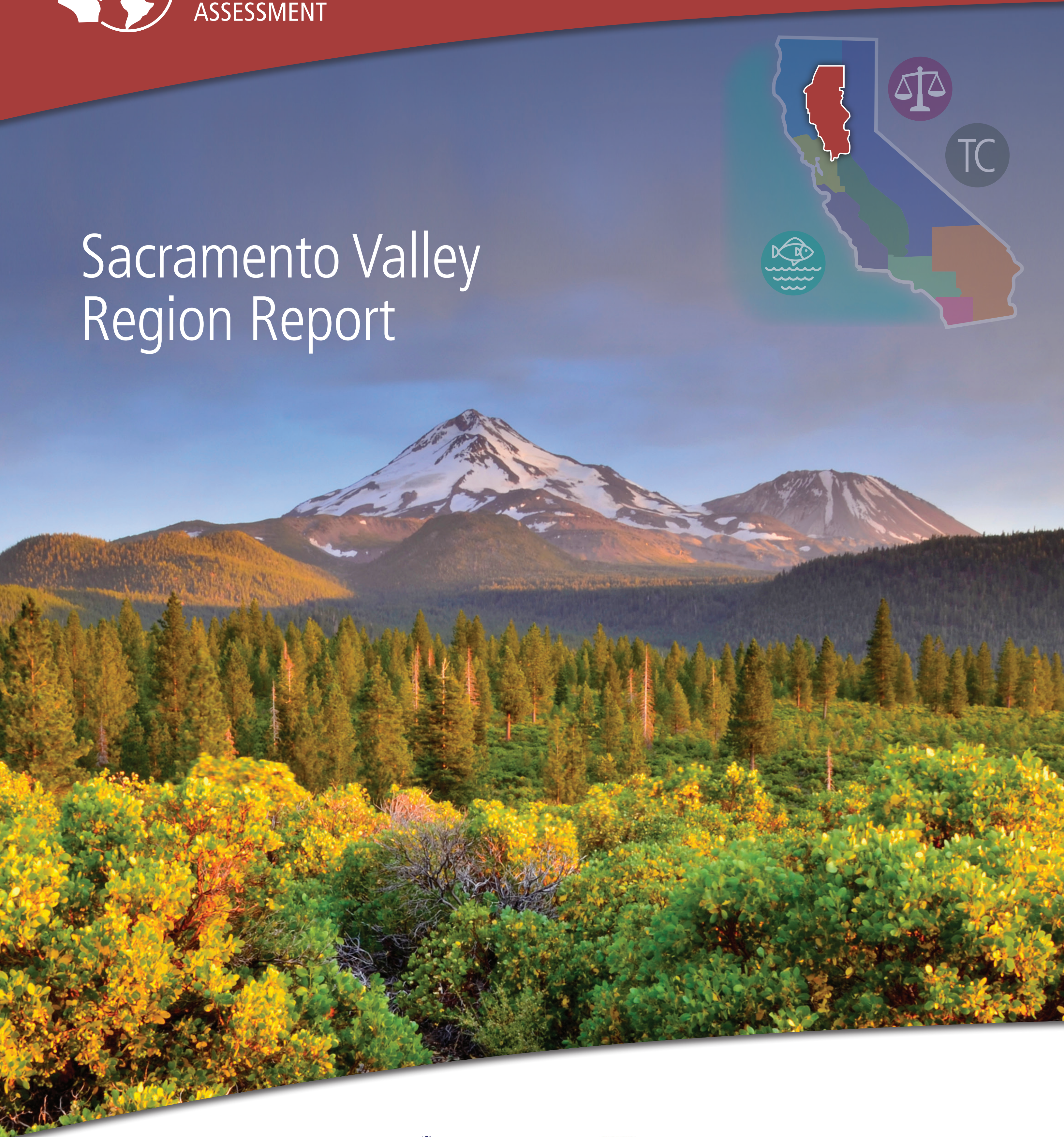
CALIFORNIA'S FOURTH
**CLIMATE CHANGE**
ASSESSMENT

# Sacramento Valley Region Report

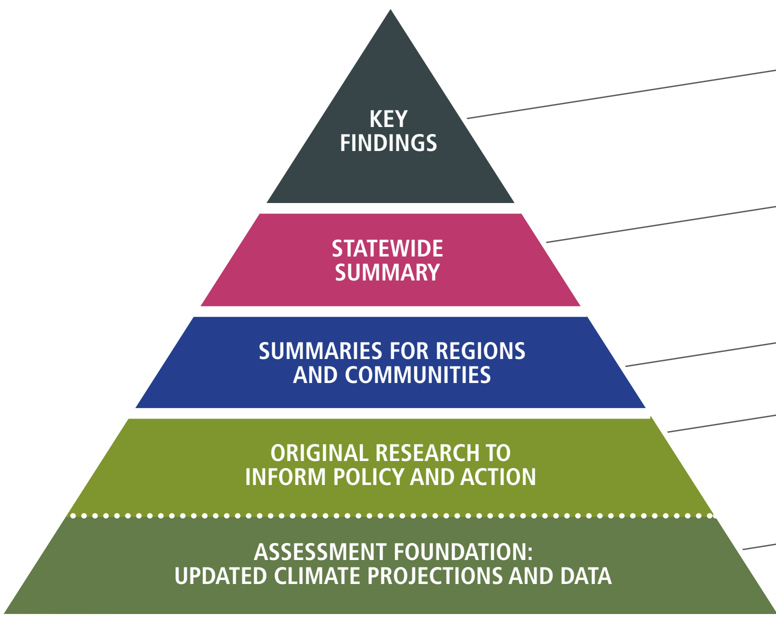



Coordinating Agencies:

# Introduction to California's Fourth Climate Change Assessment

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

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




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

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

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

## Sacramento Valley Region


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

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

CALIFORNIA'S FOURTH
**CLIMATE CHANGE**
ASSESSMENT

# Sacramento Valley Region Authors


**COORDINATING LEAD AUTHORS[1]**

**Benjamin Z. Houlton,**
***UC Davis***

**Jay Lund**
***UC Davis***

**LEAD AUTHORS**

Steven Greco,
*UC Davis*

Jonathan London,
*UC Davis*

Helene Margolis,
*UC Davis*

Debbie Niemeier,
*UC Davis*

Joan Ogden,
*UC Davis*

Steven Ostoja,
*USDA Climate Hub*

Paul Ullrich,
*UC Davis*

Stephen Wheeler,
*UC Davis*

**CONTRIBUTING AUTHORS**

Maya Almaraz
*UC Davis*

Susan Harrison
*UC Davis*

Beth-Rose Middleton
*UC Davis*

Peter Moyle
*UC Davis*

Sara Nichols
*UC Davis*

Travis O'Brien
*Lawrence Berkeley National Lab and UC Davis*

Kent Pinkerton
*UC Davis*

Chad Roberts
*Independent Conservation Ecologist*

**STAKEHOLDER ADVISORY COMMITTEE**

Kathleen Ave
*Sacramento Municipal Utilities District*

Thad Bettner
*Glen Colusa Irrigation District*

Allan Fulton
*UC Cooperative Extension*

Bonnie Holmes-Gen
*American Lung Association of California*

Campbell Ingram
*Sacramento-San Joaquin Delta Conservancy*

Ben Pennock
*Glen Colusa Irrigation District*

Liz Ponce
*Shasta County Farm Bureau and Lassen Canyon Nursery*

Glennah Trochet
*Health Effects Task Force of California*

Ernie Washington
*Butte County*

1 Contact information: bzhoulton@ucdavis.edu and jrlund@ucdavis.edu



CITATION: Houlton, Benjamin, Jay Lund. (University of California, Davis). 2018. Sacramento Summary Report. California's Fourth Climate Change Assessment. Publication number: SUM-CCCA4-2018-002.

# Table of Contents

# Highlights

This report summarizes current and future climate change impacts and risks in California's Sacramento Valley Region and highlights a set of promising climate-solutions for stakeholders, with the potential to promote resiliency, protect the environment, improve public health, create jobs, and grow the economy. Climate change is already affecting agriculture, infrastructure, transportation, energy, recreation, industry, households, human health, and natural ecosystems in the Sacramento Valley; extreme weather and natural hazards will continue to impact these and other sectors in the 21st century.

The Sacramento Valley will benefit from continued investment in climate change solutions. The region's agricultural economy can help mitigate against climate risks by investing in precision agriculture, water-sensors and drones, and planting crop varietals that are more tolerant of drought, heat, and salty soils. Climate change-driven increases in extremely hot days will contribute to existing public health challenges, including the spread of infectious disease and reductions in air quality, with the young, elderly, and disadvantaged communities most vulnerable to climate impacts.

Some of the more promising ways to reduce climate change risks in the Sacramento Valley include: climate-smart buildings and more accessible public "cooling centers" to help citizens cope with more frequent and prolonged heat waves; strategic forest thinning, controlled burning, and fire reduction practices to promote carbon storage, decrease wildfire frequency and intensity, and create cleaner air; enhanced emergency preparedness with a focus on disadvantaged communities; increased land use planning to prepare for extreme floods and drought, including innovations to levees, bypasses, and reservoir capacity; increased water availability and attention to integrated water supply management within the entire watershed; improved management for climate-adaptive native species and assisted migration to protect ecosystem services, including outdoor recreation; increased development of alternative fuel policies and active transportation programs to cut air pollution and greenhouse gas (GHG) emissions in the transportation sector; and incorporation of climate risks into regional plans for energy, water, and transportation. New economic and career opportunities focused on creating the next generation of "climate-smart" technologies, policies and community resources will grow the region's economy, protect citizens and maintain a healthy and vibrant environment.

A general summary of climate risks facing the Sacramento Valley Region include:

- Warming air and water temperatures
- More extreme heat-waves
- Drier landscapes
- Less snow
- Variable precipitation and seasonal shifts
- More intense droughts and floods with less predictability
- Higher Delta water levels compounded by subsidence
- Increased risk of wildfire
- Loss of ecosystem habitat

It is likely that climate change will have significant impacts in the following areas:

- Public health: More frequent and extreme heat waves; greater heat stress risk especially for outdoor occupations and recreation; greater air pollution exposures from wildfires.
- Energy: Reduced snowpack resulting in reduced hydropower production; increased risk to generation and transmission infrastructure from wildfires; greater use of low-carbon fuels and generation; greater air conditioning energy loads, less demand for heating.
- Agriculture: Longer growing seasons; insufficient cold for some tree crops; low elevation flooding; changes in productivity of current crop varietals; conversion of agricultural land to other land uses.
- Floods: More extreme floods; greater floodplain vulnerability; pressure to expand flood bypasses, levees, and flood storage in reservoirs; higher Delta water levels.
- Water supply: More extreme droughts; pressure to reduce water supply storage due to larger floods; possibly greater water demands from higher crop and landscape water use.
- Delta: Higher sea levels, levee subsidence, and greater floods threaten Delta levees; higher temperatures threaten Delta native species; saltwater intrusion into areas from which water is pumped for agricultural and municipal uses.
- Aquatic ecosystems: Higher temperatures threaten native species and make reservoirs less effective for sustaining salmon populations; higher Delta water levels.
- Forests: Higher temperatures, variable overall precipitation with less snow and earlier snow melt; lower soil moisture and changes in water storage and runoff; increased wildfire activity in terms of the number of fires, overall area burned, and more area burned at high severity promoting changes.
- Wildfires: More frequent and larger wildfires in both forests and shrubland ecosystems; thinning and fuel reduction can reduce risk in forests but less so in shrublands.

Some suggestions for climate solutions include:

- Public health preparations for more frequent and prolonged heat waves, impaired water supplies and quality, more frequent harmful algal blooms, and air pollution from wildfires.
- Expanded renewable power generation and fuels; distributed generation to increase community resilience.
- Local and regional preparation for floods, particularly a potential "Great Flood," including attention to levees, bypasses, and reservoirs; floodplain land use planning and building codes; and flooding of subsided Delta lands.
- Continued assessment of additional water storage solutions, reservoirs and increased stormwater capture and groundwater banking in agricultural lands.
- Continued local and regional attention to integrated water supply management, such as conjunctive use of reservoirs and groundwater, and management of water quality effects resulting from higher temperatures in rivers, lakes, and watersheds.

- Greater regional attention to forest and shrubland management for mitigating destructive wildfires and ecosystem resilience; active management of wildfire-prone lands in the state through vegetation thinning, fuels reduction, and controlled (i.e., prescribed) fire treatments and reforestation in line with Governor Brown's Executive Order B-52-18.
- Improved environmental management for native fish species, including seasonal floodplain habitat and protection and development of cold spring habitats.
- Identify opportunities with co-benefits for the economy and environment such as energy generation and conservation, forest thinning and management, and agriculture.
- Continued development of comprehensive transportation strategies to adapt to climate change with more technical expertise and financial resources for adaptation and planning.
- Promotion of state-level policies to integrate alternative fuel aspirations and driving trends (e.g., autonomous vehicles) into transportation plans and policies; implementation of long-term transportation infrastructure maintenance plans.
- Continued promotion of active transportation programs as a critical component in developing and implementing sustainable community strategies, reducing greenhouse gas (GHG) emissions, increasing public health, and making the region a more enjoyable place to live and work.
- Urban planning strategies to: increase tree canopy (with water-wise species) and utilize green building materials to reduce heat pollution and reduce the urban heat island effect; handle increased stormwater on-site; avoid placing additional housing in flood-prone locations; and establish emergency shelter and services facilities.
- Dedicated and coordinated focus on issues of social and environmental equity and the impacts of climate change on especially vulnerable populations as well as the need for climate solutions to acknowledge and address legacy injustices that render certain population (e.g., low-income communities, people of color, etc.) more vulnerable to climate risks.

# Introduction to the Sacramento Valley Region

This report summarizes major changes in climate and climate-related risks to the Sacramento Valley Region (Figure 1) and provides promising actions for local decision-makers. This assessment is focused on regionally-specific climate and extreme weather patterns, public health, community planning and environmental justice, water and energy, utilities and infrastructure, agriculture, land use change, the economy, biodiversity, and ecosystem services.

Like previous assessments, California's Fourth Climate Change Assessment reflects a statewide, collaborative process for the purpose of summarizing climate change impacts and adaptation options for California. California's Fourth Climate Change Assessment is a series of reports comprised of (1) the Statewide Report; (2) three topical reports (Oceans and Coasts, Tribes and Tribal Lands, and Climate Justice[1]); and (3) nine regional reports, of which the Sacramento Valley Region is one. We encourage the reader to review these reports online at: www.ClimateAssessment.ca.gov.

**FIGURE 1**

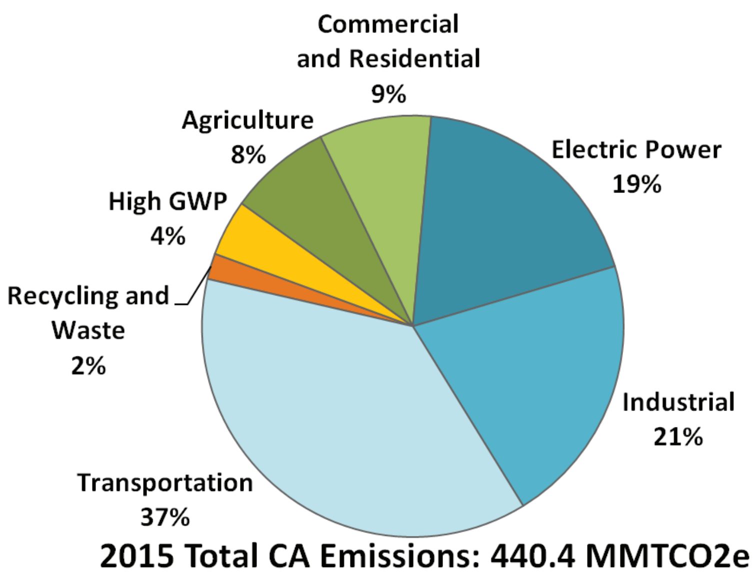

Map of the Sacramento Valley Region in Northern California. Source: Thorne 2018.

## Summary of Impacts

Climate change and extreme weather affect people, ecosystems, and the economy. Global greenhouse gas (GHG) emissions are increasing land, air, and water temperatures across the world, changing the timing and amount of precipitation and accelerating sea level rise. Such GHG-driven climate disruptions are resulting in human health, economic and environmental damages, altering patterns of human migration, harming public health, compromising national security, and harming business and industry. To avoid some of the worst climate change impacts over the next several decades, many organizations and governments are reducing GHG emissions with targets to stabilize global warming at no more than 2 degrees Celsius (°C) above pre-industrial levels (Rockström et al. 2017). Financial and educational investments in climate change resilience are critical to reducing climate-change impacts and avoiding further economic damages.

California is a world-leader in climate policy. The state continues to demonstrate how free-market policies that cut GHG emissions can work for industry, businesses, citizens, natural environments, and the economy, principally via Cap-and-Trade. As of 2015, California's GHG emissions were dominated by transportation, industry, and energy production (~77% of total), with lesser contributions from buildings (9%), agriculture (~8%), and waste (2%) (**Figure 2**). By law, California must reduce GHG emissions to 40% below 1990 levels by 2030, which is among the most aggressive climate actions taken by any economy the size of California's. California is on track to meet this GHG reduction target while experiencing significant economic growth. A climate-smart strategy for California takes advantage of economic opportunities and innovations that come from this global challenge, creating more jobs and prosperity through innovation.

**FIGURE 2**




Greenhouse gas emissions by sector based on the California Air Resources Board scoping plan categories for 2015. Source: CARB 2017. Note: GWP = Global warming potential; MMTCO2e = million metric tons of carbon dioxide (CO2) equivalent.

[2] The term "Climate Justice" was selected to be consistent with the Safeguarding California Plan and to call out this specific element of environmental justice issues. It refers to the social movement to address the cumulative ways in which social, economic political and environmental factors can produce and exacerbate disproportionate impacts of climate change on vulnerable populations (e.g., people of color, low-income people, indigenous people) and the unique role these populations have to play in efforts to mitigate and adapt to climate change. More information on the priorities of climate justice can be found in the Safeguarding California Plan: 2018 Update as well as Roos 2018. For more information about climate justice see: Shonkoff et al. 2011 and Schlosberg and Collins 2014.

Climate change is already impacting California. After several years of stabilization, global GHG emissions increased in 2017 (Jackson et al. 2017), on pace or slightly above "business-as-usual" emissions scenarios for the 21st century. Long-lived gases such as carbon dioxide ($CO_2$) can persist in the atmosphere for more than 100 years, even with efforts to reduce emissions today. Despite California's aggressive actions to reduce emissions, the state's climate and weather will continue to change without global actions to reduce GHG emissions. California contributes roughly > 1% of global GHG emissions, meaning that it can serve as a model for other governments, but cannot halt the pace and magnitude of climate change without world-wide coordination.

Policies and strategies to reduce GHG emissions have helped California spur new investments, businesses, and jobs to support these efforts. Management and planning are essential for maintaining economic prosperity and further GHG reductions. Adaptations by individuals, households, government, and businesses will be needed to support and maintain the region's prosperity and environmental health benefits in response to climate change. The transition to lower GHG emissions in the Sacramento Valley Region will reduce toxic air pollutants and create healthier local conditions for residents, especially those with chronic health conditions and those living in disadvantaged communities, as has been shown in other California regions (Hall et al. 2008). A recent analysis suggests that achieving the deep GHG emissions reductions required to meet California's 2050 emissions reductions goal would reduce statewide air pollution-related mortality by about half, with Sacramento County experiencing among the greatest reductions in air pollution-related mortality rates. The monetized value of these public health benefits is comparable to the costs associated with reducing California's emissions to 80% below the 1990 baseline by 2050 (Zapata et al. 2018).

## Report Organization

The remainder of this report is organized into the following sections:

Section 2 summarizes climate change risks and solutions for Sacramento Valley residents, governments, and businesses.

Section 3 presents major recent and likely climate changes in the Sacramento region.

Section 4 presents major climate-related risks to the region and several adaptations that support public health; community planning; energy, water, utilities and transportation; land use, natural habitats and working lands; and cross-sectoral insights.

# Summary of Key Findings

The following table summarizes climate change risks and solutions for the Sacramento Valley Region. More details appear in Sections 4.1-4.5 of this report.

