Central Valley Landscape Conservation Project:
Overview of Projected Future Changes in the California Central Valley

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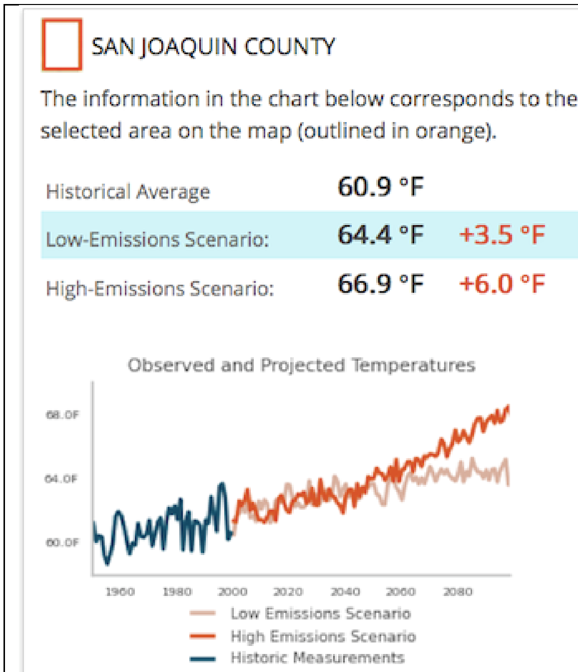
Temperature

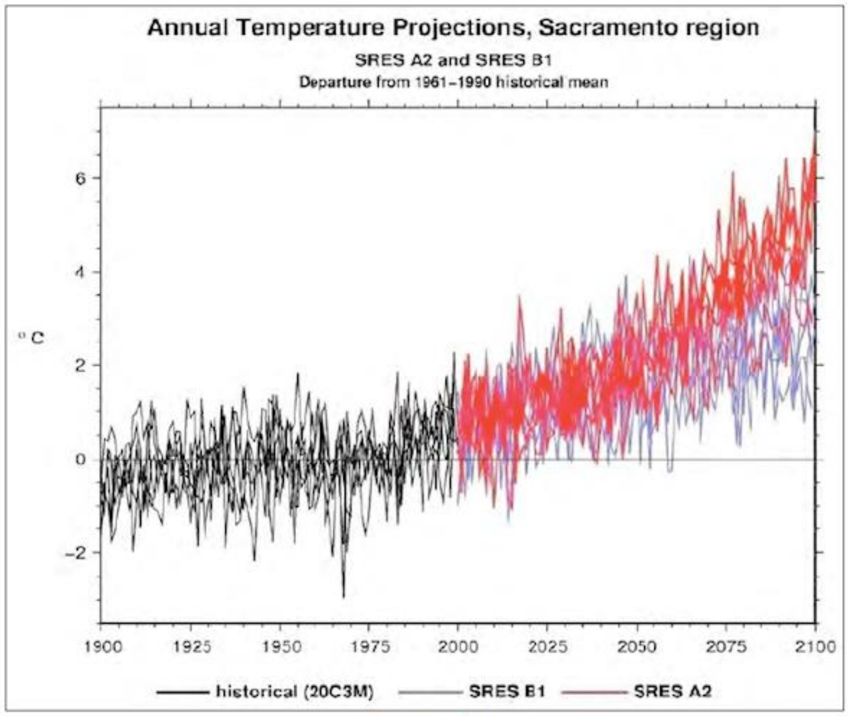
Temperatures in California will rise significantly during this century as a result of the heat-trapping gases humans release into the atmosphere. This broad conclusion holds regardless of the climate model used to project future warming. However, warming will be significantly greater with higher emissions than with lower emissions.

By 2050, California is projected to warm by approximately 2.7°F above 2000 averages, a threefold increase in the rate of warming over the last century. The different models produce similar results due to being based on greenhouse gases already emitted. By 2100, average temperatures could increase by 4.1–8.6°F, depending on emissions levels. Springtime warming — a critical influence on snowmelt — will be particularly pronounced (California Climate Change Center, 2012).

