2 Physical Effects of Climate Change on Agriculture

Temperature increases directly impact agricultural suitability in the Valley. Yet, while climate change creates thermal and water stress that can reduce economic viability of certain crops, it may also enable opportunities for novel cropping systems. We present some of the general impacts in the following sections, but also highlight climate change vulnerabilities and potential adaptation solutions for illustrative SJV crops in **Table S5**.

CHILL HOUR REDUCTION AND COLD DAMAGE

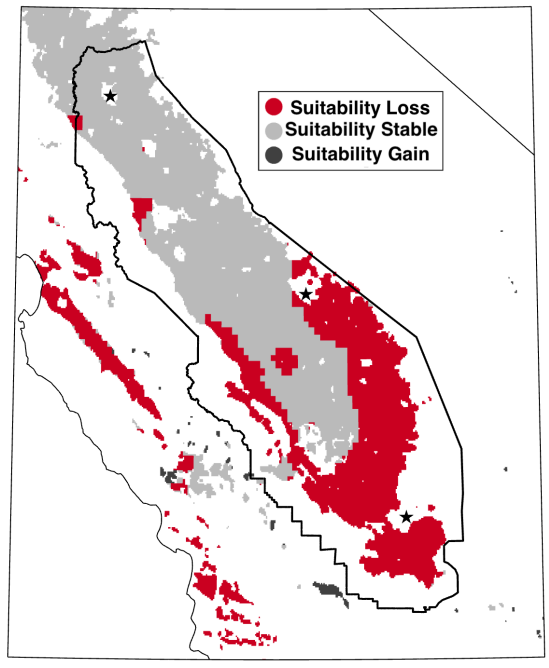
Many high-value perennial crops require a minimum number of ***chill hours*** (i.e., hours between 32–45°F [0–7.2°C]) to break dormancy, synchronize blooming, and ensure proper fruit development. Reduced chill accumulation is driven by both generally warming winter temperature trends as well as the reduction of ***Tule fog*** (Ch. 2), affecting orchard profitability for chill-dependent crops (Gray et al., 2019). Chill reduction is particularly acute in the southern portion of the SJV. Crops such as walnuts and pistachios, which have high chilling requirements, are particularly at risk (Pathak et al., 2018). Cherry, plum, and apricot cultivars that may currently be only marginally suited in terms of chill hours will become increasingly unsuitable and may require migration to cooler areas or replacement with lower chill-requirement varieties. For example, Bing cherries—a major variety primarily grown in the SJV today—are projected to become less viable in the southern SJV due to insufficient chill by the mid-21st century (**Figure 3.4**).

Warming is projected to reduce the frequency of cold damage risk to crops like citrus and almonds (Parker et al., 2021), making the widespread freeze events in 1990, 1998, and 2007 that resulted in billion dollar losses for the region less common (NOAA NCEI, 2025). Likewise, novel perennial crops, such as agave and thermally-tolerant avocado varietals, that do not historically tolerate occasional winter freezes may become more suitable with warming.

HEAT STRESS

Extreme heat events are becoming more frequent and intense, leading to direct physiological stress for both crops and livestock. Heat waves reduce photosynthesis efficiency, decrease pollen viability, and increase seed abortion rates, resulting in lower yields and quality (Siebert & Ewert, 2014). Extremely hot temperatures (e.g., daily maximum temperatures ≥113°F [45°C]) that impact pistachio crops have historically been extremely rare in the SJV, but are projected to become more prevalent by mid-century (Parker et al., 2025), leading to direct crop impacts barring adaptation efforts. Increased heat stress during specific crop phenological phases, such as flowering, can also impact crop yield and quality (e.g., tomato pollination). Processing tomatoes are projected to see 10–16 additional days of pollination, with temperatures detrimental to yield, by mid-century (Parker et al., 2025).

California dairy operations—a majority of which reside in the SJV—face particularly severe challenges. With no heat adaptation,



Modeled Thermal Suitability of Bing Cherry

Figure 3.4: *Modeled thermal suitability of Bing cherry under historical (1971–2000) and mid-century (2041–2070) climate change. Results are shown for a multi-model mean based on* ***MACAv2-gridMET*** *using a prior generation of climate projections under a high-emission scenario. Created using Climate Toolbox.*

milk production is estimated to decrease by 20% by the end of the century under a high-emissions scenario, equivalent to ~4,500 pounds of milk per cow per year (Gunn et al., 2019). Furthermore, cow mortality can occur with chronic exposure to temperatures exceeding 90°F (32.2°C) (Vitali et al., 2015; Bishop-Williams et al., 2015). Milk yield reductions are projected for two-thirds of California dairies due to climate change (Medellín-Azuara et al., 2026). Adaptation efforts to reduce such potential impacts include provision of shade and ventilation with fans and misters for dairy cattle.

WATER AVAILABILITY AND DEMAND CHANGES

Agriculture accounts for 89% of the water use in the SJV (Hanak et al., 2017). Declines in surface water flows (Ch. 2) can increase reliance on groundwater while increased evaporative demand can increase irrigation demand (Moyers et al., 2024; Williams & Abatzoglou, 2025; Liu et al., 2022). Agricultural water demand in the SJV has increased by approximately 650,000 acre-feet due to higher evaporative demand in the past four decades (Moyers et al., 2024), with human-caused climate change accounting for at least a third of this increase (Williams & Abatzoglou, 2025). Just in 2022, the human-caused climate change contribution to this increase over the Central Valley (Sacramento and San Joaquin regions together) was equivalent to the municipal water needs of 3.2 million people in CA (Williams & Abatzoglou, 2025). Rising evaporative demand (Ch. 2) will continue to impact irrigation requirements for crops and increase water scarcity. Multi-year droughts, in conjunction with existing water supply issues, have led to orchard removal and contraction of operations in some Valley farms.

Changes in crop phenology (e.g., faster maturation for certain crops) and changes in water use dynamics with rising CO_2 concentrations may partially buffer overall increases in future irrigation needs for some annual crops (Abatzoglou et al., 2025). However, while elevated CO_2 concentrations might theoretically benefit some crops through enhanced water use efficiency (Kandwhay et al., 2025), potential gains are crop-specific and may be offset by yield losses from higher temperatures (Parker et al., 2020). Thus, while more rapid crop development may somewhat offset the direct impacts of increased evaporative demand, such changes, superimposed with declines in spring snowpack, are likely to escalate the longstanding water challenges in the SJV.

EXTREME PRECIPITATION

Projected increases in storm intensity, combined with shifts from snow to rain, may strain local and riverine flood control, leading to flooding on agricultural land. Flooding during the winter may support aquifer recharge in areas with suitable soils (O'Geen et al., 2015; Knight et al., 2022; Knight et al., 2018). However, more intense rainfall or flooding can delay planting efforts for annuals or cause crop damage if events occur after planting. Similarly, flooding can cause crop damage in perennials—particularly if it occurs outside of the dormant season—and heavy precipitation can cause crop damage when events overlap with key crop development stages. For example, heavy precipitation near harvest can lead to split skin in cherries, as happened in 2019 (FreshFruitPortal, 2019), and impact quality of table grapes and raisins like it did in 2025. Finally, increases in the frequency of very heavy precipitation due to climate change may contribute to accelerated rates of soil erosion and nutrient loss.

3.3.3 Biological Effects of Climate Change on Agriculture

Climate change is impacting biological interactions in agricultural systems, creating new challenges for crop protection and ecosystem service provision. These biological effects can amplify the direct physical impacts of climate change, creating cascading effects throughout agricultural systems.

POLLINATION SYSTEM DISRUPTION

A vast majority of crops in the SJV depend on pollinators, with pollinator-dependent crops continuing to expand (Klein et al., 2007). Climate change affects these critical relationships, including shifts in pollinator species ranges, alterations in phenology and physiology of pollinators (Scaven & Rafferty, 2013), and modifications in species interactions and resource availability. The SJV's trend toward perennial tree crops intensifies pollination demands, requiring massive annual importations of managed beehives, with 60–75% of the country's commercial beehives shipped to California for almond tree pollination (Marcelino et al., 2022). The introduction of commercial honey bees competes with native bees for resources, impacting native bee populations and subsequently other ecosystems they interact with. Additionally, weather conditions—including temperature and precipitation occurrence—during the pollination window can substantially impact pollination efficacy (Freitas et al., 2023).

Climate change may further impact wild bee populations in California. For example, models suggest a loss of climatic suitability for these species in the Central Valley at present (2015–2044) relative to a 2000–2014 baseline. The Fifth Assessment report "Pollination in a Changing World: The Effects of Habitat and Temperature on the Health of California's Wild Pollinators" examines how climate change impacts *Osmia lignaria*, a California native bee species, pointing to ongoing loss of suitability for this species in the Central Valley—see the full report for more information (Gaiarsa et al., 2026). These changes will further impact pollination in the Valley and reinforce efforts to protect pollinators and their habitats.

ENHANCED PEST AND PATHOGEN PRESSURE

Warming temperatures are creating more favorable conditions for agricultural pests and pathogens while potentially disrupting natural pest control mechanisms. Higher temperatures enable increased insect reproduction rates and enhance overwinter survival, leading to larger pest populations and more generation cycles per season (Bale et al., 2002; Luedeling et al., 2011; Trumble & Butler, 2009). For example, nut crops face intensified pressure from navel orangeworm and codling moths, as warming temperatures allow their populations to build up (Pathak et al., 2021). It is less well known how climate change will impact beneficial predatory insects that are used in integrated pest management strategies in the SJV. However, beneficial insects that provide natural pest suppression are often more sensitive to climate extremes and chemical pollution than their pest targets, leading to diminished biological control effectiveness (Damien & Tougeron, 2019). Like pests, pathogens are responding to changing temperature and precipitation patterns in complex ways. While warmer winters may improve pathogen survival rates, drier conditions can limit their geographic range and growth potential. The microorganism responsible for root rot (*Phytophthora cinnamomi*) exemplifies these complex interactions, where temperature and moisture conditions determine both survival and spread (Thompson et al., 2014).

3.3.4 Externalities of Agriculture Related to Climate Change

In addition to being highly vulnerable to climate impacts, agriculture is a contributor to ***anthropogenic climate change***. For example, about 70% of emissions from California agriculture are methane emissions from livestock (Legislative Analyst's Office, 2021). Agriculture's CO_2-equivalent emissions alone, based on estimated social costs of carbon of ~$200/ton CO_2-equivalent, cost approximately $6.5 billion annually (EPA, 2023; CARB, 2024). The direct greenhouse gas (GHG) contribution from agriculture can however be reduced through farming practices that sequester carbon (e.g., biochar, compost, tilling practices) and emit less carbon (e.g., fertilizers, electric vehicles).

Changes in agricultural practices and land use can result in changes in both local climate and other hazards. For example, policy-driven reductions in irrigation may reverse the irrigation cooling influence on summer temperatures on local-to-regional scales and compound the direct influence of climate change. Secondly, recent increases in dust events in the Valley—particularly notable during multi-year drought events (Adebiyi et al., 2025) in areas of idled cropland—may become more likely due to ongoing aridification of the region due to climate change alongside changes in land use.

3.4 Biodiversity and Habitat

3.4.1 Context for Biodiversity and Habitat in the SJV

Despite landscapes having been radically transformed by development, the region is biodiverse and hosts many habitats. For example, the Valley has lost over 95% of its original wetlands with remaining habitats existing as isolated fragments within a matrix of agricultural land. However, the SJV is host to one of the highest concentrations of overwintering waterfowl in the Pacific Flyway, and remaining habitats support numerous species such as the giant kangaroo rat, blunt-nosed leopard lizard, San Joaquin kit fox, and various endemic fish species, including the Sacramento perch and Delta smelt.

Much of the native vegetation in the SJV is adapted to the significant within year variability in moisture, with native grasses and shrubs going into summer dormancy when water is scarce. Likewise, trees such as Valley Oak have significant tap roots to access groundwater in the summer months, and are found in some of the remaining riparian areas of the SJV. Blue Oak trees can be found in the uplands of the Valley. The significant year-to-year variability in winter precipitation also yields large fluctuations in biomass of annual grasslands and wildflowers during the spring.

3.4.2 Habitat Fragmentation and Conversion

Habitat fragmentation has created a matrix of isolated remnants of habitat. These fragmented lands constrain connectivity for species and increase stress on remaining natural habitats. Wetlands and riparian areas in the Valley have been nearly eliminated, with remaining fragments often degraded by altered hydrology and invasive species. Likewise, Valley grasslands have largely been converted to agriculture or invaded by non-native annual grasses. Collectively, these changes have limited habitat resources and connectivity to support endemic plants and animals.

3.4.3 Climate Impacts on Ecosystems

Warming directly influences aquatic species in the Valley. Earlier snowmelt runoff disrupts native fish life cycles, and warmer stream temperatures impact heat-intolerant species such as salmon. Declines in water resources imparted upstream diversions and climate change may further fragment aquatic habitat, barring changes in water management. Reduced seasonal wetland habitat impacts migratory birds on the Pacific Flyway. Despite the Valley supporting the world's highest waterfowl concentrations, future droughts may lead to insufficient flooding and habitat for overwintering birds (Wilson et al., 2022). Lastly, vernal pool ecosystems in the Valley are potentially at risk due to climate change. Reduced spring precipitation and increased evapotranspiration may lead to fewer, shorter-lived pools (Bauder, 2005). These changes in inundation amount and timing, coupled with warming driven changes in phenology, threaten endangered species that use vernal pools, such as the California tiger salamander, fairy shrimp, and spadefoot toad (Hendrickson et al., 2025).

Grasslands and rangelands in the Valley have significant interannual variability in productivity. Reduced productivity during drought (Dannenberg et al., 2022) preferentially drives species to seek resource availability in developed and agricultural lands in the Valley (Goldstein et al., 2024). This leads to food scarcity for herbivores, cascading through higher trophic levels and driving animal population declines. Species like the giant kangaroo rat, blunt-nosed leopard lizard, San Joaquin kit fox, and burrowing owl—all species that rely on burrows to avoid heat and cold stress—face dual threats from productivity decline due to drought and increased flood frequency. Impacts on grasslands and rangelands also include extreme heat, pushing local species like the San Joaquin kit fox to their thermal tolerance limits.

3.5 Indigenous Knowledges and Natural Systems

3.5.1 Historical and Contemporary Context

The SJV is the ancestral territory of numerous Tribes, including but not limited to the Northern Valley Yokuts, Southern Valley Yokuts, Foothill Yokuts, Tubatulabals, Kitanemuk (Tejon), Western Mono, and Miwok Peoples. The Indigenous Traditional Ecological Knowledge (TEK) espoused by these Tribes has been developed through thousands of years of reciprocal relationships with the region's land and waters (Whyte, 2018). From a western science perspective, practices based in Indigenous TEK maintain ecological health and resilience, such as water retention and flood control, soil health, natural pest control, biodiversity conservation and habitat restoration, and soil organic matter and carbon fixation (Jessen et al., 2022). For example, cultural burning regimes created a mosaic landscape that supported biodiversity, reduced extreme wildfire risk, and maintained the integrity of culturally important species (Adams et al., 2025; Fisk et al., 2024; Long et al., 2021).

Beginning in the 16th century with Spanish colonization, as in much of the Americas, these practices were disrupted through the genocide and displacement of Indigenous Peoples. This was accompanied by the introduction of non-native livestock, which disrupted plant species from grazing, as well as newly managed waterways which damaged wetland ecosystems (Hundley,

1992). A century later, the Indigenous population declined by 85% due to disease, violence, and systematic persecution brought by a surge of settler colonialism, accompanying the Gold Rush and the California statehood (Cook, 1976; Madley, 2016). On these stolen lands, western land management dramatically transformed the landscape through mining, water infrastructure, and industrial agriculture, fundamentally reshaping the Valley's hydrology, soil, and biodiversity (Hundley, 1992). Disruption of these traditional practices has contributed to ecosystem degradation, including loss of biodiversity and proliferation of invasive species (Fernández-Llamazares et al., 2021).

Despite this history of systemic violence, erasure, and dispossession, thousands of Indigenous Peoples continue to live in the region today, remain deeply connected to their ancestral lands, and continue to practice Indigenous TEK (Goode et al., 2018). There are 16 federally recognized Tribes in the SJV: the Santa Rosa Rancheria (Tachi Yokut; see **Box 3.3**), Picayune Rancheria of Chukchansi Indians, Tule River Indian Tribe, California Valley Miwok Tribe, North Fork Rancheria of Mono Indians, Dunlap Band of Mono Indians, Mariposa Southern Sierra Miwuk Tribe, Chaushilha Yokuts Tribe, Big Sandy Rancheria, Cold Springs Rancheria, Wuksachi Tribe, Table Mountain Rancheria, Dumna Woa Tribe, Choinumni Tribe, Choinumni Traditional Indian Tribe, and Wukchumni Tribe (Goode et al., 2018). Additionally, at least 11 non-federally recognized Tribes maintain strong cultural and historical ties to these ancestral territories.

Box 3.3: *Tachi Yokut Story based on Kenny Barrios personal communication (2025) and (Moreno, 2018). Kenny Barrios is the cultural liaison of the Tachi Yokuts, and part of the advisory group for the San Joaquin Valley Regional Report.*

The Tachi Yokut story reveals how Indigenous practices sustained abundant ecosystems for millennia before colonial disruption. Pa'ashi (Tulare Lake) once formed the heart of a thriving region with three villages around what was the largest freshwater lake west of the Mississippi. The Tachi Yokut were sophisticated land stewards who practiced cultural burning to maintain ecosystem health. Their resource management philosophy centered on taking only what was needed while keeping "the land better than when you received it", resulting in air quality so clear that visibility extended 50–60 miles.

Traditional life revolved around the lake's abundance. Tule reeds provided materials for homes, boats, decoy ducks for hunting, and clothing. Willow served as house frames, while various plants supplied cordage and basketry materials. The Tachi understood themselves as intimately connected to all life—their creation stories describe how each animal shared parts of themselves to create humans from the Pa'ashi lakebed. This interconnected worldview fostered caring communities where "everybody was teaching everybody's child something" and people maintained equal responsibility for land, water, and animals.

Colonization systematically dismantled this sustainable way of life. Spanish missions forcibly converted Indigenous Peoples to Christianity, forbidding their languages, songs, and ceremonies. Then, with the US colonization, the California and Federal governments incentivized an Indigenous genocide between 1850–1900 that was catastrophic for Tribes, and the Tachi Yokuts lost over 90% of their population. Survivors were confined to just 40 acres of deliberately chosen "desolate farmland" with alkali soil where nothing would grow—land selected to ensure extinction. The intention was clear: the Tachi "were not supposed to make it on the piece of land that they gave us."

Along with the genocide, the fundamental conflict became the destruction of Indigenous land to create large-scale farms. The Tachi were "caretakers of the land" with entirely different relationships to natural systems. Colonial resource extraction drove repeated forced relocations—when oil was discovered in their territory, the Tribe was displaced yet again, following a pattern repeated across the SJV.

The suppression of traditional ecological practices had profound environmental consequences that persist today. Without Indigenous fire management, California experiences unprecedented overgrowth and air quality problems. Without traditional water stewardship, agriculture and pesticides now contaminate water sources. The lake that once sustained millions of migrating birds and abundant wildlife was purposely dried and replaced by industrial farming systems that leave nearby communities like Allensworth without safe drinking water (see **Box 5.3**).

This history illuminates how colonial disruption of Indigenous Knowledge systems not only devastated Native communities but also stripped the SJV of sustainable land management practices that had maintained ecosystem health for millennia. As the region confronts climate change impacts, it is increasingly critical to understand and address the loss of this natural resilience fostered by sustainable ecological practices.

3.5.2 Climate Impacts on Culturally Important Resources

Tribal observations corroborate scientific assessments of climate change: shifts in precipitation, altered growing seasons, degraded wetland and riparian zones, changed wildlife behavior and migration patterns, and reduced populations of culturally significant species (Goode et al., 2018). Tribal observations have also identified unique impacts of climate change on lands and waters otherwise missed by western scientific assessments: plants used for food, medicine, and ceremony are declining due to drought and water mismanagement. The combination of colonial land use practices and climate change threatens both species composition and cultural accessibility of important gathering sites across the SJV (Goode et al., 2018). Many of these locations are in riparian zones, wetlands, and other water-dependent ecosystems that are particularly vulnerable to hydrological changes, in addition to land use changes (Wilson et al., 2022). For example, traditional plants used by basket weavers—including white root (*Carex barbarae*), various willow species (Salix spp.), deer grass (*Muhlenbergia rigens*), and tule

(*Schoenoplectus acutus*)—are experiencing habitat contraction and quality degradation, such as the loss of natural wetlands and floodplains (Wukchumni Tribe, personal communication, 2025; Zedler & Stevens, 2018; CIBA, 2020). In particular, tule reeds that grew in the Tulare Lake served as material for constructing shelters, watercraft, floor coverings, and fishing equipment, making both the reeds and the lake itself essential to Tribal life (Wuckchumni Tribe & Tachi Tribe, personal communications, 2025). However, as tule requires specific moisture conditions, they are especially sensitive to hydrological changes and particularly vulnerable to drought and temperature extremes. Furthermore, deer grass, also used in basketry, is recognized as key to riparian restoration. Thus the combination of climate change and land degradation has both direct and indirect effects via disrupting the key cultural practices of Tribes, on the plants themselves, and on the wildlife species that depend on them (Stevens, 2003).

3.5.3 Exclusion Versus Inclusion in Planning

Mitigation of and adaptation to these impacts requires partnerships with Tribes and representation of Indigenous voices in the planning process. However, in many areas, Tribal communities still face systemic exclusion from land-use planning and climate adaptation efforts, and the SJV is no exception. Many current legal and regulatory frameworks fail to recognize Indigenous rights to meaningfully participate or lead environmental decision-making—or even provide adequate and appropriate consultation in land management decisions, despite their extensive knowledge and historical stewardship responsibilities (ELI, 2024). At the federal level, the National Environmental Policy Act (NEPA) and Section 106 of the National Historic Preservation Act (NHPA) are procedural statutes that require Tribal consultation but do not mandate that agencies incorporate Tribal input or protect cultural resources from harm (Wilkinson, 2022). In California, SB 18 (2004) and AB 52 (2014) require Tribal consultation for local government planning and for projects that trigger the California Environmental Quality Act (CEQA), yet in interviews by the Environmental Law Institute, two-thirds of Tribal respondents reported insufficient time for consultation and indicated that Indigenous Knowledges are not given sufficient weight in decision-making (ELI, 2024). As some Tribes lack formal recognition or co-management rights, particularly non-federally recognized Tribes, this presents a significant barrier to practicing key cultural activities and caring for the land (Krol, 2019). Many culturally significant sites are now private property, within state and federal protected areas, or have been altered by agricultural and urban development.

Despite these barriers, Indigenous stewardship continues through cultural revitalization, community education, and restoration efforts. Projects led by Tribal groups—such as riparian restoration at the Wuk'na'nain Plains, led by the non-federally recognized Wukchumni Peoples, and at Dos Rios State Park, guided by the Miwok and Yokuts Tribal Communities—demonstrate the power of partnerships with traditional land stewards for land restoration, weaving together Indigenous TEK with climate resilience strategies (**Box 3.4**).

Box 3.4: *Examples of Successful Partnerships Between Indigenous Communities & Western Partners for Land Restoration*

Wuk'nain Plains Restoration

The Wuk'nain Riparian and Wetland Habitat Restoration project in Tulare County is an ongoing restoration effort that aims to rebuild Indigenous ecosystems while supporting pollinator populations and improving local groundwater systems. Specifically, this project is restoring 10.7 acres of riparian woodland, willow forest, and freshwater marsh from land that was previously a Christmas tree farm. This project is led by the Wukchumni Tribe, in partnership with Quaker Oaks Farm, and supported by a half-million-dollar investment from the Kaweah Multibenefit Land Repurposing Program. Notably, while the project does not involve transferring land ownership back to the Wukchumni Peoples, it marks a significant step forward in recognizing Tribal expertise and leadership in environmental stewardship. The initiative creates multiple benefits for both Tribal and non-Tribal community members, including training programs, recreational access, and employment opportunities that reconnect people with traditional ecological practices. The restoration work includes cultivating native species, rebuilding degraded habitats, and strengthening natural flood management systems to benefit regional environmental health.