**TABLE 1**

| FOCUS AREA | RISKS | ADAPTATION STRATEGIES AND SOLUTIONS | STATUS/ IMPLEMENTATION TIMELINE |
|---|---|---|---|
| **4.1 PUBLIC HEALTH** | • More frequent heat-related stress, illness, and human mortality due to increases in number of extremely hot days (i.e., prolonged heatwaves)<br>• More disease-causing pathogens including West Nile virus, Valley Fever, harmful algal blooms, etc. | • Reducing/managing potential exposure(s) (individual, community) to heat and other hazards<br>• Reducing heat pollution and eliminating urban heat islands | Near-term (0-10 years) |
| | • More exposure to ground-level ozone, particulate air pollution and respiratory allergens | • Promoting good health and access to quality healthcare (reduces risk and increases resiliency) | Near-term (0-10 years) |
| | • Negative impacts on mental health from chronic social and economic stressors | • Improving Emergency Preparedness and Response Action Plans and resources | Underway; near-term (0-10 years) |

**TABLE 1 CONT'D.**

| FOCUS AREA | RISKS | ADAPTATION STRATEGIES AND SOLUTIONS | STATUS/ IMPLEMENTATION TIMELINE |
|---|---|---|---|
| **4.2 COMMUNITY PLANNING** | • Potential disruptions to the housing market in response to un-mitigated flooding and concomitant economic impacts that disproportionately affect particular sociodemographic groups | • Implement zoning, building codes, and design guidelines that emphasize residential and neighborhood greening, cool roofs, climate adaptive building shells, and other techniques to reduce climate impacts on urban environments and public health | Underway; medium-term (11-30 years) |
| | • More frequent severe storms and floods<br>• Increased stress on levee systems | • Regional levee and watershed planning to retain storm water, reduce flooding, and sequester carbon | Underway; long-term (2050 and beyond) |
| | • Increased wildfire risks and impacts, especially for rural communities in hilly and forested terrain | • Supporting climate-conscious planning that restricts housing in high fire risk areas<br>• Requiring flame-resistant materials for structures and fuel reduction in residential yards | Underway; medium-term (11-30 years) |
| | • Increased susceptibility to illness from high temperatures | • Tree-planting to shade parking and other surfaces | Underway; near-term (0-10 years) |
| | • More risks from poor air quality, especially in areas with air pollution from transportation and other industrial sources | • Engaging stakeholders in adaptation planning (e.g., Sacramento Area Council of Government's Rural-Urban Connections Strategy)<br>• Sharing climate adaptation information among regional institutions (e.g., Capitol Region Climate Readiness Collaborative) | Underway; near-term (0-10 years) |
| | • Please refer to the Tribal and Indigenous Communities report for further information on how California's Tribal communities face unique threats from climate change and how these communities are spearheading adaptation and mitigation efforts (Tribal and Indigenous Communities Summary Report 2018) | • Climate adaptation strategies by tribal communities (e.g., Yocha Dehe Wintun, Karuk Tribe, Yurok Tribe)<br>• Tribal engagement in carbon sequestration to provide local employment and ecological and disaster mitigation benefits for rural communities | Underway; near-term (0-10 years) |

**TABLE 1 CONT'D.**

| FOCUS AREA | RISKS | ADAPTATION STRATEGIES AND SOLUTIONS | STATUS/ IMPLEMENTATION TIMELINE |
|---|---|---|---|
| **4.3 ENERGY, WATER, UTILITIES AND TRANSPORTATION** | • Reduced thermo-electric power plant operating efficiency and generation capacity due to increasing air and water temperatures<br>• Reduced or disrupted hydropower generation from greater evaporative losses, altered runoff timing, decreased snow pack and increased storms intensity<br>• Uncertain impacts on solar and wind power outputs (i.e., from variable wind patterns)<br>• Decreased efficiency of electric transmission and distribution systems from higher temperatures | • Principles and best practices for adaptation (e.g., Council on Environmental Quality)<br>• Continuing development of comprehensive statewide strategies to adapt to climate change (e.g., California Natural Resources Agency, California Energy Commission, electric utilities, US Department of Energy, others)<br>• Cross-sectoral approaches to better facilitate adaptation at the local level (refer to the Cross-sector Interactions Section)<br>• Rapid decarbonization of buildings and transportation<br>• Planning to deploy distributed generation and energy storage for more local control of the energy supply | Underway; Medium-term (11-30 years) |
| | • Accelerated roadway deformation and track buckling resulting from extreme heat<br>• Increased expansion and contraction at critical bridge joints resulting from temperature fluctuations<br>• Traffic and signal disruptions from extreme weather<br>• Decreased driving visibility and health hazards due to wildfire | • State policies to integrate alternative fuel aspirations and driving trends (e.g., autonomous vehicles) into transportation plans and policies, and implementation of long-term maintenance plans<br>• Integration of energy-transport long-term planning at the local level upward<br>• Developing new finance tools for ensuring long-term maintenance and adaptation funds<br>• Incentivizing climate-smart infrastructure planning to prioritize mode shift to low carbon alternatives and active transportation | Near-term (0-10 years); Medium-term (11-30 years) |
| | • Reductions in groundwater in response to drought and increased water demands | • Implement water conservation strategies<br>• Assessment of additional water storage solutions<br>• Increased stormwater capture | Underway; near-term (0-10 years); medium-term (11-30 years) |
| | • Economic impacts that disproportionately affect particular sociodemographic groups depending on location | • Understanding broader social issues of climate change, especially for low-income and disadvantaged communities | Near-term (0-10 years); medium-term (11-30 years) |

**TABLE 1 CONT'D.**

| FOCUS AREA | RISKS | ADAPTATION STRATEGIES AND SOLUTIONS | STATUS/ IMPLEMENTATION TIMELINE |
|---|---|---|---|
| **4.4 LAND USE, NATURAL HABITATS AND WORKING LANDS** | • More threats from flooding, drought and fire | • Expanding flood channels for 200+-year protection (levee setbacks); water conservation; fire and fuel management near wildland-urban interface<br>• Prescribed burn treatments in forests and shrublands under the right context, settings, and conditions | Underway; medium-term (11-30 years); long-term (2050 and beyond) |
| | • Species composition changes and reduction, and loss of iconic species | • Connecting habitats and refugia | Medium-term (11-30 years) |
| | • Increased extinction risk for most native fish species<br>• Increased threats, displacement, and/or local extinction due to invasive species, pests, disease, etc. | • Naturalizing the hydrograph of regulated rivers and assist hatchery fish migration<br>• Controlling invasive and non-native species | Underway; Near-term (0-10 years); medium-term (11-30 years) |
| | • Changes in productivity of current crop varietals and conversion of agricultural land to other land uses<br>• Loss of agricultural/semi-natural habitats | • Ecosystem agricultural practices (e.g., hedgerows, tail water ponds, enhancing riparian areas, and vegetated road verges and canal edges) | Underway |

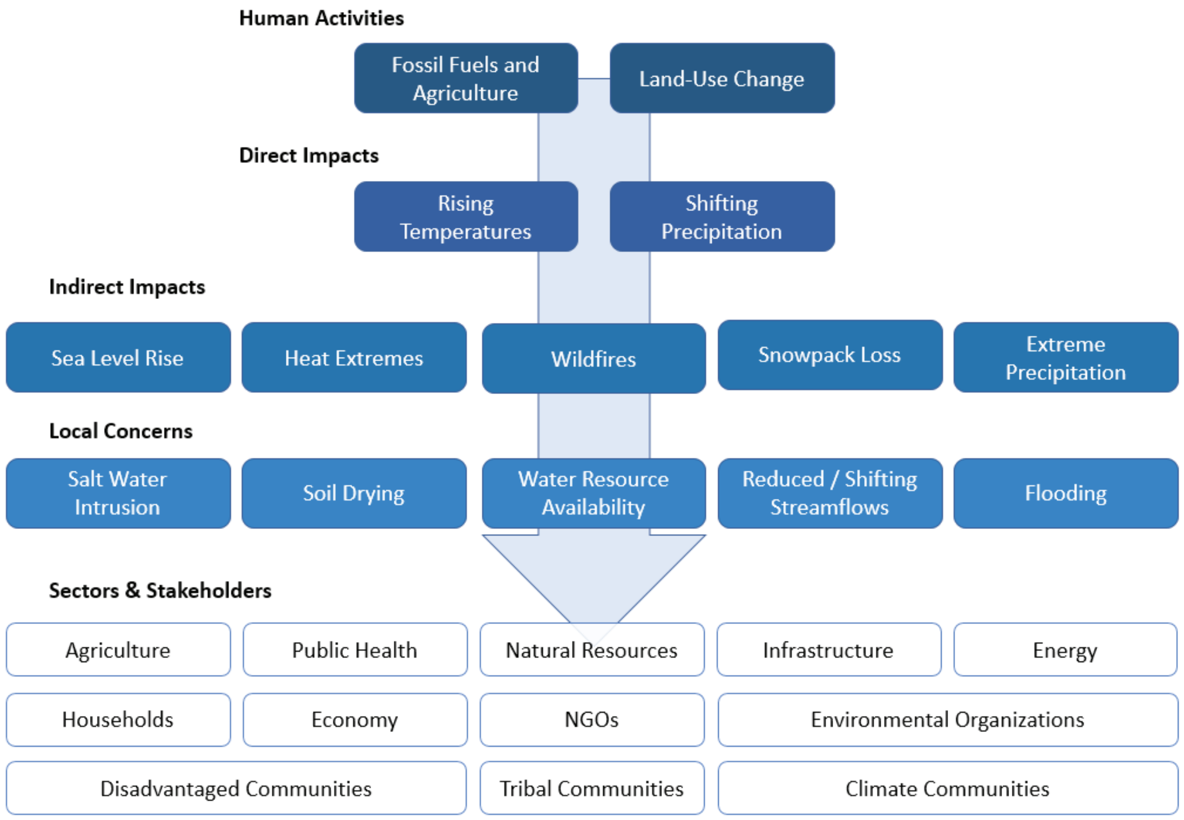
**TABLE 1 CONT'D.**

| | | | |
|---|---|---|---|
| **4.5 CROSS-SECTOR IMPACTS** | • Rebalancing of land uses between carbon sinks (rangelands, wetlands, forests) and carbon sources (urban development, intensive agriculture) | • Restoration for vegetation and wildlife habitat, carbon sequestration and water savings | Underway; Near-term (0-10 years); medium-term (11-30 years) |
| | • Seasonal/drought water scarcity impacts to vegetation and agriculture | • Increase resilience through various methods, including improving water-use and energy efficiencies<br>• Assessment of additional water storage solutions, including reservoir management and development options | Underway; near-term (0-10 years) |
| | • Increased seasonal dryness and droughts reduce rangeland forage production and wildlife habitat<br>• Occupational health temperature impacts on agriculture, construction, and rural livelihoods | • Infrastructure or restoration projects that meet goals across sectors (e.g., the Yolo Bypass mitigates flood risk, improves wildlife habitat, provides space for agricultural productivity and likely sequesters carbon relative to other uses) | Underway; medium-term (11-30 years) |
| | • Increased temperatures and extreme events increase energy demand and increase household costs | • Increasing urban tree planting to enhance biodiversity, reduce runoff, and ameliorate particulate pollution, promote green and climate-smart construction (e.g., high albedo roofing) | Underway; near-term (0-10 years) |

# Climate Changes in the Sacramento Valley Region - from Shasta to the Delta and Central Valley

Global climate change imposes substantial local impacts and risks on the Sacramento Valley, including rising temperatures, changing precipitation patterns and amounts, sea level rise, flooding, drought, and wildfire. In addition, seasonal weather patterns are becoming less predictable in California. Figure 3 shows how global climate changes are causing direct and indirect effects in California, with local issues affecting the Sacramento Valley Region. Additional information on climate change impacts to California's tribal and indigenous communities can be found in a topical report of the Fourth Assessment (Tribal and Indigenous Communities Summary Report 2018); additional information on climate justice impacts and considerations is provided in a second topical report of the Fourth Assessment (Climate Justice Summary Report 2018).

**FIGURE 3**

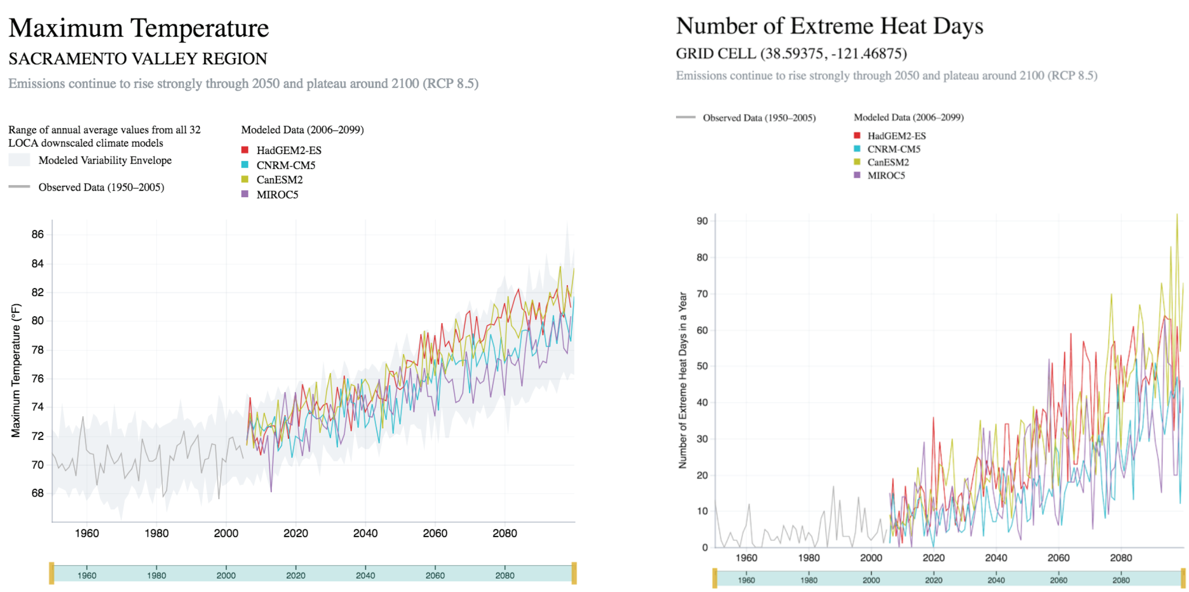



Human greenhouse gas emissions and land-use affect energy flows in the atmosphere that raise temperatures and shifts precipitation, with many direct and indirect effects in the Sacramento Valley.

## Rising Temperatures and Extreme Heat

Climate change has increased both average temperatures and the frequency and intensity of heat waves or extreme heat events. While global temperature increases of 1°C or 2°C (1.8°F or 3.6°F) are of grave concern for Earth's climate system, local observed increases that affect neighborhoods and ecosystems are far more variable and often of greater magnitude. Predicted changes over this century include higher average temperatures with more warming in the summer than the winter (with July–September increases of 2.7°F–10.8°F) and greater warming inland than in coastal regions (by as much as 7.2°F) (Pierce et al. 2018). Heat waves are expected to have both higher daytime and nighttime temperatures (versus just daytime increases), with longer duration and geographic extent (Gershunov et al. 2009).

**FIGURE 4**




(Left) The Sacramento Valley will likely see average daily maximum temperatures increase by 10 °F by end-of-century. (Right) Midtown Sacramento will likely see the average number of extreme heat days (temperatures more than 103.9 °F; right) grow from ~4 days/year to 40 days/year by end-of-century, along with a significant increase in year-to-year variability. All projections are under RCP8.5 (business-as-usual). Source: Cal-Adapt 2018.

Rising global temperatures (Figure 4) are resulting in more frequent and intense heat waves in the Sacramento Valley, with fewer cooling degree days that are essential to certain crops, optimal human health conditions, and the longevity of transportation and electrical infrastructure – trends that are expected to continue. Historical daytime temperature increases in the Sacramento Valley have likely been tempered by irrigation (Huang & Ullrich 2016; Yang et al. 2017); although the exact impact on temperatures from irrigation remains uncertain, past studies have estimated the effect at 0.6°F–3.6°F of local cooling. As total irrigation water usage has remained relatively steady over the past several decades, further local temperature reductions from irrigation appear unlikely. In fact, limiting irrigation water usage, for instance, through the use of drip irrigation, may further increase local summer temperatures.

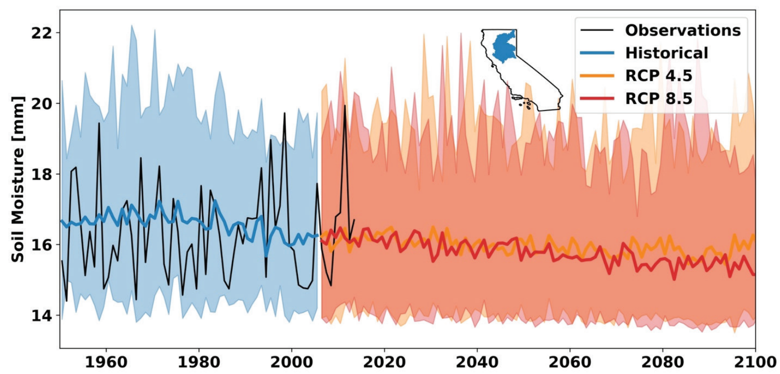
## Shifting Precipitation

California's climate oscillates between extremely dry and extremely wet periods, driven by the presence or absence of a few large winter storms or atmospheric rivers. In the last decade, Northern California experienced among the worst droughts (2012-2016) in >1000 years followed by the wettest winter on record (2016-2017). Global climate change affects precipitation by increasing the atmosphere's capacity to "hold" water vapor, so winter storms generally carry more rain. Dry years are likely to become even drier, while wet years will become even wetter in the next several decades (Dettinger 2011; Yoon et al. 2015). Whiplash events, where conditions shift rapidly from drought to deluge, are expected to increase modestly (by~25%) in Northern California (Swain et al. 2018). In the Sacramento Valley, annual precipitation is expected to remain about the same on *average*, or to increase slightly this century (Pierce et al. 2018; Huang & Ullrich 2017). However, the increased intensity of extreme storms makes the return of conditions that would trigger an extreme 1862-type "Great Flood" event more likely, even probable in the next 40 years (Swain et al. 2018). New extremes will challenge water storage and flood control systems which were designed for the historical climate patterns.

Future wet seasons will have more precipitation as rain than snow, primarily due to higher temperatures. This will shift the timing of streamflow into the Sacramento Valley from spring to winter. In particular, higher extreme rainfall will bring more surface runoff and less groundwater recharge (Pierce et al. 2018) and may require surface water reservoirs to operate at a lower capacity to ensure flood mitigation. These changes may also present opportunities for increased stormwater capture through reservoir management options.

Years with low snowpack are expected to become common in the coming decade due to higher temperatures (Mote et al. 2005). Lack of snow also reduces summertime soil moisture (**Figure 5**) and kills trees. The Northern Sierras – a primary water source for the Sacramento Valley – are expected to have almost no annual snowpack by the end of this century. The Southern Sierras are partially buffered against rising temperatures by their higher elevation but are still expected to have declines in total snow water of about 40% by the end-of-century, with the greatest losses at lower elevations (Rhoades et al. 2018).

**FIGURE 5**




Change in summer (June-August) soil moisture in Northern California (averaging region shown in inset) anticipated from two climate scenarios. Shading depicts model spread, and solid lines depict the multi-model mean. Source: Cal-Adapt (VIC simulations forced by LOCA downscaled CMIP5 output, Pierce et al. 2014).

## Sea Level Rise

Global temperature increases have driven both ice melt on land and thermal expansion of ocean water, both of which raise sea levels. End-of-century sea level rise in the San Francisco Bay area is likely to be 2.5 feet (50th percentile) to 4 feet (95th percentile) (Pierce et al. 2018). Areas around the Sacramento-San Joaquin Delta will have more flood potential. Higher sea level will also push salty ocean waters into the fresher waters of the Sacramento-San Joaquin Delta.

## Tule Fog

In the Sacramento Valley, Tule fog during California's winter season has important implications for crops and ecosystems. Reductions in Tule fog have been observed in recent years because conditions have been either too wet or too dry for fog to form (Baldocchi & Waller 2014).

## Wildfire

Wildfire (i.e., total area burned, number of fires, severity of fires) has been increasing in the Western US (Abatzoglou & Williams 2016) due to climate change and antecedent forest management activities that promoted highly-dense forests with higher accumulated fuels. As a result, wetter winters and drier summers are likely to increase summer and fall wildfire activity. Wetter winters increase plant growth, which increases the amount of fuel for wildfire in the spring and summer months (Crocket & Westerling 2018). Increases in large wildfires are posited to be driven by an earlier spring season and less summer moisture (Westerling 2016).

Recent years exemplify the meteorological extremes typical for California, with a major drought from 2012-2016, followed by the Sacramento Valley's wettest water year on record (2016-2017). The remainder of this section summarizes significant recent events during these periods and connects them with our best projections of climate.

## A Story of Three Droughts: The Infamous 2012-2016 California Drought

Droughts in California are triggered by lack of large winter storms (i.e., atmospheric rivers), and water shortages are further exacerbated by high temperatures, which increase the evaporative loss of water from soils, rivers, canals, and reservoirs. Drought conditions, particularly when persisting for several years, can cause mental and physical stress on people, reduce the number of workable farm-labor days, and lead to deteriorated air and water quality (Greene 2018; Barreau et al. 2017). The 2012-2016 period had extremely low precipitation and below average snowpack with record-low Palmer Drought Severity Index values. However, the characteristics of each drought period differed substantially.

Whereas the 2012-2013 period was a somewhat typical example of a dry year, the 2013-2014 period displayed record-high dryness and a "Ridiculously Resilient Ridge" of high atmospheric pressure that blocked and redirected atmospheric moisture northward, sending record-high precipitation to the Pacific Northwest and Alaska (Swain et al. 2014). Such patterns can be influenced by anomalous tropical heating patterns (Teng & Branstator 2018) and reduced arctic sea ice extent (Cvijanovic et al. 2017). Climate models largely agree that this type of meteorological pattern will become more frequent— a condition that increases the frequency of both wet and dry years (Wang & Schubert 2014).

The 2014-2015 period had unusually low precipitation, but far more than in 2013-2014. This period also had unusually high temperatures through the winter (6.5°F above the 20th century winter average), with record low snowpack (6% of normal for April 1st snowpack).