Higher temperatures have contributed to regional drought conditions and increased climatic water deficit by enhancing evaporation (Griffin & Anchukaitis 2014; Williams et al. 2015)

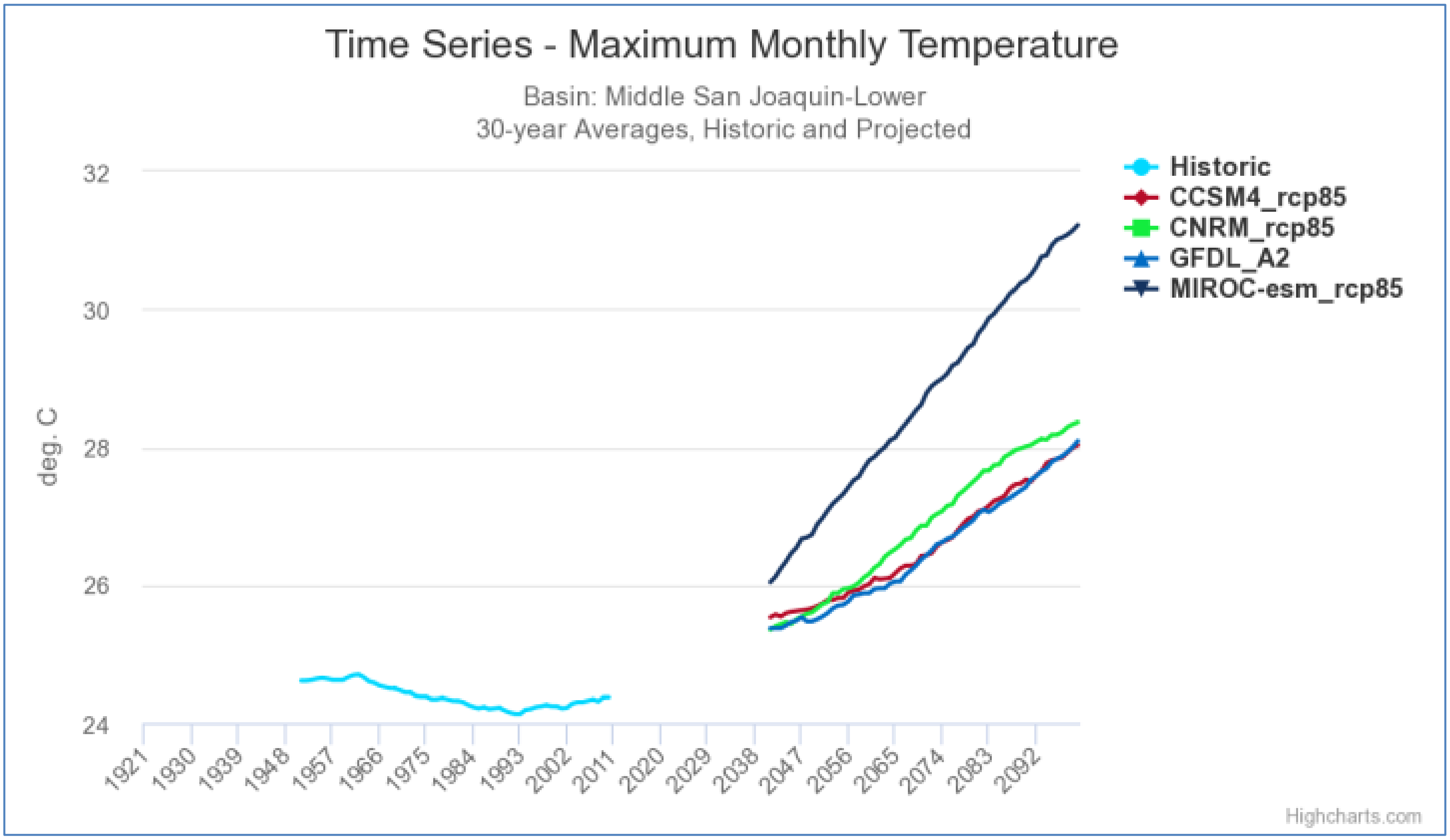


Above: Graph from CalAdapt using CMIP3 models



Source: Cayan et al. 2009

Figure 2.C-3. Simulated Historical and Future Annual Temperature Projections for the Sacramento Region