Dos Rios State Park

The Dos Rios State Park opened in 2024 as California's newest state park, and is an example of successful multi-benefit land repurposing. Situated at the confluence of the Tuolumne and San Joaquin Rivers near Modesto in Stanislaus County, this project converted 1,600 acres of a former dairy operation into open space, thus eliminating dairy-related emissions and nutrient runoff, improving local air and water quality while providing access to recreational green space to historically underserved communities. This project was made possible by $40 million in funding from multiple sources; was managed by the nonprofit organization River Partners, in partnership with community organizations; and construction and restoration activities created 250 jobs in the ***disadvantaged community*** of Grayson, providing workforce development in environmental restoration (Ch. 5).

Central to this effort was meaningful engagement with the Miwok and Yokuts Tribal Communities, who were involved throughout the planning and implementation process. Thus, guided by Indigenous TEK, the effort resulted in a restored floodplain and riparian habitat that has historically supported Indigenous communities for millennia. Under this guidance, Dos Rios became California's largest floodplain restoration project to date (**Figure 3.5**), enhancing regional climate resilience to changing precipitation and snowmelt patterns. The project provides critical flood protection, safeguarding downstream communities like Stockton and reducing pressures on levees (Ch. 4), as well as providing water storage and aquifer recharge as floodwaters infiltrate shallow aquifers, conserving 7,000 acre-feet of freshwater annually and creating critical habitats for nine priority species, including the endangered riparian brush rabbit and least Bell's vireo. Dos Rios also includes a 3-acre Native Use Garden that features plants used in traditional basketry and other cultural practices, serving as a living repository of culturally significant plants and traditional practices and acting as an active gathering place for Tribes.

Dos Rios Floodplains in Action



Figure 3.5. *Floodplains in Dos Rios. Credit: River Partners.*

3.6 Solutions and Adaptation Strategies

"As water becomes less reliable and temperatures continue to rise, we need science to help guide a fair and sustainable shift in agriculture. What practices, like crop diversification, regenerative soil strategies, or water recycling, can help farms stay productive while protecting the livelihoods of farmworkers and small-scale growers? How do we make sure that these changes don't push more people off the land or concentrate ownership further?"

— Community Leader, via survey

The primary climate adaptation strategies for natural and working lands and waters in the SJV rely on alleviating competing ***anthropogenic*** pressures on land and water resources through partnership with local communities and traditional land stewards. Significant declines in groundwater, failing wells, and subsidence all point to the chronic imbalance in water budgets in the region. While the ultimate tapestry of how SGMA plays out across water districts in the SJV is to be determined, there are calls for some of the region's croplands to be repurposed to curtail irrigation demands, particularly in heavily groundwater-dependent regions (Hanak et al., 2019; Medellín-Azuara et al., 2024). Solutions to implement SGMA are not simple, as agriculture is both culturally and economically important to many residents of the SJV (Ch. 5). Thus, a collaborative effort that considers socioenvironmental and economic benefits for all should be considered. Such transformations could include land devoted to ***agrivoltaics*** or floodplain restoration projects. Land use transitions away from water-intensive agriculture practices may be done in a way that also minimizes economic harms by considering crop mosaics that preserve the highest economic payoff and localized employment. We highlight five adaptation strategies for the SJV's natural and working lands that aim to increase regional climate resilience. While there are numerous potential adaptation and mitigation strategies for the SJV's lands, we focus on partnerships for habitat restoration, ***managed aquifer recharge (MAR)***, ***Multibenefit Land Repurposing Program (MLRP)***, climate-smart agriculture, and water markets.

3.6.1 Partnerships for Land Restoration

Habitat restoration is key for supporting not only flora and fauna, but also for groundwater resources. Moreover, conducting this habitat restoration in partnership with Indigenous communities throughout all stages of the project is key, not only to ensure the restoration activities align with teachings from Indigenous TEK but also to support traditional cultural practices. Two existing projects—Dos Rios State Park and Wuk'nain Plains—present success stories (**Box 3.4**). As another example, centering Indigenous TEK in tule marsh restoration work offers the co-benefits of floodplain restoration, wetland revival, groundwater recharge, and land repurposing in the SJV. Tribal harvesting and caretaking of tules is done for building boats, basketry, and ceremonial uses. To support this, seasonal burning around tule marshes is used by Indigenous communities to clear dead material, restore habitat, stimulate healthy tule regrowth, and improve waterfowl populations. Additional projects that are based in deep collaboration with Indigenous communities can support further transformation of degraded lands and waters into healthy ecosystems.

Collaboration should also include partnership with local communities. The Allensworth agroecology hub offers another case study of a community-led effort for land restoration for multi-benefit uses (**Box 5.3**). This project includes plans for community-led farming and

groundwater recharge, but also highlights the need for additional capacity (financial and otherwise) for such projects.

3.6.2 Managed Aquifer Recharge

The dramatic swings from low to extreme precipitation seen over the SJV in recent years (Ch. 2) highlight the need for both better flood control and an increase in groundwater recharge during wet periods to meet water demands in dry periods (Medellín-Azuara et al., 2024). This has catalyzed research on the use of natural infrastructure for aquifer recharge (Kocis & Dahlke, 2017; Kourakos et al., 2019). ***Managed aquifer recharge (MAR)*** captures winter runoff that exceeds instream flow needs and stores it for later use in the dry season and dry years (Kourakos et al., 2019; **Figure 3.6**), including during flood events (Flood-MAR). This integrated water management strategy aims to use flood flows, resulting from rainfall or snowmelt runoff, for MAR on a variety of landscapes, from agricultural lands to recharge basins or even ecosystem refuges. A subset of MAR—Agricultural Managed Aquifer Recharge (AgMAR)— includes flooding fields where crops are tolerant or dormant (e.g., annual crops and some perennials such as grapes and alfalfa; Dahlke et al., 2018), cognizant of potential groundwater quality issues (e.g., leaching from fertilizers and pesticides; Ch. 5). In addition to reducing flood risk and increasing water supply, MAR also mitigates land subsidence and reduces impacts on water infrastructure (CA DWR, 2024a).

As climate change is projected to increase the number of very wet periods and, more notably, winter runoff from the Sierra Nevada due to more precipitation falling as rain rather than snow, both the need, and opportunity, to capture excess water will only increase. However, the scale of present-day groundwater recharge facilities and infrastructure (e.g., ways to route floodwaters to areas that lack conveyance; Ch. 4) is woefully inadequate. Infrastructure and institutional barriers and constraints, such as environmental flow requirements and entitlement to some of the excess water, merit caution and have slowed its adoption.

As project sites are considered to scale up MAR, sites may be prioritized in areas subject to critical overdraft (e.g., dry wells, land subsidence) where soils and geology are receptive to recharge. Efforts to incentivize AgMAR vary by Groundwater Sustainability Agencies in the Valley, but can include directly paying landowners for each acre-foot recharged as well as providing pumping credits for recharge (e.g., a farmer can



Managed Aquifer Recharge

Figure 3.6: *Managed aquifer recharge at the UC Merced Experimental Smart Farm. Credit: Andres Morande, 2025.*

access half an acre-foot of groundwater during the growing season for every acre-foot they recharge). Furthermore, prioritizing siting projects in currently fragmented habitats (especially riparian corridors and wetlands) can have the co-benefits of flood control, MAR, and habitat restoration.

3.6.3 Multibenefit Land Repurposing Program

Following the enactment of SGMA and the filing of the first round of Groundwater Sustainability Plans for critically and highly overdrafted basins, it was evident that long-term reductions in groundwater use would necessitate permanent idling of cropland in the SJV (Hanak et al., 2019; 2024). However, the implications of transitioning such land to other uses are less understood. To fill this gap, the Multibenefit Land Repurposing Program (MLRP) was developed to provide technical and financial support for projects that reduce groundwater extraction, repurpose irrigated agricultural lands, and support ecosystem services (CA Department of Conservation, 2025). Long-term, MLRP is designed to benefit disadvantaged communities, provide local groundwater sustainability for agriculture, and demonstrate scalable land repurposing approaches that are climate-resilient (**Box 3.1**).

Dwindling water deliveries and SGMA may lead to more abrupt transitions in some agricultural areas of the Valley. For example, the Westlands Water District has proposed to repurpose up to 136,000 acres (25%) of agricultural lands for solar production, energy storage, and associated infrastructure (Westlands Water District, n.d.). Such transitions may help recoup lost tax revenue for local governments where agricultural production is curtailed, but consultation with local communities and community benefits agreements can benefit the feasibility and acceptance of those projects, while avoiding the creation of new negative externalities.

To date, MLRP has largely been incentivized through funding and grants aimed at reducing groundwater use while creating environmental and economic benefits—thus MLRP and MAR are fundamentally interconnected. One example is the LandFlex Grant Program: Initially focused on protecting groundwater for drinking water needs, growers were offered incentives to temporarily fallow fields or permanently eliminate groundwater overdraft near domestic wells. During the widespread flooding that occurred in 2023, these fallowed lands were used by the program to capture floodwaters and facilitate groundwater recharge (CA DWR, 2025b).

3.6.4 Climate-Smart Agriculture

Given the significant environmental advantages the region has, and will have, in the coming decades, the SJV will continue to be a key producer of agricultural products, even with climate change and SGMA-related changes. However, sustained production may require shifts in cropping systems, practices, and values. Some water intensive and temperature-intolerant crops may become decreasingly viable with more expensive water prices and a warming climate, and hence less financially attractive to produce (Boser et al., 2024). Meanwhile, many current agricultural systems in the SJV will remain viable and other cropping systems may become increasingly viable, including new varietals (e.g., drought and heat tolerant), novel crops (e.g., agave farms), and crops that are amenable to variable or reduced irrigation needs, such as winter cereals (Peterson et al., 2023) and oil olives (Prewitt, 2026). Yet, such opportunities will be heavily contingent on market demands for products (e.g., competition in US and global markets) and logistics (e.g., processing facilities).

Employing methods such as strategic land idling or switching to drought-tolerant and lower-water use crops can significantly decrease on-farm water demand. Moving away from water intensive perennials to flexible crops (often, but not always, annuals) may be advantageous to capitalize on groundwater recharge opportunities (FloodMAR and DWR's LandFLEX program) during wet years and use deficit irrigation during very dry years (Waring et al., 2025). Also, integrating rapidly evolving technologies (e.g., data science, automation, mechanization, and artificial intelligence) into agriculture and food production systems can help make this sector more resilient and sustainable.

Regenerative agriculture can offer significant benefits for increasing on-farm climate resilience and mitigating climate change (Mitchell et al., 2024). Regenerative agriculture practices include no-till farming, the use of cover crops, compost and biochar application, the integration of livestock and crops, and diverse crop rotations to enhance soil health by building soil organic matter. In turn, improved soil organic matter and structure can improve soil water storage capacity that makes crops more resilient to periods of drought and intense rainfall. Improved soil water holding capacity may slightly reduce irrigation demands, although in some cases the use of cover crops leads to increased transpiration while reducing soil evaporation (Flynn et al., 2025). Furthermore, by increasing the organic carbon content in the soil, regenerative agriculture practices actively remove carbon dioxide from the atmosphere and provide an opportunity for natural carbon solutions in working lands. Regenerative agriculture practices can also include integrating biodiversity with agriculture (e.g., crop hedgerows with pollinator habitat) to mutually promote both climate-resilient agricultural systems and address conservation goals. Lastly, these practices also often limit the use of synthetic agrochemicals, like fertilizers, that contribute to greenhouse gas emissions.

Another potential challenge and opportunity in the SJV and broader state is the reuse or repurposing of agricultural waste products (e.g., SB 705 [2003] which limits the burning of agricultural waste due to air quality concerns). Thus, a potential alternative outlet for agricultural residue (including orchard materials) is biochar. Studies suggest that biochar, a by-product of pyrolysis (i.e., heat-induced organic matter decomposition in the absence of oxygen) of waste biomass, may provide positive economic value to agricultural lands and jobs along with improved soil health and carbon sequestration efforts (Nematian et al., 2024). Similarly, the integration of biochar in manure composition may significantly curtail methane emissions from livestock compared to manure compost alone (Harrison et al., 2022), which could lead to up to 40% reductions in methane emissions from dairies by 2030 (SB 1383 [2016]).

There is growing public demand for agriculture to deliver positive environmental and social benefits (Baylis et al., 2008; Cook & Davíðsdóttir, 2021; Fabian & Pykett, 2022) in addition to nutritional value. Small-scale farming provides socioeconomic benefits (Ch. 5). Crops grown on diversified small farms in the SJV (e.g., vegetables) tend to have lower crop water use requirements than those in major commodity cropping systems. The heterogeneous canopies of diversified small farms also provide significant ecological benefits (Guzman et al., 2021; Guzman et al., 2019). While land idling may be a strategy for large farms, it is more difficult for small-scale farms as these farmers often need all land in production to meet economic needs. Instead, providing education opportunities for farmers—including multilingual tailored technical assistance—and encouraging regenerative and diverse cropping systems, can support these farmers in making more informed decisions and reducing water use. There is farmer interest

in many of the climate-smart approaches in California (Ikendi et al., 2024). Farmers in the Valley are concerned with water scarcity, with underrepresented farmers having greater concern about water availability. Hence, they are interested in actions such as increasing irrigation efficiency, diversifying crop portfolios, and improving soil organic matter to become more resilient to such challenges. Farmers expressed a need for information on funding programs to enact these practices. A list of example local, state, and federal funding that support farms in climate-smart practices is provided in **Table S6**.

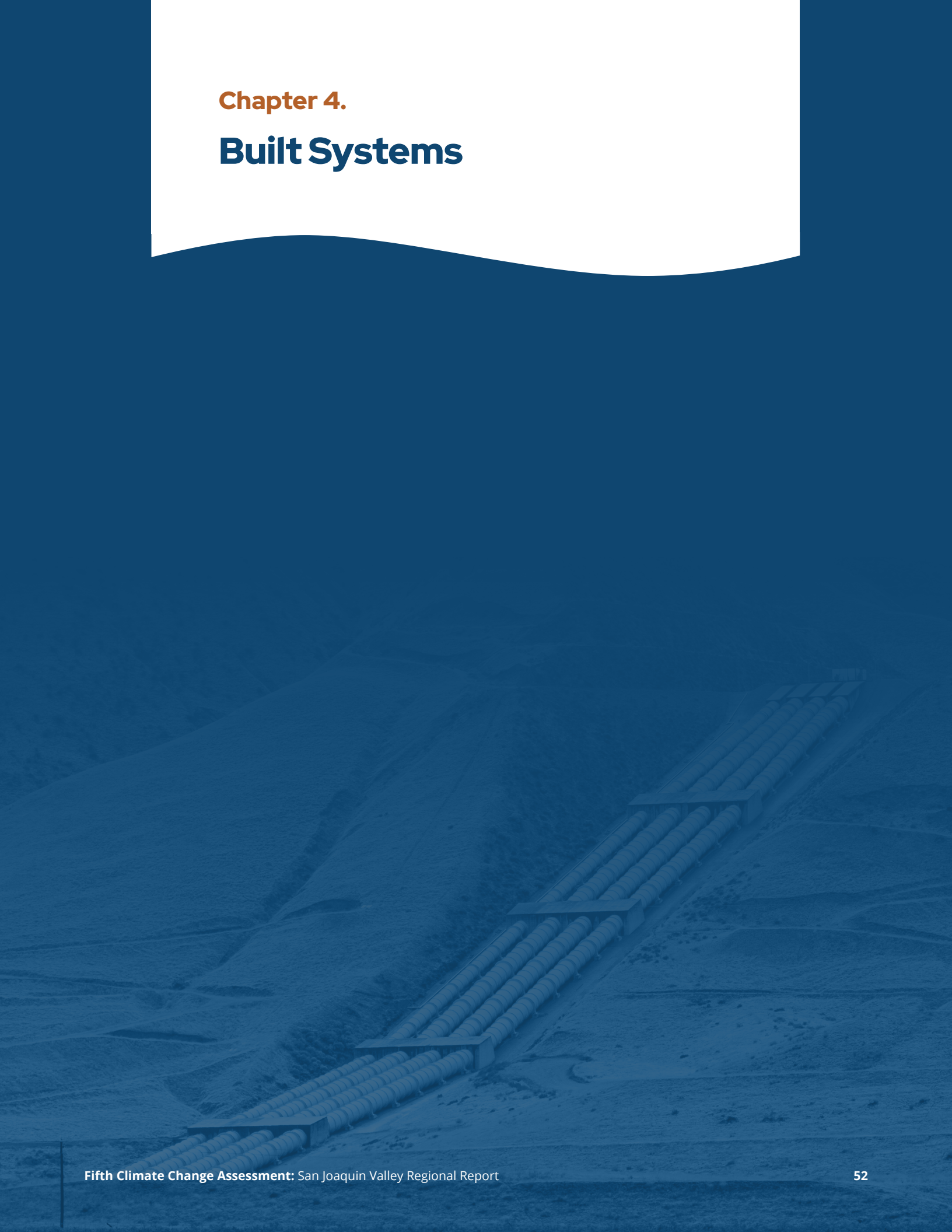
3.6.5 Water Markets

Water markets have been suggested to reduce potential economic impacts of reduced water availability by prioritizing preservation of higher value crops (Arellano-Gonzalez et al., 2021; Cole et al., 2023). In a water market, willing water users can choose to temporarily or permanently transfer their water allocation or entitlement to willing buyers. In this way, such markets allow water users to collectively manage allocation during periods of limited water such as droughts. However, a longstanding concern with water markets is their potential effects on small or disadvantaged groups, such as small-scale farmers, Tribal land stewards, and low-income communities near agricultural fields (Bajaj et al., 2022). Water markets run the risk of mirroring other market power dynamics that exclude smaller users or impose prohibitive transaction costs on those users (Dahlquist-Willard, 2024) and can create hotspots for extended land idling and unemployment (Bajaj et al., 2022; Dahlquist-Willard, 2024). Moreover, in the absence of setting a cap on total water use, water markets themselves will not reduce consumptive water use. Thus, if applied without consideration of such potential concerns, water markets can exacerbate socioeconomic inequities (Bajaj et al., 2022; Fernandez-Bou et al., 2025), and studies are inconclusive as to whether improved water efficiency and social equity objectives can be achieved at the same time (Bajaj et al., 2022).

Instead, ensuring institutional safeguards, trading rules, and locally tailored governance structures may mitigate some of the concerns regarding equity (Colby, 1990; Garrick & Aylward, 2012). Such progressive approaches to water markets aim to anticipate distributional effects in trading rules, measurement, accounting, and enforcement to protect or compensate affected parties (Nylen et al., 2017; Wheeler et al., 2017; Bruno & Jessoe, 2024). In doing so, achieving local and non-local buy-in through diverse partnerships remains central for successful implementation, particularly for parties affected directly by trading programs. Therefore, if water market strategies are to be explored, it is crucial to pursue a holistic approach that addresses all potential negative externalities along with potential economic benefits, and achieves local agreement by those who will be directly impacted by the markets (Libecap, 2022; California Agricultural Land Equity Task Force, 2025).

Chapter 4.

Built Systems



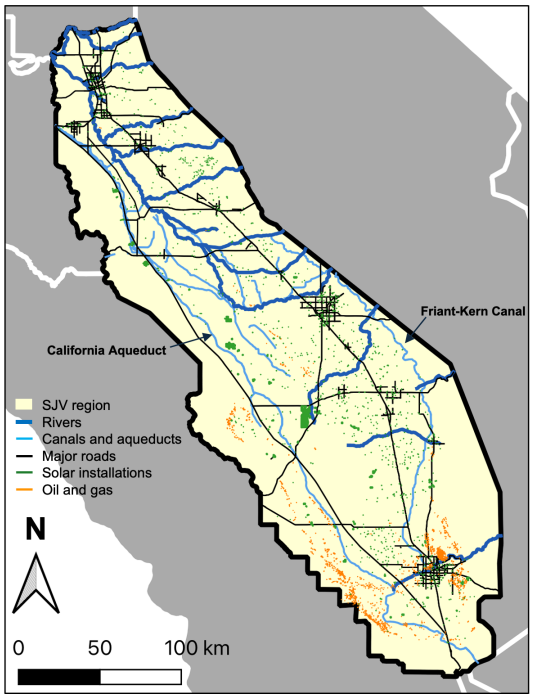
Key Message

The San Joaquin Valley (SJV or the Valley) is a highly managed landscape that supports fast-growing and interconnected cities and rural communities and a large agricultural sector through managed waterways, transportation infrastructure, and a continuously evolving energy system. This human-built infrastructure has facilitated the growth of the SJV, and the state, as an agricultural powerhouse. At the same time, this infrastructure has altered natural systems, diminished native species habitat, increased greenhouse gas emissions, and introduced contaminants to waterways and underground. Water infrastructure (including dams, aqueducts, and wells) and energy systems (including energy production, oil and gas production, and transportation) are both vulnerable to and contribute to climate change and exacerbate impacts on water resources and other natural systems. Conversely, climate change-induced precipitation volatility and warmer temperatures are likely to affect the ability of the human-built systems to perform their intended functions, which requires coordinated adaptation and mitigation strategies. Efforts such as Forecast Informed Reservoir Operations (FIRO) and floodplain restoration can aid in the resilience of water supply and flood risk, while continued growth of solar developments in the Valley further help with climate mitigation goals.

4.1 Water Supply Built Infrastructure

4.1.1 Context for Built Water Systems in the SJV

Following the end of hydraulic mining in the 1880s, California's Mediterranean climate (Ch. 2) provided the impetus to create one of the most highly engineered water systems in the world. Major water supply and flood prevention systems in California were built in the decades following statehood, alongside rapidly expanding populations and irrigated agriculture, often at the expense of ecosystems. Water infrastructure in California was built to close the inherent spatial and temporal disconnect in water abundance and water demand across the state, with the former peaking in winter in mountainous regions and the latter peaking in summer in agricultural regions (Ch. 2). The establishment of ***irrigation districts***, and later the 1902 Reclamation Act, marked the beginning of California's Hydraulic Era, characterized by large-scale infrastructure development (Hanak et al., 2011). Early efforts focused on diverting



Built Systems in the San Joaquin Valley

Figure 4.1: *Built systems in the San Joaquin Valley. Rivers and major (federal and state) canals and aqueducts; major roads; oil and gas fields; and solar installations.*

local streams to irrigate crops and supply water to population centers, later supplemented by the introduction of the centrifugal pumps to extract groundwater from underlying aquifers. Concerns over aquifer depletion, fully allocated local surface water supplies, and an appetite for interbasin transfers facilitated the development of projects like the ***Central Valley Project (CVP)***, which includes the Friant-Kern Canal; the Colorado River Aqueduct, the Hetch Hetchy Project, which includes the O'Shaughnessy Dam; and the ***State Water Project (SWP)***, which includes the California Aqueduct and transports water to the southern part of the Valley (**Figures 4.1, 4.2**). Completion of the Oroville Dam, the largest reservoir in the SWP, marked the decline in the Hydraulic Era, as environmental regulation and modern water policy began to take hold. In recent decades, growth in agricultural and urban water demand has flattened, while regulations to protect ecosystems and water quality have driven systemwide changes in water supply and flood management operations.

4.1.2 Description of Water Supply System Features

As one of the most diverse and productive agricultural regions in the world, agricultural ***applied water*** represents the largest water use in the SJV, accounting for approximately 90% of total demand in an average year (Hanak et al., 2017). Conversely, urban water uses in the SJV only account for approximately 5% of total water demand (Ayres et al., 2021). While most of this urban demand is met by large community water systems (those serving more than 10,000 urban connections), medium-to-small systems support rural communities in meeting their water demands and often rely on groundwater (Water Foundation, 2020). Domestic water users not connected to a system often meet their demand with groundwater extraction. However, in recent years, rural residents have been challenged by reductions in water quantity (e.g., groundwater overdraft reducing well water availability) and water quality (e.g., contaminants mobilized by declining groundwater levels; Ch. 3).

Given the Valley floor receives relatively little precipitation outside the winter months (Ch. 2), the SJV relies heavily on imported and transported surface water flows. Surface water resources in the SJV are highly managed through reservoir and canal systems, reducing water supply within the region (Hanak et al., 2019; CA DWR, 2016). The CVP and the SWP, two of the largest systems, are interconnected with smaller local projects. Water imports from the SWP and CVP collectively contribute about 20% of the ***consumptive water use*** in the Valley (Hanak et al., 2019). However, these surface water supplies can vary greatly year-to-year due to climate variability.