The 2015-2016 period brought an extremely strong El Niño that some had predicted would bring drought relief, as the record-breaking 1997-1998 water year had a similarly strong winter El Niño. However, the 2012-2016 drought and 2016-2017 wet year show that El Niño is not the primary factor governing wet winters in the Sacramento Valley. While El Niño tends to increase precipitation in Southern California (Castello & Shelton 2004), the 2015-2016 El Niño was unusual. Against predictions, this El Niño worsened the drought in Southern California and caused record rainfall in the Pacific Northwest from shifted and intensified northward storm tracks. There is some evidence that climate change is expanding the tropical belt, which might make this drought condition more common (Seidel et al. 2008).

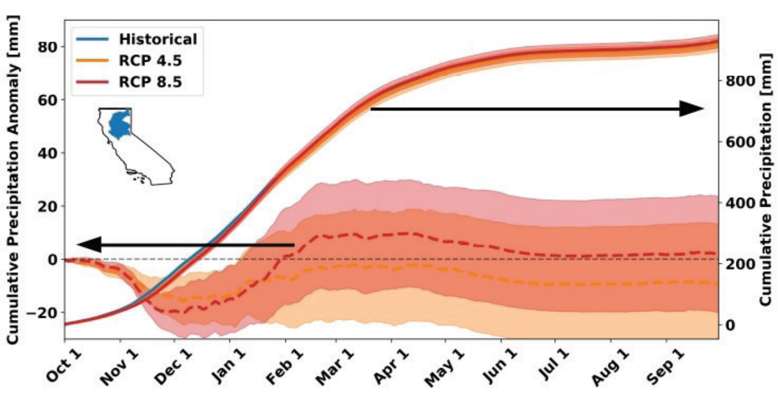
## Extreme Precipitation in the 2016-2017 Winter season: An Example of Future Wet Years?

The winter of 2016-2017 had record-breaking precipitation, a large snow pack, and an above-average number of atmospheric rivers. The year had a semi-persistent jet stream that consistently directed storms toward California; contrasting sharply with the 2012-2016 drought ridge which directed storms north from California.

Daily precipitation extremes have intensified in most areas of the country, including California (Kunkel et al. 1999). Extreme precipitation should increase as the atmosphere warms, since storms can hold ~6-7% more water for each degree Celsius of warming. Climate model simulations that consider such effects suggest that this trend will continue into the future (Dominguez et al. 2012).

Simulations of future climate indicate only modest changes in annual precipitation accumulation (Figure 6). However, simulations do hint at some shifts in the seasonality of precipitation that may be relevant for water management: less precipitation during November-January, and possibly more during February-May.

**FIGURE 6**




Simulated precipitation totals from a region containing 3 key watersheds in northern CA: American River, Sacramento River, and Feather River (averaging region shown in inset): simulations include present-day (historical) and two climate change scenarios. Solid curves (right axis) show cumulative seasonal totals, and dashed curves show anomalies in these curves (RCP minus historical) in the climate-change simulations, relative to the historical simulation. Shading depicts intermodal spread, and lines depict multimodel mean. Source: Cal-Adapt 2018 (LOCA downscaled CMIP5 output, Pierce et al.; 2014).

# Climate Impacts, Vulnerabilities and Adaptation

This section summarizes climate-related risks and adaptive counter-measures to mitigate such risks for the benefit of public health; community planning; energy, water, utilities and transportation; and land use, natural habitats and working lands. Cross-sectoral impacts (i.e., interactions across these areas) and selected climate adaptation case studies are presented at the end of the section.

## Public Health

### OVERVIEW OF THE PUBLIC HEALTH CHALLENGE

Climate change can harm people. This includes mental well-being and physical health. Vulnerability to climate change impacts are determined by biologic factors; physical environment and exposure characteristics; and the social, behavioral, and economic factors that may influence biological and physical factors (Margolis 2014). Solutions to address complex environmental health challenges require a holistic approach that considers individual, community, population, and social-economic conditions.

### PUBLIC HEALTH IMPACTS

Climate change has direct and indirect effects on human health. Extreme events, such as heatwaves or air pollution from wildfire, impose serious risks to people. Long-term exposure to toxins from automobile exhaust and stationary fossil fuel combustion can results in upper respiratory disease, with high temperatures increasing the potency of air pollution on health. Climatic and environmental changes may increase overall psychosocial stress and mental health challenges (Trombley et al. 2017; Basu 2017).

There are many climate change-related health hazards (USGCRP 2016). Here, we focus on impacts of high temperatures, and their interaction with other exposures in the Sacramento Valley, where air pollution and allergens affect a large portion of the population. We also discuss changing hydrology and wildfire activity effects on Sacramento Valley residents.

### VULNERABILITY

As with most any public health issue, climate change impacts on health cannot necessarily be generalized to all members of a given community or region. Population and individual vulnerability depends on many interconnected factors, including: overall health and biologic susceptibility; physical environment and exposure characteristics; and the social, behavioral, and economic factors that may influence both biologic response and exposure (Margolis 2014). Thus, populations and communities already impacted by social inequity and/or health disparities are more vulnerable to deleterious environmental conditions, ecosystem services disruption, and social disorder (e.g., due to population displacement).

Social inequity and health disparities are not constrained to urban communities. Rather, rural residents are more likely to die from heart disease, cancer, unintentional injuries, stroke, and chronic lower respiratory disease (Moy et al. 2017). In California, rural residents tend to be older, less healthy, have higher rates of obesity, physical inactivity, food insecurity, and less access to medical resources (CHHSA 2003; Durazo et al. 2011). Health disparities were notable in the 2006 heat wave deaths in Central Valley areas where more than half of the residents live below the poverty line, and most were older adults with chronic diseases whose heat exposure likely occurred inside of residences without air conditioners (Trent et al. 2008)

### HIGH TEMPERATURE HEALTH IMPACTS

A single heat wave can levy a high toll on human health and emergency and healthcare systems. The 2006 California heat wave resulted in higher than normal daytime and nighttime temperatures for more than two weeks, resulting in an estimated 600 deaths, 16,000 emergency room visits, and 1,100 hospitalizations (Gershunov et al. 2009; Ostro et al. 2009; Hoshiko et al. 2010; Knowlton et al. 2009). The marginal damages of this single event were estimated at $5.4 billion (Knowlton et al. 2011). Such human and economic tolls of extreme heat are likely to increase in the future (USEPA 2017).

Increasing average summer temperatures can be harmful to human health (Hajat & Kosatky 2010; Ye 2012). A wider range of health effects occur from respiratory and cardiovascular processes that are triggered by an overheating body. Acclimating to warmer temperatures (gradual heat exposure over 1-2 weeks, especially while exercising) can reduce the risk of heat stress.

Heat-associated deaths and illnesses are preventable (CDC 2017; Luber & McGeehin 2008; USGRCP 2016; Margolis 2014). Primary risk factors include age (children and the elderly are most at risk), hydration status, and chronic disease, such as obesity, cardiovascular or respiratory disease, or psychiatric illness (Asplund & O'Connor 2016; Choudhary & Vaidyanathan 2014; Ha et al. 2014; Hess et al. 2014; Knowlton et al. 2009; Reid et al. 2012; Trent 2007; Worfolk 2000; Ye et al. 2012).

### HIGH TEMPERATURES, GROUND-LEVEL OZONE, PARTICULATE AIR POLLUTION & AEROALLERGENS

Climate change can worsen existing health risks from ozone, particulate air pollution, and respiratory allergens. Ozone exposure is worsening asthma and respiratory allergies (McConnell et al. 2002; McDonnell et al. 1999). Combined exposure to ozone and heat increases risk of death (Analitis et al. 2014). Higher levels of carbon dioxide combined with higher temperatures can increase ragweed pollen allergies (Ziska 2003; Ziska and Beggs 2012; Ziska and McConnell 2016; Ziska et al. 2003; Albertine et al. 2014). Extreme heat can also increase Hay Fever risk (Upperman et al. 2017).

### DROUGHT & EXTREME PRECIPITATION

The Sacramento Valley is especially prone to water shortages and impaired water quality. Dehydration is a major risk factor for adverse health outcomes, especially during the warm season. The Central Valley will be more prone to droughts and floods arising from increased weather extremes. Extreme floods could pose especially large public health threats (Swain et al. 2015).

### MENTAL HEALTH

Climate change can impair mental health (Aitsi-Selmi & Murray 2016; Trombley et al. 2017; Vins et al. 2015; Ziegler et al. 2017; Basu 2017). Slow-moving disasters, such as drought, can affect mental health over many years (Vins et al. 2015). Common initial and immediate responses to experiencing a traumatic event, such as a climate-related disaster, can include hypervigilance, avoidance, anger, flashbacks, guilt, anxiety, emotionality, difficulty concentrating, rumination, preoccupation, and social withdrawal (Trombley et al. 2017). Climate change-related disasters, such as floods, strong storms, hurricanes, and wildfires, can also disrupt and significantly affect quality of life, including through forced relocation and rebuilding, loss of income and relationships, and disruptions to education (Trombley et al. 2017).

### COMMUNICABLE DISEASES

Alternating drought and extreme wet precipitation, with higher temperatures, promote the spread of disease-causing pathogens. This might include vector-borne diseases (Belova et al. 2017; Chen et al. 2013; Harrigan et al. 2014; Hongoh et al. 2012) such as West Nile Virus (Belova et al. 2017). Valley Fever (caused by soil-borne fungal spores) is endemic to the Central Valley; counties south of Sacramento with greater agricultural acreage (e.g., Fresno and Kern Counties) have the most cases, though some cases are reported each year in Sacramento County (Tabnak et al. 2016). Counties outside of the Central Valley, especially in agricultural areas, also have a modest but notable number of cases each year (Tabnak et al. 2016). There is concern that the number of Valley Fever cases will increase throughout the U.S. Southwest (Brown 2014; Sprigg 2014) with increased climate variability (Zender & Talamantes 2006).

### PUBLIC HEALTH ADAPTATION

Preventative care is the best way to reduce human health risks of climate change. There are three main strategies for preventative care:

- Promoting good health and access to quality healthcare.
- Reducing/managing individual and community exposure(s) to heat and other hazards.
- Ensuring appropriate and adequate emergency response capacity with Emergency Preparedness and Response Action Plans.

### PROMOTING GOOD HEALTH, ACCESS TO HEALTHCARE AND BUILDING RESILIENCE

Healthier individuals are less susceptible to climate-related health risks. Public health campaigns and community designs that promote health and address root causes of poor health such as social inequity and its many drivers will substantially reduce the health impacts of climate change on individuals and communities. For example, obesity, which affects about 30% of adults and 15% of children and teens nationwide, increases the risk for many chronic diseases, such as asthma and diabetes, and increases the risk of heat-related adverse health outcomes (Bedno et al. 2014; Crider et al. 2014; Margolis 2014; Yardley et al. 2013). Health education and elimination of food deserts (i.e., geographic locations, usually impoverished areas, lacking fresh fruit, vegetables, and other healthful whole food options) in socioeconomically disadvantaged neighborhoods can be coupled with community design strategies that increase walkability or bicycle safety, or add green space in urban neighborhoods. These strategies can achieve multiple physical and mental health benefits.

#### REDUCING EXPOSURES

Increased heatwaves, which are expected to cause both hotter day- and night-time temperatures, will have negative impacts on physical and mental health. High nighttime temperatures lead to inadequate cooling of buildings for residents (Steinberg et al 2018); implementation of strategies that minimize heat gain, such as cool roofs, can help address this problem. New strategies are needed for reducing exposure to heat (see Community Planning section below). Such strategies should reduce exposure while minimizing GHG emissions (e.g., using electricity from renewable energy sources) and increasing carbon storage (e.g., increasing urban tree canopy). For instance, a major GHG emissions reduction strategy is to reduce Vehicle Miles Traveled (VMT), which also reduces gaseous and particulate pollutants that have direct adverse health effects. In contrast, promoting in-fill development may reduce regional GHG emissions, but will also increase exposure to neighborhood air pollutants until the transportation sector is significantly electrified. Community efforts to reduce heat pollution and eliminate the heat island effect can contribute to the protection of public health.

#### EMERGENCY RESPONSE PREPAREDNESS AND CAPACITY

California is not optimally prepared to absorb additional patient loads from natural or manmade disasters or disease outbreaks. The American College of Emergency Physicians assigned California an overall emergency care grade of F (ranking 42 among States) for access to emergency care and a C- (ranking 30 among States) for Disaster Preparedness (Report Card Task Force and Staff 2014). Enhancing emergency response, public health, and clinical infrastructures in advance of crisis will save lives and reduce the societal and economic costs of climate hazards (Lauland et al 2018).

## Community Planning

#### RURAL COMMUNITIES IMPACTS

Many climate-related impacts affect rural communities in the Sacramento Valley. Such areas also house many historically underserved populations, such as farm workers, tribal communities, prisoners, and low-income people. Climate change may prompt population displacement from rural to urban areas, as resource-based industries and communities are pressured by more frequent droughts, floods, wildfires, and other extreme and chronic weather patterns.

Climate change is increasing the extent and rate of sea level rise (OPC 2018) which, in combination with frequent and severe storm events, contributes to more intensive flooding. This will be particularly impactful in the Sacramento-San Joaquin Delta areas with low or compromised levees and in other subsided parts of the Delta (Suddeth et al 2010). Recent field measurements of rates of levee subsidence indicate that many levees will fail to meet protective standards for overtopping between 2050 and 2080, given the combined effects of levee subsidence and sea level rise (Brooks et al. 2018).

Wildfire brings significant air quality risks as well as economic disruptions to rural communities. Rural communities in hilly and forested and chaparral-dominated terrain are exposed to greater fire risk with climate change. Increased rural sprawl puts housing in high fire risk areas, increases surface and groundwater demand and depletion, and extends electric utility lines that can lead to fires (Collins 2005). Limited communications infrastructure in rural areas worsens disaster warning and response. Rural communities have greater difficulties with disaster funding, policy decisions, and implementation.

### RURAL COMMUNITIES ADAPTATION

Climate adaptation efforts among rural communities in the Sacramento Valley are in the early stages. New climate-conscious planning that restricts housing in high fire risk areas is needed. Disaster recovery resources are limited and may be difficult to access by rural residents and undocumented immigrants. However, progress is being made. Plans to increase carbon sequestration on natural and working lands is one promising area to help create new economic opportunities for rural residents.

The Sacramento Area Council of Governments initiated a Rural-Urban Connections Strategy in 2008 to develop analyses and engage stakeholders for climate adaptation. The Capital Region's Climate Readiness Collaborative (CRC) shares information on climate adaptation among the region's cities, counties, nonprofit agencies, public utilities, and educational institutions.

### URBAN COMMUNITIES IMPACTS

Sacramento is one of the US cities at greatest risk from catastrophic floods. While the city has not seen a megaflood since 1861-1862, when an inland sea of flood water 30 feet deep covered the area (Ingram 2013), the city is still susceptible to another major destructive storm event.

Over 950,000 of the region's 2.4 million residents (or 40%) live within 500-year floodplains in the Sacramento River watershed. Much of the Sacramento region is protected by levees, but failure remains a risk, with more extreme wet weather and projected sea level rise compounded by levee subsidence (Brooks et al 2018). Considerations of compound climate change-driven events (Zscheischler et al 2018) including severe changes in temperature and storm events have the potential to swamp much of the city and outlying metro region. Homeless people, those without flood insurance, and other vulnerable groups will be hardest hit.

Disruptions to local real estate markets, such as those in flood-plains (e.g., North Natomas), may occur in response to unmitigated flooding in the Sacramental Valley Region. These economic impacts would disproportionately affect particular sociodemographic groups depending on their location and the level of public-private investment in flood mitigation.

Portions of the Sacramento region with extensive asphalt surfaces and rooftops that have limited urban forest canopy have summer temperatures up to 7°F warmer than the metropolitan average. Urban heat island dynamics can retain these high temperatures into the night, which can be dangerous to residents without air conditioning, particularly for the elderly, handicapped, and non-English speakers (Huang et al. 2011; Steinberg et al. 2018). Recent observational evidence from analysis of high spatial density weather stations and mobile transect measurements shows that increases in neighborhood-scale roof albedo and canopy cover are associated with reductions in near-surface air temperature (Taha et al. 2018).

### URBAN COMMUNITY ADAPTATION

Poorer urban governments are sometimes hindered by lack of capacity for new climate mitigation and adaptation. The recent Capitol Region's CRC has potential to share information and coordinate strategies across the region (http://climatereadiness.info).

Since flooding is among the Sacramento Valley's highest climate-related risks, levee and bypass improvements are promising adaptation strategies, along with managing flood vulnerabilities within less protected floodplains and some improvements in flood operations for reservoirs (Lund 2012; Willis et al. 2011).

The most common climate adaptation strategy in the region is tree-planting. Sacramento County has adopted plans to increase urban tree cover. The nonprofit Sacramento Tree Foundation, working with the Sacramento Municipal Utility District and other agencies, plans to plant 5 million trees region-wide to improve air quality. Urban forests can reduce air pollution (Scott et al. 1998) and temperatures in urban neighborhoods, and improve urban biodiversity, but can also increase water use depending on the species selected.

Cities should consider adding cool refuge facilities, including adequate public transportation connections for low-income, elderly, and homeless populations, to their climate adaptation strategies. These shelters provide air-conditioned spaces for residents who lack cooling at home, improving human comfort and reducing mortality during heat waves (Sampson et al. 2013). The City and County of Sacramento are preparing such centers and increasing public awareness of heat risks, publicized through portals such as the County's Sacramento Ready website. The state is preparing the California Heat Assessment Tool (Steinberg et al. 2018) to include extreme heat considerations in long-term policy and planning decisions. Zoning, building codes, and design guidelines that emphasize residential and neighborhood greening, white roofs, climate adaptive building shells (Loonen et al. 2013), and other techniques can reduce the impacts of climate change on urban environments and public health.

### TRIBAL COMMUNITIES IMPACTS

Depending on the specific location, Native American populations in the region will experience climate impacts which will exacerbate existing vulnerabilities in these communities stemming from the loss of ancestral lands and traditional ecological knowledge. Native American populations also face significant threats to culturally significant lifeways and places due to climate change-related flooding, shifts in vegetation, and fire. While significant, these impacts have not been well-documented by the non-native scientific community, and thus merit further study. More information on California's tribal and indigenous communities is provided in a topical report of the Fourth Assessment (Tribal and Indigenous Communities Summary Report 2018).

### TRIBAL COMMUNITIES ADAPTATION

In response to the mid-2010s drought, the Yocha Dehe Wintun Nation in the Capay Valley asked tribal members to reduce water use by 20% in 2014, and declared a drought emergency, as did the Hoopa Valley tribe further north. The Karuk Tribe in the Salmon and Klamath basins of Northern California prepared a plan in 2010 entitled "Integrating Traditional Ecological Knowledge within Natural Resource Management." This plan specifically seeks to address climate change through strategies such as restoring landscape resilience and reducing risk of destructive wildfires. In 2011, the Yurok Tribe prepared a climate change prioritization plan identifying climate and environmental justice risks, and modeling flood risk over a 100-year period.

Tribal engagement in carbon sequestration (from forest and watershed stewardship) can provide employment as well as ecological and disaster mitigation benefits for rural communities (Maldonado et al. 2014). Traditional ecological knowledge can assist with climate adaptation by learning from the traditional fire use of the Karuk Tribe in Northern California to reduce fuel loads and prevent destructive forest fires. These and other specifically Native people-oriented adaptation programs need further investigation and investment.

## Energy, Water, Utilities and Transportation

### ENERGY SYSTEMS OVERVIEW

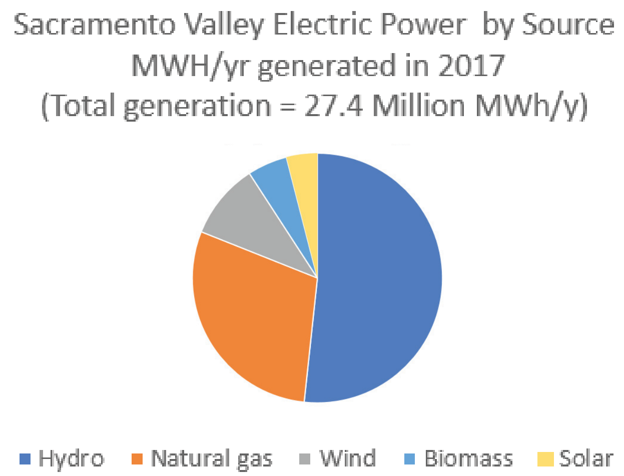
The Sacramento Valley region is served by a number of public and private electricity and gas utilities, some of which also provide water and wastewater services. The largest energy utility is Pacific Gas & Electric (PG&E); however, some jurisdictions are served by municipal utilities including the Sacramento Municipal Utility District (SMUD) and Roseville Electric. Many smaller communities are members of the Northern California Power Agency, which operates and maintains its own fleet of power plants. The entire region is part of the Western Electricity Coordinating Council (WECC), which manages the reliability of the bulk electric system, though power in the region is balanced by both the California Independent System Operator (ISO) and the Balancing Authority of Northern California (BANC).