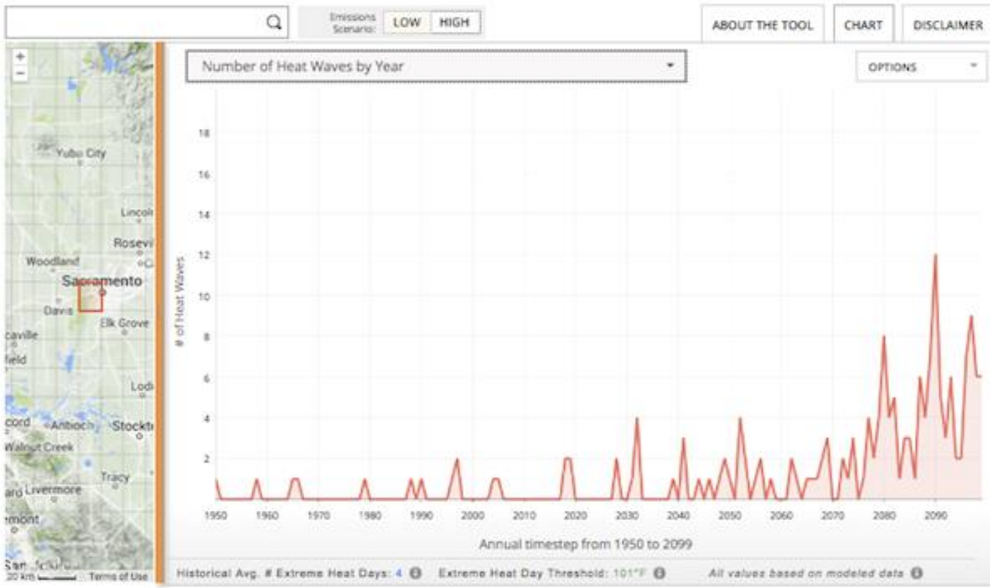


Above: Maximum monthly temperatures averaged over 30 years for the Middle San Joaquin-Lower HUC-8 watershed, showing overall warming trend and differences between four models using high greenhouse gas scenarios. Data source: 2014 CA Basin Characterization Model access using the California Climate and Hydrology Change Graphs.

Heat Waves and Extreme Heat

All models project a significant rise in the frequency, intensity, duration, and spatial footprint of heat waves as well as an expansion of the season in which they occur. Several model simulations for a location near Sacramento contain a more-than-threefold increase in frequency and an increase in intensity of hot days. Within a given heat wave, there is an increasing tendency for multiple hot days in succession (Cayan et. al. 2009)

In the graph below from CalAdapt, every year in the last quarter of the century is projected to have one or more 5-day periods with temperatures exceeding today's threshold considered extreme for the region.



Above: A chart from CalAdapt showing a count of 5 day heat waves projected for 1950-2099.