Friant-Kern Canal

Figure 4.2: *The Friant-Kern Canal is a 152-mile Central Valley Project aqueduct that transports water from Friant Dam to farms in the southern San Joaquin Valley, playing a critical role in irrigating the agricultural regions. Credit: DWR, 2016.*

The SJV also relies heavily on groundwater to meet agricultural

and community water demands, accounting for approximately 15% of consumptive water use during 1988–2017 (Ch. 3; Hanak et al., 2019). There are approximately 15 groundwater basins in the Valley, nearly all of which are considered ***critically overdrafted*** (CA DWR, 2025a). Dependence on groundwater as a water supply source varies within the SJV, with some regions fully dependent on groundwater for their water supply. While groundwater overdraft is a major characteristic of the SJV, the regional soils and underlying geology can prime the region for both natural and managed recharge. Groundwater storage in the SJV is estimated to be at least 20 times larger than the combined surface water storage of the region (Hanak et al., 2018). Such storage potential has led to consideration of recharge opportunities and the implementation of on-ground recharge activities, including recharge basins and flood ***managed aquifer recharge*** (Flood-MAR; Ch. 3). Additionally, water recycling and reuse has grown as a water supply, predominantly in urban areas of the SJV, with increasing interest and pilot studies in applied agricultural water use as well (CA DWR, 2023; CA DWR, 2024b).

Historically, flooding in the SJV has resulted from melting snowpack runoff over a lengthy runoff period or large, often intermittent, wet-weather rainfall events. In response, multipurpose projects (e.g., reservoirs that provide both flood control and water supply) have been established throughout the Valley, especially along major rivers emerging from the Sierra Nevada (see **Box 3.4**, Ch. 3). In more recent times, flood management has shifted from mitigating flood flows to utilizing them for multiple benefits, including ecosystem services or managed aquifer recharge (MAR) in a more conjunctive management of surface flows with groundwater (CA DWR, 2022; Ch. 3).

4.1.3 Direct Climate Impacts on Built Water Systems

While the built water systems in the SJV were developed to compensate for the region's climate, the combined strain of drought (Ch. 2) and demand from agriculture (Ch. 3) have decreased the resilience of these systems. Climate change is projected to further increase the intensity of drought in headwaters (a primary water source for the region), extreme precipitation, and hydroclimate whiplash (Ch. 2), further testing the Valley's built water systems (e.g., Liu et al., 2021; Maskey et al., 2022; Ray et al., 2020). While such changes may further impact water security in the SJV, efforts such as improved reservoir operations and water transfers can improve adaptation to future climate extremes and ensure the reliability of water for agriculture, the environment, and human needs (Dourado et al., 2024; Medellín-Azuara et al., 2024).

DROUGHT RISKS

Droughts often diminish the surface water available for agriculture, communities, and ecosystems in surface storage and runoff (Ch. 2). With depleted surface water reserves, human-built systems usually turn to groundwater to meet major demands such as crop irrigation (Ch. 3). Groundwater overdraft (i.e., the net difference between extractions and recharge) in the SJV averages 2.2 million acre-feet per year (Hanak et al., 2019) with much higher rates during drought years. Some of the negative consequences of overdraft include the loss of conveyance capacity in canals due to chronic land subsidence; more domestic wells going dry; a decline in groundwater-dependent ecosystems functions; increased flood risks due to subsidence and potential expansion of the floodplain; and a higher concentration of pollutants in groundwater (Ch. 3).

California's highly engineered water supply system distinguishes it from other regions where drought leads more directly to local water shortages. Reservoirs and conveyance systems provide

significant drought buffers for developed lands (e.g., agricultural, municipal) and can limit or delay water shortages to these systems. However, water shortages occur during chronic droughts. The droughts of 2012–2016 and 2020–2022 highlight how multi-year droughts can differ in their regional impacts. During the 2012–2016 drought, precipitation and surface storage deficits were concentrated in the SJV (Lund et al., 2018), leading to extensive groundwater overdraft supplemented by imported surface water. By contrast, the 2020–2022 drought was marked by exceptionally low precipitation and reservoir levels in the wetter Sacramento Valley, reducing water inputs from Northern California to the SJV. Such multi-year droughts have added pressure to expand reservoir storage to buffer dry years, as well as to hasten the scale of groundwater recharge. Lastly, while groundwater pumping has provided significant relief for agricultural and domestic water supply during drought, ***SGMA*** policy may alter the ability of this buffer to absorb shorter-duration droughts.

FLOOD RISKS

As with droughts, wet years have highlighted precipitation extremes that challenge human-built water supply infrastructure. Climate projections suggest an increase in both extreme precipitation events and extreme wet years in the SJV and headwater regions (Huang & Swain, 2022; Pierce et al., 2023; Ch. 2). Increased precipitation rates and rain-on-snow events may increase flood potential in some watersheds that drain into the SJV (Rhoades et al., 2024). These changes may be compounded by increases in large, high-severity wildfires in headwater regions that not only increase runoff in the years post-fire but also lead to increased sedimentation into reservoirs that reduces water storage (Dow et al., 2024). Collectively, such changes in runoff rates are likely to impact reservoir operations, potentially increasing flood risk to downstream communities and agriculture in the Valley (CA DWR, 2022; Ch. 2). Localized urban flooding from short-duration precipitation extremes is projected to increase across the SJV (Huang et al., 2020). Urban flood risk can be further compounded by development (e.g., increased impervious surfaces) and land subsidence, though ameliorated through a variety of approaches including increased permeable surfaces (e.g., urban green spaces) and stormwater basins (e.g., multipurpose flood-recharge basins used by Fresno Metropolitan Flood Control District).

ENVIRONMENTAL FLOWS AND REGULATION

Major declines in native fish populations in California following decades of operation of the SWP and CVP led to stronger protections for aquatic habitat. These protections combine water allocation rules, water quality standards, and instream flow requirements in the Sacramento and San Joaquin River basins, both of which drain into the Delta. Within the Delta, management actions aim to keep the salinity line as close as possible to the San Francisco Golden Gate Bridge to ensure appropriate fresh water for fish and human uses. Actions include rerouting flows, regulating export pumping, adjusting upstream diversions, coordinating reservoir releases, and ultimately influencing water availability for SJV diverters, in-Delta users, and Delta export contractors serving the SJV.

Climate change affects compliance with environmental flow regulations in several ways. Sea level rise, higher temperatures and more volatile precipitation patterns challenge efforts to keep salinity levels low and potentially necessitate higher Delta outflows via reduced upstream

diversions, increased reservoir releases, or reduced exports. Furthermore, water temperature management requires reservoir operators at Shasta Dam—the CVP's main reservoir—to maintain a cold-water pool essential for salmon reproduction in the Sacramento River. Warmer river temperatures with climate change and shifting hydrology will likely require additional water temperature management strategies that could further limit agricultural water deliveries to the SJV.

COMMUNITY IMPACTS

Small rural groundwater-dependent water systems suffer the most during droughts as their water supply portfolios are more limited than those of urbanized areas and they may also face competition for groundwater from nearby large agricultural operations. The recent droughts resulted in more dry wells adjacent to large agricultural operations in areas of intense groundwater extraction (Perrone & Jasechko, 2017; Pauloo et al., 2020; Jasechko & Perrone, 2020). The vulnerability of such systems depends on several factors including well depths, the density of irrigation and domestic wells, the proportion of permanent crops, and socioeconomic conditions (Rodríguez-Flores et al., 2023). Further declines in groundwater will not only impair water reliability for communities and small farms reliant on shallow wells but will also degrade water quality as pollutants concentrate above permissible levels for safe drinking water (Ch. 3).

Communities downstream of flood control infrastructure face increasing risks as extreme precipitation events become more frequent and intense (Flores-Landeros et al., 2022). The aging levee system, designed for historical flow patterns, may be inadequate for projected future conditions, especially in locations experiencing subsidence or where climate change will dramatically increase flood risks. Flood events can have severe consequences on communities, as illustrated in 2023 when widespread flooding occurred in low-lying areas of the SJV (see **Box 4.1**). Efforts such as floodplain restoration (e.g., **Box 3.4**, Ch. 3) may help mitigate flood impacts.

Box 4.1: *Drought and Flooding in Planada*

"Overpumping has caused groundwater levels to drop, which is decreasing water quality and availability, especially in unincorporated communities like Planada and Le Grand. Ironically, these same communities are also at high risk for flooding because they lack proper infrastructure and flood control systems. It's a double burden: they're facing both water shortages and flood dangers, without the support or resources to deal with either."

— Community Leader, via survey

The unincorporated community of Planada in Merced County is vulnerable to both droughts and floods. The community is largely low-income and largely Spanish speaking, which presents barriers to accessing both state and federal aid and resources (Ch. 5). Planada was known to be at high risk for flooding due to non-flood-resilient infrastructure and poor flood control systems. Then in 2023—a year of record snowpack and heavy snowmelt—Planada suffered devastating floods due to levee breaches and inadequate stormwater infrastructure. The impacts of the flood were compounded as many were under- or uninsured, had limited savings, and lost income from missed work. Local mutual aid networks and organizations helped to coordinate recovery efforts, including rapid mobilization to support displaced families, ensuring bilingual outreach, and advocating for infrastructure improvements (UC Merced Community and Labor Center, 2023).

4.2 Energy Systems & Transportation

4.2.1 Context for Energy Systems and Transportation in the SJV

In the SJV, energy systems are a concern, in terms of both local demand and production of energy used both statewide and internationally. Across the region, most energy demand is for non-residential purposes (CEC, 2025a). The agricultural sector demands significant energy for irrigation, processing, and transportation: totaled across Merced, Tulare, Fresno, and Kern counties, agriculture accounts for 30% of energy consumption (CEC, 2025b). Many communities within the Valley have limited access to clean energy and transportation options while simultaneously facing significant grid reliability issues and disproportionately higher energy costs (Ch. 5).

Moreover, rapid load growth has occurred, driven by groundwater pumping, increased cooling demand, increased population, and electrification. While much of the Valley is serviced by Pacific Gas & Electric and SoCal Edison, smaller publicly-owned utilities, such as Modesto Irrigation District, Turlock Irrigation District, and Merced Irrigation District, service residential and agricultural uses. Load growth may disproportionately threaten grid reliability issues for smaller utilities due to economies of scale for procuring new energy and smaller customer bases. Further, geographic constraints in transmission through the SJV mean that smaller utilities are more limited in their ability to procure energy from other parts of the state, making them more reliant on local sources.

Most oil extraction in California occurs in the SJV, specifically in Kern County (CEC, 2020), creating economic activity and energy while also leading to environmental and social impacts, including local pollution and contributing to climate change via direct and indirect greenhouse gas emissions. The SJV is also an important hub of renewable energy production; in 2023, Kern County produced the most photovoltaic (PV) energy of any county in the state (CEC, 2024) and approximately half of the state's large-scale solar PV facilities are located in the Valley (Fujuta et al., 2025). The Valley also has a significant share of California biomass energy production, due in part to the extensive agricultural byproducts grown in the region. While biomass aims to address economic and environmental goals, local downstream air quality impacts to disadvantaged communities and the existing poor air quality of the region has led to a decrease in use of biomass for energy production.

Finally, the SJV's transportation infrastructure is heavily reliant on highways and trucking, contributing to both air pollution and greenhouse gas emissions. In particular, Interstate 5 (I-5) and State Route 99 (SR-99), which both run the full length of the Central Valley, are California's primary north-south arteries and are associated with both significant emissions and pollution, affecting nearby communities.

4.2.2 Climate Impacts on Energy & Transportation

DIRECT CLIMATE IMPACTS ON ENERGY INFRASTRUCTURE

Like the rest of the state, the electrical grid in the SJV is vulnerable to climate impacts. However, unlike the rest of the state, the SJV does not often experience power outages due to strategic

de-energization designed to avoid powerline ignitions. Instead, extreme heat poses a threat to electricity distribution in the region via impacts on demand peaks, although increased battery storage in recent years has helped buffer impacts of high energy demand during statewide heat waves. Rising temperatures are expected to result in even higher energy demand for cooling. For example, Stockton is projected to experience a 75% increase in ***cooling degree days*** by mid-century (Ch. 2). Increased cooling demands will most impact those who can least afford proactive adaptation measures (e.g., lacking adequate insulation, solar). Utilities in California are not allowed to disconnect service in case a household cannot make a payment when temperatures are above 100°F (37.8°C) (LIHEAP, 2025). However, increased energy costs due to an increased frequency of hot days may contribute to households being disconnected due to non-payment (Barreca et al., 2022).

The widespread implementation of PV energy in the Valley serves to create jobs and support the transition to renewable energy. Yet, the efficiency of solar cells declines during heat waves, resulting in losses in potential energy production during periods when energy demand is highest. These impacts are not specific to solar energy, as temperature extremes also impact the performance of fossil fuel and natural gas power plants and other renewables. Certain strategies may be implemented to buffer the wane on energy production during heat waves. For example, integrated solutions such as ***agrivoltaics*** and the solar canal project piloted by the Turlock Irrigation District offer synergistic solutions that reduce ambient temperatures of solar panels while also reducing evaporation from canals. The scalability of such solutions may be challenging logistically and financially but is a proof of concept of mutually beneficial adaptations for both water and energy.

DIRECT CLIMATE IMPACTS ON TRANSPORTATION INFRASTRUCTURE

Transportation in the region is vulnerable to climate-induced changes, including subsidence from groundwater depletion, heat-related impacts, and flooding from extreme precipitation and storm surges. First, subsidence can cause roadways and railways to buckle or break. Significant subsidence has occurred in the past two decades in the SJV along the route and development areas for California's high-speed rail project (Lees & Knight, 2024). Second, extreme heat can damage transportation infrastructure, causing accelerated and exacerbated wear on and deformation of pavement and railway buckling and expansion (Lara et al., 2022). Third, extreme precipitation and storm surges can lead to roadway flooding and washout of transportation infrastructure. For example, massive flooding accompanied the re-emergence of the Tulare Lake during 2023 (Ch. 2), which resulted in many roads being flooded and communities being either *flooded-in* or *flooded-out* around Allensworth (Ch. 5). Highways along the Sacramento-San Joaquin River Delta (especially State Route 12 and Interstate 5) are also vulnerable to flooding, increased scour, and increased erosion as a result of sea level rise and storm surges. Finally, the combination of wildfires in the neighboring Sierra Nevada region combined with extreme precipitation can result in landslides, flooding, and post-wildfire debris flows that can impact transportation infrastructure in the region.

4.2.3 Impact of Energy & Transportation on Climate Change

INFLUENCE OF ENERGY TO CLIMATE CHANGE

The processes used to extract hydrocarbons, transportation associated with extraction, and the products themselves contribute to both greenhouse gas emissions (GHGs) and local air pollution (e.g., ***PM2.5***). This includes stationary (e.g., oil and gas wells, power plants) and non-stationary (e.g., transportation) sources of emissions. Notably, studies have identified and quantified the contribution of industrial carbon producers—including companies operating in oil and gas fields in the SJV—to climate-related impacts in California, ranging from wildfire-burned areas (with implications for smoke transport and public health; Dahl et al., 2023) to extreme heat (Quilcaille et al., 2025).

In 2019, the average ***carbon intensity*** of oil produced in California was ~98 kg CO_2eq/barrel, compared to ~64 kg CO_2eq/barrel of crude produced outside of California (Fleming et al., 2021). The higher carbon intensity of California crude is due to the heaviness of the crude and the enhanced techniques required to extract it. Notably, the carbon intensity of California oil fields is increasing at a faster rate than oil produced outside of California (Fleming et al., 2021) due to increased adoption of extraction methods used to access otherwise hard-to-reach hydrocarbons. Furthermore, 61% of California's upstream emissions are linked to just five of the 158 oil fields in the state (Midway-Sunset, South Belridge, Cymric, Kern River, and San Ardo), four of which are in Kern County (Fleming et al., 2021). There are also many *idle wells* in the region, particularly around Bakersfield (Sierra Club, 2022; CalGEM, 2025), which can leak methane, a powerful greenhouse gas (Lebel et al., 2020). Furthermore, electricity generating facilities in the SJV emit roughly 5 million metric tons of CO_2 annually, roughly 17% of total CO_2 emissions from California electricity generators (CARB, 2025).

These stationary sources produce co-pollutants (including PM2.5, NO2, and O3), which can harm human health (Gonzalez et al., 2020; Vohra et al., 2025; Ch. 5). Across California, 18% of people live within one mile of an oil or gas well (Fleming et al., 2021), though in the SJV there is a particularly high concentration of people living close to oil and gas production, such as in Shafter, Lost Hills, and Bakersfield (Ferrar, 2020). However, recent legislation (SB 1137 [2022]) will prevent new wells from being built within a 1-mile buffer from residences, schools, and parks (State of California, 2024).

There is competition for water in the region between communities, agriculture, and energy, as oil and gas extraction uses freshwater due to enhanced extraction techniques such as cyclic steam injection and hydraulic fracturing. Furthermore, oil and gas production contributes to water quality issues as the chemicals used in hydrocarbon extraction can seep into groundwater (Anders et al., 2022; Stanton et al., 2022). In the SJV, up to 10% of domestic water wells are within 2 miles of an oil and gas well (Perrone & Jasechko, 2017).

Solar energy in the SJV comprises an important growing portion of the state's renewable energy portfolio. Part of SGMA-driven land repurposing likely involves an escalation in the number of large PV installations in former agricultural land. While this will further boost the SJV's ability to help the state meet its goals of 100% renewable non-carbon-based retail electric energy by 2045 (SB 100 [2018]), studies have shown that large PV installations lead to a heat island effect (Barron-

Gafford et al., 2016). Such considerations may be localized but could be mitigated so as not to compound heat-related impacts to communities.

INFLUENCE OF TRANSPORTATION ON CLIMATE CHANGE

In 2024, on-road transportation activity in the SJV resulted in over 21 million tons of CO_2, accounting for approximately 14% of California's on-road transportation emissions. These SJV emissions were linked to over 3 million vehicles cumulatively traveling over 35 billion vehicle-miles (CARB EMFAC, 2025). Given the high level of agricultural activity in the region, its centrality within the state, and the presence of two major highways (I-5 and SR-99) traversing the entire region from north-to-south, there is substantial freight activity within the Valley. For example, San Joaquin County has the second highest concentration of transportation and warehouse employment in the US (San Joaquin County, 2020). However, as a result, there is enormous air pollution associated with these two highways, corresponding to ***smog corridors***, affecting the health of nearby communities (Ch. 5). There are relatively high amounts of commuting within the SJV—especially in the northern parts of the region in Merced, Stanislaus, and San Joaquin Counties. In these three counties, roughly 25% of employees work outside the county where they reside and have an average commute of roughly 1 hour (Caltrans, 2019).

The SJV also lags behind much of California in the uptake of zero emission vehicles (ZEVs) (e.g., electric vehicles and plug-in hybrid electric vehicles). As of 2024, ZEVs comprise 7.5% of the light-duty vehicle population statewide, but only 4.5% of the light-duty vehicle population within the SJV (CARB EMFAC, 2025). However, projects have been piloted in the region to increase availability and uptake of ZEV freight vehicles (**Box 4.3**).

Box 4.3: *Frito-Lay Zero- and Near-Zero-Emission Project*



Figure 4.3: *Electric semitrucks that are part of the Frito-Lay Zero- and Near-Zero-Emission Project at the Modesto facility. Credit: CALSTART.*

To accelerate the transition to a zero-emission freight sector, Frito-Lay undertook a pilot project toward electrifying the company's supply chain at its Modesto facility (Thorson et al., 2023). Through a partnership with state agencies, researchers, and companies like Tesla, the project has deployed zero-emission vehicles, including semis, for commercial use at the facility and for distribution (**Figure 4.3**). By leveraging the Modesto facility's large-scale solar production and storage, the initiative aims to achieve significant sustainability benefits, directly supporting the state's transportation decarbonization goals and the sustainability commitments of its parent company, PepsiCo. This transition away from diesel-powered equipment also alleviates local air quality concerns and could reduce pollution along the I-5 and SR-99 freight corridors.

However, a challenge with electrifying heavy-duty vehicles is competition for limited electricity. Therefore, the benefits of transportation electrification may also introduce challenges associated with load increases for electricity, leading to reliability concerns in certain regions. While rollout is in a nascent stage, projects like this Frito-Lay pilot will reveal scale of potential and increased electricity demand in shipping corridors.

4.3 Solutions and Adaptation Strategies

4.3.1 Water Supply Built Infrastructure

As climate change intensifies existing water management challenges to built systems in the SJV, multibenefit water solutions may be needed that address issues including flood control, water supply, and ecosystem services. The following are adaptation and mitigation strategies that may ease challenges to California's built water systems. Note that these strategies can be considered in conjunction with strategies based on the SJV's natural and working lands (Ch. 3).

FORECAST INFORMED RESERVOIR OPERATIONS (FIRO)

Changes from snowmelt to rain-red flows in terminal dams of the SJV can increase pressure on dam operators to manage for variable flows. With flashier rain-driven flows into terminal dams and declining water storage in snowpack projected into the future (Ch. 2), one adaptation strategy is ***Forecast Informed Reservoir Operations (FIRO)***. FIRO uses weather forecasts of ***atmospheric rivers*** and runoff within a season to guide reservoir operation decisions. Improved forecasts could be used to increase reservoir storage for expected storm flows, minimize flood risk, and

better prepare water releases for other surface storage, groundwater recharge, or environmental needs.

Absent any changes in water management, the region faces increased groundwater overdraft, flood risk, and degraded ecosystem quality due to climate change. In an exploratory watershed-scale analysis conducted by DWR with the Merced Irrigation District, various adaptation strategies meeting multiple benefits were evaluated, including FIRO, FloodMAR (Ch. 3), and in combination FIRO-MAR (CA DWR, 2024a).The study found that integrated management strategies, especially FIRO-MAR, could significantly reduce flood risk, improve water supply through conjunctive use, and enhance conditions for local ecosystems.

CONSERVING AND RECONNECTING FLOODPLAINS

Floodplains serve as buffers for high flows, benefiting ecosystems by enhancing aquatic habitat, improving water quality, and building hydrologic resilience through groundwater recharge and attenuating floodwaters. Yet, land use change (e.g., agriculture and urbanization) and diversions along California's rivers altered these natural functions. Water management in the Valley recognizes the value of restoring flow regimes. As such, there are multibenefit projects such as the Dos Rios Project (**Box 3.4**, Ch. 3) that seek to pair conservation efforts with downstream benefits to water infrastructure and security that lead to more resilient river systems (Yarnell et al., 2020).

4.3.2 Energy Systems

There will continue to be a high demand for energy in the SJV. Meeting this demand and achieving the state's greenhouse gas emission targets will require reliable energy sources which do not further contribute to climate change.

ELECTRICITY PROCUREMENT

The Valley is a leader in photovoltaic electricity procurement and battery storage. Land repurposing visions to comply with SGMA include potentially large expansions in solar installations in former agricultural lands (agrivoltaics) or in ecologically informed approaches (ecovoltaics), thus providing revenue-generation for retired lands and furthering efforts to address state carbon neutrality goals (SB 100 [2018]). Given the temporal mismatches in solar production and energy demand through the day, solar projects could be paired with storage to optimize reliability and benefits.

Relatedly, the state has a goal to phase out oil and gas production by 2045 (CARB, 2022). This phase-out can help improve air quality and health impacts for neighboring communities while meeting the state's climate goals. Oil and gas production is currently an important sector of the economy and employment in Kern County and neighboring parts of the south Valley. Efforts are needed to retrain and transition jobs in oil and gas industries to those in renewable energy industries as well as workforce training programs to foster future employment outcomes, particularly in rural and disadvantaged communities. Further, Community Benefit Agreements between solar developers and a coalition of community organizations can help ensure that such projects provide tangible benefits to the local community.

CARBON CAPTURE AND STORAGE

Carbon Capture and Storage (CCS) has been suggested for the region as a climate and energy strategy (e.g., LLNL, 2023). Portions of the SJV, especially Merced County and Kern County, have been identified as sites with high potential for direct air capture (DAC) and geologic carbon storage (LLNL, 2023). CCS is a technology that purports to remove carbon dioxide from industrial sources and store it underground, serving as a sink for carbon. However, it is currently an unproven and expensive technology with little evidence of its ability to significantly reduce emissions at scale (Abdulla et al., 2020). Certain types of CCS also carry significant risks, including air pollution, groundwater contamination, and the potential for earthquakes, ruptures, and leaks that can impact neighboring communities. One of the most common forms is carbon capture utilization and storage (CCUS), which includes enhanced oil recovery where carbon is injected to extract additional oil, thus leading to additional greenhouse gas emissions (Abdulla et al., 2020). Importantly, enhanced oil recovery is banned in California (IEA, 2022). There are several other concerns regarding DAC and geologic carbon storage: DAC requires energy, and for it to yield net carbon reductions, substantial renewable energy (in excess of what is needed for local demand in the SJV otherwise) would need to be built out (Grubert & Hastings-Simon, 2022). Finally, CCS is hard to scale economically (Abdulla et al., 2020). Because of this, as of 2021, there were no commercial-scale CCS projects in energy procurement, and energy projections out to 2040 assume little contribution of CCS (IEA, 2021; Williams et al., 2021). While some CCS-related technologies may help address mitigation goals, there is caution in rapidly deploying them in the SJV until technology, economics, and most importantly, community concerns can be addressed.