### ANTICIPATED IMPACTS TO THE ENERGY SYSTEM

The Sacramento Valley is supported by diverse energy infrastructure, including over 200 power plants with an aggregate nameplate capacity of over 8 GW, thousands of miles of electric transmission lines (PG&E 2018), 2000 miles of natural gas and oil transmission pipelines, oil terminals, and natural gas storage facilities. Hydropower is the dominant source of electricity in the region, accounting for about 52% of annual electricity production, followed by natural gas fired power plants (29%), wind (10%), biomass power (mostly landfill gas, 5%), and solar photovoltaics (PV, 3%) (**Figure 7**) (CEC 2017c; EIA 2018).

Energy infrastructure throughout the Sacramento Valley region is vulnerable to impacts of climate change such as higher temperatures, flooding, dry years, and wildfires

**FIGURE 7**




Annual electricity generation in the Sacramento Valley regions, based on California Energy Commission data for Butte, Colusa, Glenn, Napa, Sacramento, Shasta, Solano, Sutter, Tehama, Yolo and Yuba counties. Source: CEC 2017c.

(USDOE 2015; Dell et al. 2014). Hydropower electricity generation (the largest electricity source in the region) will be reduced by greater evaporative losses, changed precipitation timing, decreased snowpack, and more intense storms (Avanzi et al. 2018; Madani & Lund 2009). Power generation facilities fueled by natural gas (the second largest electricity source), geothermal, and solar power could suffer reductions in operating efficiency and generation capacity due to higher temperatures. Rising air temperatures could reduce the output from solar and natural gas fired power plants, and variable wind patterns could affect output of wind power facilities. Electric transmission and distribution systems also operate less efficiently at higher temperatures, decreasing the capacity available to move power from remote generation sites to consumers. A recent study by Sathaye et al. (2012) identified transmission lines in the Sacramento region as potentially vulnerable to rising temperatures.

All energy facilities in the region (power plants, transmission and distribution lines, natural gas and oil production, storage, and pipelines) could be at risk of damage and disruption from larger storm events, sea level rise, and wildfires (Bruzgul et al. 2018a, 2018b; CEC 2017a).

Warming will increase electricity demand for air conditioning in warmer months but decrease energy demand for winter heating. The net annual effect for the residential sector is almost no change in energy demand. Seasonal and peak demand for cooling, however, will increase with increased temperatures (see Statewide Assessment). Less natural gas might be needed for winter heat, but more natural gas will be needed for electricity generation and lower efficiency at summer peak times. In the longer term, the electric sector will have to increase production and storage capacity to support decarbonization throughout the state.

### AN OVERVIEW OF THE SACRAMENTO VALLEY'S TRANSPORTATION SYSTEM

The Sacramento Valley transportation infrastructure supports roughly 2.5 million people with roads, bridges, airports, trains, and transit facilities. Major highway corridors include Interstates 5 and 80, as well as a number of state highways including SR 113, SR 99, and SR 20. Airport facilities include the Sacramento Metropolitan Airport and many small public and private airfields. Both commercial and passenger trains traverse the Valley; commercial trains include the BNSF and Union Pacific Railways. Amtrak's Capital Corridor and Zephyr trains run regularly through the region. Road, rail and air transport facilities support the shipment of goods valuing more than $1,476,407 million each year (BTS 2012).

Pursuant to California Senate Bill 99 and Assembly Bill 101, the Active Transportation Program (ATP) was created to fund bicycle and pedestrian infrastructure and non-infrastructure projects in the six-county Sacramento Valley region including El Dorado, Placer, Sacramento, Sutter, Yolo, and Yuba counties (SACOG 2018a). As of 2015, the Sacramento region contained over 480 miles of multi-use paths, 1,100 miles of bike lanes, and 300 miles of bike routes, which are used for transportation and recreational purposes (SACOG 2018b).

Aggressive expansion of active transport is an efficacious yet currently underutilized policy option in California with significant public health co-benefits for mitigating carbon emissions (Maizlish et al. 2017). Significant increases in active transportation in California will likely require separation of motorized traffic and active travelers and reduced driving speeds on some local and arterial roads (Maizlish et al. 2017).

## ANTICIPATED IMPACTS TO TRANSPORTATION

The primary effects of climate change on transportation occur through higher temperatures, more frequent extreme events, and changes in precipitation (Ball et al. 2010). Climate change impacts on transportation infrastructure could increase in the second half of the 21st century (Neuman et al. 2015).

Extreme heat can accelerate roadway deformation (e.g., rutting and cracking) and track buckling (FTA 2011; Radke et al. 2018); temperature fluctuations can create expansion and contraction at critical bridge joints. Wildfires affect roads, traffic patterns, and create driving (decreased visibility) and health hazards (poor air quality).

Localized flooding can occur due to inadequate or under-sized drainage facilities relative to stormwater runoff increases. Flood damages to transportation can include pavement deterioration and bridge scour (Wright et al. 2012). Flooding also can increase landslides, road closures, and transit disruptions, including operational delays and stoppages.

## FUTURE ENERGY AND TRANSPORTATION SCENARIOS

California will host a diverse mix of vehicle types and transportation fuels over the next several decades as it implements policies supporting zero emission vehicles, electrification, and low carbon or renewable fuels (Jones et al. 2018). Many options are available for meeting California's policy goals for transportation and GHG emissions. Yeh et al. (2016) compared six energy/economic/environmental models that have helped inform California's climate policies. These models provide useful insights on the energy and transportation system transformations required. Key findings show broad agreement on many aspects of a low carbon emission transport sector future in California:

- Unlike today's transport sector, which relies on petroleum fueled engines, a variety of fuels and vehicles are employed in a low carbon emission future, including biofuels, electricity, hydrogen, and natural gas, as well as gasoline and diesel.
- The reference cases estimate that on-road transportation fuel use will remain flat or slightly decrease to 2030, primarily due to improved vehicle efficiency.
- However, in scenarios that meet California's 2050 GHG emissions target (80% reduction from 1990 levels), reductions in transportation GHG emissions generally result from combined reductions in vehicle miles traveled, vehicle and gasoline efficiency improvements, and diesel displacement with low-carbon alternative fuels
- The exact mix of fuels and vehicles in a low carbon emission future (e.g. number of electric vehicles or amount of biofuels consumed) can vary with different model assumptions. Biofuel availability will be a factor determining this mix, along with the cost of zero emission technologies and the level of achievable efficiency.

Future transport fuels like electricity, hydrogen, and biofuels will require infrastructure to produce and deliver fuel to consumers. Many components of low carbon fuel systems (for example, solar plants, biorefineries, transmission lines) remain vulnerable to climate change.

The Sacramento Metropolitan Air Quality Management District was recently awarded SB-1 funds from Caltrans to conduct an advanced heat study in a significant portion of the Sacramento Valley region, and to develop a Heat Pollution Reduction Plan for the Transportation Sector. This work is launching in the summer of 2018.

# Review of California's Climate Change Adaptation Plans and Policies for the Energy Sector

## PRINCIPLES OF ADAPTATION

In 2010, the White House Council on Environmental Quality proposed a set of guiding principles for adaptation policies (**Figure 8**). These principles included prioritizing integrated approaches and protecting "people, places and infrastructure" most vulnerable to climate effects, using the best-available science, developing partnerships across sectors and scales, incorporating risk management strategies, protecting critical ecosystems, maximizing mutual benefits, and continuously evaluating performance (WHC 2012).

Climate impacts on infrastructure are occurring faster and in fundamentally different ways from the past. An adaptive, integrated approach to managing and managing climate change risks must be in place. Adaptation includes activities that plan for climate change effects across integrated systems and protect vulnerable infrastructure and environmental assets.

California is developing comprehensive strategies to adapt to climate change. Beginning in 2009, the California Natural Resources Agency (CNRA), working with the Climate Action Team and coordinating with seven state agencies, issued a series of reports on safeguarding California (CNRA 2009, 2014, 2016, 2017, 2018). These reports summarize the best-available science on climate change impacts, assess vulnerabilities, and outline possible solutions that can be implemented within and across state agencies to adapt to climate change. All sectors of the economy are considered.

**FIGURE 8**

**Guiding Principles for Adaptation**

**Adopt Integrated Approaches:** Adaptation should be incorporated into core policies, planning, practices, and programs whenever possible.

**Prioritize the Most Vulnerable:** Adaptation plans should prioritize helping people, places and infrastructure that are most vulnerable to climate impacts and be designed and implemented with meaningful involvement from all parts of society.

**Use Best-Available Science:** Adaptation should be grounded in the best-available scientific understanding of climate change risks, impacts, and vulnerabilities.

**Build Strong Partnerships:** Adaptation requires coordination across multiple sectors and scales and should build on the existing efforts and knowledge of a wide range of public and private stakeholders.

**Apply Risk-Management Methods and Tools:** Adaptation planning should incorporate risk-management methods and tools to help identify, assess, and prioritize options to reduce vulnerability to potential environmental, social, and economic implications of climate change.

**Apply Ecosystem-based Approaches:** Adaptation should, where relevant, take into account strategies to increase ecosystem resilience and protect critical ecosystem services on which humans depend to reduce vulnerability of human and natural systems to climate change.

**Maximize Mutual Benefits:** Adaptation should, where possible, use strategies that complement or directly support other related climate or environmental initiatives, such as efforts to improve disaster preparedness, promote sustainable resource management, and reduce greenhouse gas emissions including the development of cost-effective technologies.

**Continuously Evaluate Performance:** Adaptation plans should include measureable goals and performance metrics to continuously assess whether adaptive actions are achieving desired outcomes.

Guiding Principles for adaptation. Source: The White House Council on Environmental Quality 2010.

Several in-depth studies have explored adaptation issues and strategies for California's energy sector. The California Energy Commission (Energy Commission) was the first to examine climate adaptations for electricity, natural gas, and petroleum supply (Franco et al. 2005; Perez 2009; Stoms et al. 2013; Bruzgul et al. 2018a, 2018b; Radke et al. 2018;). Other studies include assessments by electric utilities that serve Northern California (PG&E 2016; SMUD 2012), and Energy Commission-supported research on energy sector vulnerabilities and actions (Sathaye et al. 2012; CEC 2017a). Other regional energy system climate adaptation studies by the US Department of Energy (2013, 2015, 2016) and the National Academies (Dell et al. 2014) are also relevant for California.

### Regional Adaptation for the Sacramento Valley

The 2015 Sacramento Region Climate Adaptation Plan (SAC-CAP 2015) prepared by the Sacramento Council Governments and CivicSpark offers a regional adaptation plan. The SAC-CAP plan builds on federal adaptation principles (Figure 8) with "no regrets" strategies that can be embedded into existing work.

The SAC-CAP recommends four broad adaptation categories: (1) maintain and manage, (2) strengthen and protect, (3) enhance redundancy, and (4) retreat. Manage and maintain targets those actions that improve preparedness and response. Strengthen and protect includes actions that focus on retrofitting existing infrastructure and building new infrastructure with higher standards. Enhancing redundancy includes actions that help create mode and network alternatives. Finally, retreat identifies actions that relocate or abandon infrastructure in highly vulnerable locations.

Sacramento County recently completed a vulnerability assessment that identified critical adaptations (CCAP 2017). This effort included vulnerability analysis around population, functions, and structures. One tool used was Cal-Adapt, an interactive, online tool developed by the University of California, Berkeley with Energy Commission funding to enable exploration of local climate risks in California based on peer-reviewed science (Thomas et al. 2018). Although the Sacramento County Plan identified adaptations for each category of potential climate change effects, the plan lacks an overall coherent implementation framework.

Despite little progress toward identifying and implementing adaptation strategies themselves, Caltrans did solicit development of a guidance document to assist regional governments in addressing climate change in their transportation plans (RTP) (Caltrans 2013). With transport facility lifetimes of 50 to 100 years, transportation investment decisions must consider not only the potential climate change effects, but also how vulnerable and important facilities are to the overall transportation network. Caltrans guidance lays out a five-step evaluation process for Metropolitan Planning Organizations to incorporate climate change assessment and adaptation.

The Sacramento Region will grow, resulting in land-cover change and increased pressure on transportation infrastructure. While substantial research has addressed how climate change is predicted to affect California (e.g., Cayan et al. 2008; Moser et al. 2009; Franco et al. 2011), far less research has focused on regional adaptation plans, policy, and implementation. Many regional, county, and local governments will need enhanced coordination and collaboration among transportation jurisdictions to address climate change impacts and risks. Many local governments have made inter-jurisdictional collaboration a high priority and seem to be more reliant on other agencies to ensure the inter-connectivity elements of transportation networks and their co-dependent sectors (Oswald et al. 2016). State agencies may need to be more prominent in coordinating and managing transportation system adaptation.

### LOCAL ADAPTATION FOR TRANSPORTATION PLANNING AND ENGINEERING

Despite the lack of direct state mandates, local governments have been the vanguard of action in both climate mitigation and adaptation. Drawing from 2008 and 2010 surveys, Bedsworth and Hanak (2013) found that, by 2010, most local governments had created elements of climate action plans. For transportation, most communities have focused on developing bicycle and pedestrian master plans, implementing complete street policies, and charging parking fees. Such actions reflect mitigation more than adaptation.

The Institute for Local Government has made available several local climate adaptation and resilience plans. For example, Berkeley's adaptation goal (City of Berkeley 2016) is to "Embrace and implement innovative, multi-benefit natural resource management, urban planning, and infrastructure design solutions." Strategies include integrating multi-benefit green infrastructure into street improvements and using the latest climate science to protect and modify existing assets and to design new infrastructure. Santa Cruz' adaptation plan calls for building resilience into all programs, plans, and infrastructure. The City has identified at risk infrastructure, conducted a public participation process, and begun critical actions, including prioritizing bridge replacement and relocating or upgrading vulnerable public infrastructure.

Currently, there are no requirements to incorporate climate adaptation into regional transportation plans. Barriers to adaptation exist at the local level (She et al. 2015), including technical expertise and financial resources (NRC 2010). State level funding incentives coupled with local information on changing conditions and leadership will further the goal of local adaptation planning and implementation in response to climate change (She et al. 2015).

## Land Use, Natural Habitats, and Working Lands

### OVERVIEW

Climate change impacts on the Sacramento Valley's natural resources include the risks of higher temperatures, flooding, drought, and fire imposed on natural and working lands. Higher temperatures affect human health, economic, and ecosystem processes and outcomes. Flood threats to urban areas may be addressed by flood detention basins, levee setbacks, and improved land use planning. Drought impacts are addressed through agricultural adaptation, surface water supply augmentation, improved groundwater management, and conservation. Solutions that promote sustainable water storage and enhanced reservoir capacity should also be considered. Fire is of greatest concern in the wildland-urban interface, where both fuel management and improved planning are important adaptation tools. Implementation of climate-smart agricultural best management practices (BMPs) for this region encompasses both adaptation and mitigation measures.

### LAND USE: FLOODING IMPACTS AND ADAPTATION

High-intensity rainfall is a risk for urban areas. In the Delta, sea level rise will increase flooding, especially during high tide events (Maendly 2018; Suddeth et al. 2010). Flood protection for the Sacramento metropolitan area has received considerable attention, but other smaller towns and cities in the Valley as well as rural households and businesses, are likely to face more expensive flooding challenges and risks in the coming decades.

The Yolo Bypass is an overflow channel of the Sacramento River that routes floodwaters away from the main channel; it's a mosaic of agriculture, flood control management, and nature conservations areas, and is more ecologically and hydraulically functional than conventional flood control (Greco & Larsen 2014; Opperman et al. 2017). The Lower Elkhorn Basin Levee Setback (LEBLS) project is an example of a multi-benefit approach to the management of flood risks. The LEBLS project, estimated to cost $175 million and be completed in 2023, will set back the levees of the Yolo Bypass to attain 200-year recurrence interval level protection (Greco & Larsen 2014; CDWR 2017a, 2017b), helping to protect 780,000 people and $53 billion in assets in the Sacramento Valley. The increased floodplain inundation will also benefit fish by expanding habitat. The expansion of floodplains with riparian forests, wetlands and prairies will create habitat and improve connectivity for many terrestrial species. At the same time, the project will maintain productivity of rice and other crops and increase recreational opportunities for a variety of stakeholders. However, the likelihood of inland mega-floods can be expected to increase with climate change and a 200-year level of protection is not sufficient to meet disasters such as the "Great Flood" event of 1861-1862 (Swain et al. 2018).

### LAND USE: DROUGHT & FIRE IMPACTS AND ADAPTATION

Past land-management and -use practices, the long-standing policy of fire suppression, and, more recently, human development in fire-prone and -dependent ecosystems, have increased the intensity and extent of fire in the region, a risk exacerbated by climate change. Climate changes, including increased temperatures and soil moisture deficits, longer and more intense droughts, as well as rising population demands, all play a role in wildfire intensity and duration. The largest increases in the area burned by wildfire occurred in conifer forests and shrub ecosystems in the last two decades (Cal Fire FRAP 2018; Schwartz et al. 2015) coinciding with increases in human caused ignitions (Westerling 2016). The region is also experiencing increases in total fires per year (Westerling 2016) and increases in fires at higher elevations (Mallek et al. 2013; Schwartz et al. 2015). Climate appears to drive the variability of high severity fires, especially at lower elevation forests (Keyser & Westerling 2017).

Several studies suggest future climate change will further increase wildfire risk in the state. Westerling et al. (2011) estimate that wildfire area for much of the Sierra Nevada and other forested areas of Northern California will increase ~300% this century (assessed for three 30-year time periods centered on 2020, 2050, and 2085, relative to a 30-year reference period centered on 1975); however, this analysis does not consider all factors affecting fire (e.g., vegetation shifts on response to a changing climate, impacts of climate on wind, etc.). Hurteau et al. (2014) reported the potential for increase in wildfire $CO_2$ emissions due to future climate effects and development.

There are several management and invention strategies that can be employed to reduce fire risk in response to climate change.

Prescribed burns and strategic thinning of forest stands can reduce fuels loads for fire and reduce the number of smaller trees that allow for increased growth and carbon sequestration capacity of the remaining larger trees. Healthy forests that result from these types of treatments, in addition to larger, landscape-scale mechanical restoration treatments, are more adaptive in the face of climate change, less susceptible to large megafires, and have the potential to sequester more carbon. Recent research also points to the potential for high carbon sequestration capacity in grasslands and tree-sparse rangelands in response to climate change impacts this century (Dass et al. 2018). For more information on how our forests can help realize the states GHG reduction targets please see the

States Forest Carbon Plan. We also refer the reader to Governor Brown's Executive Order B-52-18 (May 2018) to improve the health of California's forests and help mitigate the threat and impacts of wildfires.

Additional responses to increased fire include improved land use planning and intensified fuels management, particularly in the wildland-urban interface. One example is the Lakeview Hazardous Fuels Reduction Project on the north shore of Clear Lake. This project spans the boundary between private lands and the Mendocino National Forest, a rugged landscape of chaparral, open oak woodlands, and conifer forests. In 1996 this area was the location of the human-caused 83,000-acre Fork Fire. The Lakeview project is designed to increase the likelihood that a fire beginning on the National Forest will be controlled before reaching private lands, and vice versa. Tools include thinning, particularly of conifer forests; shredding of trees and shrubs; and prescribed fire, often applied after thinning. The Forest Service has prescribed guidelines that prevent wholesale destruction of chaparral ecosystems. The project currently focuses only on the National Forest lands but may expand onto adjacent private land in the future.

The Sacramento Valley region can implement a variety of other drought remediation measures for climate-related land use impacts. These include: holistic water management, developing new sources of groundwater recharge and supply, groundwater regulation, infiltration basins, the use of aquifers as reservoirs, and water conservation (Herman et al. 2018).

### NATURAL HABITATS: DROUGHT IMPACTS AND ADAPTATION IN UPLAND, AQUATIC, AND RIPARIAN ECOSYSTEMS

Rising temperatures, drought and fire are threatening natural ecosystems and their services in the Sacramento Valley (Cook et al. 2014; Thorne et al. 2016, 2017; Young et al. 2017). Higher fuel loads, combined with more people, are projected to increases the wildland area burned by wildfire (Lenihan et al. 2008; Westerling et al. 2011). Species composition in natural habitats will be altered and iconic species (e.g., valley oak and blue oak) may become uncommon or lost from the Sacramento Valley under long-term business-as-usual scenarios (Barbour & Kueppers 2012; Kueppers et al. 2005; Hannah et al. 2012; Lenihan et al. 2008; Thorne et al. 2017). The ability of plants and animals to move or shift their ranges in response to climate change may be impeded by landscape fragmentation from land use and transportation (e.g., highways) (Keeley et al. 2018). Species migrations in response to climate changes may be limited or blocked (Spencer et al. 2010; Damschen et al. 2012; Corlett & Westcott 2013; Loarie et al. 2009). Climate change is expected to increase the abundance of exotic species in most plant communities, particularly with fire or human disturbance (Bradley et al. 2010). Altered composition may result in the evolution of novel communities and loss of desired ecosystem services (Williams& Jackson 2007; Hobbs et al. 2009, 2014). Proposed mitigation strategies, such as adding compost to natural and semi-natural grasslands, may result in increased carbon sequestration; however, they may also pose unknown but potentially large risks to native plant and animal diversity (Flint et al. 2018; Silver et al. 2018).

Promoting climate resiliency among species, habitats and ecosystems will benefit from improved habitat connectivity and refugia (i.e., habitats with reduced vulnerability) within Sacramento Valley landscapes (Spencer et al. 2010; Beier & Brost 2010; CDFW 2015, Keeley et al. 2018). Climate change solutions within the region will need to consider fuel management options (e.g., prescribed fire) (Moghaddas et al. 2018), land use planning, locating development to protect wildlands and ecosystem functions/services, and management for ecosystem services (e.g., invasive species removal, introducing new species or subspecies to maintain ecosystem services).