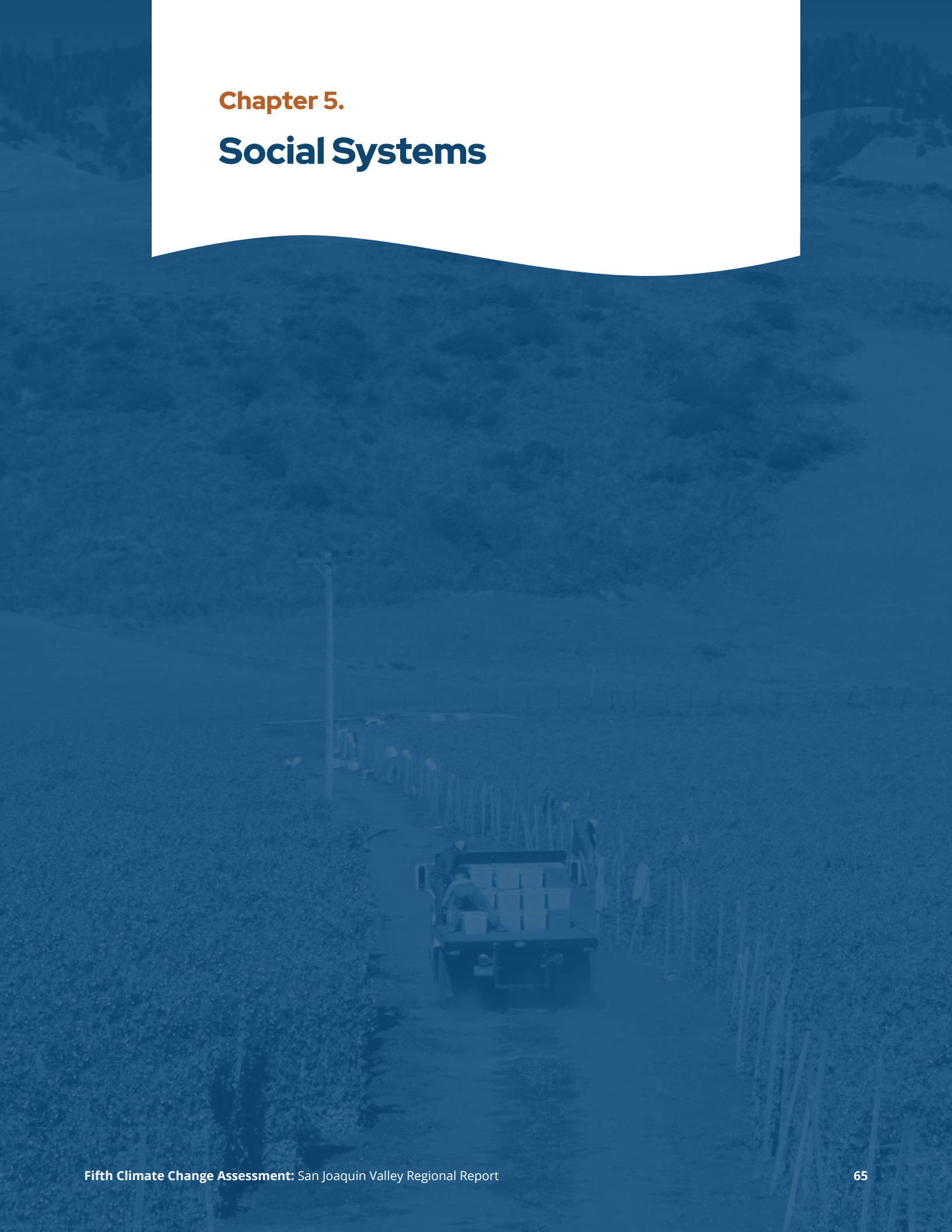
TRANSPORTATION INFRASTRUCTURE

Solutions for addressing impacts from and to the transportation sector in the SJV resemble those for other parts of the state and require a multifaceted approach. A key solution involves accelerating the electrification of medium- and heavy-duty vehicles, along with agricultural and off-road equipment, to zero-emission technologies. Such transitions will also help improve air quality (e.g., nitrous oxides and PM2.5) near transportation corridors and in adjacent communities. Beyond vehicle electrification, preparing the physical infrastructure for changes in future temperature and precipitation extremes will be necessary. This includes selecting and utilizing road and bridge materials that can withstand higher temperatures, such as more heat-resistant asphalt and flexible expansion joints.

Critically, improvements to transportation networks (e.g., biking and walking infrastructure, shared community transit, high-speed rail) can be strategically linked to other community goals. By enhancing mobility, the region can foster denser, transit-oriented residential growth, which reduces urban sprawl and, in turn, limits vehicle miles traveled. This comprehensive strategy not only curbs greenhouse gas emissions and improves air quality but also creates opportunities for residential growth and the expansion of local services.

Chapter 5.

Social Systems



Key Message

Climate change has led to both direct and ripple effects on communities across the San Joaquin Valley (SJV) through impacts on the economy, including labor and housing, and public health, which has exacerbated longstanding environmental justice issues. Due to its distinct demographic and socioeconomic characteristics, the Valley is particularly vulnerable to climate change. Climate change is greatly impacting social systems by adding to pre-existing poor air quality and heat hazards, a lack of climate-resilient infrastructure, and a high concentration of disadvantaged communities. In response, a range of mitigation and adaptation strategies have emerged, including improved monitoring and early warning systems, institutional interventions for job retraining, and economic and other forms of assistance for disadvantaged communities with public health burdens exacerbated by climate change.

5.1 Overview of Communities in SJV

5.1.1 Historical Context

The SJV has undergone a massive social transformation over the past two centuries, driven first by colonialism and later by large-scale migration. Spanish colonization brought genocide, forced relocation, mission enslavement, and widespread mortality among the region's Indigenous Peoples (Ch. 3). With the US takeover of California, Tribes faced continued violence, land and water dispossession through federal and state policies, enslavement under the 1850 "Protection of Indians" Act, the removal of children to boarding schools, and the spread of introduced diseases. These systemic assaults contributed to an 85% decline in California's Indigenous populations from 1850–1890. The passage of the Homestead Act and later policies gave settlers free or heavily subsidized land (taken from Indigenous Peoples), water (via the ***State Water Project*** and the ***Central Valley Project***; Ch. 4), and access to labor (e.g., via the Bracero program). Importantly, immigrant labor—including those of Chinese, Japanese, Hmong, Portuguese and Mexican origin—has long been part of the region and relied upon to make the region an agricultural powerhouse (Greene et al., 2021), with circular migration for Mexican farmworkers playing a key role in the Valley's agricultural dominance. In the late 19th and early 20th centuries, Scandinavian immigrants, particularly from Sweden, Norway, and Denmark, settled in parts of the Central Valley, with towns like Kingsburg developing a distinct Swedish identity. Additionally, Black communities, many from the southern US, moved to the area and established towns such as Allensworth and Fairmead, drawn by the availability of affordable agricultural land and the opportunity to legally purchase property at a time when discriminatory policies elsewhere severely restricted Black land ownership. In later decades, another wave of migration into the region came from those escaping the Dust Bowl, primarily from Oklahoma, Texas, Arkansas, Missouri, and Kansas; Hmong people arriving as refugees in the 1970s following the Vietnam war; and Punjabi Sikhs migrating from Northern India.

Today, the sociodemographic context of the region is just as diverse as the history of the region. Sixteen Tribes across Tulare, Kings, Fresno, Madera, and Mariposa counties maintain a presence in the region. Over 90% of farmworkers in California are Latino, with two-thirds of farmworkers born in Mexico (CRB, 2013; Hernandez et al., 2016; Greene et al., 2021), and many farmworkers in California self-identify as undocumented (UC Merced Community and Labor Center, 2022).

5.1.2 Socioeconomic Characteristics of SJV

The SJV ranks among the most productive agricultural regions in the world yet also has the highest concentration of ***disadvantaged communities*** in California. The top five industry sectors in SJV counties (based on annual employment from 2023–2024) are: agriculture, natural resources, and mining; trade, transportation, and utilities; education and health services; leisure and hospitality; and manufacturing. In contrast, employment in some private industry sectors remains small. For example, the information sector in SJV employed only around 7,000 workers annually between 2023 and 2024. At least 20% of the workforce in census tracts within the SJV is employed in outdoor sectors (farming, fishing, and forestry; construction and extraction; natural resources: installation, maintenance, and repair; building and grounds cleaning; and firefighting). Moreover, this is likely to be an underestimate, as many census tracts in the SJV are classified as "hard to count" (Thorman et al., 2018).

About half of the population in the Valley lives in disadvantaged communities (OEHHA, 2014); per capita income in the SJV is significantly below the California state average, while the housing price index remains lower than the state average (except in San Joaquin and Stanislaus counties). Compared to the California state average, SJV counties have a relatively larger proportion of low-income households earning less than $10,000 annually, and a smaller share of high-income households with annual income exceeding $150,000. The region also experiences a higher overall poverty rate, particularly among children: the average percentage of children living in poverty across SJV counties in 2023 exceeds 21%, compared to the state average of 15%. The relatively high portion of the population in poverty indirectly leads to increased vulnerability to environmental stressors (e.g., ability to mitigate the impacts of chronic heat). These poverty trends are driven in part by a workforce with comparatively low levels of educational attainment. For example, the share of college graduates is notably smaller than the statewide average, contributing to limited economic mobility. Major climate action initiatives in California, including community choice clean energy programs, climate action planning, and building decarbonization, are woefully underrepresented in the SJV (Almeida, 2026).

5.2 Climate Change Impacts on Labor Market and the Economy

5.2.1 Population Changes and Migration Forces

The increasing frequency and intensity of extreme heat, drought, and wildfire smoke can influence worker decisions to relocate. For example, the increasing frequency of extreme heat—particularly days exceeding 100°F (37.8°C) (Ch. 2)—can contribute to "brain drain" as skilled workers may leave the Valley for milder climates (Fan et al., 2016), as can days of poor air quality due to large fires burning in adjacent areas which exacerbates existing poor air quality. Additionally, persistent and severe drought conditions in the region influence household relocation decisions. Areas experiencing higher levels of unmet water demand are particularly susceptible to population decline, as residents seek more sustainable living conditions elsewhere (Shen et al., 2024). Furthermore, relative decreases in housing values in the Valley have been found in areas of high subsidence and groundwater overdraft due to issues tied to water insecurity, damage to structure and local infrastructure, and increased flood risk (Nemati et al., 2025).

Feedbacks from the housing and labor markets act as an invisible mechanism to counterbalance dramatic climate-induced changes in labor flows (Fan et al., 2018). For instance, as individuals migrate toward areas with higher amenity values and enhanced quality of life, the resulting increase in housing demand tends to drive up housing prices, assuming other factors remain constant. Concurrently, an influx of labor supply can intensify competition in the labor market, potentially lowering wages, assuming labor demand remains unchanged. These economic feedbacks may moderate migration outcomes. The higher living costs and in the cooler and often more affluent regions outside of the SJV—such as coastal areas of California—can act as a deterrent to outward migration and similarly promote internal migration from those regions toward more affordable inland regions like the SJV. The Valley has a higher proportion of younger population relative to the rest of the state. Similarly, the relatively lower cost of living and competitive wages—particularly in expanding sectors such as health services—can serve as a draw for new residents flowing into the SJV. See the Fifth Assessment's "Climate Impacts to the Economy Statewide Topical Report" and "Climate-Induced Human Displacement and Migration Statewide Topical Report" for more on how these dynamics unfold in the region.

Notably, educational attainment rates are increasing in the SJV. The population growth rate between 2019 and 2023 in SJV counties outpaced the state average. Notably, the proportion of college graduates in SJV counties has increased at a faster rate than the statewide trend, although the proportion remains below the state average. At the same time, there has been a marked decline in high school dropout rates in the region—over 8% in Fresno, Kern, and Tulare counties—compared to the state average decrease of approximately 7% in 2023 relative to 2019, while the rates remain comparatively higher than state average. Likewise, recent population projections show moderate growth for counties in SJV in the coming decades relative to much of the rest of the state (California Department of Finance, 2024).

5.2.2 Impacts on the Regional Labor Market in the SJV

Climate change poses significant risks to the SJV's labor market by threatening the long-term stability of its most employment-intensive industries. In agriculture, increasing temperatures, more frequent droughts, and water supply uncertainty may reduce the viability of labor-intensive crops (Ch. 3), leading to fewer farm jobs and accelerating the shift toward mechanization. In addition, because agricultural workers are required to take more frequent breaks and work shorter shifts in summer with rising temperatures, small farms that are often more labor-intensive (e.g., lacking mechanization) may experience the effects of climate change more intensely (UC Merced Community and Labor Center, 2022). These conditions may also reduce the willingness of potential workers to accept jobs in environments where exposure to extreme heat and other climate-related stresses poses significant risks to their health. Additionally, climate-related disruptions to infrastructure, such as heat-damaged roads or power outages, may affect sectors like construction, transportation, and logistics, where outdoor work and reliable energy access are critical. While adaptation efforts may generate some new jobs (e.g., infrastructure repair or grid upgrades), these are often reactive, unevenly distributed, and may not offset the broader employment instability caused by climate impacts. Overall, these impacts could lead to job displacement, greater seasonal employment fluctuations, and increased demand for new skills.

5.2.3 Economic Impacts on the Agricultural Sector

Agriculture in particular faces mounting challenges tied to climate-related water scarcity (Ch. 3). Agriculture accounts for 16.4% of the SJV gross domestic product (US BEA, 2024), and severe and prolonged droughts have led to negative economic impacts on this sector. The acute droughts of 2012–2016 and 2020–2022 resulted in 2.6–5.9% of income losses for California agriculture, up to 3.8% loss of farmworker and agricultural processing jobs (Howitt et al., 2014; Medellín-Azuara et al., 2022), and an increase of 5–10% in idle farmland, causing crop revenue losses of $900–1,200 million (Lund et al., 2018). Other climate extremes, such as flooding, have also resulted in temporary losses to agricultural income and employment (Foy, 2023; Purohit, 2024).

In addition to immediate productivity losses, climate change creates long-term instability by making it difficult to plan for what crops can be sustained under shifting water conditions. Water availability, drought conditions, temperature, and precipitation affect farmers' crop choices and irrigation decisions (Fan et al., 2023). As water supplies become more variable and constrained, growers may be forced to fallow land, switch to less profitable crops, or exit the industry altogether (Ch. 3), putting regional food systems, jobs, and export revenues at risk. Small-scale, underserved farmers are particularly vulnerable to this (see *Section 5.4 Environmental Justice Dimensions* section below).

While farmers may partially offset crop losses through insurance, coverage typically excludes farmworker displacement and broader community impacts. Furthermore, many small farmers do not have crop insurance (National Sustainable Agriculture Coalition, 2025). Rising costs also threaten the long-term viability of crop insurance, underscoring the importance of comprehensive economic resilience strategies that support both individual operations and regional systems.

5.2.4 Economic Disruptions of Other Established and Emerging Industries

Climate change is also disrupting other key industries that form the backbone of the Valley's economy. One of the most affected is leisure and hospitality, which accounts for a substantial share of regional employment. This sector is particularly vulnerable to environmental volatility. Increasing frequency and severity of wildfires and smoke in national parks (e.g., Yosemite, Sequoia-Kings Canyon), for which the SJV is a gateway, directly impacts tourism, an economic mainstay of the region. These disruptions also have second-order effects, such as dampening investor confidence and curbing opportunities for future development.

Emerging industries are not immune to these challenges. Rising temperatures are driving up energy costs across the region, placing pressure on energy-intensive sectors like high-tech and artificial intelligence (AI). This trend may dissuade such industries from remaining in or relocating to the Valley, despite its geographic proximity to key players in the AI sector and lower costs of living relative to the Bay Area or Southern California (**Box 5.1**).

Box 5.1: *AI and Tech in Agriculture in the SJV*

While the Valley is one of the most prosperous food production regions globally, the region has not yet capitalized on certain technological innovations that could support this agricultural production. In response, initiatives have been proposed to promote ag tech in the region (e.g., F3 Initiative). These initiatives argue that innovation is needed to tackle the combination of mounting climate stressors, groundwater policies, and escalating costs of agricultural production. Moreover, their goal is to help make the region's farmers competitive and resilient to environmental and economic stressors.

Integrating rapidly evolving technologies—such as digitalization, data science, automation, mechanization, and AI—into agriculture and food production systems can help transit this sector to be more resilient and sustainable. Specifically, AI-powered systems can help farmers optimize water use, apply chemicals with greater precision, and monitor crop health in real time, thus improving water allocation decisions and reducing environmental impact while boosting productivity. These innovations would ease pressure on the region's constrained agricultural workforce and create new, higher-skill jobs in ag tech and environmental services, by providing opportunities for retraining and upskilling agricultural workers. A focus on technology and AI could both address certain climate challenges as well as promote economic development.

However, advances in agricultural technologies could have several unintended consequences, including downsizing the agricultural workforce and increasing demand for both energy and water in the region. First, through automation, there is a risk of permanently downsizing the agricultural workforce which could lead to negative economic impacts and an increase in unemployment in a region that already has a high poverty level. Surveys have indicated that ag tech is the least preferred job for many low-income workers in the region (Cossyleon & Almeida, 2025), raising concerns about the inclusivity of this transition. Ensuring that technology adoption is paired with opportunities for incumbent workers to retrain and upskill will be critical for a just transition.

In addition, the infrastructure required to support AI poses significant challenges. For example, AI data centers, essential for cloud computing and analytics, depend heavily on water for cooling and large amounts of energy to operate. Yet water scarcity is already a severe and growing problem in the Valley (Ch. 2, 3). Similarly, data centers have been shown to compete with neighboring communities for energy (IER, 2025) and in some cases drive up energy costs (Martin & Peskoe, 2025), and grid reliability is already a concern for this region and will likely become worse in future decades absent a change in energy procurement (Ch. 4). On the other hand, the rapidly changing renewables landscape in the SJV may ultimately alleviate some concerns. These challenges need to be addressed if the region is to successfully pursue such sectors.

5.3 Public Health

Climate change is considered the single biggest global health threat of the 21st century by the World Health Organization. The increase in the frequency, intensity, duration, and extent of extreme weather events such as heat, air pollution, and drought present existential threats to public health. The Valley is increasingly affected by the growing frequency and intensity of climate extremes, including number of heat waves, prolonged drought and water scarcity, groundwater overdraft and contamination, and poor air quality due to increased wildfire activity in nearby mountainous regions (Ch. 2). These changes are having pronounced effects on public health, with certain populations uniquely exposed and vulnerable to these changes (**Table S7**). Moreover, surveys of populations in the SJV have indicated that it is very important that the government takes action to address extreme heat and air pollution (South Central Valley Community Needs Assessment, 2025). See the Fifth Assessment's "Public Health" report prepared by the California Department of Public Health (CDPH) for more on how climate change is affecting public health in this region.

5.3.1 Heat

The human body functions optimally within a narrow range of temperature from 97–99°F (36–37.2°C). Homeostasis, the self-regulating process by which humans maintain their internal

biological and chemical balance, can help regulate body temperature when one is exposed to temperatures between 95–106°F (35–41.1°C). However, prolonged exposure to extreme heat significantly increases health risks by compromising the normal homeostatic process.

Epidemiologic studies around the world have consistently linked extreme temperature exposures to a wide range of health outcomes, including mental health issues, cardiorespiratory complications, adverse reproductive outcomes, and mortality (Ebi et al., 2021; USEPA, 2025). Data also suggest that underserved communities, which have limited resources to respond to and adapt to heat events, may be disproportionately impacted (Fernandez-Bou et al., 2021). These groups may include those with low income, socially marginalized groups, children, pregnant people, elderly, outdoor workers, and people with underlying health problems (NIHHIS, 2025). For low-income residents who either do not have or cannot afford air conditioning, extreme heat days and warm nights combined with closed windows (often kept shut to avoid pesticide drift from nighttime agricultural applications, or during wildfire smoke events) create dangerous indoor heat conditions—particularly during prolonged heat waves.

The SJV faces severe heat-related health challenges that disproportionately affect vulnerable populations (Shonkoff et al., 2011; Fernandez-Bou et al., 2021; see **Table S7**). The SJV has higher heat-related emergency room visits than the rest of the state (Ganesh & Smith, 2017). Heat events are linked to outcomes such as emergency room visits and hospitalizations due to all-cause as well as a range of cardiovascular, respiratory, mental health complications, and pregnancy outcomes (Ndovu et al., 2025; Santodomingo et al., 2024; Teyton et al., 2024; Ha et al., 2024). Research suggests that by 2050 there will be increased emergency room visits due to extreme heat-related exposure with rising temperatures (Gould et al., 2025).

Heat health impacts are particularly exacerbated for urban areas of the Valley due to a lack of green space; furthermore, metro areas of the Valley are substantially hotter in the summer than most other urban areas in the state. As discussed in Ch. 2, the urban heat island effect means that local temperatures are even hotter than surrounding regions. Urban areas of the SJV Valley, particularly those in lower socioeconomic communities, have limited urban forestry that could otherwise mitigate heat impacts (O'Connell et al., 2023). In addition, rural areas in the SJV often lack shaded infrastructure or public cooling centers, which makes the heat even more dangerous.

5.3.2 Air Quality

The SJV experiences some of the worst air quality in the US, with climate change exacerbating existing pollution challenges. The region regularly fails to meet federal health standards for both ***ozone*** and particulate matter (***PM2.5***), with air quality rankings consistently placing SJV metropolitan areas among the most polluted in the nation (American Lung Association, 2024). Sources of poor air quality include agricultural sources, pollutants from oil and gas production, and transportation-related emissions, while the valley's topography traps air pollution emitted both locally and advected from nearby regions, including from industrial sources in southern California and the Bay Area. Climate change intensifies air quality problems through increased wildfire activity and higher temperatures that promote ozone formation (Ch. 2).

Poor air quality contributes to significant public health impacts. Poor air quality has been consistently shown to have deleterious impacts on human health through biologic mechanisms

such as oxidative stress, systemic inflammation, and endocrine disruption (Pryor et al., 2022). Pollution exposures impact just about every body system and organs, with impacts ranging from minor irritation to respiratory, cardiovascular, and mental health complications; as well as cancer and reproductive outcomes (Jung et al., 2025; American Lung Association, 2025). Notably, poor air quality has resulted in elevated asthma rates among all age groups in the SJV. Pregnant people and fetuses, when exposed to higher air pollution levels, also have increased health risks compared to those unexposed (Ha et al., 2022, 2014; Fussell et al., 2023). In addition, outdoor workers—especially farmworkers—face heightened vulnerability due to prolonged exposure to the combination of extreme heat and poor air quality, making occupational health and safety a growing concern in the region. Notably, co-exposure to heat and poor air quality can result in even greater health burdens than each extreme alone (see **Box 5.2**), though research on the compounding impacts of these two exposures on morbidity and mortality is limited.

While large fires within the confines of the SJV are less common, significant wildfire activity in neighboring regions (e.g., Sierra Nevada region), atmospheric circulation patterns, and topography of the SJV, have resulted in severe air quality impacts from large fires in recent decades. For example, during the 2020 fire season, the SJV had the highest count of wildfire smoke days in the western US, accompanied by excess mortality (Zhou et al., 2021). Wildfires have reversed decades of air quality improvement in western US; such improvements were tied to the implementation of environmental policies and associated advances and adoption of clean air technologies (Thilakaratne et al., 2023). In addition, wildfire smoke exposure has also been linked to adverse birth outcomes, including preterm delivery, with evidence suggesting compounding effects between wildfire smoke and heat exposures (Heft-Neal et al., 2022; Fernández et al., 2023; Ha et al., 2024). Such increases in mortality and morbidity are projected to increase in the future with increased burned area (Qiu et al., 2025).

Box 5.2: *Compounding Impacts from Heat and Poor Air Quality: Stockton Case Study*

The combination of extreme heat and poor air quality can lead to compounding health effects (Rosenthal et al., 2022; Rahman & Meng, 2024), particularly for outdoor workers. A collaborative project between Little Manila Rising (a community-based organization in Stockton, CA) examined the confluence of the urban heat island effect, poor air quality, land cover, and sociodemographic variables (Rousseau et al., 2024). They identified south Stockton as a hotspot of these factors, where "urban heat, air pollution, low canopy coverage, and sociodemographic vulnerability" converge to make the area more at risk of health impacts from health and poor air quality compared to other parts of the city.

5.3.3 Water Security

Water quality and access issues represent critical public health challenges in the SJV. Most communities in the region rely exclusively on groundwater, making them particularly vulnerable to groundwater contamination and depletion. Areas fully dependent on groundwater, especially rural communities, are particularly vulnerable during droughts (Flores-Landeros et al., 2022). These communities generally rely on small water systems or private wells, and are surrounded by large-scale industrial agriculture which both leads to competition for water supply during drought periods and risks contamination of water systems from agricultural pollutants. Ultimately, when communities lack access to safe drinking water, they are forced to choose between drinking bottled water or contaminated groundwater.

Climate change has and will continue to affect both water quantity and water quality in the SJV. Climate change drives groundwater overdraft in the region as a result of reductions in water supply for recharge (Ch. 2) and increases in local demand (especially from agriculture, Ch. 3), contributing to numerous shallow wells going dry (Ch. 4). Climate change can also increase flooding events that overwhelm water treatment infrastructure and lead to bacterial contamination of groundwater due to proximity to livestock (Ch. 4).

Many people in the SJV also lack access to reliable information about the safety of well water. Nitrate levels in the region often exceed maximum safe thresholds, with rural disadvantaged communities of color experiencing the highest burden (Balazs et al., 2011). Long-term intake of elevated nitrate concentration in water can cause serious health hazards in children and other vulnerable populations (e.g., pregnant people) (Ward et al., 2018). Elevated concentrations of arsenic in well water—observed in portions of the SJV (Smith et al., 2018)—is linked to increased risk of cancer, heart disease, and diabetes. Despite known health risks, long-term solutions to water quality issues remain elusive for some SJV communities. For example, the rural, ***disadvantaged community*** of Lanare received a $1.3 million water treatment plant for arsenic removal; however, it was disconnected shortly after it began operations because the community could not afford maintenance costs, illustrating systemic barriers to water security in disadvantaged communities (Fernandez-Bou et al., 2023).

5.3.4 Vectors and Pathogens

Climate change can increase the presence of certain vectors and pathogens, by shifting precipitation patterns and warming temperatures that, in particular, affect mosquito populations, which can carry West Nile Virus, and fungal spore distribution, or Valley Fever. The SJV in particular is vulnerable to such expansion due to a lack of natural vector predators, due to industrial agriculture and application of pesticides.

Mosquito-borne diseases, including West Nile Virus, occur with warmer temperatures (e.g., minimum temperatures above 50°F [10°C]) and standing water (Hernandez et al., 2019; Hernandez et al., 2023). Various management efforts, including agricultural and irrigation practices that limit breeding habitat and efforts to introduce sterile mosquitoes, can help curtail rampant population increases. However, given the large outdoor workforce, there is still a large population of people in the SJV that are exposed to mosquitos.

Valley Fever (*Coccidioidomycosis*) thrives in the SJV's climate, with the south Valley having the highest incidence rate in the state. Symptoms of this fungal infection include fever, cough, and fatigue, and can progress to severe respiratory illness. The infection is difficult to diagnose due to overlapping symptoms with other conditions such as flu, leading to a high chance of misdiagnosis. The highest number of Valley Fever cases in California were in 2023 and 2019, with over 20 cases per 100,000 people (CDPH, 2025). Both of these years had unusually wet conditions the prior winter. Studies suggest that Valley Fever is more prolific during wet-to-dry sequences where atypically wet conditions during winter promote fungal growth while very dry periods in the months after, combined with wind events, promote spore dispersal (Camponuri et al., 2025; Head et al., 2022). Climate change intensifies wet-to-dry hydroclimatic whiplash (Swain et al., 2025) and thus may favor Valley Fever.

5.3.5 Mental Health Impacts

Climate change-related impacts have been shown to have psychological implications, particularly related to mental health (Rosas et al., 2024; Ha, 2024), which may be especially present for youth (Majeed & Lee, 2017; Rosas et al., 2024; Ha, 2024). This is of concern as the SJV already has some of the highest rates of mental health challenges in the state, coupled with very low numbers of mental health practitioners (Ganesh & Smith, 2017). Water insecurity during drought leads to stress for farmers and rural communities who rely on small-scale groundwater systems (Barreau et al., 2017). This stress is particularly felt by farmworkers (Berman et al., 2021; Greene et al., 2021; Rosas et al., 2024) and can have serious ramifications, as evidenced by recent droughts where there was an increase in calls from small-scale farmers to suicide hotlines (UCANR, 2021). Increased temperatures also increase emergency room visits for mental health disorders in California (Basu et al., 2018). Furthermore, the combined impacts of exposure to wildfire smoke and extreme heat can force people to stay indoors, resulting in various mental health challenges. Finally, populations in the Valley lack access to green space, which comes with a psychological toll (Rosas et al., 2024). While not a direct climate impact, this is exacerbated during extreme heat events when people cannot access these cooler spaces (Huang et al., 2024).

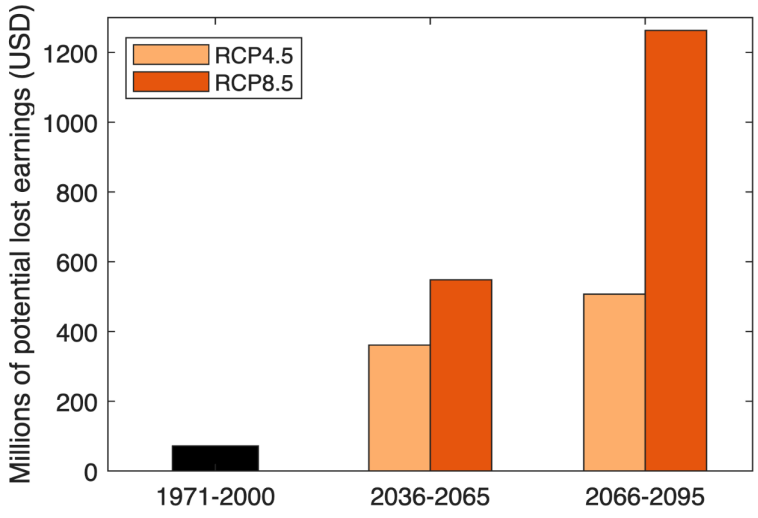
5.4 Environmental Justice Dimensions

While all communities in the SJV are exposed to climate-exacerbated impacts on labor, economy, and human health, certain communities are disproportionately at risk. A substantial portion of the population—particularly in small rural communities—resides in disadvantaged communities that are vulnerable to climate change. While **Table S7** highlights communities who bear unique vulnerabilities and exposures to public health-relevant climate impacts, here, we introduce a few of these communities who face unique, outsized vulnerabilities to climate change impacts and inaction more broadly: small farmers; farmworkers; Tribal communities; incarcerated communities;
and other historically marginalized and disadvantaged communities.

5.4.1 Farmworkers

The SJV is home to nearly half of the state's agricultural workforce (USBLS, 2025). Many of those in the agricultural sector are farmworkers, who provide an essential component of the broader food supply chain and agricultural economy in the SJV. The outdoor workforce is the most exposed to environmental impacts such as heat and poor air quality and hence has much higher rates of health impacts compared to the general population. Farmworkers are 20 times more likely to die from heat and heat-related illnesses than the average worker in the US (Jackson & Rosenberg, 2010; Luginbuhl et al., 2008). Furthermore, nearly half of farmworkers have reported never receiving extreme heat safety training from employers (UC Merced Community and Labor Center, 2022) and half of farmworker households in the region have reported experiencing an employment interruption due to climate extremes (Cossyleon & Almeida, 2025). Such impacts are compounded by poor social services and inadequate housing among farmworkers. For example, poorly insulated housing and high energy costs for cooling lead to high ambient sleeping temperatures and poor rest. Such chronically high temperatures escalate the risk of work-related

injuries (Spector et al., 2016) and decrease labor productivity (Castillo et al., 2021). Farmworker settlements, often in low-income rural communities, can lack access to critical information and resources related to climate mitigation and adaptation strategies. These extreme working conditions and low wages have led to farmworker scarcity in California. Such impacts may be further magnified for migrant farmworkers who are more vulnerable to compound societal, economic, and environmental stressors.



Lost Income from Extreme Heat for Outdoor Workers

Figure 5.1: *Estimated potential total lost income annually due to extreme heat across the SJV for outdoor workers. Results for the eight counties covering the SJV are shown for the (a) historical period (1971–2000), (b) mid-century (2036–2065), and (c) late-century (2070–2099). Results are shown as the 20-model mean for a moderate emissions pathway (RCP4.5) and a high emissions pathway (RCP8.5) considering no change in population and no change in work schedule to adapt to heat. Results are from Licker et al., 2022.*

Climate projections indicate that farmworkers will be increasingly exposed to temperatures that are unsafe for outdoor work (Dasgupta et al., 2024; Tigchelaar et al., 2020). California's Division of Occupational Safety and Health (Cal/OSHA) guidelines have protections to mitigate heat impacts—including allowing for breaks or full-stoppage of work at higher temperatures. For example, when accounting for such guidelines, Merced County is projected to have 11 working days per year by mid-century of potential lost employment compared with just one day per year during the late 20th century (Licker et al., 2022). However, work stoppages are not always well practiced or enforced. Conversely, absent significant modifications in work schedules or efforts to abate heat impacts for workers, work stoppages can negatively impact farmworker income and result in reduced overall agricultural productivity. Scaled across the Valley, the total potential lost income from the outdoor workforce due to heat stress increases from an average of 72 million a year during 1971–2000 to an average of over 350 million a year by the mid-century and over 1.2 billion a year by the end of the century under a high-end warming scenario (**Figure 5.1**). While mitigation efforts, such as shading and changes in work schedules can reduce exposure, increases in extreme heat means fewer hours that farmworkers can safely work in the fields creating both humanitarian and economic costs.

5.4.2 Small Farmers

As small farms are often family-run and more labor-intensive than their larger counterparts, many small farmers have some of the same vulnerabilities and exposures as farmworkers do. Since the 2000s, farmland purchases by limited liability companies have surged, reflecting land ownership consolidation, while between 2017–2022, thousands of small and mid-size farms disappeared as farms over 1,000 acres grew in number (Rempel et al., 2024). This consolidation tends to promote excessive water use and monoculture practices (which are often less climate-resilient) while reducing consumer choices and threatening food system resilience (Woodall & Shannon, 2018). Furthermore, non-local corporations typically contribute less to community economies than local farmers who live and spend their earnings locally. Lack of economic resilience translates in substandard infrastructure and decreased well-being, making agriculture-dependent disadvantaged communities more susceptible to climate impacts.

Small farmers often grow ***annual crops*** (and some ***perennial crops***) for local consumption (**Figure 5.2**), thus providing important economic and social benefits including food quality and access, diversification, higher yields and economic outputs per acre, indirect employment in rural areas, production of culturally important produce, and food sovereignty (e.g., Ricciardi et al., 2021). However, small farmers are particularly vulnerable to weather and climate impacts (Dahlquist-Willard & Sowerwine, 2021). These operations typically lease land with shallower irrigation wells that are first to fail when groundwater is over extracted during acute droughts (Ch. 4), while facing growing challenges from slim profit margins, unpredictable water access, and lack of representation in policy-making processes (Rempel et al., 2024). For example, smallholder Hmong farmers—primarily concentrated in Fresno County, with additional communities in Merced and San Joaquin counties—are particularly concerned about increased uncertainty in irrigation water availability, worsening drought conditions on their farms, and crop damages from extreme heat (Taku-Forchu et al., 2024).



Figure 5.2: *Diversified, small farm in Fresno County. Credit: UCANR.*

5.4.3 Urban Communities

Urban communities in the SJV continue to grow unlike many other metropolitan areas of the state. Similar to other urban areas, historical redlining and continued suburban sprawl have resulted in large disparities for low-income urban communities in the Valley. The ***urban heat island*** effect is often magnified in disadvantaged portions of SJV cities due to the extent of impervious surfaces that absorb and retain heat and devoid of green space and urban forestry (e.g., Rousseau et al., 2024). These factors compound background warming due to climate change, intensify existing health impacts for residents and escalate costs for air conditioning among those who can least afford it. Health impacts from heat stress are further compounded

by various air quality pollutants in urban cores, particularly near major transportation corridors and industrial complexes (Houston et al., 2024). In addition, urban flooding can be more pronounced in locations with limited green space, further increasing direct impacts from extreme weather for such communities.

Efforts to ameliorate such inequities include urban forestry projects. In Stockton, the Urban Forest Renovation Project has not only planted trees in areas that have seen declines in tree canopies and in locations identified by the community but also educated residents and provided free trees (Karpman et al., 2024). Likewise, Fresno has a goal of achieving 20% canopy cover for the City by 2060, prioritizing areas with the most vulnerable populations and lowest tree cover (City of Fresno, 2024). However, the decadal time horizons for urban forest to fully develop requires sustained long-term funding (e.g., tree planting and maintenance).

5.4.4 Tribal Communities

As described in Chapter 3, Tribal communities in the Valley have many of the same exposures and vulnerabilities to climate change as seen with other communities, plus several unique vulnerabilities, as well as unique perspectives, on climate solutions. Climate change, as the most recent manifestation of harmful environmental change and an extension of colonial extractivism (Whyte, 2016), has led to singular impacts to Tribal communities, including on culturally important plants and animals species, as well as traditional gathering areas and ceremonial sites. Furthermore, Tribal communities are often excluded from decision-making processes, which presents a significant barrier to addressing these harms. This is particularly a challenge for those Tribal communities without state or federal recognition. However, recent efforts designed to promote restoration of culturally important areas, which have prioritized Tribal partners in the planning and implementation of these projects (e.g., Dos Rios State Park and Wuk'nain Plains Restoration in **Box 3.4**, Ch. 3), offer a glimpse for how some of these impacts can be ameliorated. In addition, Tribes across the region are creating Tribally-led climate adaptation plans which explore ways to manage climate impacts in a culturally-sensitive way while promoting Tribal sovereignty (e.g., Tule River Indian Tribe of California, 2024; North Fork Rancheria of Mono Indians of California, 2022).

5.4.5 Rural, Unincorporated Frontline Communities

Rural, unincorporated communities of the Valley face compounding socioenvironmental and economic issues that are exacerbated by climate change. Disadvantaged communities experience disproportionate burdens from water insecurity, food and nutrition insecurity, lack of sanitation, air pollution (Liu et al., 2025), and climate-related hazards, while having very limited political representation and public infrastructure (Flores-Landeros et al., 2022). Water insecurity and poor air quality are two of the most pressing challenges in unincorporated communities. Most communities rely completely on groundwater for their water needs, and thus face both water quality and quantity issues (Ch. 3). As these communities often live within close proximity to agricultural fields, pesticide drift and dust from farming operations significantly impact community health.

Box 5.3: *Allensworth Community Transformation: A Model for Just Land Transition*

Allensworth, a historically Black township in Tulare County, is implementing a comprehensive community-owned land transition to address environmental injustice and create economic opportunities through regenerative agriculture. Allensworth is grappling with effects from historical discrimination and disinvestment, polluted water, depleted soils, and inadequate infrastructure. Recent droughts and floods have only compounded these issues. Allensworth is developing a 100-acre Agroecology Hub that will integrate regenerative agriculture, ***agrivoltaics***, workforce development, and land access initiatives for farmers of color. This demonstration project aims to show how land repurposing can simultaneously address environmental justice concerns, honor Traditional Ecological Knowledge, create economic opportunities, and deliver ecosystem services, offering a framework for agricultural communities in the Valley.

5.4.6 Incarcerated Communities

The SJV has a disproportionately high number of California's prisons (Lucas, 2022). Furthermore, as with most of the correctional facilities in the rest of the state, people of color are overrepresented in these facilities (Lucas, 2022). Incarcerated communities have a unique vulnerability to climate change since they have no decision-making authority regarding their environmental situation and therefore rely on the institutions to reduce their exposure and vulnerability to climate change-related impacts (Abdala et al., 2023; Pellow, 2024). A state-led audit of California's correctional facilities found that the institutions are "...not adequately prepared to respond to emergencies posed by natural disasters," due to both overcrowding and insufficient evacuation plans (Office of the Inspector General, 2025).

In recent years, several climate extremes have highlighted this unique vulnerability: flood risks, heat extremes, and epidemics of pathogens and vectors. The record snowpack in 2023 led to heavy snowmelt in the spring and flooding in the Valley (Ch. 2). Two prisons were at high risk of flooding; though they ultimately did not flood, their evacuation plan would have taken over 10 days to implement (Mihalovich, 2025). Furthermore, incarcerated people in prisons are co-exposed to extreme heat and wildfire smoke, yet many correctional institutions do not have central air conditioning or adequate shade (Abdala et al., 2023). Instead, the institutions' cooling plans rely on water bottles, fans, and ice (CDCR, 2025), though people report inadequate access (Abdala et al., 2023). OSHA rules for indoor workers and extreme heat also do not apply to incarcerated workers (Smith, 2024). Finally, overcrowding contributes to increased transmission of diseases, with higher rates of Valley Fever among the prison population compared to the surrounding region (Lee et al., 2017; Lucas, 2022). These impacts are likely to continue and potentially grow both with projected climate impacts and the increase in immigration-related detention facilities in the region (e.g., Montalvo, 2025). See the Fifth Assessment's "Racial Equity and Climate Justice Statewide Topical Report" and "Climate Change-Related Occupational Hazards" report for more on current and projected climate change exposure for incarcerated communities.

5.4.7 Other Issues Facing Marginalized Communities

ENERGY COSTS

With increased heat extremes, there is a need for more reliable and affordable cooling systems. Energy costs are higher in poorly insulated houses and those without solar, which compounds

heat-related burdens on lower socioeconomic groups in the Valley. Despite state solar incentives, many community members lack information about available programs or face barriers to accessing clean energy solutions. Furthermore, there are no cooling requirements for housing stock in the state. Therefore, many rural communities, especially disadvantaged and farmworker communities, rely on swamp coolers for cooling which provide limited to no air filtration during episodes of poor air quality and become less effective at higher temperatures. It is estimated that while only 1% of households in the region have no form of cooling, around 10% of households in the Valley rely on swamp coolers (CPUC, 2021). Furthermore, many of these communities do not have air purifiers, so are also exposed to poor air quality. Continued increases in heat waves will continue to disproportionately impact lower income communities in the SJV.

BARRIERS FOR COMMUNITY ACTION

> ***"Communities we serve—especially immigrant and disadvantaged populations—face significant information gaps and barriers to civic participation and social mobility. Language access, digital exclusion, and a lack of culturally relevant outreach prevent people from engaging in decision-making processes that impact their health, environment, and future."***
>
> ***— Community Leader***

Frontline and marginalized communities in the Valley face significant barriers to climate adaptation. This includes information and resource gaps, with limited awareness, access, and sometimes eligibility for available climate programs and incentives. Furthermore, challenges exist related to language and information access, as critical climate information is sometimes not available in Spanish and Hmong, thereby limiting community participation in adaptation planning (Thao et al., 2019; Fernandez-Bou et al., 2021). Despite these barriers, frontline communities express interest in community engagement to address climate impacts, including those from extreme heat and wildfire smoke (Brostrom et al., 2024). However, when asked about attending and participating in civic engagement in climate action, several other issues were prioritized, including housing costs, utility costs, access to health care, low wages, and water pollution. To motivate participation, other pressing community needs may be incorporated into public participation programs. Also, climate communication needs to be relayed in straightforward language, as more people reported they were willing to attend a local meeting to address "extreme heat" than "climate adaptation" (Almeida, 2026). Investing in the types of local organizations that encourage civic engagement in general, appears as a strategy to widen public participation in climate resiliency and adaptation efforts. This in particular can inform municipal-level climate action plans to ensure community concerns are heard and addressed.

A majority of surveyed residents across the eight counties of the SJV also support more local action to address climate change (Almeida, Naseif, & Haddad, 2026) with many individuals, particularly younger people and women, being willing to personally commit time to such efforts (Almeida et al., 2023; Ha, 2024). While SJV residents tend to be familiar with alternative energy systems such as wind and solar power, they are less familiar with other technologies such as ***carbon capture and storage***, biomass carbon removal and storage, and dairy digesters. More investment in public education campaigns with trusted community partners such as community-based organizations, labor unions, and environmental justice organizations on the risks and benefits of these emerging technologies and initiatives may increase public participation (Almeida, 2026).

5.5 Solutions and Adaptation Strategies

5.5.1 Economy

> *"Economic concerns have become important for us in the sense that it's hard for small farmers to access stable and fair markets, which impacts the choices they make on their farms. We are, of course, concerned with environmental aspects of farming—particularly, soil health, air quality, and water use/quality. But, in order to inspire farmers to implement practices that will improve the health of our systems, there has to be market/financial support to de-risk trying new things. This is why incentives are important—but incentives without trying to change the overarching structure of the food system may just be a band aid."*
>
> *— Community Leader*

Given that the economy of the SJV is heavily dependent on agriculture, and that agriculture is climate sensitive (Ch. 3), solutions may include making current economic sectors more climate resilient, as well as considering certain larger-scale economic shifts in the region to less climate vulnerable sectors. This involves several themes: (1) improving the water and energy efficiency of industries already in the region, (2) encouraging growth of existing industries in the region that are already water- and energy-efficient, and (3) transitioning into new climate-resilient industries that do not yet have a substantial presence in the region.

First, to increase energy and water efficiency of existing industries such as agriculture, practices ranging from irrigation choices, cropping choices, and even farm size can help (Ch. 3). Second, there are a number of industries in the region that are already more climate resilient than others, such as health and education. Ensuring investment in these industries, including competitive wages in these sectors compared to surrounding regions, can support the growth of these industries. In particular, investing in health will help address public health impacts of climate change, and education can help address the "brain drain" of the region (skilled workers leaving the Valley). Third, fostering growth in climate resilient sectors where the SJV has lagged—such as information, financial activities, professional and business services, renewable energy, leisure and hospitality and other services—along with the skilled workforce that supports them can be a win-win for the region. Community and regional development strategies that prioritize sustainable economic growth and improved quality of life (Fan et al., 2016), alongside comprehensive climate change mitigation and adaptation plans, could play a crucial role in attracting and retaining skilled talent in the Valley.

To facilitate such an economic transition, providing resources, such as job training, to workers will be crucial. For those in the agricultural sector, re-skilling workers to new agricultural technologies as well as climate-smart and regenerative agriculture will allow the workforce to be adaptive. The genuine integration of farmers, practitioners, and researchers in the Valley through the development of technology and education clusters is essential for effective implementation of climate mitigation and adaptation strategies. Moreover, while there has been a shift toward larger farms in the SJV, economic transitions that promote small farms with diverse crop portfolios, flexible water use, and with crops that are suited to climate change can have direct benefits for local communities and economies.

For those transiting out of the agricultural sector, proactively preparing the workforce through re-skilling and education services, climate-resilient job creation, and investments in adaptive technologies will be essential to ensure long-term economic security (e.g., Brostrom et al., 2024; Almeida et al., 2024). Programs could include efforts to retrain farmworkers for jobs in ecological restoration and conservation, renewable energy, and other green jobs, and current programs offer a blueprint (e.g., Rising Sun Center for Opportunity; Kern Community College's *California Renewable Energy Laboratory*). It is crucial to ensure that these programs provide an onramp to jobs that are well-paying, high road jobs, thus improving access to more employment opportunities and promoting upward socioeconomic mobility. This is particularly important for individuals who have been historically marginalized and do not have access to such training otherwise.

5.5.2 Community and Public Health

> ***"We can buy bottled water, but we cannot buy clean air"***
>
> ***— Community leader, via Flores-Landeros et al. (2022)***

Solutions regarding community health and hazards (e.g., poor water and air quality, and extreme heat) generally fall into three categories: 1) improved monitoring and early warning systems, 2) reducing exposure to a hazard, and 3) reducing the hazard itself.

The first category involves more geographically dispersed monitoring systems and efforts to ensure broad access to the information from those monitoring systems. Distributing sensors to communities who do not currently have them can help increase the geographic and social distribution of access to early warning systems. For example, various organizations work with communities to sometimes build and then distribute sensors in otherwise under-resourced communities (e.g., SocioEnvironmental Education Network; UCM SJV Center for Air Injustice Reduction), though resources are needed to scale this type of community-based monitoring. For water quality, programs to provide free testing of water well quality (e.g., Kings River Water Quality Coalition) can help communities monitor their water quality. However, while community-based monitoring is crucial, efforts may be made to ensure that the full burden of that monitoring does not fall on communities (e.g., more systematic monitoring by local agencies, accessible results, warnings given when risks are detected).