Wetlands in the Sacramento Valley have been reduced by 90%, yet remain internationally significant for bird migration, particularly waterfowl and shorebird species in the Pacific flyway (Shuford 2014; Shuford & Dybala 2017). Aquatic habitats of the Sacramento River and its tributaries support important salmon and steelhead runs, as well as other native species, many of which are endangered and declining (Moyle et al. 2011). The highest number of California endemic fishes are found in the Sacramento Valley and 82% of native fishes have a probability of becoming extinct by 2100. Wetland and riparian systems are especially imperiled by longer droughts and issues of warmer water temperatures, poorer water quality, as well as altered timing and greater variability of water delivery. Anticipated impacts include rising dominance of non-native species and extinctions of many native and endemic species (Moyle et al. 2011, 2015).

Adapting to climate change requires reestablishing functioning river/floodplain/riparian systems, as well as creating solutions to shrinking water supplies including, but not limited to, creating additional water storage in reservoirs and creating flow regimes that are beneficial to animals and fishes. Riparian areas with both natural aquatic features and constructed irrigation and drainage structures are the most broadly connected habitat type in the Sacramento Valley and can form the kernel of an interconnected habitat lattice for the region (Seavy et al. 2009; Spencer et al. 2010; Fremier et al. 2015). Riparian area protection, restoration, and enhancement must be combined with reestablishing more natural water flow regimes and connections among rivers/streams and their floodplains, including setting back levees to widen floodplains, expanding bypasses, restoring and enhancing riparian areas, and restoring wetland areas (CDWR 2016, 2017a). The restored floodplain systems will significantly enhance flood protection in the Sacramento Valley while benefiting fish and wildlife (Greco & Larsen 2014; Opperman et al. 2017). Dwindling salmon runs in the Sacramento Valley now depend on cold water released from dams, hatcheries, and assisted migration (i.e., transporting juvenile hatchery fish to the San Francisco Bay) to sustain populations (Moyle et al. 2017), all of which become more difficult to sustain with higher temperatures and extreme weather conditions (Durand et al. 2018).

## AGRICULTURE & SEMI-NATURAL HABITATS: CLIMATE IMPACTS, ADAPTATION, AND MITIGATION

Much of the Sacramento Valley supports agriculture. Climate change may reduce the economic viability of some agricultural lands in the Sacramento Valley. Climate change is expected to alter the variety of crops that can be grown in the region (CalCAN 2011) and diminish the productivity of some crops, while increasing the productivity of others (Medellin-Azuara et al. 2018). Of 12 crop groups reviewed by Howitt et al. (2009) for the Sacramento region, half of the crop group yields are projected to decline 1.9-11% (e.g., field crops, orchards, grains, grapes, corn, and truck crops), while others remain neutral or slightly increase by 0-5% (e.g., cotton, alfalfa, citrus, rice, tomato, and pasture) (Howitt et al. 2009). Such projected 21st century declines in crop productivity are consistent with climate change risks to a variety of tree crops, maize, cotton, sunflower, and rice throughout California (Pathak et al. 2018). Within the Sacramento Valley, the total cultivated acreage is expected to decrease for nearly all crop groups, especially field crops, despite increases in expected yields of some the crop groups (Howitt et al. 2009).

Some irrigated farmland is being converted to urban and other land uses, at a rate of about 53,000 acres/year (DOC 2016). Regulations or incentives may be useful for managing these abandoned lands to maintain wildlife habitat values. The combined pressures of climate change and land conversion will affect wildlife that depend on agricultural or grazed lands, such as the burrowing owl, the Swainson's hawk, the giant garter snake, as well as waterfowl and shorebirds that use winter-flooded cropland. Other agricultural landscape BMPs that can help alleviate the effects of climate change on wildlife in agricultural and semi-natural landscapes include hedgerows, tail water ponds, enhanced riparian areas, vegetated road verges and canal edges, and groundwater recharge (Donald & Evans 2006; Kreiling et al. 2018).

Agriculture is also a source of GHG's in California, estimated at 8% of total emissions, 67% of which comes from livestock production, 20% from fertilizer, and 13% from fuel (Byrnes et al. 2017). "Climate-smart agriculture" (CSA; Steenwerth et al. 2014) proposes a set of actions to reduce these impacts. A major tenet of CSA is reduction of water, energy, nutrient, and chemical inputs. Manipulating feed composition and manure BMPs to capture and reuse methane with anaerobic digesters and other methods can help reduce methane emissions. Native oak and riparian zone restoration on range lands may aid carbon sequestration (Kroeger et al. 2009; Lewis et al. 2015). Another important adaption measure is crop improvement using traditional crossing techniques and genomic methods. New sources of surface water supply for agriculture may also be needed to offset projected snow pack losses, using a variety of techniques such as meadow restoration in the Sierra Nevada (Rodriguez et al. 2017) or off-stream storage facilities like the Sites Reservoir proposal in the Sacramento Valley (Bureau of Reclamation 2017). Sources of new surface water should minimize environmental impacts to the maximum extent practicable and mitigate for cumulative effects and lost ecosystem services, especially in large water development projects such as the North of Delta Off-stream Storage (NODOS) program's Sites Reservoir proposal (Fremier et al. 2014). Integrating multiple strategies and a diversity of practices will be needed to offset climate change impacts on agricultural production and the effects of agricultural production on climate change (Byrnes et al. 2017).

# Cross-sector Interactions

Here, we evaluate a set of interactions across different core sectors of this report and highlight several case-examples of multiple benefits of climate adaptation and mitigation in the Sacramento Valley.

## CROSS-SECTOR IMPACTS

The Sacramento Valley region includes the fast-growing Sacramento metropolitan area. Despite the large Sacramento urban area, surrounding areas are rural with towns and small cities and large intersecting expanses of rangelands, working lands, agricultural production, wetlands, and riparian habitats. The Sacramento region represents among the best historical examples of infrastructural modifications due to pressures on the natural environment for the benefit of society. Such modification is particularly evident in the case of flood management in response to heavy rainfall and runoff events that historically inundated the southern portions of the Sacramento Valley. The current levees, catchment basins, weirs, and bypasses (e.g., Yolo Bypass) are so integral to the region that we may not appreciate their role in promoting societal resilience to climatic extremes. They serve as reminders of how climate change may directly and indirectly interact across sectors and stakeholder groups within the region.

## CROSS-SECTOR ADAPTATION AND MITIGATION CO-BENEFITS

Adaptation to climate change requires adjusting actions, institutions, and infrastructure to present and anticipated climate risks (Mach et al. 2014). Adaptation is successful when it is capable of collectively avoiding and effectively responding to dangerous climate impacts in the future. In many cases, strategic climate adaptation investments can create jobs that are focused on weather-proofing existing systems to avoid future economic damages, saving taxpayer dollars and creating co-benefits for people and the environment (Agrawala & Fankhauser 2008). It will be critical for policymakers, managers, and land owners to avoid the most dangerous risks of climate change, but to also take advantage of beneficial situations and increased flexibility that comes with climate-smart planning. Mitigation can also include reductions in GHGs that contribute to climate change (e.g., reduction in GHG emissions from ruminant livestock given the proper incentives). Although the region is not a significant dairy producer relative to other locations in the state, California's dairy digester research and development and alternative manure management programs provide financial assistance to producers to reduce GHGs.

Not all sectors will respond to climate-related stressors and disturbances in the same way. Quite the opposite: there are several sectors under the general umbrellas of (1) Public Health, (2) Energy, Water, Utilities, and Transportation, and (3) Land Use, Natural Habitats, and Working Lands, where cross-sectoral interactions might result in unintended consequences. Actions to avoid negative climate impacts on any given sector can confer benefits or unwanted risks on other sectors (Berry et al. 2015). This is why it is important to consider systemic interactions and feedbacks among sectors when developing coordinated climate change planning. Co-benefits are achieved when outcomes that promote carbon sequestration (mitigation) improve, for example, system adaptation and ecosystem or economic performance. What follows is a simple consideration of the cross-sectoral effects of these sectors in the Sacramento Valley, or where co-benefits might result.

#### Public health

Several adaptation measures could reduce risks from extreme heat and poor air quality. Among them are planting of urban trees, development of reflective surfaces (white roofs on houses, for example), and greenspaces. Added co-benefits of these kinds of investments include increased carbon storage, reduced energy costs, and reduced air conditioning demand and particulate pollution, albeit with higher water use in some cases. As previously discussed, reflective cool roofs on residential and commercial buildings have been shown to reduce nearby neighborhood surface temperatures, thus reducing urban heat island effects (Taha et al. 2018).

#### Energy, Water, Utilities, and Transportation

With increasing population growth in the region and increased temperatures and reductions to Sierra Nevada snowpack, the importance of water conservation will continue to grow. Incentives that reduce water use in residential landscaping could help cut water use in households. Groundwater banking strategies in croplands can aid in local groundwater recharge and advanced micro-irrigation technologies and remote sensing techniques can continue to promote water-use efficiency in croplands. Larger scale opportunities to improve reservoir storage and management of flow regimes for maximum agricultural and environmental benefit can help the Sacramento Region become more climate resilient and improve the economic and recreational value of natural resources.

#### Land Use, Natural Habitats, and Working Lands

Ranching and rangelands are important to the region's land use and economy. To adapt to climate change, ranchers and scientists are working to restore the region's rangelands by including hardy bunchgrass species to provide higher quality forage and increase carbon in the soil. Soils with more organic carbon also can hold more water. Such adaptations also can enhance wildlife habitat.

Improved irrigation techniques, fertilization, and precision agriculture have the potential to save water and energy, reduce carbon dioxide emissions by increasing soil organic carbon, decrease methane emissions from rice production via intermittent irrigation, and reduce nitrogen emissions to the air and water.

## SACRAMENTO BIOREGION CASE STUDIES FOR ADAPTATION AND MITIGATION TO CLIMATE CHANGE

Several case studies in the Sacramento Valley highlight examples of cross-sector benefits of climate smart approaches.

### CASE STUDY 1 | Improving Rangeland For Climate Change Adaptation

Point Blue Conservation Science's Rangeland Watershed Initiative (RWI) implements collaborative, science-based management to restore rangelands and watersheds for wildlife and human communities. RWI has embedded Partner Biologists in 15 California Natural Resource Conservation Service (NRCS) field offices to increase NRCS's wildlife biology capacity and expertise.

Partner biologists work with local landowners to inventory resources and concerns, identify suitable conservation practices, and identify funding programs – such as the Farm Bill's Environmental Quality Incentives Program – that provide conservation cost-share to incentivize landscape enhancements. The partner biologist model works through a cooperative agreement with NRCS, which provides partner biologists access to NRCS offices and conservation planning resources to help engage networks of landowners and other conservation partners, such as Cooperative Extension, Resource Conservation Districts, and Land Trusts.

RWI facilitates the application of prescribed grazing and other rangeland conservation practices to increase soil water retention and carbon sequestration, increase downstream water supplies, improve forage and overall ranch productivity, and enhance and expand riparian and wetland habitat for migratory birds and other wildlife (Flint et al. 2018; Silver et al. 2018).

Partner biologists advance conservation by cultivating land stewardship with collaborating land owners, engaging local communities, and ecological monitoring across a network of 80 collaborating ranches. The monitoring protocols are available for anyone to use. More information on the programs can be found at www.pointblue.org.

## CASE STUDY 2 | Planned Rotational Grazing And Perennial Grasses To Improve Soil Health And Extend Grazing Season

In Yolo County's Capay Valley, the Rangeland Watershed Initiative is building on an existing relationship between the NRCS and Yocha Dehe Wintun Nation (Yocha Dehe). This Native American tribe owns several properties used primarily for crop production and cattle ranching. The NRCS assists with conservation plans and conservation practices.

On one rangeland property, a Yocha Dehe ranch manager, Adam Cline, employs rotational grazing in the fall through spring. Well-planned rotational grazing allows grasses and wildflowers to recover, maintain vigor, and produce adequate seed. Vigorous above-ground growth means more productive below-ground growth and biological activity, usually resulting in soils with more organic matter. Such soils increase carbon storage and improve water infiltration and holding capacity.

**FIGURE 9**

The perennial grass planting area at Yocha Dehe's ranch prepped and seeded in January 2015.

Cline and NRCS Rangeland Specialist, Nick Gallagher, co-developed a conservation plan for this property in 2013, including fencing, livestock water troughs, and perennial grass seeding (**Figure 9**) supported by cost-share incentives from the NRCS's Environmental Quality Incentives Program.

## CASE STUDY 2 | CONT'D

Cline expressed interest in building on the success of a few-acre seeding of Harding grass (*Phalaris aquatica*) on the ranch (**Figure 10**). Results revealed higher forage biomass and, consistent with other perennial grasses, higher green biomass into the dry season vs. surrounding annual grasses (**Figures 11 and 12**). The ranch has managed over 20 acres with perennial grasses that extend foraging even in drought years, while increasing carbon sequestration and other soil benefits.

**FIGURE 10**

Harding grass seedlings (blue-green understory) amidst other annual grasses in late April 2015.

Point Blue's partner biologist, Corey Shake, began monitoring the ranch's soil, vegetation, and bird life in 2014. The monitoring model of the Rangeland Watershed Initiative and Rangeland Monitoring Network is to collect key data on soil carbon, soil compaction, water infiltration, plant communities, and bird populations to assess how conservation practices are working to achieve their objectives. They periodically present this data to ranchers and the NRCS to inform future adaptive management.

**FIGURE 11**

Perennial grass seeding area from hill above in late April 2015.

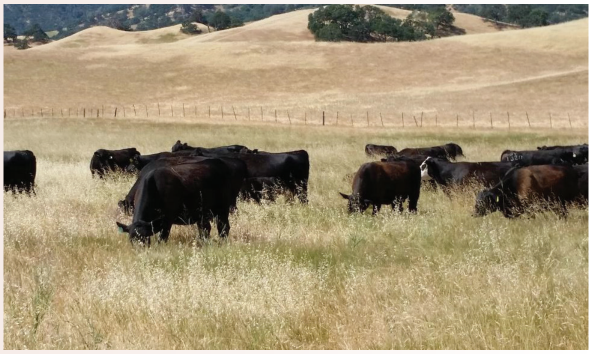
**FIGURE 12**

Green of Harding grass seedlings still visible in late May 2015 amidst red and brown annual grasses.

## CASE STUDY 3 | Evaluating Compost Application To Rangelands In The Sacramento Valley Foothills

Spreading residential green waste compost on rangelands has been shown to increase soil carbon and boost forage productivity in coastal California grasslands (Flint et al. 2018; Silver et al. 2018). The owners of Yolo Land & Cattle Company were eager to test this method in the hotter and drier Sacramento Valley foothills near Esparto, California (**Figure 13**).

FIGURE 13



Cattle grazing on a field in mid-May at Yolo Land & Cattle's home ranch where compost will be applied fall 2018.

The Yolo County Resource Conservation District (Yolo Co. RCD) coordinated the funding effort to help offset costs of compost and its application. They teamed up with Corey Shake to develop a proposal to the California Department of Food and Agriculture's Healthy Soils Initiative. Chris Potter of CASA Systems 2100 joined the proposal to measure GHG emissions from the soil.

The grant was recently awarded to Yolo Co. RCD and team members. Work has commenced on gathering pre-treatment data on soil and vegetation. The grant requires the project to focus on demonstrating the effects of the soil health beneficial practices to at least 100 other ranchers. To measure these effects, Point Blue and CASA Systems have designed a monitoring program that evaluates soil organic carbon and other soil health metrics, soil $CO_2$ flux, plant communities, and forage production at control and treatment sites, both before and after application.

## CASE STUDY 4 | Increasing Water Efficiency And Reducing Greenhouse Gas Emissions For Walnut And Almond Orchards In Glenn Co.

With a grant from the CDFA's State Water Efficiency and Enhancement (SWEEP) Program, Bruce and Kerwin Grivey converted a 48-acre walnut orchard and 13-acre almond orchard from flood to sprinkler irrigation via a 50 kilowatt (kW) solar generating facility. The project resulted in substantial water savings (14.33-acre inches per year) and a net reduction in GHG emissions (20.195 tons $CO_2E$/Year). With the installation of the solar system, micro sprinklers, variable-frequency drive (VFD), flow meters, soil sensors, and referencing CIMIS, Bruce has observed substantial improvements in water efficiency and reductions in energy use and on-farm GHG emissions.

Bruce's new irrigation technology has saved water. Using micro sprinklers ensured that the orchard floor can still be adequately soaked, while allowing for full coverage of his trees' extensive root systems. While drip irrigation can be highly effective when planting a new orchard, micro sprinklers are better for converting an existing orchard from flood irrigation to ensure that established roots still receive full coverage. Bruce also installed soil moisture sensors, which take the "guess work" out of irrigation by insuring the proper amount of water is applied in response to changes in soil moisture.. Finally, a VFD and flow meter help Bruce detect leaks within his irrigation system.

Bruce was very happy with the results of his SWEEP project and the significant water and energy savings he has enjoyed as a result. The new micro sprinkler irrigation system has helped with water penetration and improved the health of his crops. The micro sprinklers are also better for frost protection and for greater distribution of soil moisture.

For more information on the program, visit the CDFA SWEEP program webpage, your local Resource Conservation District, UC Cooperative farm advisors, US Department of Agriculture Natural Resource Conservation District, the technical assistance workshop from Resource Conservation District, or Ag Alert.

# References

Abatzoglou, JT, and AP Williams. 2016. Impact of anthropogenic climate change on wildfire across western US forests. Proc Natl Acad Sci USA 113:11770-11775.

Agrawala, S. and S. Fankhauser 2008. Economic Aspects of Adaptation to Climate Change: Costs, Benefits and Policy Instruments. (eds) OECD, Paris 133 pp.

Aitsi-Selmi, A. and V. Murray. 2016. Protecting the health and well-being of populations from disasters: health and health care in the Sendai Framework for disaster risk reduction 2015-2030. Prehospital and Disaster Medicine 31: 74-78.

Albertine, J. M., W.J. Manning, M. DaCosta, K.A. Stinson, M.L. Muilenberg, and C.A. Rogers. 2014. Projected carbon dioxide to increase grass pollen and allergen exposure despite higher ozone levels. PLoS One 9: e111712. doi:10.1371/journal.pone.0111712.

Allen, CD, DD Breshears, and NG McDowell. 2015. On underestimation of global vulnerability to tree mortality and forest die-off from hotter drought in the Anthropocene. Ecosphere 6(8):129.

Altizer, S., R.S. Ostfeld, P.T. Johnson, S. Kutz, and C.D. Harvell. 2013. Climate change and infectious diseases: From evidence to a predictive framework. Science 341: 514-519.

Analitis, A., P. Michelozzi, D. D'Ippoliti, F. de'Donato, B. Menne, F. Matthies, R.W. Atkinson, C. Iñiguez, X. Basagaña, A. Schneider, A. Lefranc, A. Paldy, L. Bisanti, and K. Katsouyanni. 2014. Effects of heat waves on mortality: effect modification and confounding by air pollutants. Epidemiology 25: 15-22.

Asplund, C.A. and F.G. O'Connor. 2016. Challenging return to play decisions: Heat stroke, exertional rhabdomyolysis, and exertional collapse associated with sickle cell trait. Sports Health 8: 117-125.

Avanzi, F., T. Maurer, S. Malek, S. D. Glaser, R. C. Bales, M. H. Conklin. (UC Berkeley and UC Merced). 2018. Feather River Hydrologic Observatory: Improving Hydrological Snowpack Forecasting for Hydropower Generation Using Intelligent Information Systems. California's Fourth Climate Change Assessment, California Energy Commission. Publication Number: CCCA4-CEC-2018-001.

Balazs, Carolina L., and Isha Ray. 2014. The drinking water disparities framework: on the origins and persistence of inequities in exposure. American Journal of Public Health 104.4: 603-611

Balbus, J.M., J.B. Greenblatt, R. Chari, D. Millstein, and K.L. Ebi. 2014. A wedge-based approach to estimating health co-benefits of climate change mitigation activities in the United States. Climatic Change 127:199–210.

Balbus, J., A. Crimmins, J.L. Gamble, D.R. Easterling, K.E. Kunkel, S. Saha, and M.C. Sarofim. 2016. Introduction: Climate Change and Human Health. In U.S. Global Change Research Program. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. U.S. Global Change Research Program, Washington, DC.

Baldocchi, D. and Waller, E., 2014. Winter fog is decreasing in the fruit growing region of the Central Valley of California. Geophysical Research Letters, 41(9), pp.3251-3256.

Bale, A. E., S. E. Greco, B. J. L. Pitton, D. L. Haver, and L. R. Oki. 2017. Pollutant loading from low-density residential neighborhoods in California. Environmental Monitoring and Assessment 189:1-19. DOI: 10.1007/s10661-017-6104-2

Ball, M., C. Barnhart, M. Dresner, M. Hansen, K. Neels, A. Odoni, E. Peterson, L. Sherry, A. A. Trani, and B. Zou, 2010: Total Delay Impact Study: a Comprehensive Assessment of the Costs and Impacts of Flight Delay in the United States. 91 pp.