Early warning systems could also be improved, in order to ensure that those people most exposed to these events know that they are happening. This involves both ensuring that warnings are issued during these events, as well as improved outreach and communication efforts. For early warnings to be effective, agencies may emphasize efforts to consider how to make early warnings relevant, accessible, and actionable for all—including in appropriate languages (e.g. Spanish, Hmong) and formats (e.g., short memos in clear language, via radio).

For people who have the means to respond to early warning systems, that may be sufficient to ensure community health. However, particularly in the SJV where there is a large proportion of people who live in disadvantaged communities, not everyone has the means. Thus, reducing exposure involves access to resources (e.g., materials, physical spaces) and changes in policies to ensure that when an early warning system is activated, people can act on that warning. Reducing exposure to poor air quality and extreme events can take the form of ensuring there are enough

cooling centers with air filtration systems throughout the region, and that people know about these centers. Furthermore, affordable and reliable access to energy and transportation, (e.g., free public transit to cooling centers) during these events can help prevent health impacts. Similarly, as some people in the region lack air conditioning, or cannot afford to run it, energy bill assistance programs, like (e.g., heavily subsidized energy use for low-income households) could be lifesaving. As outdoor workers are the most exposed to poor air quality and extreme heat, it is important to ensure paid work stoppages during heat waves. While there are OSHA guidelines for work stoppages during extreme heat, this does not exist for air quality levels. Furthermore, there is no requirement that outdoor workers get paid during these stoppages. To continue providing salaries or stipends during such stoppages, models could be pursued where the payout comes from the employer (for large employers) or from state-run assistance (for small employers). To reduce exposure to poor water quality, a simple response is to provide low income households with bottled water. A more sustainable step might be to provide filters to households or entire communities to address certain types of water contaminants.

Finally, reducing hazards can limit the need for early warning systems and for lowering exposure. Each of these hazards—water quality, air quality, and extreme heat—are worsened by climate change, so reducing the intensity of the hazard is reliant on decreasing greenhouse gas emissions. In addition, there are local actions in the SJV that can be taken to reduce other, non-climate contributions to that hazard. For extreme heat, creating more green space through nearby parks or an increase in urban forestry can lead to cooler local temperatures and better air quality (Han et al., 2024). Conversion and restoration of farmland for green space (e.g., Dos Rios State Park, Ch. 3) and urban forestry programs (e.g., Little Manila Rising, Fresno Urban Forestry Plan) offer examples for how this might be done. Improvements in both water and air quality can also come about through addressing other systems in the region, such as agricultural practices (Ch. 3), aquifer recharge (Ch. 3), water treatment (Ch. 4), transportation (Ch. 4), and energy production (Ch. 5). These all require changes that are tractable and enforceable across sectors. See Chapter 6 for a discussion of cross-cutting solutions.

5.5.3 Environmental Justice & Community Engagement

Environmental justice communities, described in the *Section 5.4 Environmental Justice Dimensions*, generally are those that have the least ability (resources, political and social capital, etc.) to adapt to climate change impacts, and are usually the least responsible for climate change in the first place (Mohai et al., 2009; Flores-Landeros et al., 2022; Shonkoff et al., 2011). Not all climate solutions, however, advance environmental justice; indeed in some cases, proposed policies can exacerbate pre-existing inequities (e.g., Cushing et al., 2018; Dahlquist-Willard, 2024). Therefore, the solutions presented above were selected as they, at the very least, should not deepen current environmental and social injustices in the region, and in some cases actively promote environmental justice. As part of these solutions, promoting civic engagement, such as through community-based organizations (CBOs) or labor unions, is an important step, as it promotes procedural justice and can help identify potential unintended consequences of proposed climate policies, thus ensuring that proposed policies meet local needs (e.g., González et al., 2026).

Chapter 6.

Summary of Cross-Cutting Issues & Solutions



6.1 Summary of Cross-Cutting Issues

This report explored the ways in which climate change has and is projected to impact the people, land, waters, and built sectors in the San Joaquin Valley (SJV). Better comprehension of climate impacts complemented by success stories of climate resilience from Valley communities can aid in the development of adaptation strategies. We provide a brief synopsis of the climate challenges from each chapter below and then emphasize a set of key cross-cutting issues and solutions.

Chapter 2 introduced the climatological setting of the SJV. While being conducive to cultivating agriculture by leveraging the state's extensive water infrastructure, this region has much hotter summer temperatures than in other regions, particularly in urban locations. In recent decades, below normal precipitation coupled with warming has affected water resources, increased heat stress, and exacerbated already-poor air quality. With projected warming, as well as swings between very wet and very dry years, the region is very likely to experience further heat waves, droughts, and floods, increasing exposure to many climate extremes that can impact sectors across the region.

Chapter 3 addressed the natural and working lands of the SJV, which have undergone perhaps the most dramatic transformation in California over the past two centuries. Most land use today is tied to industrial-scale agriculture, which is both uniquely impacted by and contributes to climate change, and moreover both forms the backbone of the economy in the Valley and can compete with communities and local ecosystems for limited water supply. Unsustainable groundwater use across the Valley had led to dry wells and unsafe drinking water for certain communities. Changes in water supply and quality imparted by climate change factor heavily into the climate impacts and resilience of natural and working lands of the SJV.

Chapter 4 explained the context of the built environment of the SJV, focusing on built water systems and energy and transportation. Water infrastructure and energy systems are both vulnerable to and (in some cases) contribute to climate change and exacerbate impacts on water resources and other natural systems. Conversely, warmer temperatures and changes in hydrology are likely to affect the ability of the human-built systems to perform their intended functions, which requires coordinated adaptation and mitigation strategies.

Finally, **Chapter 5** detailed the numerous and interconnected ways that climate change is affecting communities across the region, via the effects on systems described in Chapters 2–4. Impacts range from the economy to public health to exacerbating pre-existing environmental justice issues. Social systems in the SJV are particularly vulnerable to climate change due to the dominance of the agricultural-based employment in the region, the pre-existing air quality and heat hazards, the lack of climate-resilient infrastructure and green space, and the high concentration of disadvantaged communities exposed to these changes.

However, the issues raised in each chapter are seldom relevant to only that chapter. Instead, a number of cross-cutting issues were identified in each of the chapters. By *cross-cutting*, we refer to problems which impact natural and working lands and waters, built systems, and social systems. **Table 6.1** presents some of those cross-cutting issues identified in the SJV regional report.

Table 6.1. *Cross-Cutting Climate-Related Issues for the San Joaquin Valley.*

Impact Category	Climate Science (Ch. 2)	Natural and Working Lands & Waters (Ch. 3)	Built Systems (Ch. 4)	Social Systems (Ch. 5)
Water security & quality	Reduced water supply and increased atmospheric demand promote drought.	Declining groundwater levels and increased extent of inflexible water-intensive crops impacts agriculture. Relatively little groundwater recharge limits aquifer recovery during wet years.	Declining groundwater levels lead to dry wells. Impermeable surfaces and water infrastructure limits groundwater recharge.	Rural communities solely dependent on groundwater are impacted by dry wells, poor water quality, and impacts to agricultural economy.
Flooding	Increased extreme precipitation events and years.	Agricultural flooding leads to crop losses. Conversion of floodplains to croplands in conjunction with land subsidence amplifies flood risks.	Flooding impacts communities and transportation networks. Impermeable surfaces in urban landscapes heighten community risk.	Disadvantaged communities in urban and rural areas are most at risk.
Air quality	Increased ozone, dust from drought, and pm2.5 from wildfires.	Potential reduced crop yields or quality. Exacerbation of poor air quality via pesticides and dust from conventional agriculture practices.	Exacerbation of poor air quality tied to local oil and gas emissions.	Direct health impacts, particularly to the outdoor labor force that are more exposed and those without mitigation resources.
Extreme heat (night & day)	More frequent, intense, and persistent extreme heat events.	Heat-related crop losses and increased irrigation requirements.	Reduced efficiency of solar energy and increased demand. Exacerbation of extreme heat via the ***urban heat island*** effect.	Public health impacts, especially on the outdoor labor force and those lacking well-insulated houses or other mitigation resources. Escalating energy costs for cooling.

6.2 Integrated Solutions

Here, we present adaptation and mitigation strategies that have the potential to address the cross-cutting issues identified in **Table 6.1**. We prioritize solutions which (1) consider the numerous and interconnected ways that the issue impacts the SJV; (2) promote multiple benefits across different sectors; and (3) align with California's climate goals (State of California, 2022) (**Table 6.2**).

These integrated solutions prioritize the concepts of climate and environmental justice and a just transition. The Valley has been identified as a region with pronounced environmental and climate injustices (Flores-Landeros et al., 2022). Thus, solutions stemming from this concept may help ensure that any actions do not re-create or compound the processes that have led to injustices in the first place (Shonkoff et al., 2011). In particular, they may prioritize systems-level sustainability (i.e., across environmental, economic, and social dimensions) and fit within just transition frameworks (Fernandez-Bou et al., 2025; Cha et al., 2020). It is important that actions are inclusive by ensuring that environmental justice communities are part of the decision-making process throughout the planning and implementation process (Fernandez-Bou et al., 2021). Inclusive actions include centering efforts on frontline communities that have been historically marginalized, addressing systemic inequities, and supporting community-driven solutions.

Table 6.2. *Potential strategies to address SJV climate challenges and their alignment with the state's climate goals (State of California, 2022).*

Topic	Public Health	Climate / Decarbonization	Economy
State Climate Goals	"Cut air pollution 71%" & "Save California $200 billion in health costs due to pollution"	"Slash greenhouse gas emissions 85%" & "Drop gas consumption 94%"	"Create 4 million new jobs"
Relevant Problems in the SJV	The SJV has chronically poor air quality and pollution-related impacts to public health (exacerbated by extreme heat)	TheSJV produces greenhouse gas (GHG) emissions, both directly (via transportation) and indirectly (via oil and gas production in the region)	The SJV has higher poverty rates than the state average, and high levels of unemployment
Solution 1: Agricultural Land Transition & Climate-Smart Farming	Prioritizing land transitions near communities reduces the air pollution burden on those communities	Agrivoltaics can increase available energy for electrification; regenerative agriculture can sequester carbon and reduce GHG emissions	Repurposing agricultural lands for multibenefit uses creates numerous jobs with similar skill requirements; climate-smart agriculture can keep the SJV an economic powerhouse
Solution 2: Greening Urban Spaces	Improves air quality and decreases heat exposure	Reduced gas consumption via more walkable cities and usable public transport; reduced urban heat island, hence lower energy demands for cooling	Requires labor, hence has the potential to create new jobs
Solution 3: Energy Transition	By reducing pollution, can reduce associated health costs	Would reduce GHG emissions from oil and gas produced within the state	Has the potential to create many well-paying, sustainable jobs

6.2.1 Strategies

AGRICULTURAL LAND TRANSITION

Here, agricultural land transition includes both the implementation of climate-smart farming practices, which offer community and environmental benefits, as well as strategic cropland repurposing.

Strategic Cropland Repurposing

Strategic cropland repurposing refers to transitioning agricultural land to multiple other uses (**Figure 5.1**). It is intended to improve climate resilience and community health by reducing water consumption, reducing on-farm pesticide and fertilizer use, restoring habitat, and addressing ***disadvantaged community*** needs (e.g., health), while preserving agricultural identities and improving rural economies (Fernandez-Bou et al., 2023, 2025; Penny et al., 2025; EDF, 2021; Union of Concerned Scientists, 2023). ***Multibenefit Land Repurposing (MLRP)*** can take on various flavors as shown in case studies evident in the Valley (e.g., Dos Rios State Park; Fairmead Stormwater Basin Project; Ch. 3). For example, nature-based cropland repurposing projects can restore historical floodplains while creating habitat corridors and enhancing groundwater recharge including serving as groundwater recharge zones and being accessible parks. Landscape restoration is also part of the MLRP process, with some former agricultural lands being actively restored to enhance habitat and ecological connectivity to adjacent lands (Butterfield et al., 2025). Other strategic cropland repurposing projects may involve the use of ***agrivoltaics*** that combine solar energy generation with agricultural production, or eco-voltaics, that combine solar energy

production in landscape restoration projects that can even promote ecosystem health. Agrivoltaics offer the potential for multiple benefits. Not only can energy production offset on-farm energy costs and provide an alternative revenue stream, but agrivoltaics also provide synergistic benefits by increasing solar energy generation efficiency through understory vegetation cooling effects as well as the shading of solar panels reducing heat stress for certain crops and livestock (Adeh et al., 2018; Warmann et al., 2024).

Efforts to prioritize locations for cropland repurposing may consider land transitions near communities that can offer co-benefits (Fernandez-Bou et al., 2025). Creating buffer zones around communities serves multiple functions: expanding access to green space, improving local air and water quality (e.g., removal of agricultural pollutants to air and groundwater), helping with flood control, and providing opportunities to local economies (e.g., Allensworth, **Box 5.3**). In particular, floodplain restoration is shown to be at least five times cheaper than the potential costs of disaster relief (Johnson et al., 2020). Partnering with Tribes when choosing where to site projects can help prioritize multibenefit landscapes, cultural resources, and ecosystem health. For example, the Wuk'nain restoration project has repurposed a Christmas tree farm in Tulare County into native habitat and gardens that help with Tribal food sovereignty and honor traditional ecological knowledge while supporting biodiversity and groundwater sustainability.

Finally, the transition of agricultural lands can create job opportunities that require large-scale workforce development and education. Workforce development initiatives can facilitate transitions from traditional agriculture into precision agriculture, agroecology, solar energy systems, conservation work, and native plant production. Such economic transitions tied to land repurposing will shift job opportunities but can foster the development of a more resilient, diverse, and sustainable economy.

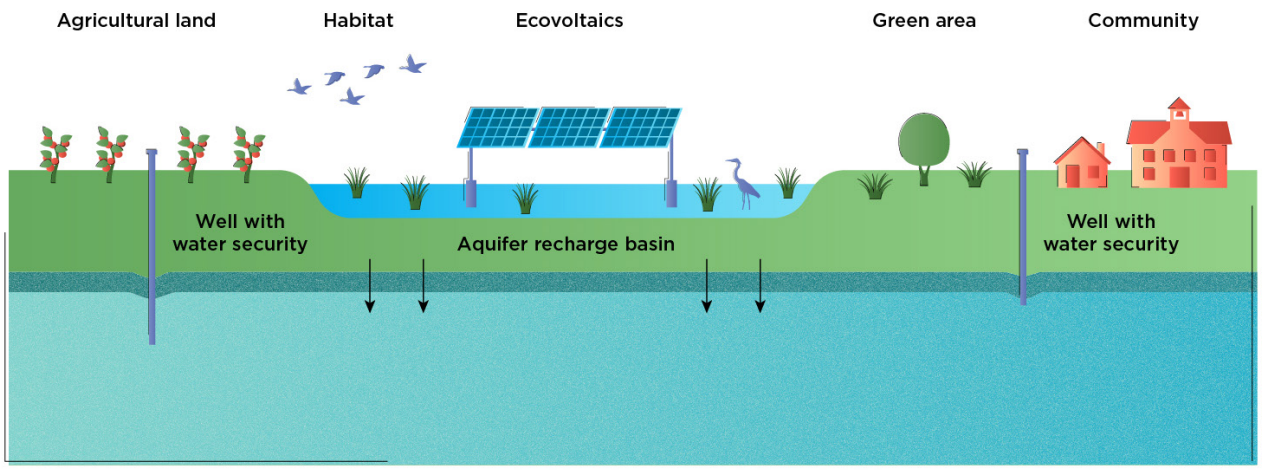


Figure 6.1: *Conceptual diagram depicting how multibenefit land repurposing can work. From the Union of Concerned Scientists, used with permission.*

Climate-Smart Agriculture

The composition of crops in the Valley has changed over the past century as a function of water infrastructure, market demands, and technology. These factors, along with water security and climate resiliency, will likely continue to shape cropland composition of SJV. Almonds will remain thermally suitable in the SJV with climate change (Parker & Abatzoglou, 2018) and likely an important economic contributor to Valley agriculture in the coming decades. Yet, transitioning some water-intensive ***perennial crops*** to more drought-tolerant crops suited to a future climate can support a more robust water management strategy for easing drought impacts to agriculture while including more opportunities for on-farm groundwater recharge. Additional strategies may include selecting cultivars and rootstocks that bolster climate resilience; increasing the extent of current crops that are climate resilient (e.g., oil olives) and flexible to varying water demand (e.g., annual row crops, alfalfa; Waring et al., 2025); and introducing crops that are novel to the Valley (e.g., agave). Efforts to identify the next wave of crops to the Valley that are climate-resilient, provide economic returns, and meet water sustainability goals are needed. Innovations in agricultural landscapes can not only increase the resilience of the agricultural sector to climate variability and change, but also help sustain the strong agricultural economy of the Valley.

Climate-smart regenerative agriculture practices such as applications of biochar and compost can improve soil health, sequester carbon, and reduce methane emissions, potentially benefiting agricultural productivity, reducing crop water use, and mitigating climate change (Harrison et al., 2022). Moreover, some climate-smart agricultural practices may foster a circular economy within the Valley. For example, biochar has the potential to convert agricultural waste (e.g., orchard debris that was historically burned and impacted Valley air quality) to usable and saleable material with multiple benefits (Thengane et al., 2021).

GREENING URBAN SPACES

Greening urban spaces refers to the creation and expansion of accessible green spaces in urban or residential communities. This is complementary to the creation or improvement of greenspace around such communities described above (i.e., through cropland repurposing). Green infrastructure includes trees that provide shade and reduce population exposure to extreme heat (Ch. 5) and other vegetation types (e.g., grass, shrubs) that further allow for increased water absorption and can help with flood control (Ch. 4). Urban green spaces can also reduce local temperatures by counteracting the ***urban heat island*** effect, thereby reducing energy demands for cooling (Han et al., 2024). Planning for urban forestry and green spaces may also consider sustainable and resilient systems. These include species suitable for present and future environmental conditions from water demands to costs of maintenance to impacts to other infrastructure, such as root systems' effects on roads and sidewalks (Esperon-Rodriguez et al., 2025).

Efforts to enhance urban green spaces and urban forestry in the SJV may increase the climate resilience of urban communities to direct temperature stressors. This can be particularly important in disadvantaged urban areas that currently have very limited green space. Green spaces can also provide places for community connection, which can improve mental health by helping foster resilience to stressors including those from climate change. Increased tree cover can also encourage more pedestrian-friendly conditions that may reduce reliance on personal vehicles, improve public health, and benefit local businesses. Finally, creating and maintaining urban green spaces requires labor, which can be a job creator, though funded by taxpayers (Ch. 5).

ENERGY TRANSITION

The SJV hosts the majority of California's oil and gas production, giving rise to: impacts on local air quality (via these stationary sources as well as associated transport); potential impacts on water quality; competition for limited water resources in communities near oil and gas wells; and greenhouse gas emissions, particularly given that California oil is more emissions-intensive than many foreign sources. Therefore, retiring oil and gas wells in the SJV would help meet California's climate goals of cutting air pollution, saving health costs related to pollution, and slashing greenhouse gas emissions. The health benefits are particularly true if the transition is prioritized near communities, which California has already begun addressing via creating buffer zones between oil and gas wells and communities (SB 1137 [2022]).

The SJV is also the top producer of solar in the state. Increasing deployment of renewables and energy storage would also align with the state's climate goals, including creating new jobs and slashing greenhouse gas emissions, in addition to potentially increasing grid reliability and available energy to meet certain types of economic growth. California is already meeting much of its energy demand with renewable sources (CAISO, n.d.). Continuing this trajectory—such as through promoting agrivoltaics (see *Agricultural Land Transition* above)—can dramatically increase this deployment. Furthermore, renewable energy development can be a job creator in the Valley. However, certain "transition" technologies should be carefully evaluated due to potential unintended consequences (e.g., biomethane, hydrogen, CCS). Moreover, ***renewable energy*** itself is not synonymous with a just transition; sustainable, good-paying, high road jobs are key (Cha et al., 2020; Grubert & Hastings-Simon, 2022). As there are a number of workers in the Valley employed in the oil and gas sector (e.g., Grubert, 2020), it is important to ensure that these job opportunities have benefits (e.g., salary, union) that are comparable to current oil and gas employment.

Disadvantaged communities in the region struggle to access reliable and affordable energy, leading to health impacts in the face of extreme heat and poor air quality. Addressing energy costs for low-income households is a critical component of climate justice (Farley et al., 2021) as such households are more likely to have inadequate insulation, inefficient air conditioning, and lack rooftop solar. Efforts to promote distributed renewable energy and storage as part of MLRP, possibly in conjunction with agrivoltaics, can empower communities and build energy independence. An energy transition in the region could address these concerns while creating jobs.

6.3 Gaps & Needs

The synthesis of climate science, impacts, and solutions specific for the SJV highlighted several outstanding region-specific gaps, both in scientific questions as well as actions to improve the climate resiliency of the Valley. We highlight a few illustrative gaps and needs spanning the topics covered in the report.

6.3.1 Research Gaps

Several research questions specific to the future climate of the SJV remain.

While the climate of the SJV is more homogenous than other regions of the state, changes in land use in response to the ***Sustainable Groundwater Management Act (SGMA)*** (e.g., reduction of irrigation in areas) may further contribute to how climate change unfolds. For example, widespread fallowing may lead to a reversal of the irrigation cooling effect of summer temperatures and compound climate-change-driven warming in the region, but the magnitudes, patterns, and secondary effects (e.g., dust) are unknown. Further, while ***Tule fog*** has decreased, likely due to reduced pollutants and changes in climate, it is unclear how future changes in climate will shape the frequency and persistence of the phenomenon.

As water resources are a common thread across social and environmental systems in the Valley, efforts to better understand the resilience of water systems to projected climate change and ***anthropogenic*** (e.g., land use, management) changes is needed. This includes changes in the arrival of soaking autumn rainfall and the persistence of mid-winter dry spells which impact agriculture, transportation hazards, and flood risk. Similarly, research can better elucidate efforts to scale ***Managed Aquifer Recharge (MAR)*** to achieve SGMA goals. While there is extensive research on the impacts of climate change to surface water supplies, additional studies may be needed to isolate the contribution of climate change to observed and projected changes in groundwater.

The Valley's future agricultural lands will likely look different from those today, and several economic, labor, technology, and environmental factors will shape how they evolve. A synthesis of agricultural systems that are adaptive to current and future climate, cognizant of water resource goals, and economically attractive to producers, can help ensure the SJV will continue to be an agriculture powerhouse. Likewise, improved understanding of agricultural practices that provide multiple benefits (e.g., regenerative agriculture, agrivoltaics, recharge potential) in terms of management and economics can further propel action in this space.

Climate change impacts to human health in the Valley are critically important to understand. Overall, a better analysis of health impacts specific to the region—including data on emergency room or other hospital visits as a function of extreme heat, smoke exposure, and overall poor air quality that climate change can exacerbate—as well as how these stressors can worsen health outcomes when occurring simultaneously, is needed. While there is significant work on direct heat-related impacts, improved understanding of indirect ways through which climate change and ongoing land transitions impact air quality could help adaptation efforts. For example, widespread land idling without adequate management can potentially enhance dust mobilization in the Valley, particularly during droughts (Adebiyi et al., 2025), which are projected to become more common. Whereas most models project increases in wildfire activity, smoke burden, and smoke-related mortality in the western US in the coming decades (Qiu et al., 2025), efforts to better protect communities from wildfire smoke and proactive land management strategies such as prescribed fires, cultural burning, and other fuels treatments may buffer such projections. It is unclear what the tradeoffs are from an air quality and human health perspective from a massive scaling up of prescribed fire compared with wildfire on vulnerable populations in the SJV.

6.3.2 Barriers to Action

While research gaps exist, these gaps are not the main barrier to climate resiliency and adaptation—instead, other material, institutional, and financial barriers exist. The Valley has gaps in monitoring that undermine efforts to track water and air quality as well as groundwater concerns. There is a need for more long-term monitoring of air and water quality to identify spatiotemporal heterogeneity in pollutants, and their sources. Better data can pinpoint pollution sources and help prioritize efforts and actions to reduce health-related impacts. Likewise, advances in measurements of water use and application across the Valley through local observations and satellite-based mapping (e.g., OpenET) may improve efforts to understand water use efficiencies of crops and a host of water management issues.

The Valley is home to many underserved communities. Therefore, adaptation measures that might work in more affluent areas may not translate directly to SJV communities. Adaptation measures that don't involve underserved communities in the planning process, or make the planning process accessible (e.g., language access, meeting times) may leave them vulnerable to both the direct impacts of climate change and the unintended consequences of new policies. Similarly, adaptation measures that do not take into account community or sector-based knowledge may promote solutions that cannot be implemented. For example, it is crucial to include farmers in designing solutions to ensure that they are implementable. More resources for doing community-engaged research are needed to identify solutions that are context-appropriate and equitable.

Finally, while climate adaptation plans are a key step toward solutions, implementation remains a major challenge. Resources (e.g., financial, personnel) are a major barrier. For example, the Dos Rios restoration project (**Box 3.4**) was made possible in part due to securing $40 million in funding. Conversely, while the community of Lanere received $1.3 million for a water treatment plant, it closed shortly after opening due to a lack of funding for ongoing maintenance costs (Fernandez-Bou et al., 2023). As the SJV is less affluent than its neighboring regions of the state, additional resources are needed to implement climate adaptation efforts.

6.4 Conclusion

While there are many uncertainties for this highly diverse and important region, one thing is certain: climate change is already impacting the people, lands, waters, and ecosystems of the SJV, and the associated risks will grow over the coming decades. The Valley stands at a critical moment for profound transformation, with opportunities to build climate resilience, advance socioenvironmental justice, and create sustainable prosperity.

Understanding the current and projected climate in the Valley is a crucial first step toward making this region more climate-resilient. Any actions taken—whether policy, community-led, industry-led, or otherwise—should be rooted in this understanding to ensure that they function as effective solutions and promote a healthier, more resilient Valley for both current and future generations.

Appendices



Glossary

Agrivoltaics: The use or implementation of solar photovoltaics (PV) in agricultural lands. May refer to interspersing PV with crops.

Anthropogenic Climate Change: Changes in the climate due to emissions from human activities —largely the combustion of fossil fuels, deforestation, and large-scale agriculture. Emissions include both greenhouse gases (GHGs) (e.g., carbon dioxide, methane), which contribute to warming, and aerosols (e.g., pollutants) which sometimes counteract the GHG changes in certain locations.

Annual Crops: Crops that die after a single growing season and must be replanted each year.

Anthropogenic: Effects originating from human activities.

Applied water: The total amount of water diverted for a specific use.

Atmospheric Rivers: Concentrated bands of atmospheric moisture that transport large amounts of water vapor, often leading to significant precipitation events when they make landfall. Many of the largest precipitation events in California and the SJV are tied to atmospheric rivers.

Carbon Capture and Storage (CCS): Technologies that capture and store carbon dioxide emissions, thereby limiting them from contributing to the enhanced greenhouse effect.

Carbon intensity: The carbon dioxide equivalent (CO_2e) emitted per unit of hydrocarbon (e.g., barrel of oil).

Central Valley Project (CVP): Federally-owned water infrastructure that provides water for agriculture, municipal, industrial, and environmental uses in California's Central Valley.

Chill hours: The sum of hours during the cool season when temperatures drop below 45°F (7.2°C), a metric relevant to many perennial fruit and nut trees that require a sufficient amount of cool weather to blossom.

Climate model: Numerical representations of the Earth's climate system that simulate the physics, chemistry, and biology of the atmosphere, land, and oceans and their interactions, that are used to understand and predict climate behavior.

Consumptive water use: Water removed from a system for a specific use without flowing back into that system.

Cooling degree days: A measure of how much and for how long the outside air temperature was above a specific base temperature (65°F [18.3°C]), used as a proxy for energy needed for air conditioning.

Critically overdrafted basins: Groundwater basins with the largest imbalances between extraction and recharge that under status-quo practices would likely result in eventual environmental, social, or economic harms due to water scarcity.

Disadvantaged community: A population group recognized by the State of California which experiences disproportionately high economic, social, and environmental burdens. Groups are designated as *disadvantaged communities* based on metrics used in CalEnviroScreen.

Downscaling: Analytical methods to transform coarse-resolution climate model output into finer-scale, localized information that is more directly usable for impact modeling.

Evaporative demand: Refers to the atmospheric "thirst" for water, representing the amount of water that would evaporate and transpire from a reference, well-watered grass surface.

Forecast Informed Reservoir Operations (FIRO): Water management strategy using weather and hydrologic forecasts to make decisions about reservoir releases, balancing the dual goals of flood control and water conservation.

Idle well: Hydrocarbon (e.g., oil or gas) well that has not been in production for at least two years, has not been properly sealed (plugged), and is abandoned.

Inversions: A layer of the atmosphere where temperature increases with altitude instead of decreasing, often trapping pollutants close to the surface.

Irrigation districts: Publicly-governed agencies that acquire, manage, and deliver surface water—primarily sourced from the Central Valley Project and the State Water Project—to agricultural lands and other users. Irrigation districts such as the Merced Irrigation District, Turlock Irrigation District, and Modesto Irrigation District also serve dual roles as local energy utilities.

LOCA2-Hybrid: A downscaling technique that combines the statistical efficiency of the Localized Constructed Analogues (LOCA) method with the physical realism of dynamical downscaling. In the report, 15 climate models participating in the sixth Coupled Model Intercomparison Project (CMIP6) were downscaled using the LOCA2-Hybrid method to examine projected changes in climate.

MACAv2-gridMET: Statistically downscaled data that uses the Multivariate Adaptive Constructed Analogs (MACA) approach and a surface gridded meteorological data (gridMET) to downscale the CMIP5 climate models.

Managed Aquifer Recharge (MAR): The intentional recharge of groundwater basins using a variety of methods to increase the amount of water stored underground. This can occur in agricultural lands (often called Ag-MAR), or during flooding events (often called Flood-MAR).

Megadrought: A chronic period of severe drought often lasting multiple decades that leads to a semi-persistent period of shortfalls in water resources.

Multibenefit Land Repurposing Program (MLRP): As a result of the State Groundwater Management Act (SGMA), hundreds of thousands of irrigated cropland may need to be idled, retired, or repurposed to address critical groundwater sustainability goals. MLRP aims to achieve these goals by repurposing water-intensive agricultural land while simultaneously providing economic, environmental, and other benefits to local communities.

nClimGrid: A high-resolution gridded dataset of temperature and precipitation that is developed by the National Oceanic and Atmospheric Administration (NOAA) to monitor and study long-term climate variability.

Ozone: A harmful air pollutant near the Earth's surface formed by reactions between pollutants from vehicles and industrial emissions in the presence of sunlight.

Palmer Drought Severity Index (PDSI): A widely used drought index that accounts for precipitation and evaporative demand using a water balance approach and is a proxy for normalized soil moisture anomalies relative to historical conditions. Negative PDSI values indicate drought.

Perennial Crops: Crops that live for more than a single growing season and thus may require irrigation outside of the growing season.

PM2.5: Fine particles (particles with a diameter of 2.5 micrometers or less) in the air that come from a variety of human-caused and natural sources. These particles are a significant component of air pollution and are associated with various health impacts.

Parameterized Regression on Independent Slopes Model (PRISM): A climate mapping approach and dataset that uses station observations and topographic factors to create spatially continuous gridded climate data across the United States.

Rain shadow: An area that is comparatively dry due to lying on the lee side of a mountain range (away from the direction from which the wind blows—in California, typically the east side). The mountain barrier causes winds to lose moisture before reaching the rain shadow.

Radiative Forcing: The change in energy flux at the top of the atmosphere (how much energy is entering versus leaving, measured in watts per square meter) compared to a pre-industrial baseline due to factors like additional greenhouse gases.

Shared Socioeconomic Pathways (SSPs): Scenarios used in climate model experiments to explore how different future societal development pathways that include population growth, economies, technologies, and policies might influence greenhouse gas emissions and radiative forcing changes by the year 2100.

Standardized Precipitation Evapotranspiration Index (SPEI): A drought index that reflects precipitation minus evaporative demand anomalies over different timescales (e.g., 1-, 3-, 12-, 36-month) relative to historical data for the same period. Negative SPEI values indicate drought.

Standardized Precipitation Index (SPI): A drought index that reflects precipitation anomalies over different timescales (e.g., 1-, 3-, 12-, 36-month) relative to historical data for the same period. Negative SPI values indicate drought.

State Water Project (SWP): State water management system and infrastructure of reservoir and canals that delivers water captured from runoff in the northern Sierra Nevada to meet the water demands in Central and Southern California.

Sustainable Groundwater Management Act (SGMA): A California law that seeks to balance groundwater levels in the state's critically overdrafted groundwater basins by the year 2042. SGMA requires local agencies to sustainably manage groundwater through a combination of reduced groundwater withdrawals and increased recharge, preventing chronic overdraft and related issues like land subsidence and contaminated water supplies.

Tule Fog: Widespread dense persistent fog that forms in the Central Valley of California, particularly during the winter months, often leading to very low visibility and an accumulation of PM2.5.

Urban Heat Island: A phenomenon where urban areas are warmer than surrounding rural areas, primarily due to human activities and land surface modifications that absorb and retain more heat.

Vapor Pressure Deficit: The difference between the amount of moisture the air can hold when saturated and the actual amount of moisture it holds, which drives a plant's ability to pull water from the soil.

Supplementary Figures

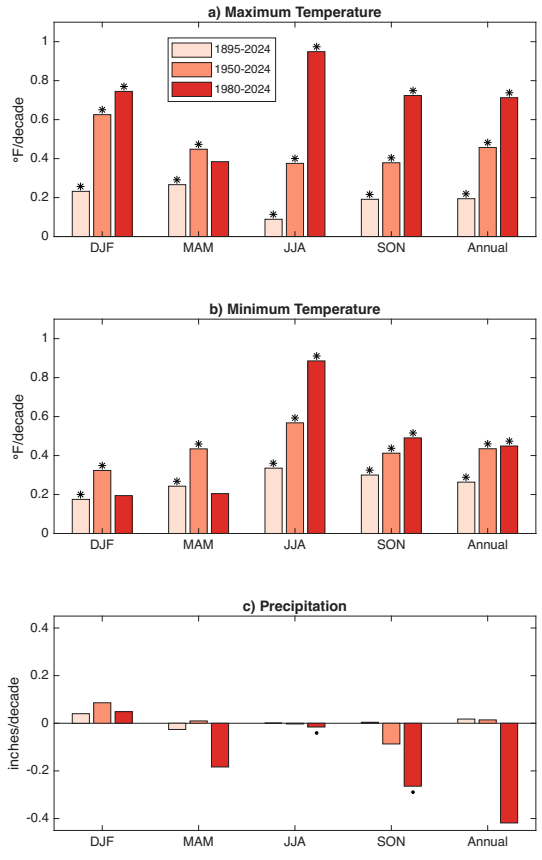


Figure S1: *Linear trends in annual and seasonal (a) daily maximum temperature, (b) daily minimum temperature, and (c) accumulated precipitation from* ***nClimgrid****. Trends were calculated for three time periods, all ending in 2024 (1895–2024, 1950–2024, and 1980–2024) and reported in units of degrees Fahrenheit per decade for temperature, and inches per decade for precipitation. Seasonal trends are shown for December–February (DJF), March–May (MAM), June–August (JJA), and September–November (SON). Trends that are statistically significant at p<0.05 and p<0.1 are reported with an asterisk and dot, respectively.*

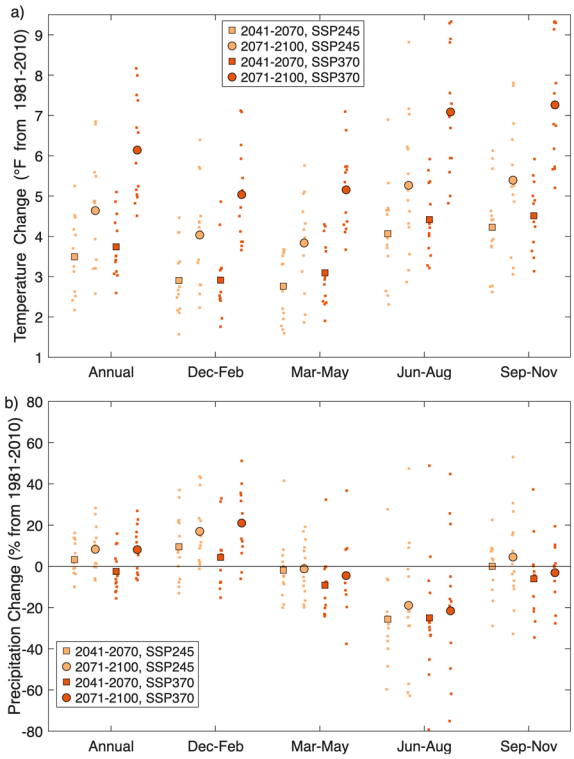


Figure S2: *Projected change in (a) mean annual and seasonal temperature in Fahrenheit and (b) annual and seasonal precipitation averaged across the SJV in percent relative to the 1981–2010 historical climate. Results for individual models are shown by small dots, whereas the multi-model mean change is depicted by the square and large dot.*

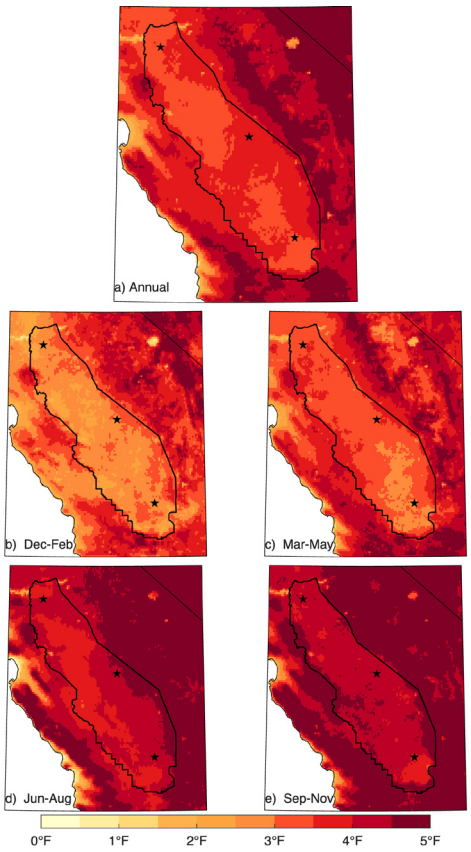


Figure S3: *Projected change in daily maximum temperature for (a) annual, (b) December–February, (c) March–May, (d) June–August, and (e) September–November for the mid-century (2041–2070) relative to historical (1981–2010) averages. Results shown are the multi-model median for the first ensemble member from 15 models for SSP2–4.5. The black outline shows the SJV Region.*

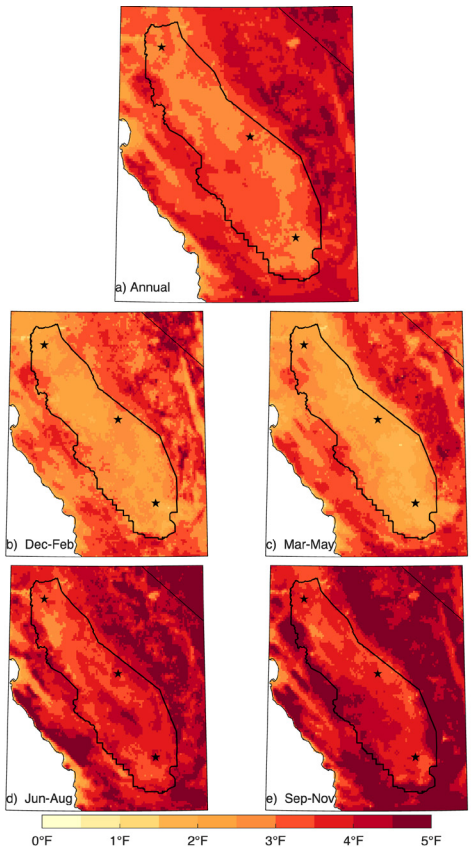


Figure S4: *Projected change in daily minimum temperature for (a) annual, (b) December–February, (c) March–May, (d) June–August, and (e) September–November for the mid-century (2041–2070) relative to historical (1981–2010) averages. Results shown are the multi-model median for the first ensemble member from 15 models for SSP2–4.5. The black outline shows the SJV Region.*

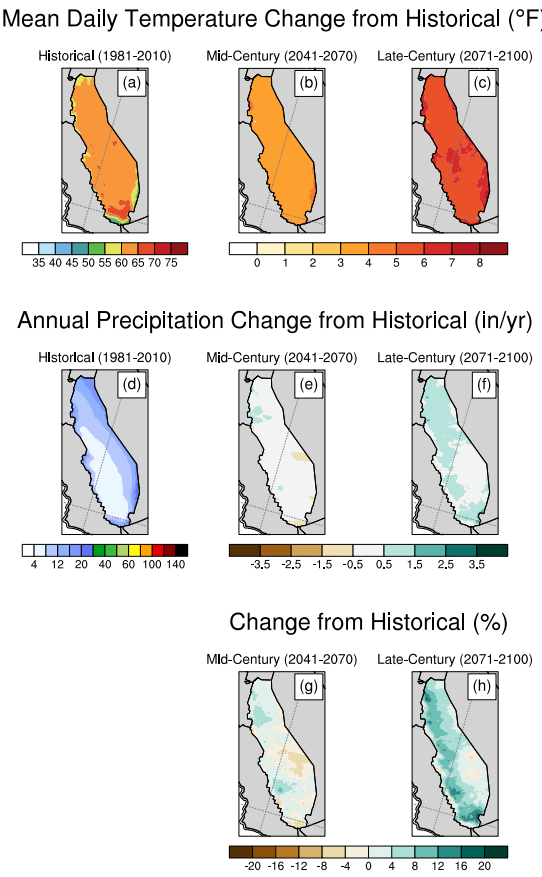


Figure S5: *Map of change from historical (1981–2010) in (a-c) mean daily temperature (°F), (d-f) precipitation (in/yr), and (g-h) precipitation (% of 1981–2010 in/yr), for mid-century (2041–2070) and late-century (2071–2100) as projected under the SSP3–7.0 scenario. Credit: Paul Ulrich (UCD/LBNL).*

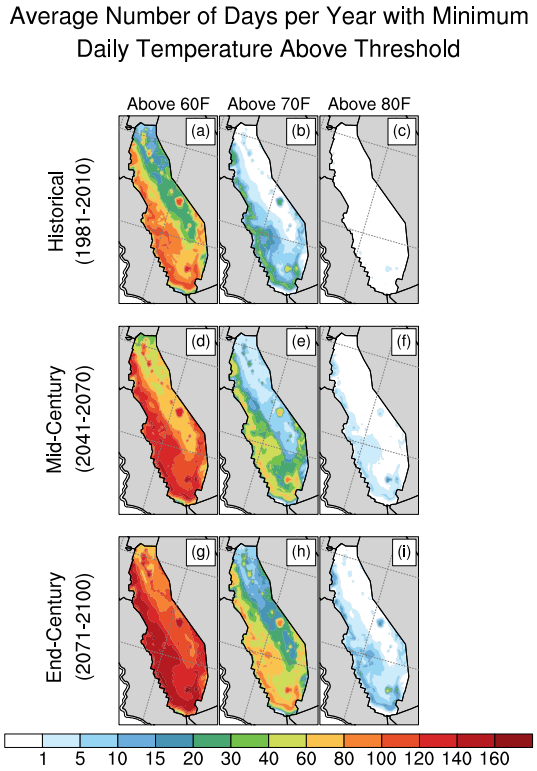


Figure S6: *Map of the number of days each year where daily minimum temperatures exceed one of three different temperature thresholds (60°F, 70°F, 80°F) for (a-c) historical (1981–2010), (d-f) mid-century (2041–2070), and (g-i) end-century (2071–2100) under the SSP3–7.0 scenario. Results show the multi-model mean change. Credit: Paul Ullrich (UCD/LLNL).*

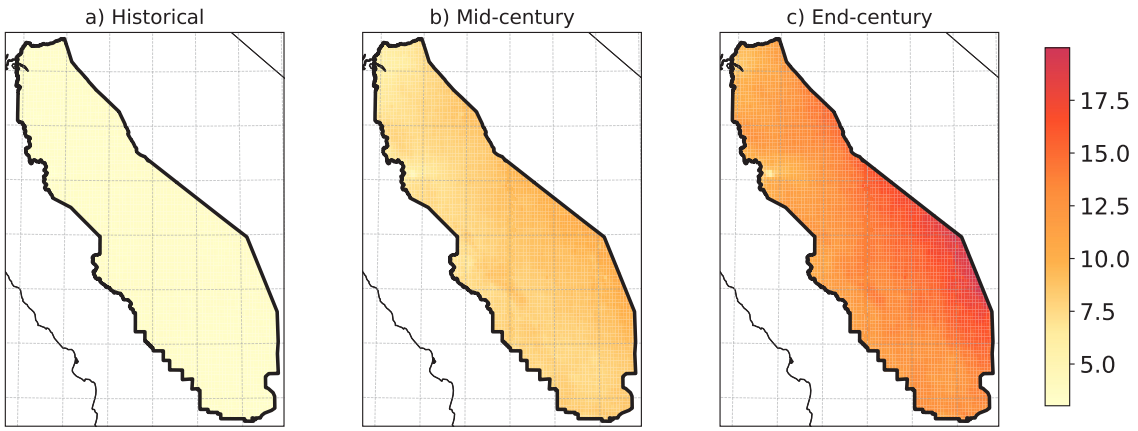


Figure S7: *Projected average duration of the longest heat wave per year (defined as duration of consecutive days with temperature above the 98th percentile of 1981–2010 temperature distribution), for (a) historical (1981–2010), (b) mid-century (2041–2070), and (c) end-century (2071–2100) as projected under the SSP3–7.0 scenario. Credit: Samantha Stevenson (UCSB).*

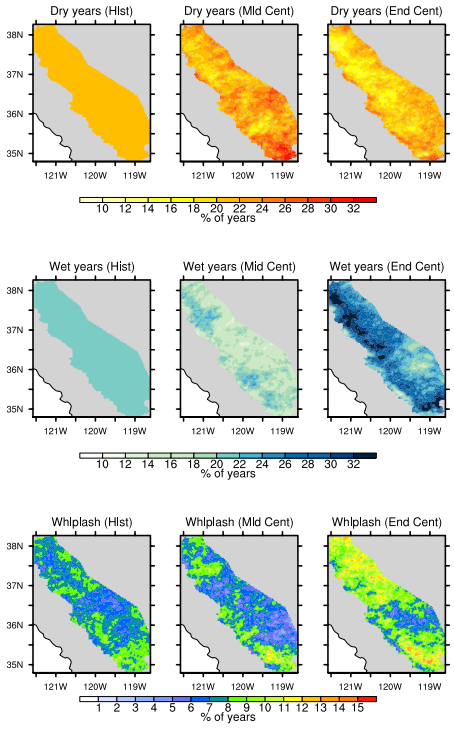


Figure S8: *Projected change in precipitation variability under the SSP3–7.0 scenario, based on change in frequency of (top) dry years (below the 20th percentile of historical (1981–2010) precipitation), (middle) wet years (above the 80th percentile), and (bottom) whiplash years (consecutive occurrence of wet and dry years, using same definitions). By definition, historical occurrence of wet and dry years is 20% everywhere. Projections are averaged over 14 LOCA2 models that had historical and SSP3–7.0 simulations (all but HadGEM3-GC31-LL). Credit: Jessie Norris (UCLA).*

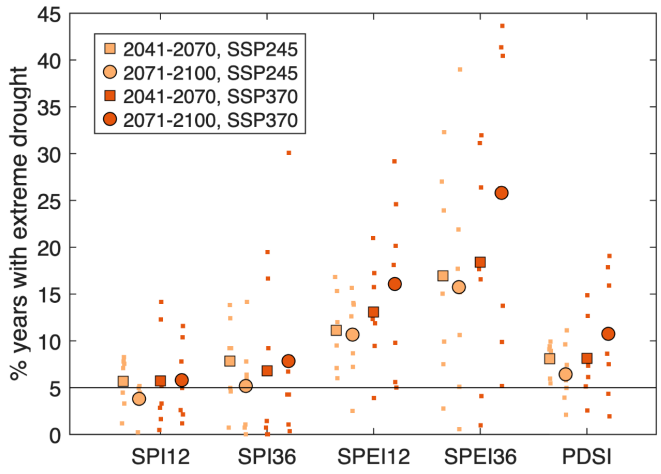


Figure S9: *Modeled occurrence of extreme drought averaged across the San Joaquin and Tulare basins, the basins that provide the primary water supply for the SJV. Results are shown for the 12-month and 36-month Standardized Precipitation Index (SPI12 and SPI36, respectively) and the 12-month and 36-month Standardized Precipitation Evapotranspiration Index (SPEI12 and SPEI36, respectively) and Palmer Drought Severity Index (PDSI). Results show the probability of extreme drought, defined as 5% of data for 1951–2000, for mid-century (2041–2070) and late-century (2071–2100) for SSP2–4.5 (light orange) and SSP3–7.0 (dark orange). Results for individual models are shown by small dots, whereas the multi-model mean change is depicted by large symbols.*