Basu, R., L. Gavin, D. Pearson, K. Ebisu, and B. Malig, 2017: Examining the Association Between Temperature and Emergency Room Visits from Mental Health-Related Outcomes in California. Am J Epidemiol.

Barbour, E, and LM Kueppers. 2012. Conservation and management of ecological systems in a changing California Climatic Change 111:135-163.

Tracy Barreau et al. "Physical, Mental, and Financial Impacts From Drought in Two California Counties, 2015", American Journal of Public Health 107, no. 5 (May 1, 2017): pp. 783-790.

Bedno, S.A., N. Urban, M.R. Boivin, and D.N. Cowan. 2014. Fitness, obesity and risk of heat illness among army trainees. Occupational Medicine 64: 461-467.

Bedsworth, L., W. Bedsworth, E. Hanak. 2013. Climate policy at the local level: Insights from California, Global Environmental Change, Volume 23, Issue 3, 2013, Pages 664-677, ISSN 0959-3780, https://doi.org/10.1016/j.gloenvcha.2013.02.004 and http://www.sciencedirect.com/science/article/pii/S0959378013000344.

Beier, P, and B Brost. 2010. Use of land facets to plan for climate change: conserving the arenas, not the actors. Conservation Biology 24:701-710.

Bell, J.E., S.C. Herring, L. Jantarasami, C. Adrianopoli, K. Benedict, K. Conlon, V. Escobar, J. Hess, J. Luvall, C.P. Garcia-Pando, D. Quattrochi, J. Runkle, and C.J. Schreck. 2016. Ch. 4: Impacts of Extreme Events on Human Health. In U.S. Global Change Research Program. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. U.S. Global Change Research Program, Washington, DC.

Belova, A., D. Mills, R. Hall, A.S. Juliana, A. Crimmins, C. Barker, and R. Jones. 2017. Impacts of increasing temperature on the future incidence of west nile neuroinvasive disease in the United States. American Journal of Climate Change 6: 166-216.

Berry, PM, S Brown, M Chen, A Kontogianni, O. Rowlands, G. Simpson, and M Skourtos. 2015. Cross sectoral interactions of adaptation and mitigation measures. Climatic Change 128: 381-393.

Bouchama, A., M. Dehbi, G. Mohamed, F. Matthies, M. Shoukri, and B. Menne. 2007. Prognostic factors in heat wave related deaths: A meta-analysis. Archives of Internal Medicine 167: 2170-2176.

Brooks, Benjamin, Jennifer Telling, Todd Ericksen, Craig L. Glennie, Noah Knowles, Dan Cayan, Darren Hauser, and Adam LeWinter. (U.S. Geological Survey). 2018. High Resolution Measurement of Levee Subsidence Related to Energy Infrastructure in the Sacramento-San Joaquin Delta. California's Fourth Climate Change Assessment, California Energy Commission. Publication Number: CCCA4-CEC -2018-003.

Brown, H.E., A. Comrie, D. Drechsler, C.M. Barker, R. Basu, T. Brown, A. Gershunov, A.M. Kilpatrick, W.K. Reisen, and D. Ruddell. 2013. Health effects of climate change in the Southwest. In Garfin, G., A. Jardine, R. Merideth, M. Black, and S. LeRoy (eds.) 2013. Assessment of Climate Change in the Southwest United States. Island Press, Washington, DC.

Brown, H.E., A. Young, J. Lega, T.G. Andreadis, J. Schurich, and A. Comrie. 2015. Projection of climate change influences on U.S. West Nile virus vectors. Earth Interactions 19: 18. doi:10.1175/EI-D-15-0008.1.

Brown, H.E., A.C. Comrie, J. Tamerius, M. Khan, J.A.Tabor, and J.N. Galgiani. 2014. Climate, windstorms, and the risk of valley fever (Coccidioidomycosis). In Institute of Medicine. The Influence of Global Environmental Change on Infectious Disease Dynamics: Workshop Summary. National Academies Press, Washington, DC.

Bruzgul, Judsen, Robert Kay, Andy Petrow, Beth Rodehorst, Dave Revell, Maya Bruguera, Dan Moreno, Ken Collison. (ICF and Revell Coastal). 2018. Rising Seas and Electricity Infrastructure: Potential Impacts and Adaptation Actions for San Diego Gas & Electric. California's Fourth Climate Change Assessment, California Energy Commission. Publication number: CCCA4-CEC-2018-004.

Bruzgul, Judsen, Robert Kay, Andy Petrow, Beth Rodehorst, Dave Revell, Maya Bruguera, Dan Moreno, Ken Collison. (ICF and Revell Coastal). 2018. Rising Seas and Electricity Infrastructure: Potential Impacts and Adaptation Actions for San Diego Gas & Electric. California's Fourth Climate Change Assessment, California Energy Commission. Publication number: CCCA4-CEC-2018-004.

Bucci, M., S.S. Marques, D. Oh, and N.B. Harris 2016. Toxic stress in children and adolescents. Advances in Pediatrics 63: 403-428.

Buonocore, J.J., P. Luckow, J. Fisher, W. Kempton, and J. I. Levy. 2016. Health and climate benefits of offshore wind facilities in the Mid-Atlantic United States. Environmental Research Letters 11: 074019. doi:10.1088/1748-9326/11/7/074019.

Bureau of Reclamation. 2017. North-of-the Delta Offstream Storage Investigation Draft Feasibility Study, U.S. Department of the Interior Bureau of Reclamation Mid-Pacific Region by URS Group, Inc., Contract No. GS23F0232L / R13PD20055, Task Order R13PD20055.

Bureau of Transportation Statistics. 2012. Freight Shipments by State of Origin. https://www.bts.gov/content/freight-shipments-state-origin.

Burton, Christopher, and Susan L. Cutter. 2008. Levee failures and social vulnerability in the Sacramento-San Joaquin Delta area, California. Natural Hazards Review 9.3 (2008): 136-149.

Byrnes, R., V. Eviner, E. Kebreab, W. R. Horwath, L. Jackson, B. M. Jenkins, S. Kaffka, A. Kerr, J. Lewis, F. M. Mitloehner, J. P. Mitchell, K. M. Scow, K. L. Steenwerth and S. Wheeler. 2017. Review of research to inform California's climate scoping plan: Agriculture and working lands. California Agriculture 71(3):160-168.

Communitywide Climate Action Plan (CCAP). 2017. Climate Change Vulnerability Assessment for the Sacramento County Climate Action Plan: Communitywide Greenhouse Gas Reduction and Climate Change Adaptation, Sacramento County, Planning and Review, Sacramento: 63pps, url: http://www.per.saccounty.net/PlansandProjectsIn-Progress/Documents/Climate%20Action%20Plan/Climate%20Change%20Vulnerability%20Assessment.pdf

Cal Fire – Fire and Resource Assessment Program, accessed June 2018. FRAP Maps: Fire Perimeters (http://frap.fire.ca.gov/data/frapgismaps-fire_perimeters_download)

California Air Resources Board. 2017. Greenhouse Gas Inventory Data – Graphs. https://www.arb.ca.gov/cc/inventory/data/graph/graph.htm

California Climate and Agricultural Network (CalCAN). 2011. Climate change impacts on agriculture. Sacramento, CA.

California Department of Fish and Wildlife (CDFW). 2015. California State Wildlife Action Plan, 2015 Update: A Conservation Legacy for Californians. Edited by Armand G. Gonzales and Junko Hoshi, PhD. Prepared with assistance from Ascent Environmental, Inc., Sacramento, CA.

California Department of Transportation (Caltrans). 2013. Addressing climate change adaptation in regional transportation plans, Prepared for the California Department of Transportation, Sacramento: 296pp.

California Department of Water Resources (CDWR). 2016. Central Valley Flood Protection Plan Conservation Strategy. California Department of Water Resources, Sacramento, CA. Available online: http://www.water.ca.gov/conservationstrategy/cs_new.cfm.

California Department of Water Resources (CDWR). 2017a. Central Valley Flood Protection Plan Update 2017. California Department of Water Resources, Sacramento, CA.

California Department of Water Resources (CDWR). 2017b. Lower Elkhorn Basin Levee Setback Project. California Department of Water Resources, Sacramento, CA.

California Energy Commission (CEC). California Climate Change Center. 2017a. Assessment of California's Natural Gas Pipeline Vulnerability to Climate Change. White Paper CEC-500-2017-008 http://www.energy.ca.gov/2017publications/CEC-500-2017-008/CEC-500-2017-008.pdf

California Energy Commission (CEC). 2017b. The Electric Program Investment Charge: Proposed 2018 – 2020 Triennial Investment Plan. Publication Number: CEC-500-2017-023-CMF. http://www.energy.ca.gov/research/epic/17-EPIC-01/

California Energy Commission (CEC). 2017c. Energy Almanac Annual Generation by County, http://www.energy.ca.gov/almanac/electricity_data/web_qfer/Annual_Generation-County.php?goSort=plant_table.county&year=2017

California Energy Commission (CEC). 2018. Energy Maps of California. http://www.energy.ca.gov/maps/

California Environmental Protection Agency (CalEPA). 2015. Climate Action Team, Climate Change Research Plan for California. http://climatechange.ca.gov/climate_action_team/reports/CAT_research_plan_2015.pdf

California Natural Resources Agency (CNRA), 2009. California Climate Adaptation Strategy, A Report to the Governor of the State of California in Response to Executive Order S-13-2008. http://resources.ca.gov/docs/climate/Statewide_Adaptation_Strategy.pdf

California Natural Resources Agency (CNRA). 2014. Safeguarding California: Reducing Climate Risk: An update to the 2009 California Climate Adaptation Strategy. http://resources.ca.gov/docs/climate/Final_Safeguarding_CA_Plan_July_31_2014.pdf

California, Natural Resources Agency (CNRA). 2016. Safeguarding California: Implementation Action Plans, 2016. http://resources.ca.gov/docs/climate/safeguarding/Safeguarding%20California-Implementation%20Action%20Plans.pdf

California, Natural Resources Agency (CNRA). 2017. Safeguarding California Draft Plan: 2017 Update. http://resources.ca.gov/wp-content/uploads/2017/05/DRAFT-Safeguarding-California-Plan-2017-Update.pdf

California, Natural Resources Agency (CNRA). 2018. Safeguarding California Draft Plan: 2018 Update. http://resources.ca.gov/docs/climate/safeguarding/update2018/safeguarding-california-plan-2018-update.pdf

Capon, S. J., L. E. Chambers, R. MacNally, R. J. Naiman, P. Davies, N. Marshall, J. Pittock, Michael Reid, T Capon, M. Douglas, J. Catford, D. S. Baldwin, M. Stewardson, J. Roberts, M. Parsons, and S. E. Williams. 2013. Riparian Ecosystems in the 21st Century: Hotspots for Climate Change Adaptation? Ecosystems 16: 359-381.

Castello, A.F. and Shelton, M.L., 2004. Winter precipitation on the US Pacific coast and El Nino–Southern Oscillation events. International Journal of Climatology, 24(4), pp.481-497.

Cayan, D. R., E. P. Maurer, M. D. Dettinger, M. Tyree, and K. Hayhoe, 2008: Climate change scenarios for the California region. Climatic Change, 87, 21–42, doi: https://doi.org/10.1007/s10584-007-9377-6.

Central Valley Joint Venture (CVJV). 2006. Central Valley Joint Venture Implementation Plan – conserving bird habitat. US Fish and Wildlife Service, Sacramento, CA.

Chen, C.C., E. Jenkins, T. Epp, C. Waldner, P.S. Curry, and C. Soos. 2013. Climate change and West Nile virus in a highly endemic region of North America. International Journal of Environmental Research and Public Health 10: 3052-3071.

CHHSA (2003). Strategic plan for an aging California population: Getting California ready for the "Baby Boomers". California Health and Human Services Agency (CHHSA). Sacramento, California: 258.

Chornesky, E.A., D. Ackerly, P. Beier, F. W. Davis, L. E. Flint, J.J. Lawler, P.B. Moyle, M. A. Moritz, M. Scoonover, K. Byrd; P. Alvarez, N. E. Heller, E. R. Micheli, and S. B. Weiss. 2015. Adapting California's ecosystems to a changing climate. BioScience 65(3):247-262. doi: 10.1093/biosci/biu233

Choudhary, E. and A. Vaidyanathan. 2014. Heat stress illness hospitalizations--environmental public health tracking program, 20 States, 2001-2010. Morbidity and Mortality Weekly Report Surveillance Summaries 63: 1-10.

Chung, E.K., B.S. Siegel, A. Garg, K. Conroy, R.S. Gross, D.A. Long, G. Lewis, C.J. Osman, M.J. Messito, R. Wade, H.S. Yin, J. Cox, and A.H. Fierman. 2016. Screening for social determinants of health among children and families living in poverty: A guide for clinicians. Current Problems in Pediatric and Adolescent Health Care 46: 135-153.

City of Berkeley. 2016. Berkeley Resilience Strategy, City of Berkeley, Berkeley CA: 56pps., url: http://www.ca-ilg.org/sites/main/files/file-attachments/berkeley_resilience_strategy_lowres.pdf

Collins, Timothy W. 2005. Households, forests, and fire hazard vulnerability in the American West: a case study of a California community. Global environmental change Part B: environmental hazards 6.1 (2005): 23-37.

Cook BI, Smerdon JE, Seager R, Coats S. 2014. Global warming and 21st century drying. Climate Dynamics 43: 2607-2627. DOI 10.1007/s00382-014-2075-y

Corlett, RT, and DA Westcott. 2013. Will plant movements keep up with climate change? Trends in Ecology and Evolution 28:482-488.

Crockett, J.L. and Westerling, A.L., 2018. Greater temperature and precipitation extremes intensify Western US droughts, wildfire severity, and Sierra Nevada tree mortality. Journal of Climate, 31(1), pp.341-354.

Crider, K.G., E.H. Maples, and J.M. Gohlke. 2014. Incorporating occupational risk in heat stress vulnerability mapping. Journal of Environmental Health 77: 16-22.

Cvijanovic, I., Santer, B.D., Bonfils, C., Lucas, D.D., Chiang, J.C. and Zimmerman, S., 2017. Future loss of Arctic sea-ice cover could drive a substantial decrease in California's rainfall. Nature Communications, 8(1), p.1947.

Damschen, EI, S Harrison, DD Ackerly, BM Fernandez-Going, and BL Anacker. 2012. Endemic plant communities on special soils: early victims or hardy survivors of climate change? Journal of Ecology 100:1122-1130.

Das, T., Dettinger, M.D., Cayan, D.R. and Hidalgo, H.G., 2011. Potential increase in floods in California's Sierra Nevada under future climate projections. Climatic Change, 109(1), pp.71-94.

Das T, Maurer EP, Pierce DW et al. 2013. Increases in flood magnitudes in California under warming climates. Journal of Hydrology 501:101-110. doi: https://doi.org/10.1016/j.jhydrol.2013.07.042.

Dass, P., Houlton, B. Z., Wang, Y.P., Warlind, D. 2018. Grasslands may be more reliable carbon sinks that forests in California. Environmental Research Letters, 13: 074027.

Dell, J., S. Tierney, G. Franco, R. G. Newell, R. Richels, J. Weyant, and T. J. Wilbanks, 2014: Ch. 4: Energy Supply and Use. Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 113-129. doi:10.7930/J0BG2KWD.

Dettinger, M., 2011. Climate change, atmospheric rivers, and floods in California–a multimodel analysis of storm frequency and magnitude changes. JAWRA Journal of the American Water Resources Association, 47(3), pp.514-523.

Department of Conservation (DOC). 2016. California Farmland Conversion Summary. www.conservation.ca.gov/dlrp/fmmp/trends/Pages/FastFacts.aspx.

Diffenbaugh NS, Swain DL, and Touma D. 2015. Anthropogenic warming has increased drought risk in California. Proceedings of the National Academy of Sciences 112(13):3931-3936. doi: 10.1073/pnas.1422385112.

Donald PF, and Evans AD. 2006. Habitat connectivity and matrix restoration: the wider implications of agri-environment schemes. Journal of Applied Ecology 43: 209–218.

Donatuto, J., E. Grossman, J. Konovsky, S. Grossman, L. Campbell. 2014. Indigenous community health and climate change: Integrating biophysical and social science indicators. Coastal Management 42: 355–373.

Durazo, E. M., M. R. Jones, S. P. Wallace, J. V. Arsdale, M. Aydin and C. Stewart (2011). The health status and unique health challenges of rural older adults in California. E. R. Brown. Los Angeles, California, University of California, Los Angeles (UCLA) Center for Health Policy research.

Eisenman, D. P., and Coauthors, 2016: Heat Death Associations with the built environment, social vulnerability and their interactions with rising temperature. Health & Place, 41, 89-99.

Every-Palmer, S., S. McBride, H. Berry, and D.B. Menkes. 2016. Climate change and psychiatry. Australian and New Zealand Journal of Psychiatry 50: 16-18.

Federal Transit Administration. 2011. Flooded Bus Barns and Buckled Rails: Public Transportation and Climate Change Adaptation. Online.

Flint, L., Flint, A., Stern, M., Mayer, A., Vergara, S., Silver, W., Casey, F., Franco, F., Byrd, K., Sleeter, B., Alvarez, P., Creque, J., Estrada, T., Cameron, D. (U.S. Geological Survey). 2018. Increasing Soil Organic Carbon to Mitigate Greenhouse Gases and Increase Climate Resiliency for California. California's Fourth Climate Change Assessment, California Natural Resources Agency. Publication number: CCCA4-CNRA-2018-006.

Franco, G., M. Wilson. 2005. Climate Change Impacts and Adaption in California. California Energy Commission Publication Number: CEC-500-2005-103-SD http://www.energy.ca.gov/2005publications/CEC-500-2005-103/CEC-500-2005-103.PDF

Franco, G., D. R. Cayan, S. Moser, M. Hanemann, and M. A. Jones. 2011. Second California Assessment: Integrated climate change impacts assessment of natural and managed systems. Climatic Change, 109, 1–19, doi: https://doi.org/10.1007/s10584-011-0318-z.

Fremier, AK, E. H. Girvetz, S. E. Greco, and E. W. Larsen. 2014. Quantifying process-based mitigation strategies in historical context: separating multiple cumulative effects on river meander migration. PLOS ONE. DOI: 10.1371/journal.pone.0099736

Fremier, A. K., M. Kiparsky, S. Gmur, J. Aycrigg, R. K. Craig, L. K. Svancara, D. D. Goble, B. Cosens, F. W. Davis, J. M. Scott. 2015. A riparian conservation network for ecological resilience. Biological Conservation 191: 29–37.

Gershunov, A., D. Cayan, and S. Iacobellis. 2009. The great 2006 California heat wave: Signal of an increasing trend. Journal of Climate 22: 6181-6203.

Gershunov, A, Guirguis K. 2012. California heat waves in the present and future. Geophysical Research Letters 39 10.1029/2012gl052979

Guirguis, K, Gershunov A, Tardy A, Basu R. 2014. The impact of recent heat waves on human health in California. Journal of Applied Meteorology and Climatology 53:3-19. 10.1175/jamc-d-13-0130.1

Guirguis, K., A. Gershunov, D.R. Cayan and D. Pierce, 2017: Heat wave probability in the changing climate of the Southwest US. Climate Dynamics DOI 10.1007/s00382-017-3850-3

Global Carbon Project. Global Carbon Budget 2017. http://www.globalcarbonproject.org/carbonbudget/

Greco, S. E., and E. W. Larsen. 2014. Ecological design of multifunctional open channels for flood control and conservation planning. Landscape and Urban Planning 131:14-26. DOI: 10.1016/j.landurbplan.2014.07.002

Greene, Christina. Broadening understandings of drought: the climate vulnerability of farmworkers and rural communities in California (USA) (Revised and Resubmitted, 2018). Environmental Science & Policy.

Ha, S., E.O. Talbott, H. Kan, C.A. Prins, and X. Xu, 2014. The effects of heat stress and its effect modifiers on stroke hospitalizations in Allegheny County, Pennsylvania. International Archives of Occupational and Environmental Health 87: 557-565.

Haines, A, A.J. McMichael, K.R. Smith, I. Roberts, J. Woodcock, A. Markandya, B.G. Armstrong, D. Campbell-Lendrum, A.D. Dangour, M. Davies, N. Bruce, C. Tonne, M. Barrett, and P. Wilkinson. 2009. Public health benefits of strategies to reduce greenhouse-gas emissions: overview and implications for policy makers. Lancet 374: 2104-2114.

Hajat, S. and T. Kosatky. 2010. Heat-related mortality: A review and exploration of heterogeneity. Journal of Epidemiology and Community Health 64: 753-760.

Hall, J. V., V. Brajer, and F. W. Lurmann. 2008. "Measuring the gains from improved air quality in the San Joaquin Valley." Journal of Environmental Management 88.4: 1003-1015.

Hannah, L, MR Shaw, M Ikegami, PR Roehrdanz, OSoong, and J Thorne. 2012. Consequences of climate change for native plants and conservation. California Energy Commission. Publication number: CEC-500-2012-024.

Harlan, S.L., A.J. Brazel, L. Prashad, W.L. Stefanov, and L. Larsen. 2006. Neighborhood microclimates and vulnerability to heat stress. Social Science and Medicine 63: 2847-2863.

Harlan, S. L., J. H. Declet-Barreto, W. L. Stefanov, and D. B. Petitti, 2013: Neighborhood effects on heat deaths: social and environmental predictors of vulnerability in Maricopa County, Arizona. Environmental Health Perspectives, 121, 197-204.

Harrigan, R.J., H.A. Thomassen, W. Buermann, and T.B. Smith. 2014. A continental risk assessment of West Nile virus under climate change. Global Change Biology 20: 2417-2425.

Hess, J.J., S. Saha, and G. Luber. 2014. Summertime acute heat illness in U.S. emergency departments from 2006 through 2010. Analysis of a nationally representative sample. Environmental Health Perspectives 122: 1209-1215.

Herman, J., M. Fefer, M. Dogan, M. Jenkins, J. Medellín-Azuara, J. Lund. (University of California, Davis). 2018. Advancing Hydro-Economic Optimization to Identify Vulnerabilities and Adaptation Opportunities in California's Water System. California's Fourth Climate Change Assessment, California Natural Resources Agency. Publication number: CCCA4-CNRA-2018-016.

Hobbs, R.J., E. Higgs, C.M. Hall, P. Bridgewater, F.S. Chapin, III, E.C. Ellis, et al. 2014. Managing the whole landscape: Historical, hybrid, and novel ecosystems. Front. Ecol. Environ 12:557–564. doi:10.1890/130300

Hobbs, J, E Higgs, and JA Harris. 2009. Novel ecosystems: implications for conservation and restoration. Trends in Ecology and Evolution 24:599-605.

Hongoh, V., L. Berrang-Ford, M.E. Scott, and L.R. Lindsay. 2012. Expanding geographical distribution of the mosquito, Culex pipiens, in Canada under climate change. Applied Geography 33: 53-62.

Hornor, G., 2017. Resilience. Journal of Pediatric Health Care 31: 384-390.

Hoshiko, S., P. English, D. Smith, and R. Trent. 2010. A simple method for estimating excess mortality due to heat waves, as applied to the 2006 California heat wave. International Journal of Public Health 55: 133-137.

Howitt, R., J. Medellín-Azuara, and D. MacEwan (2009). Measuring economic impacts of agricultural yield related changes. California Energy Commission PIER Program Report, CEC-500-2009-042-F, Sacramento, CA.

Huang, Ganlin, Weiqi Zhou, and M. L. Cadenasso. 2011. Is everyone hot in the city? Spatial pattern of land surface temperatures, land cover and neighborhood socioeconomic characteristics in Baltimore, MD. Journal of environmental management 92.7: 1753-1759.

Huang, X. and Ullrich, P.A., 2016. Irrigation impacts on California's climate with the variable-resolution CESM. Journal of Advances in Modeling Earth Systems, 8(3), pp.1151-1163.

Hurteau, M.D., A.L. Westerling, C. Wiedinmyer, and B.P. Bryant. 2014. Projected effects of climate and development on California wildfire emissions through 2100. Environmental Science and Technology, 48:2298-2304.

Ingram L. B. 2013. California Megaflood: Lessons from a Forgotten Catastrophe. Scientific American. January 1 2013. https://www.scientificamerican.com/article/atmospheric-rivers-california-megaflood-lessons-from-forgotten-catastrophe/

Intergovernmental Panel on Climate Change (IPCC). 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press. p. 1535.

Jardine, D.S. 2007. Heat illness and heat stroke. Pediatrics in Review 28: 249-258.

Jackson RB, Quéré CL, Andrew RM et al. . 2017. Warning signs for stabilizing global CO 2 emissions. Environmental Research Letters 12(11):110202.

Jones, C.M., Wheeler, S.M. and Kammen, D.M., 2018. Carbon Footprint Planning: Quantifying Local and State Mitigation Opportunities for 700 California Cities. Urban Planning, 3(2), pp.35-51.

Keeley, JE. 2002. Fire management of California shrubland landscapes. Environmental Management 29:395-408.

Keeley A.T.H., D. Ackerly, G. Basson, D.R. Cameron, L. Hannah, N.E. Heller, P.R. Huber, A.M. Merenlender, P.R Roehrdanz, C.A Schloss, J.H. Thorne, S. Veloz. (University of California, Berkeley). 2018. Migration Corridors as Adaptation to Climate Change: Why, How, and What Next. California's Fourth Climate Change Assessment, California Natural Resources Agency. Publication number: CCCA4-CNRA-2018-001.

Kelley R. 1989. Battling the Inland Sea. University of California Press, Berkeley, CA.

Keyser A and AL Westerling 2017. Climate drives inter-annual variability in probability of high severity fire occurrence in the western United States. Environmental Research Letters 12: 065003. https://doi.org/10.1088/1748-9326/aa6b10

Kjellstrom, T. and A.J. McMichael. 2013. Climate change threats to population health and well-being: the imperative of protective solutions that will last. Global Health Action 6: 20816.

Knowlton, K., M. Rotkin-Ellman, G. King, H.G. Margolis, D. Smith, G. Solomon, R. Trent, and P. English. 2009. The 2006 California heat wave: Impacts on hospitalizations and emergency department visits. Environmental Health Perspectives 117: 61-67.

Knowlton, K., M. Rotkin-Ellman, L. Geballe, W. Max, and G.M. Solomon. 2011. Six climate change-related events in the United States accounted for about $14 billion in lost lives and health costs. Health Affairs 30: 2167-2176.

Krakoff, Sarah. 2007. "American Indians, climate change, and ethics for a warming world." Denv. UL Rev. 85: 865.

Krau, S.D. 2013. Heat-related illness: A hot topic in critical care. Critical Care Nursing Clinics of North America 25: 251-262.

Kravchenko, J., A.P. Abernethy, M. Fawzy, and H.K. Lyerly. 2013. Minimization of heatwave morbidity and mortality. American Journal of Preventive Medicine 44: 274-282.

Kroeger T, Casey F, Alvarez P, et al. 2009. An economic analysis of the benefits of habitat conservation on California Rangelands. Conservation economics white paper. Defenders of Wildlife, Washington D.C.

Kueppers, LM, MA Snyder, LC Sloan, ES Zavaleta, and B Fulfrost. 2005. Modeled regional climate change and California endemic oak ranges. Proceedings of the National Academy of Sciences USA 102: 16281–16286.

Larsen, Larissa. 2015. Urban climate and adaptation strategies. Frontiers in Ecology and the Environment 13.9: 486-492.

Lauland, Andrew, Tom LaTourette, Jordan Fischbach, Neil Berg, Chuck Stelzner. (RAND Corporation). 2018. Assessing Vulnerability and Improving Resilience of Critical Emergency Management Infrastructure in California in a Changing Climate. California's Fourth Climate Change Assessment, California Natural Resources Agency. Publication number: CCCA4-CNRA-2018-015.

Lenihan JM, Bachelet D, Neilson RP, Drapek R. 2008. Response of vegetation distribution, ecosystem productivity, and fire to climate change scenarios for California. Climatic Change 87 (Suppl 1):S215–S230 doi: 10.1007/s10584-007-9362-0

Lewis DJ, Lennox M, O'Geen A, et al. 2015. Creek carbon: Mitigating greenhouse gas emissions through riparian restoration. University of California Cooperative Extension in Marin County. Novato, California.

Littell, JS, D McKenzie, DL Patterson, and AL Westerling. 2009. Climate and wildfire area burned in western U.S. ecoprovinces, 1916–2003. Ecological Applications, 19:1003-1021.

London. Jonathan et. al., 2018. The Struggle for Water Justice in California's San Joaquin Valley: A Focus on Disadvantaged Communities. Davis CA: UC Davis Center for Regional Change.

Loonen, R. C., Trčka, M., Cóstola, D., & Hensen, J. L. M., 2013. Climate adaptive building shells: State-of-the-art and future challenges. Renewable and Sustainable Energy Reviews, 25, 483-493.

Luber, G. and M. McGeehin. 2008. Climate change and extreme heat events. American Journal of Preventive Medicine 35: 429-435.

Lund, J.R., "Flood Management in California," Water, Vol. 4, pp. 157-169; doi:10.3390/w4010157, 2012.

Mach, K.J., Planton, S. and von Stechow, C., 2014. Annex II: Glossary K. J. Mach, S. Planton, & C. von Stechow, eds. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, pp.117–130.

Macmillan, A., J. Connor, K. Witten, R. Kearns, D. Rees, and A. Woodward. 2014. The societal costs and benefits of commuter bicycling: simulating the effects of specific policies using system dynamics modeling. Environmental Health Perspectives 122: 335–344.

Madani, Kaveh and J. Lund. 2009. Modeling California's high-elevation hydropower systems in energy units. Water Resources Research, 45. 10.1029/2008WR007206.

Maendly, Romain. (California Department of Water Resources). 2018. Development of Stage-Frequency Curves in the Sacramento – San Joaquin Delta for Climate Change and Sea Level Rise. California's Fourth Climate Change Assessment, California Energy Commission. Publication number: CCCA4-EXT-2018-011.

Maldonado, Julie Koppel; Benedict Colombi; and Rajul Pandya, eds. 2014. Climate Change and Indigenous Peoples in the United States: Impacts, Experiences and Actions. Springer.

Mallek, C., H. Safford, J. Viers, and J. Miller. 2013. Modern departures in fire severity and area vary by forest type, Sierra Nevada and southern Cascades, California, USA. Ecosphere 4:153.

Margolis, H. G. (2014). Heat Waves and Rising Temperatures: Human Health Impacts and the Determinants of Vulnerability. Global Climate Change and Public Health. K. E. Pinkerton and W. N. Rom. New York, © Springer Science+Business Media.

Marinucci, G.D., G. Luber, C.K. Uejio, S. Saha, and J.J. Hess. 2014. Building resilience against climate effects—A novel framework to facilitate climate readiness in public health agencies. International Journal of Environmental Research and Public Health 11: 6433-6458.

Matchett EL, and Fleskes JP. 2017. Projected Impacts of Climate, Urbanization, Water Management, and Wetland Restoration on Waterbird Habitat in California's Central Valley. PLOS ONE 12(1):e0169780. doi: 10.1371/journal.pone.0169780.

Maughan, D.L., A. Patel, T. Parveen, I. Braithwaite, J. Cook, R. Lillywhite, and M. Cooke. 2016. Primary-care-based social prescribing for mental health: An analysis of financial and environmental sustainability. Primary Health Care Research and Development 17: 114-121.

McConnell, R., K. Berhane, F. Gilliland, S.J. London, T. Islam, W.J. Gauderman, E. Avol, H.G. Margolis, and J.M. Peters. 2002. Asthma in exercising children exposed to ozone: A cohort study. Lancet 359: 386-391.

McDonald, Y.J., S.E. Grineski, T.W. Collins, and Y.A. Kim. 2015. A scalable climate health justice assessment model. Social Science and Medicine 133: 242-252.

McDonnell, W.F., D.E. Abbey, N. Nishino, and M.D. Lebowitz. 1999. Long-term ambient ozone concentration and the incidence of asthma in nonsmoking adults: the AHSMOG Study. Environmental Research 80: 110-121.

McKibben, S.M., W. Peterson, A.M. Wood, and V.L. Trainer, M. Hunter, and A.E. White. 2017. Climatic regulation of the neurotoxin domoic acid. Proceedings of the National Academy of Sciences of the USA 114: 239-244.

McMichael, A.J. 2013. Globalization, climate change, and human health. New England Journal of Medicine 368: 1335-1343.

Medellin-Azuara, Josue, Daniel A. Sumner, Qianyao Yolanda Pan, Hyunok Lee, Victoria Espinoza, Andrew Bell, Selina Davila Olivera, Jonathan Herman, Jay R. Lund. (University of California, Davis and University of California, Merced). 2018. Economic and Environmental Implications of California Crop and Livestock, Adaptation to Climate Change. California Natural Resources Agency. Publication number: CCCA4-CNRA-2018-018.

Medina-Ramon, M., A. Zanobetti, D.P. Cavanagh, and J. Schwartz. 2006. Extreme temperatures and mortality: Assessing effect modification by personal characteristics and specific cause of death in a multi-city case-only analysis. Environmental Health Perspectives 114: 1331–1336.

Millar, CI, and NL Stephenson. 2015. Temperate forest health in an era of emerging megadisturbance. Science 349:823-826.

Moghaddas, Jason, Gary Roller, Jonathan Long, David Saah, Max Moritz, Dan Stark, David Schmidt, Thomas Buchholz, Travis Freed, Erin Alvey, John Gunn. (Spatial Informatics Group). 2018. Fuel Treatment for Forest Resilience and Climate Mitigations: A Critical Review for Coniferous Forests of the Sierra Nevada, Southern Cascade, Coast, Klamath, and Transverse Ranges. California Natural Resources Agency. Publication number: CCCA4-CNRA-2018-017.

Montag, J.M., K. Swan, K. Jenni, T. Nieman, J. Hatten, M. Mesa, D. Graves, F. Voss, M. Mastin, J. Hardimann, and A. Maule 2014. Climate change and Yakama Nation tribal well-being. Climatic Change 124: 385–398.

Moser, S., G. Franco, S. Pittiglio, W. Chou, and D. Cayan, 2009: The future is now: An update on climate change science impacts and response options for California. California Climate Change Center Rep. CEC-500-2008-071, 114 pp. http://www.energy.ca.gov/2008publications/CEC-500-2008-071/CEC-500-2008-071.PDF.

Morello-Frosch, Rachel, Manuel Pastor, and James Sadd. 2011. Environmental justice and Southern California's "riskscape" the distribution of air toxics exposures and health risks among diverse communities. Urban Affairs Review 36.4: 551-578.

Mote, P.W., Hamlet, A.F., Clark, M.P. and Lettenmaier, D.P., 2005. Declining mountain snowpack in western North America. Bulletin of the American meteorological Society, 86(1), pp.39-49.

Moy E, Garcia MC, Bastian B, Rossen LM, Ingram DD, Faul M, Massetti GM, Thomas CC, Hong Y, Yoon PW, Iademarco MF. Leading Causes of Death in Nonmetropolitan and Metropolitan Areas- United States, 1999-2014. MMWR Surveill Summ. 2017 Jan 13;66(1):1-8. doi: 10.15585/mmwr.ss6601a1.

Moyle, P.B. 2014. Novel aquatic ecosystems: the new reality for streams in California and other Mediterranean climate regions. River Research and Applications 30: 1335-1344

Moyle, P.B., J. V. E. Katz and R. M. Quiñones. 2011. Rapid decline of California's native inland fishes: a status assessment. Biological Conservation 144: 2414-2423.

Moyle, P.B., J. D. Kiernan, P. K. Crain, and R. M. Quiñones. 2013. Climate change vulnerability of native and alien freshwater fishes of California: a systematic assessment approach. PLoS One. http://dx.plos.org/10.1371/journal.pone.0063883

Moyle, P.B., R. M. Quiñones, J.V.E. Katz, and J. Weaver. 2015. Fish Species of Special Concern in California. 3rd edition. Sacramento: California Department of Fish and Wildlife. https://www.wildlife.ca.gov/Conservation/Fishes/Special-Concern

Moyle, P. B., R. Lusardi, P. Samuel, and J. Katz. 2017. State of the Salmonids: Status of California's Emblematic Fishes 2017. Center for Watershed Sciences, University of California, Davis and California Trout, San Francisco, CA. 579 pp. https://watershed.ucdavis.edu/files/content/news/SOS%20II_Final.pdf

National Oceanic and Atmospheric Administration (NOAA). 2018. National Centers for Environmental Information. Available at: https://www.ncdc.noaa.gov/cag/statewide/time-series

National Research Council (NRC). 2002. Riparian areas – functions and strategies for management. National Academies Press, 2101 Constitution Avenue NW, Washington, DC.

Naughton, G.A. and J. S. Carlson. 2008. Reducing the risk of heat-related decrements to physical activity in young people. Journal of Science and Medicine in Sport 11: 58-65.

Naughton, M.P., A. Henderson, M.C. Mirabelli, R. Kaiser, J.L. Wilhelm, S.M. Kieszak, C.H. Rubin, and M.A. McGeehin. 2002. Heat-related mortality during a 1999 heat wave in Chicago. American Journal of Preventive Medicine 22: 221-227.

Neumann, James E., Jason Price, Paul Chinowsky, Leonard Wright, Lindsay Ludwig, Richard Streeter, Russell Jones, et al. "Climate Change Risks to US Infrastructure: Impacts on Roads, Bridges, Coastal Development, and Urban Drainage." Climatic Change 131, no. 1 (July 1, 2015): 97–109. https://doi.org/10.1007/s10584-013-1037-4.

North American Cooperation on Energy Information (NACEI). http://nacei.org/#!/maps).

Ocean Protection Council (OPC). 2018. Updating the State of California Sea-Level Rise Guidance Document. State of California Ocean Protection Council (OPC). Retrieved from http://www.opc.ca.gov/climate- change/updating-californias-sea-level-rise-guidance/

Oleson, K. W., A. Monaghan, O. Wilhelmi, M. Barlage, N. Brunsell, J. Feddema, L. Hu, D.F. Steinhoff. 2015. Interactions between urbanization, heat stress, and climate change. Climatic Change 129: 525-541.

Ostro, B.D., L.A. Roth, R.S. Green, and R. Basu. 2009. Estimating the mortality effect of the July 2006 California heat wave. Environmental Research 109: 614-619.

Oswald Beiler, Michelle, Leylin Marroquin, and Sue McNeil. "State-of-the-Practice Assessment of Climate Change Adaptation Practices across Metropolitan Planning Organizations Pre- and Post-Hurricane Sandy." Transportation Research Part A: Policy and Practice 88, no. Supplement C (June 1, 2016): 163–74. https://doi.org/10.1016/j.tra.2016.04.003

Opperman, J.J, P.B. Moyle, E.W. Larsen, J.L. Florsheim, and A.D. Manfree. 2017 Floodplains: Processes, Ecosystems, and Services in Temperate Regions. Berkeley: University of California Press.

Pacific Gas and Electric (PG&E). 2016. Climate Change Vulnerability Assessment. http://www.pgecurrents.com/wp-content/uploads/2016/02/PGE_climate_resilience.pdf

Pathak, T.B.; Maskey, M.L.; Dahlberg, J.A.; Kearns, F.; Bali, K.M.; Zaccaria, D. 2018. Climate Change Trends and Impacts on California Agriculture: A Detailed Review. Agronomy 8, 25.

Paull, S.H., D.E. Horton, M. Ashfaq, D. Rastogi, L.D. Kramer, N.S. Diffenbaugh, and A.M. Kilpatrick. 2017. Drought and immunity determine the intensity of West Nile virus epidemics and climate change impacts. Proceedings of the Royal Society of London B 284: 20162078. doi:10.1098/rspb.2016.2078.

Perez, Pat. 2009. Potential Impacts of Climate Change on California's Energy Infrastructure and Identification of Adaptation Measures, California Energy Commission, CEC-150-2009-001. http://www.energy.ca.gov/2009publications/CEC-150-2009-001/CEC-150-2009-001.PDF

Pierce, D. W., D. R. Cayan, and B. L. Thrasher, 2014: Statistical Downscaling Using Localized Constructed Analogs (LOCA)*. J. Hydrometeorol., 15, 2558–2585, doi:10.1175/JHM-D-14-0082.1. https://doi.org/10.1175/JHM-D-14-0082.1

Pierce, D. W., J. F. Kalansky, and D. R. Cayan, (Scripps Institution of Oceanography). 2018. Climate, Drought, and Sea Level Rise Scenarios for the Fourth California Climate Assessment. California's Fourth Climate Change Assessment, California Energy Commission. Publication Number: CNRA-CEC-2018-006.

Quiñones, R.M and P.B. Moyle. 2014. Climate change vulnerability of freshwater fishes in the San Francisco Bay Area. San Francisco Estuary and Watershed Science 12(3). doi: http://dx.doi.org/10.15447/sfews.2014v12iss3art3.

Radke, J.D, G.S. Biging, K. Roberts, M. Schmidt-Poolman, H. Foster, E. Roe, Y. Ju, S. Lindbergh, T. Beach, L. Maier, Y. He, M. Ashenfarb, P. Norton, M. Wray, A. Alruheil, S. Yi, R.

Radke, J.D, G.S. Biging, K. Roverts, M. Schmidt-Poolman, H. Foster, E. Roe, Y. Ju, S. Lindbergh, T. Beach, L. Maier, Y. He, M. Ashenfarb, P. Norton, M. Wray, A. Alruheil, S. Yi, R. Rau, J. Collins, D. Radke, M. Coufal, S. Marx, D. Moanga, V. Ulyashin, A. Dalal. (University of California, Berkeley). 2018. Assessing Extreme Weather-Related Vulnerability and Identifying Resilience Options for California's Independent Transportation Fuel Sector. California's Fourth Climate Change Assessment, California Energy Commission. Publication Number: CCCA4-CEC-2018-012.

Raukar, N., R. Lemieux, G. Finn, R. Stearns, and D. J. Casa. 2015. Heat illness - A practical primer. Rhode Island Medical Journal 98: 28-31.

Rauken, T., P. K. Mydske, and M. Winsvold. 2015. Mainstreaming Climate Change Adaptation at the Local Level. Local Environment 20, no. 4: 408–23. https://doi.org/10.1080/13549839.2014.880412.

Reid, C. E., J.K. Mann, R. Alfasso, P.B. English, G.C. King, R.A. Lincoln, H.G. Margolis, D.J. Rubado, J.E. Sabato, N.L. West, B. Woods, K.M. Navarro, and J.R. Balmes. 2012. Evaluation of a heat vulnerability index on abnormally hot days: An environmental public health tracking study. Environmental Health Perspectives 120: 715-720.