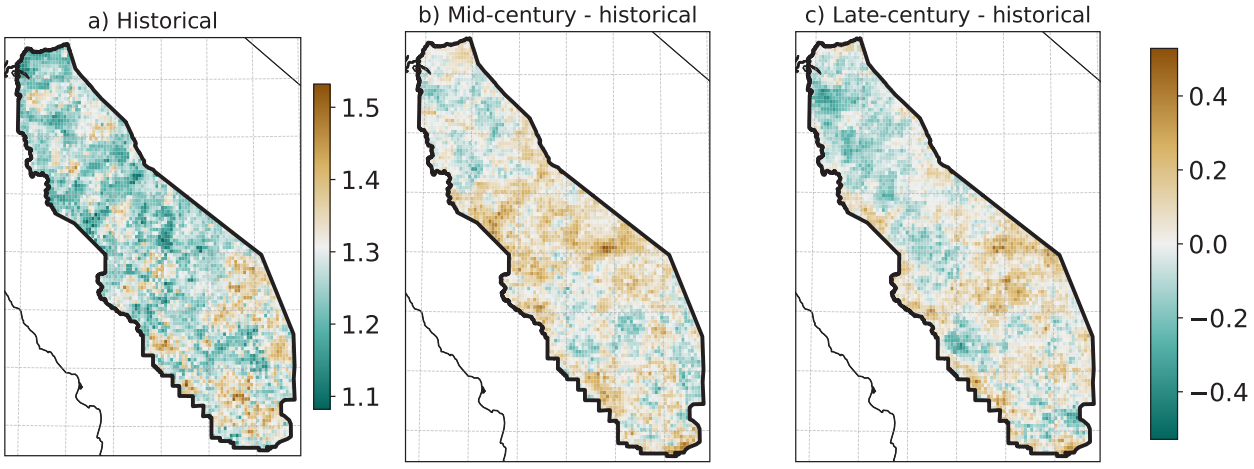


Figure S10: *Change in the duration in the longest precipitation drought from historical period (1981–2010) to mid-century (2041–2070) and late-century (2071–2100) as projected under the SSP3–7.0 scenario. Drought was defined as water year precipitation below the 10th percentile of the historical distribution. Credit: Samantha Stevenson (UCSB).*

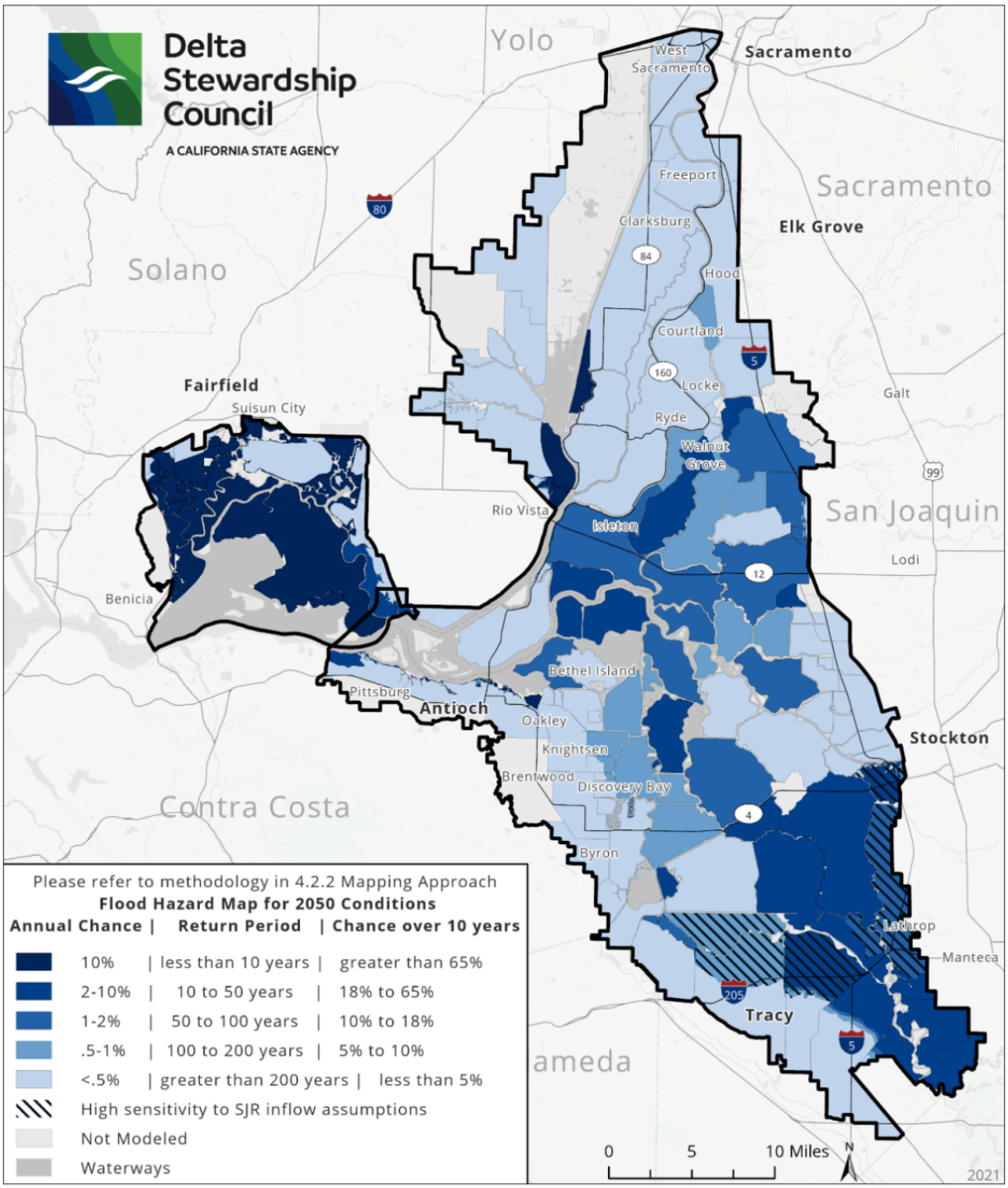


Figure S11: *Flood hazard map for Delta communities in the San Joaquin Valley. Mid-century simulations of flood hazard that reflect a combination of significant sea level rise by mid-century (2050) and inflow from the San Joaquin River. Reproduced from the Delta Stewardship Council (2021)*

Supplementary Tables

Table S1: *Recent climatology of key cities in the San Joaquin Valley. Metrics come from long-term data from Stockton, Fresno, and Bakersfield airports. All measures reflect annual averages for the period 1991–2020, except for periods of record extremes which cover 1948–present for Fresno and Stockton, and 1937–present for Bakersfield. Calculations of chill hours were normalized by the number of missing hours each year (often 1–3% for stations). The units for cooling degree days are the sum of daily mean temperature exceeding 65°F, and is denoted as CDD.*

1991–2020 averages	Stockton	Fresno	Bakersfield
Mean annual Temperature	62.4°F	65.2°F	65.9°F
Average winter (Dec–Feb) minimum temperature	39.2°F	40.3°F	40.4°F
Average summer (Jun–Aug) maximum temperature	92.4°F	96.4°F	95.9°F
Days ≥ 100°F	18.9 days	38.4 days	35.5 days
Cooling Degree Days	1490 CDD	2285 CDD	2413 CDD
Freezing nights	18.9 days	10.7 days	9.9 days
Chill hours	1062 hours	944 hours	818 hours
Annual precipitation (inches)	13.43”	10.97”	6.35”
Days with measurable precipitation	56.3 days	46.4 days	37.5 days
Hottest on record	115°F	114°F	115°F
Coldest on record	16°F	18°F	19°F
Wettest recorded day (inches)	2.38”	3.01”	2.29”

Table S2: *Observed trends in climate data at three stations in the San Joaquin Valley. Climate indicators denoted come from long-term data from airport stations at Stockton, Fresno, and Bakersfield, with trends reported per decade calculated during 1948–2024. Due to sparseness of hourly data at Stockton prior to 1974, trends for chill hours are limited to the period 1974–2024.*

Observed Trends	Stockton	Fresno	Bakersfield
Mean annual Temperature	+0.33°F/decade	+0.67°F/decade	+0.28°F/decade
Average winter (Dec–Feb) minimum temperature	+0.25°F/decade	+0.68°F/decade	+0.26°F/decade
Average summer (Jun–Aug) maximum temperature	+0.34°F/decade	+0.51°F/decade	+0.23°F/decade
Days ≥ 100°F	+1.0 days/decade	+2.7 days/decade	+1.1 days/decade
Cooling Degree Days	+42 CDD/ decade	+134 CDD/ decade	+57 CDD/ decade
Freezing nights	-1.5 days/decade	-3.8 days/decade	-1.4 days/decade
Chill hours	-67 hr/ decade	-116 hr/ decade	-40 hr/decade
Annual precipitation (inches)	-0.14”/decade	-0.01”/decade	+0.11”/decade

Table S3: Projected changes in key climate statistics for three cities in the San Joaquin Valley. *Projected changes in climate for 2041–2070 relative to 1981–2010. Results are shown for the **moderate** emissions pathway (SSP2–4.5) and reported as the multi-model mean. Supplemental Table S4 provides a list of historical (1981–2010) and mid-century (2041–2070) projections for SJV cities with populations exceeding 10,000 for a reduced set of climate metrics.*

Projected Change	Stockton	Fresno	Bakersfield
Mean annual temperature	+3.2°F	+3.3°F	+3.2°F
Average winter minimum temperature	+2.8°F	+2.9°F	+2.9°F
Average summer maximum temperature	+3.9°F	+4.2°F	+3.9°F
Days ≥ 100°F	+22 days	+38 days	+36 days
Cooling Degree Days	+1125 CDD	+1330 CDD	+1396 CDD
Chill hours	-276 hours	-231 hours	-161 hours
Freezing nights	-9.5 days	-8.9 days	-8.1 days
Annual precipitation	5.70%	1.20%	3.30%

Table S4: *Summary statistics for select higher-population towns and cities in the SJV. Results show summaries for 1981–2010 and mid-century (2041–2070) for the **moderate** emissions scenario (SSP2–4.5). Results show the 15-model average from LOCA2-hybrid extracted at the city center. The climate summaries show: (1) mean annual temperature, (2) number of days per year where the daily maximum temperature exceeds 100°F, (3) cooling degree days (°F), (4) annual total precipitation in inches (“), and (5) annual maximum 1-day precipitation total in inches (“).*

City	Mean Annual Temperature		Days of at least 100°F		Cooling degree days°F		Annual Total Precipitation		Annual max daily rain	
Years	**1981–2010**	**2041–2070**	**1981–2010**	**2041–2070**	**1981–2010**	**2041–2070**	**1981–2010**	**2041–2070**	**1981–2010**	**2041–2070**
Arvin	65.4°F	68.4°F	63	102	2699	3586	7.26”	7.70”	0.99”	1.17”
Atwater	62.8°F	65.9°F	36	69	2060	2872	12.45”	13.31”	1.30”	1.41”
Avenal	63.5°F	67.0°F	25	54	2425	3274	7.05”	7.28”	1.13”	1.18”
Bakersfield	67.4°F	70.6°F	78	114	3538	4503	6.34”	6.55”	0.86”	0.99”
Ceres	62.7°F	66.1°F	19	46	1988	2811	11.74”	12.51”	1.23”	1.39”
Chowchilla	61.3°F	64.5°F	31	67	1705	2496	11.61”	11.90”	1.24”	1.38”
Clovis	63.7°F	67.0°F	52	94	2370	3281	12.3”	12.71”	1.40”	1.55”
Coalinga	64.3°F	67.7°F	52	89	2572	3454	7.34”	7.20”	1.18”	1.23”
Corcoran	63.6°F	66.9°F	46	84	2471	3365	7.47”	7.49”	1.07”	1.14”
Delano	62.9°F	66.0°F	35	74	2171	2995	7.26”	7.72”	0.98”	1.12”
Dinuba	61.2°F	64.6°F	26	67	1690	2540	10.79”	10.44”	1.24”	1.35”
Dos Palos	62.6°F	65.8°F	39	73	2069	2905	8.66”	8.89”	1.08”	1.06”
Escalon	60.3°F	63.6°F	23	52	1404	2151	14.47”	15.31”	1.40”	1.52”
Exeter	61.6°F	64.8°F	25	65	1756	2577	10.76”	10.60”	1.24”	1.29”
Farmersville	61.0°F	64.2°F	20	57	1591	2406	10.24”	10.12”	1.21”	1.21”
Firebaugh	62.8°F	66.1°F	46	82	2161	3027	8.23”	8.35”	1.01”	1.07”
Fowler	61.9°F	65.2°F	37	79	1844	2711	9.56”	9.47”	1.17”	1.24”
Fresno	65.2°F	68.5°F	61	99	2903	3827	10.73”	10.86”	1.21”	1.29”
Gustine	62.4°F	65.6°F	34	65	1936	2742	10.06”	10.84”	1.23”	1.35”
Hanford	62.6°F	65.9°F	29	67	2142	2967	7.85”	7.91”	1.01”	1.09”

City	Mean Annual Temperature		Days of at least 100°F		Cooling degree days°F		Annual Total Precipitation		Annual max daily rain	
Hughson	60.4°F	63.7°F	14	39	1355	2103	12.85″	13.72″	1.26″	1.49″
Huron	64.2°F	67.6°F	51	91	2481	3414	6.85″	6.78″	1.05″	1.08″
Kerman	61.9°F	65.1°F	43	83	1870	2729	8.60″	8.84″	1.07″	1.21″
Kingsburg	61.7°F	65.1°F	36	78	1822	2668	9.43″	9.15″	1.09″	1.22″
Lathrop	60.7°F	64.0°F	17	40	1396	2150	11.30″	12.31″	1.13″	1.29″
Lemoore	63.2°F	66.6°F	46	85	2347	3241	7.42″	7.51″	1.07″	1.16″
Lindsay	61.9°F	65.1°F	25	66	1851	2677	10.71″	10.72″	1.19″	1.25″
Livingston	61.7°F	64.8°F	22	52	1657	2443	11.73″	12.47″	1.24″	1.38″
Lodi	60.6°F	63.8°F	12	29	1350	2083	16.19″	17.28″	1.54″	1.74″
Los Banos	62.5°F	65.8°F	30	59	1988	2816	8.79″	9.10″	1.09″	1.15″
Madera	63.3°F	66.5°F	46	84	2322	3174	10.42″	10.95″	1.19″	1.26″
Manteca	62.8°F	66.1°F	27	56	2036	2876	12.04″	13.06″	1.21″	1.36″
Maricopa	64.9°F	68.1°F	33	69	2761	3641	6.30″	6.32″	0.95″	1.09″
McFarland	63.5°F	66.8°F	40	80	2311	3162	7.15″	7.43″	0.99″	1.12″
Mendota	63.3°F	66.6°F	49	86	2316	3204	7.70″	7.89″	1.03″	1.06″
Merced	63.4°F	66.5°F	42	75	2329	3145	12.17″	12.56″	1.16″	1.25″
Modesto	63.7°F	66.9°F	30	61	2305	3128	11.61″	12.13″	1.25″	1.40″
Newman	62.3°F	65.4°F	33	65	1887	2679	10.05″	10.92″	1.22″	1.38″
Oakdale	61.8°F	65.1°F	27	60	1799	2608	15.20″	16.08″	1.52″	1.65″
Orange Cove	62.2°F	65.5°F	33	77	2018	2921	12.13″	11.99″	1.39″	1.51″
Parlier	61.7°F	65.1°F	38	81	1798	2658	10.42″	10.20″	1.15″	1.29″
Patterson	61.5°F	64.6°F	20	47	1624	2365	9.84″	10.83″	1.18″	1.39″
Porterville	63.5°F	66.8°F	40	82	2296	3173	10.12″	10.15″	1.14″	1.21″
Reedley	64.0°F	67.2°F	60	101	2521	3435	11.04″	10.93″	1.23″	1.35″
Ripon	62.3°F	65.5°F	25	54	1828	2637	11.79″	12.40″	1.29″	1.29″
Riverbank	61.9°F	65.1°F	25	55	1764	2550	13.79″	14.49″	1.35″	1.48″
San Joaquin	63.1°F	66.5°F	57	95	2278	3172	6.85″	7.03″	0.91″	0.98″
Sanger	61.5°F	65.0°F	31	75	1736	2612	11.4″	11.56″	1.26″	1.36″
Selma	61.8°F	65.2°F	38	79	1811	2666	9.69″	9.51″	1.11″	1.24″
Shafter	63.3°F	66.6°F	41	80	2275	3115	6.54″	6.55″	0.94″	1.03″
Stockton	61.6°F	64.8°F	19	41	1664	2446	15.11″	15.98″	1.46″	1.52″
Taft	64.8°F	68.0°F	33	69	2695	3575	5.68″	5.57″	0.93″	1.04″
Tracy	64.0°F	67.2°F	28	54	2317	3168	9.36″	10.02″	0.96″	1.10″
Tulare	62.1°F	65.4°F	30	70	1900	2726	8.76″	8.44″	1.08″	1.08″
Turlock	63.1°F	66.3°F	17	42	2083	2880	11.30″	12.03″	1.17″	1.37″
Visalia	63.9°F	67.0°F	38	77	2483	3331	9.76″	9.54″	1.17″	1.21″
Wasco	63.9°F	67.1°F	48	88	2466	3316	6.56″	6.73″	0.98″	1.06″
Waterford	60.5°F	64.0°F	17	46	1446	2240	14.17″	14.93″	1.38″	1.52″
Woodlake	62.2°F	65.6°F	32	77	1932	2792	12.43″	12.42″	1.41″	1.48″

Table S5. *Particularly vulnerable agricultural systems. Agricultural systems (crops and livestock) and their vulnerabilities to climate change, including potential solutions. Symbols denote heat stress (🌡️), cold stress (🥶), chill hours (🧊), drought stress (🏀), pollination (🐝), smoke (🔥)and rain damage (🌧️).*

Crop / Livestock	Vulnerabilities	Effects of climate change	Potential solutions
Almonds	🌡️🐝🏀	Delayed or uneven bloom; reduced nut set and reduced yield; increased frost damage risk in the near-term; increased irrigation requirements; mismatch in pollinator activity and timing of bloom.	Apply kaolin clay or rest-breaking chemicals; use drought-tolerant rootstock; utilize localized weather monitoring; increase irrigation efficiency through soil improvements.
Pistachios	🌡️🧊🏀	Delayed or uneven bloom; reduced nut set and reduced yield; increased risk of early bud break followed by frost damage; higher evaporative demand.	Apply kaolin clay or rest-breaking chemicals; increase irrigation efficiency through soil improvements.
Grapes	🌡️🔥	Sunburn, desiccation, and negative impacts to grape chemistry including smoke taint.	Implement precision irrigation and canopy management methods—shade cloth, increased irrigation, alternative trellising, and cover crops.
Stone fruits	🌡️🌧️🧊🔥	Delayed or uneven bloom and reduced yield; sunburn and desiccation; smoke taint; late-season precipitation during ripening, increasing risk of fruit cracking and fungal disease.	Apply kaolin clay or rest breaking chemicals; increase irrigation and cover crops; develop high tunnels.
Citrus	🥶	Flower and fruit damage from late-season frost events; reduced quality.	Increase use of wind machines, orchard heaters, and microsprinklers; grow frost-tolerant varieties.
Tomatoes	🌡️🐝	Blossom damage; reduced fruit set; poor color development; increased pest pressures.	Manage canopies with shade cloths; grow heat-tolerant varieties; adjust planting dates; increase methods to support pollinators.
Alfalfa	🌡️🏀	Reduced yields; lower protein content; increased irrigation demand.	Improve irrigation efficiency; grow drought-tolerant cultivars; rotate grazing; apply deficit irrigation.
Cotton	🌡️🏀	Reduced yields and fiber quality; increased irrigation demand.	Grow heat-tolerant cultivars; apply deficit irrigation techniques; implement soil moisture conservation practices.
Dairy cattle	🌡️🏀	Reduced milk production; higher mortality during heat waves; impact to milk quality; increased water needs.	Use shade structures, fans, and sprinklers; provide nutritional supplements; adjust milking schedules during heat.
Bee hives	🌡️🏀	Reduced pollination efficiency; increased pest and disease pressure; colony collapse.	Relocate to cooler microclimates; use clean water; provide diversified floral resources; reduce pesticide exposure.
Specialty vegetables	🌡️🏀	Reduced yield and quality; increased pest outbreaks; heat-induced bolting (premature flowering).	Provide shade; improve irrigation efficiency; improve soil health; adjust planting times.

Table S6. *Select funding opportunities that support climate-smart agricultural practices from California Department of Food and Agriculture (CDFA), the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) , and the San Joaquin Valley Air Pollution Control District (SJVAPCD).*

Program Name (Agency)	Focus Areas	Typical Funded Practices (Examples)
Healthy Soils Program (CDFA)	Carbon sequestration, soil health, biodiversity.	Cover cropping, low-to-no-tillage, compost application, mulching, biochar application, prescribed Indigenous burning.
State Water Efficiency and Enhancement Program (CDFA)	Water use reduction and energy efficiency in irrigation.	Irrigation water management systems and sensors, improved fuel efficiency including renewables for pumping.
Alternative Manure Management Program (CDFA)	Non-digester practices for reducing methane on dairies and livestock operations.	Solid separation, composting, drying of collected manure, and pasture-based management.
Environmental Quality Incentives Program (NRCS)	Financial and technical assistance for conservation practices.	A federal program that helps farmers implement climate-smart practices like nutrient management, irrigation scheduling, and cover crops.
Regional Conservation Partnership Program (NRCS)	Partner-driven initiatives focused on resource challenges.	The San Joaquin Valley Land and Water Conservation Collaborative funded under this program has worked to protect critical farmland, increase regenerative agricultural practices, and support the next generation of farmers.
Ag Burn Alternatives Grant Program (SJVAPCD)	Financial incentives for alternatives to open-field burning of agricultural material.	Funds practices like whole-orchard recycling, chipping, and composting, which sequester carbon into the soil.

Table S7: Populations in the SJV most at risk to public health effects of climate change. *This table is not comprehensive but rather is intended to provide an overview of these unique vulnerabilities.*

Demographic	Heat	Air Quality	Vectors & Pathogens	Water (quality & quantity)
Children	Heightened physiological risks	Vulnerable due to developing respiratory systems	Outdoor activities increase exposure risk	Heightened risks from nitrate exposure and waterborne illness
Elderly	Limited mobility to access cooler areas; exacerbation of existing health conditions	Age-related health conditions exacerbated by poor air quality	Age-related immune system changes increase susceptibility	Heightened risk from weakened systems and underlying chronic conditions
People w/ disabilities & pre-existing conditions	Limited mobility and social connections limit access to help	Asthma, chronic obstructive pulmonary disease (COPD), and heart disease patients face heightened risks	Underlying health conditions increase severity of vector-borne illness	Weakened immune systems increase susceptibility
Unhoused populations	Lack of shelter increases direct exposure to urban heat	Lack of shelter increases direct exposure to poor air quality	Lack of shelter increases direct exposure vectors and pathogens	Often rely on informal or contaminated water sources; limited access to sanitation or bottled water
Outdoor workers	Direct occupational exposure to extreme heat	Direct occupational exposure to air pollution during work hours	Direct exposure to dust and airborne pathogens	Risk of dehydration and exposure to unsafe drinking water on job sites
Low-income residents	Economic barriers prevent access to cooling, which can be particularly dangerous during warm nights	Often live near pollution sources and lack resources for air filtration	Often live in areas with untreated vector/ pathogen habitat	Cannot afford bottled water or home treatment systems or deepening of domestic wells
Undocumented residents	Face barriers to healthcare access during heat emergencies	Live or work in high-exposure areas but may avoid healthcare due to immigration status concerns	May avoid public services that could mitigate vector exposure due to immigration status concerns; often housed in substandard housing with higher pest risks	Avoid reporting problems due to immigration status concerns; ineligible for government programs
Rural residents	Limited access to cooling centers, typically less reliable energy infrastructure	Exposure to agricultural emissions, wildfire smoke, and unregulated dust sources	Proximity to irrigation systems and dust sources increases exposure	Rely on small water systems and wells, which are most vulnerable to contamination

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