Report Card Task Force and Staff. 2014. America's emergency care environment, A state-by-state Report Card: 2014 edition. Annals of Emergency Medicine 63: 97-242.

Rhoades, A.M., Ullrich, P.A. and Zarzycki, C.M., 2018. Projecting 21st century snowpack trends in western USA mountains using variable-resolution CESM. Climate Dynamics, 50(1-2), pp.261-288.

Richardson, L.A., P.A. Champ, and J.B. Loomis. 2012. The hidden cost of wildfires: Economic valuation of health effects of wildfire smoke exposure in Southern California. Journal of Forest Economics 18: 14-35.

Riparian Habitat Joint Venture (RHJV). 2004. Version 2.0. The riparian bird conservation plan: a strategy for reversing the decline of riparian associated birds in California. California Partners in Flight.

Rising Voices. 2014. Adaptation to Climate Change and Variability: Bringing Together Science and Indigenous Ways of Knowing to Create Positive Solutions. National Center for Atmospheric Research, Boulder, CO.

Rockström J, Gaffney O, Rogelj J et al. . 2017. A roadmap for rapid decarbonization. Science 355(6331):1269-1271. doi: 10.1126/science.aah3443.

Rodriguez K, Swanson S, and McMahon A. 2017. Conceptual models for surface water and groundwater interactions at pond and plug restored meadows. J Soil Water Conserv 72:382-394; doi: 10.2489/jswc.72.4.382

Roy-Poirier A, Champagne P, Filion Y (2010) Review of Bioretention System Research and Design: Past, Present, and Future. Journal of Environmental Engineering-Asce 136:878-889 doi:10.1061/(asce)ee.1943-7870.0000227

Rudolph, L., J. Caplan, K. Ben-Moshe, and L. Dillon. 2013. Health in All Policies: A Guide for State and Local Governments. American Public Health Association, Washington, DC, and Public Health Institute, Oakland, CA.

Ryan Holifield, Jayajit Chakraborty, Gordon Walker 2017. The Routledge Handbook of Environmental Justice. London UK: Routledge.

SAC-CAP. 2015. Sacramento Region Transportation Climate Adaptation Plan, Sacramento Council of Governments and CivicSpark, Sacramento, 92 pp. http://www.sacog.org/sites/main/files/file-attachments/fullplanwithappendices.pdf

Sacramento Area Council of Governments (SACOG). 2018a. Active Transportation Program (ATP). https://www.sacog.org/active-transportation-program.

Sacramento Area Council of Governments (SACOG). 2018b. Active Transportation. https://www.sacog.org/active-transportation.

Sacramento Municipal Utility District (SMUD). 2012. Climate Readiness Strategy Overview and Summary Findings Research and report drafts completed by Scientific Applications International Corporation (SAIC).

Sampson, Natalie R., et al. 2013. Staying cool in a changing climate: Reaching vulnerable populations during heat events. Global environmental change 23.2: 475-484.

Sathaye, Jayant, Larry Dale, Peter Larsen, Gary Fitts, Kevin Koy, Sarah Lewis, and Andre Lucena. 2012. Estimating Risk to California Energy Infrastructure From Projected Climate Change. California Energy Commission. Publication Number: CEC-500- 2012-057.

Schlaepfer, MA, DF Sax, and JD Olden. 2011. The Potential conservation value of non-native species. Conservation Biology 25:428-437.

Schwartz, M. W., N. Butt, C. R. Dolanc, A. Holguin, M. A. Moritz, M. P. North, H. D. Safford, N. L. Stephenson, J. H. Thorne, and P. J. van Mantgem. 2015. Increasing elevation of fire in the Sierra Nevada and implications for forest change. Ecosphere 6(7):121. http://dx.doi.org/10.1890/ES15-00003.1

Schwartz, H. G., M. Meyer, C. J. Burbank, M. Kuby, C. Oster, J. Posey, E. J. Russo, and A. Rypinski, 2014: Ch. 5: Transportation. Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 130-149. doi:10.7930/J06Q1V53.

Scott, Klaus I., E. Gregory McPherson, and James R. Simpson. 1998. Air pollutant uptake by Sacramento's urban forest. Journal of Arboriculture 24: 224-234.

Seavy, NE, T Gardali, GH Golet, FT Griggs, CA Howell, R Kelsey, SL Small, JH Viers and JF Weigand. 2009. Why climate change makes riparian restoration more important than ever: recommendations for practice and research. Ecological Restoration 27:330-338.

Seidel, D.J., Fu, Q., Randel, W.J. and Reichler, T.J., 2008. Widening of the tropical belt in a changing climate. Nature geoscience, 1(1), p.21.

Semenza, J.C., J.E. McCullough, W.D. Flanders, M.A. McGeehin, and J.R. Lumpkin. 1999. Excess hospital admissions during the July 1995 heat wave in Chicago. Am J Prev Med, 16, 269-277.

Shonkoff, Seth B., et al. 2011. The climate gap: environmental health and equity implications of climate change and mitigation policies in California—a review of the literature." Climatic Change 109.1: 485-503.

Shi, L., E. Chu, and J. Debats. 2015. Explaining Progress in Climate Adaptation Planning Across 156 U.S. Municipalities, Journal of the American Planning Association, 81:3, 191-202, DOI: 10.1080/01944363.2015.1074526

Shuford, WD. 2014. Coastal California (BCR 32) Waterbird Conservation Plan: Encompassing the coastal slope and Coast Ranges of central and southern California and the Central Valley. A plan associated with the Waterbird Conservation for the Americas initiative. US Fish and Wildlife Service, Region 8, 2800 Cottage Way, Sacramento, CA 95825.

Shuford, WD, and KE Dybala. 2017. Conservation objectives for wintering and breeding waterbirds in California's Central Valley. San Francisco Estuary and Watershed Science 15(1), Article 4.

Silver, Whendee, Sintana Vergara, Allegra Mayer. (University of California, Berkeley). 2018. Carbon Sequestration and Greenhouse Gas Mitigation Potential of Composting and Soil Amendments on California's Rangelands. California's Fourth Climate Change Assessment, California Natural Resources Agency. Publication number: CCCA4-CNRA-2018-002.

Spector, J. T., J. Krenz, E. Rauser, and D. K. Bonauto, 2014. Heat-related illness in Washington State agriculture and forestry sectors. American Journal of Preventive Medicine 57: 881-895.

Sprigg W., A.S. Nickovic, J.N. Galgiani, G. Pejanovic, S. Petkovic, M. Vujadinovic, A. Vukovic, M. Dacic, S. DiBiase, A.K. Prasad, and H.M. El-Askary. 2014. Regional dust storm modeling for health services: The case of Valley fever. Aeolian Research 14: 53–73.

Spencer, WD, P Beier, K Penrod, K Winters, C Paulman, H Rustigian-Romsos, J Strittholt, M Parisi, and A Pettler. 2010. California Essential Habitat Connectivity Project: a strategy for conserving a connected California. Prepared for California Department of Transportation, California Department of Fish and Game, and Federal Highways Administration.

State of California. 2014b. Contingency Plan for Excessive Heat Emergencies. A Supporting Document to the State Emergency Plan. California Office of Emergency Services, Sacramento, CA.

Steinberg, Nik, Emilie Mazzacurati, Josh Turner, Colin Gannon, Robert Dickinson, Mark Snyder, Bridget Thrasher. (Four Twenty Seven and Argos Analytics). 2018. Preparing Public Health Officials for Climate Change: A Decision Support Tool. California's Fourth Climate Change Assessment, California Natural Resources Agency. Publication number: CCCA4-CNRA-2018-012.

Steenwerth KL, Hodson AK, Bloom AJ et al. 2014. Climate-smart agriculture global research agenda: scientific basis for action. Agriculture and Food Security 3:11. https://agricultureandfoodsecurity.biomedcentral.com/articles/10.1186/2048-7010-3-11

Stollberger, C., W. Lutz, and J. Finsterer. 2009. Heat-related side-effects of neurological and non-neurological medication may increase heatwave fatalities. European Journal of Neurology 16: 879-882.

Stoms, D., G. Franco, H. Raitt, S. Wilhelm, S. Grant. 2013. Climate Change and the California Energy Sector. California Energy Commission. Publication. Number CEC-100-2013-002.

Stone, B., J. Vargo, P. Liu, D. Habeeb, A. DeLucia, M. Trail, Y. Hu, and A. Russell. 2014. Avoided heat-related mortality through climate adaptation strategies in three US cities. PLoS One, 9: e100852. doi:10.1371/journal.pone.0100852.

Suddeth, R., J.F. Mount, and J.R. Lund, "Levee decisions and sustainability for the Sacramento San Joaquin Delta", San Francisco Estuary and Watershed Science, Volume 8, No. 2, 23pp, August 2010.

Swain, D.L., Tsiang, M., Haugen, M., Singh, D., Charland, A., Rajaratnam, B. and Diffenbaugh, N.S., 2014. The extraordinary California drought of 2013/2014: Character, context, and the role of climate change. Bulletin of the American Meteorological Society, 95(9), p.S3.

Swain, D.L., 2015. A tale of two California droughts: Lessons amidst record warmth and dryness in a region of complex physical and human geography. Geophysical Research Letters, 42(22), p.9999.

Swain, D.L., , B. Langenbrunner, J. D. Neelin and A. Hall. 2018. Increasing precipitation volatility in twenty-first-century California. Nature Climate Change. Volume 8, pages 427–433. April 2018. https://www.nature.com/articles/s41558-018-0140-y

Syphard, AD, VC Radeloff, JE Keeley, TJ Hawbaker, MC Clayton, SI Stewart, and RB Hammer. 2007. Human influence on California fire regimes. Ecological Applications, 17:1388-1402.

Syphard, AD, JE Keeley, AH Pfaff, and K Ferschweiler. 2017. Human presence diminishes the importance of climate in driving fire activity across the United States. Proceedings of the National Academy of Sciences USA 114:13750–13755.

Tabnak F, K Knudson, G Cooksey, A Nguyen, D Vugia 2016. Epidemiologic Summary of Coccidioidomycosis in California. California Department of Public Health. June 2017.

Taha, Haider, George Ban-Weiss, Sharon Chen, Haley Gilbert, Howdy Goudey, Joseph Ko, Arash Mohegh, Angie Rodriguez, Jonathan Slack, Haider Taha, Tianbo Tang, Ronnen Levinson. (Lawrence Berkeley National Laboratory). 2018. Modeling and Observations to Detect Neighborhood-Scale Heat Islands and Inform Effective Countermeasures in Los Angeles. California's Fourth Climate Change Assessment, California Energy Commission. Publication Number: CCCA4-CEC-2018-007.

Teng, H. and Branstator, G., 2017. Causes of extreme ridges that induce California droughts. Journal of Climate, 30(4), pp.1477-1492.

The Economics of Ecosystems and Biodiversity. 2018. Ecosystem Services. Available at: http://www.teebweb.org/resources/ecosystem-services/.

Thomas, Nancy, Shruti Mukhtyar, Brian Galey, Maggi Kelly. (University of California, Berkeley). 2018. Visualizing Climate-Related Risks to the Natural Gas System using Cal-Adapt. California's Fourth Climate Change Assessment, California Energy Commission. Publication number: CCCA4-CEC-2018-015

Thorne, JH, RM Boynton, AJ Holguin, JAE Stewart, and J Bjorkman. 2016. A climate change vulnerability assessment of California's terrestrial vegetation. California Department of Fish and Wildlife (CDFW), Sacramento, CA.

Thorne, J. H., H. Choe, R. M. Boynton, J. Bjorkman, W. Albright, K. Nydick, A. L. Flint, L. E. Flint, and M. W. Schwartz. 2017. The impact of climate change uncertainty on California's vegetation and adaptation management. Ecosphere 8(12):e02021. 10.1002/ecs2.2021.

Trent, R.B. 2007. Review of July 2006 Heat Wave Related Fatalities in California. California Department of Health Services, Sacramento, CA.

Trombley, J., S. Chalupka, L. Anderko. 2017. Climate Change and Mental Health. American Journal of Nursing: April 2017 - Volume 117 - Issue 4 - p 44–52. doi: 10.1097/01.NAJ.0000515232.51795.fa. Available online https://journals.lww.com/ajnonline/fulltext/2017/04000/Climate_Change_and_Mental_Health.28.aspx

Under2 Coalition. 2018. The Under2 MOU. http://www.under2coalition.org/under2-mou. [Accessed on June 7, 2018].

United Nations Framework Convention on Climate Change (UNFCCC). 2018. The Paris Agreement. https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement. [Accessed on June 7, 2018].

Upperman, Crystal Romeo, J. D. Parker, L. J. Akinbami, C. Jiang, X. He, R. Murtugudde, F. C. Curriero, L. Ziska, and A. Sapkota. Exposure to extreme heat events is associated with increased hay fever prevalence among nationally representative sample of US adults: 1997–2013 J Allergy Clin Immunol Pract. 2017 ; 5(2): 435–441.e2. doi:10.1016/j.jaip.2016.09.016.

U.S. Department of Energy (USDOE), Office of Energy Policy and Systems Analysis, "Climate Change and the U.S. Energy Sector. Regional Vulnerabilities and Resiliency Solutions," October 2015. https://energy.gov/sites/prod/files/2015/10/f27/Regional_Climate_Vulnerabilities_and_Resilience_Solutions_0.pdf

U.S. Department of Energy (USDOE), Office of Electricity Delivery & Energy Reliability (OE), State Energy Risk Profile. 2016. https://energy.gov/sites/prod/files/2016/09/f33/CA_Energy%20Sector%20Risk%20Profile.pdf

U.S. Energy Information Administration (EIA), 2018. California - State Energy Profile Overview - https://www.eia.gov/state/maps.php

U.S. Energy Information Administration (EIA), 2018. 2016 Form EIA-860 Data - Schedule 3, 'Generator Data' (Operable Units Only). https://www.eia.gov/electricity/data/eia860/

U.S. Environmental Protection Agency (US EPA). 2017. Multi-Model Framework for Quantitative Sectoral Impacts Analysis: A Technical Report for the Fourth National Climate Assessment.

United States Environmental Protection Agency, Report EPA 430-R-17-001, Washington, DC.

U.S. Global Change Research Program (USGCRP). 2016. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. Crimmins, A., J. Balbus, J.L. Gamble, C.B. Beard, J.E. Bell, D. Dodgen, R.J. Eisen, N. Fann, M.D. Hawkins, S.C. Herring, L. Jantarasami, D.M. Mills, S. Saha, M.C. Sarofim, J. Trtanj, and L. Ziska, Eds. U.S. Global Change Research Program, Washington, DC.

Ulmer, Jared M., Kathleen L. Wolf, Desiree R. Backman, Raymond L. Tretheway, Cynthia JA Blain, Jarlath PM O'Neil-Dunne, Lawrence D. Frank, Multiple health benefits of urban tree canopy: The mounting evidence for a green prescription, Health & Place, 42, 2016: 54-62. https://doi.org/10.1016/j.healthplace.2016.08.011.

Vahmani, P., F. Sun, A. Hall, and G. Ban-Weiss. 2016. Investigating the climate impacts of urbanization and the potential for cool roofs to counter future climate change in Southern California. Environmental Research Letters 11: 124027. doi:10.1088/1748-9326/11/12/124027.

Vins, H., J. Bell, S. Saha, and J.J. Hess. 2015. The mental health outcomes of drought: a systematic review and causal process diagram. International Journal of Environmental Research and Public Health 12: 13 251-13 275.

Wang, H. and Schubert, S., 2014. Causes of the extreme dry conditions over California during early 2013. Bulletin of the American Meteorological Society, 95(9), p.S7.

West, J.J., S.J. Smith, R.A. Silva, V. Naik, Y. Zhang, Z. Adelman, M.M. Fry, S. Anenberg, L.W. Horowitz, and J.F. Lamarque. 2009. Co-benefits of mitigating global greenhouse gas emissions for future air quality and human health. Nature Climate Change 3 : 885–889.

Westerling, AL, BP Bryant, HK Preisler, TP Holmes, HG Hidalgo, T Das, and SR Shrestha. 2011. Climate change and growth scenarios for California wildfire. Climatic Change 109 (Suppl 1):S445–S463.

Westerling, A.L., 2016. Increasing western US forest wildfire activity: sensitivity to changes in the timing of spring. Phil. Trans. R. Soc. B, 371(1696), p.20150178.

White House Council on Environmental Quality. 2010. Progress Report of the Interagency Climate Change Adaptation Task Force: Recommended Actions in Support of a National Climate Change Adaptation Strategy. Report available https://obamawhitehouse.archives.gov/sites/default/files/microsites/ceq/Interagency-Climate-Change-Adaptation-Progress-Report.pdf

Wilder, M., D. Liverman, L. Bellante, and T. Osborne. 2016. Southwest climate gap: Poverty and environmental justice in the US Southwest. Local Environment 21: 1332-1353.

Williams, JW, and ST Jackson. 2007. Novel climates, no-analog communities, and ecological surprises. Frontiers in Ecology and the Environment 5:475-482.

Willis, A.D., J.R. Lund, E. S. Townsley, and Beth Faber, "Climate Change and Flood Operations in the Sacramento Basin, California," San Francisco Estuary and Watershed Science, Vol. 9, No. 2, 18 pp., July, 2011.

Woodruff, S.C. and M. Stults. 2016. Numerous strategies but limited implementation guidance in US local adaptation plans. Nature Climate Change 6: 796-802.

Worfolk, J.B. 2000. Heat waves: their impact on the health of elders. Geriatric Nursing 21: 70-77.

Wright L, Chinowsky P, Strzepek K, Jones R, Streeter R, Smith JB, Mayotte J-M, Powell A, Jantarasami L, Perkins W (2012) Estimated effects of climate change on flood vulnerability of U.S. bridges. Mitig Adapt Strateg Glob Change 17(8):939–955

Yang, Z., Dominguez, F., Zeng, X., Hu, H., Gupta, H. and Yang, B., 2017. Impact of irrigation over the California Central Valley on regional climate. Journal of Hydrometeorology, 18(5), pp.1341-1357.

Yardley, J.E., J.M. Stapleton, R.J. Sigal, and G.P. Kenny. 2013. Do heat events pose a greater health risk for individuals with type 2 diabetes? Diabetes Technology and Therapeutics 15: 520-529.

Yates, D., J. Meldrum, and K. Averyt. 2013. The influence of future electricity mix alternatives on Southwestern US water resources. Environmental Research Letters 8: 045005. doi:10.1088/1748-9326/8/4/045005.

Ye, X., R. Wolff, W. Yu, P. Vaneckova, X. Pan, and S. Tong. 2012. Ambient temperature and morbidity: a review of epidemiological evidence. Environmental Health Perspectives 120: 19-28.

Yeh, Sonia, Christopher Yang, Michael Gibbs, David Roland-Holst, Jeffery Greenblatt, Amber Mahone, Dan Wei, Gregory Brinkman, Joshua M. Cunningham, Anthony R. Eggert, Ben Haley, Elaine Hart, Jim Williams (2016) A Modeling Comparison of Deep Greenhouse Gas Emissions Reduction Scenarios by 2030 in California. Energy Strategy Reviews 13, 168 – 180

Yoon, J.H., Wang, S.S., Gillies, R.R., Kravitz, B., Hipps, L. and Rasch, P.J., 2015. Increasing water cycle extremes in California and in relation to ENSO cycle under global warming. Nature communications, 6, p.8657.

Young, DJN, JT Stevens, J M Earles, J Moore, A Ellis, AL Jirka, and AM Latimer. 2017. Long-term climate and competition explain forest mortality patterns under extreme drought. Ecology Letters 20:78-86.

Zapata C.B., Yang C., Yeh S., Ogden J., and Kleeman M.J. 2018. Low Carbon Energy Generates Public Health Savings in California. Atmos. Chem. Phys. https://www.atmos-chem-phys-discuss.net/acp-2017-796/.

Zender, C.S. and Talamantes, J., 2006. Climate controls on valley fever incidence in Kern County, California. International Journal of Biometeorology, 50(3), pp.174-182.

Ziegler, C., V. Morelli, and O. Fawibe. 2017. Climate change and underserved communities. Primary Care 44: 171-184.

Ziska, L.H. 2003. Evaluation of the growth response of six invasive species to past, present and future atmospheric carbon dioxide. Journal of Experimental Botany 54: 395-404.

Ziska, L.H. and L.L. McConnell. 2016. Climate change, carbon dioxide, and pest biology: monitor, mitigate, manage. Journal of Agricultural and Food Chemistry 64, 6-12.

Ziska, L.H. and P.J. Beggs. 2012. Anthropogenic climate change and allergen exposure: The role of plant biology. Journal of Allergy and Clinical Immunology 129: 27-32.

Ziska, L.H., D.E. Gebhard, D.A. Frenz, S. Faulkner, B.D. Singer, and J.G. Straka. 2003. Cities as harbingers of climate change: common ragweed, urbanization, and public health. Journal of Allergy and Clinical Immunology 111: 290-295.

Zscheischler J., Westra S., van den Hurk B.J.J.M. , Seneviratne S.I., Ward P.J., Pitman A., AghaKouchak A., Bresch D.N., Leonard M., Wahl T., Zhang X., 2018, Future climate risk from compound events, Nature Climate Change.