Precipitation

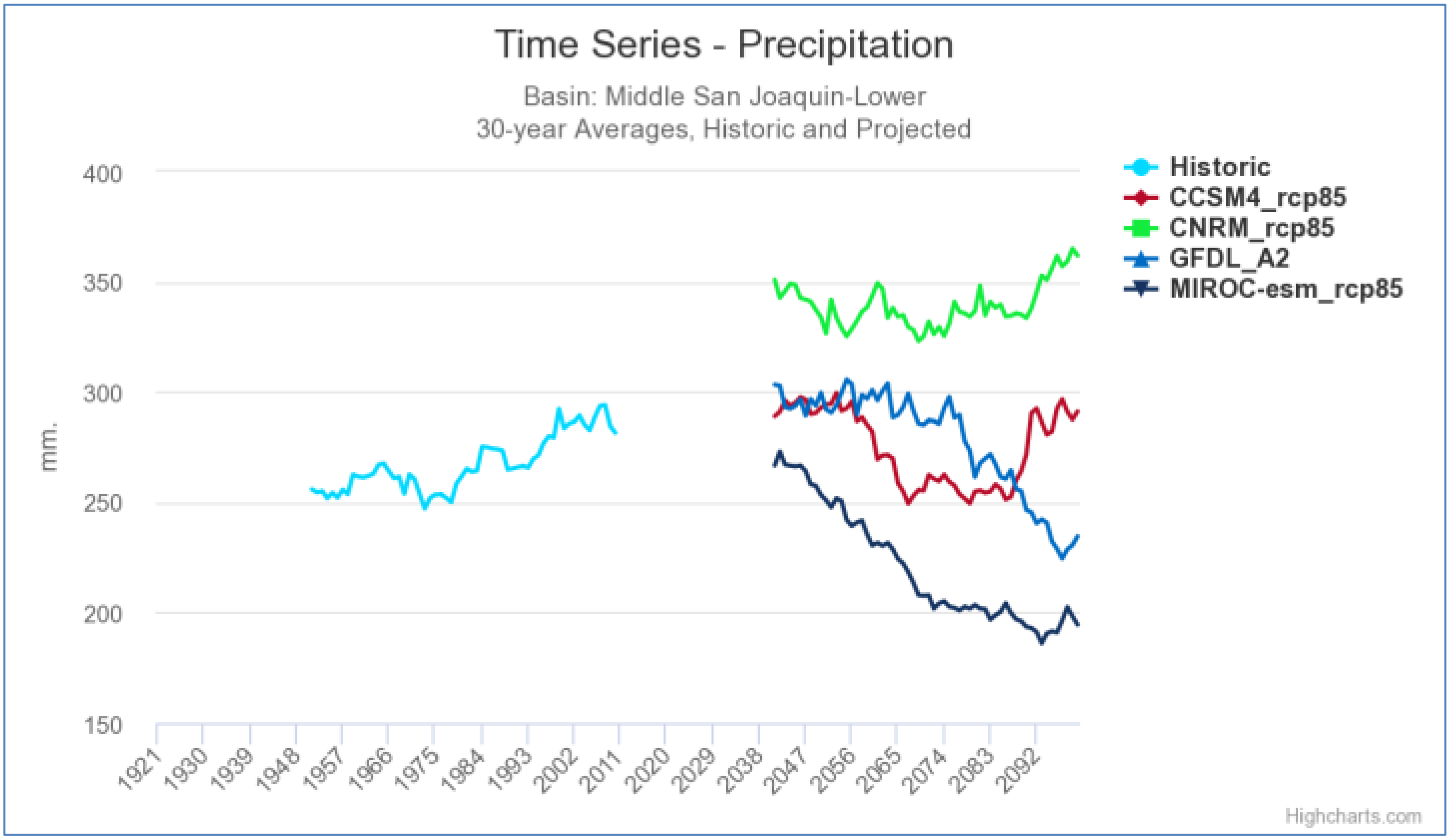
Models indicate a wide range of potential future changes in precipitation for California and the Central Valley. The direction of change is uncertain, with some models projecting more overall average rainfall and others projecting less rainfall, however, by the mid and late century, most models project drier conditions than the historical annual average for California (Cayan 2012).

Precipitation in the Central Valley is on a north-south gradient, with more rain falling in the northern regions; annual amounts range widely from 165-611 mm (Scanlon et al. 2012). 79-85% of the region's precipitation is received between November and March (Scanlon et al. 2012). There has been a slight trend towards decreased and more variable precipitation in central and southern California over the last 100 years (Hunsaker et al. 2014).

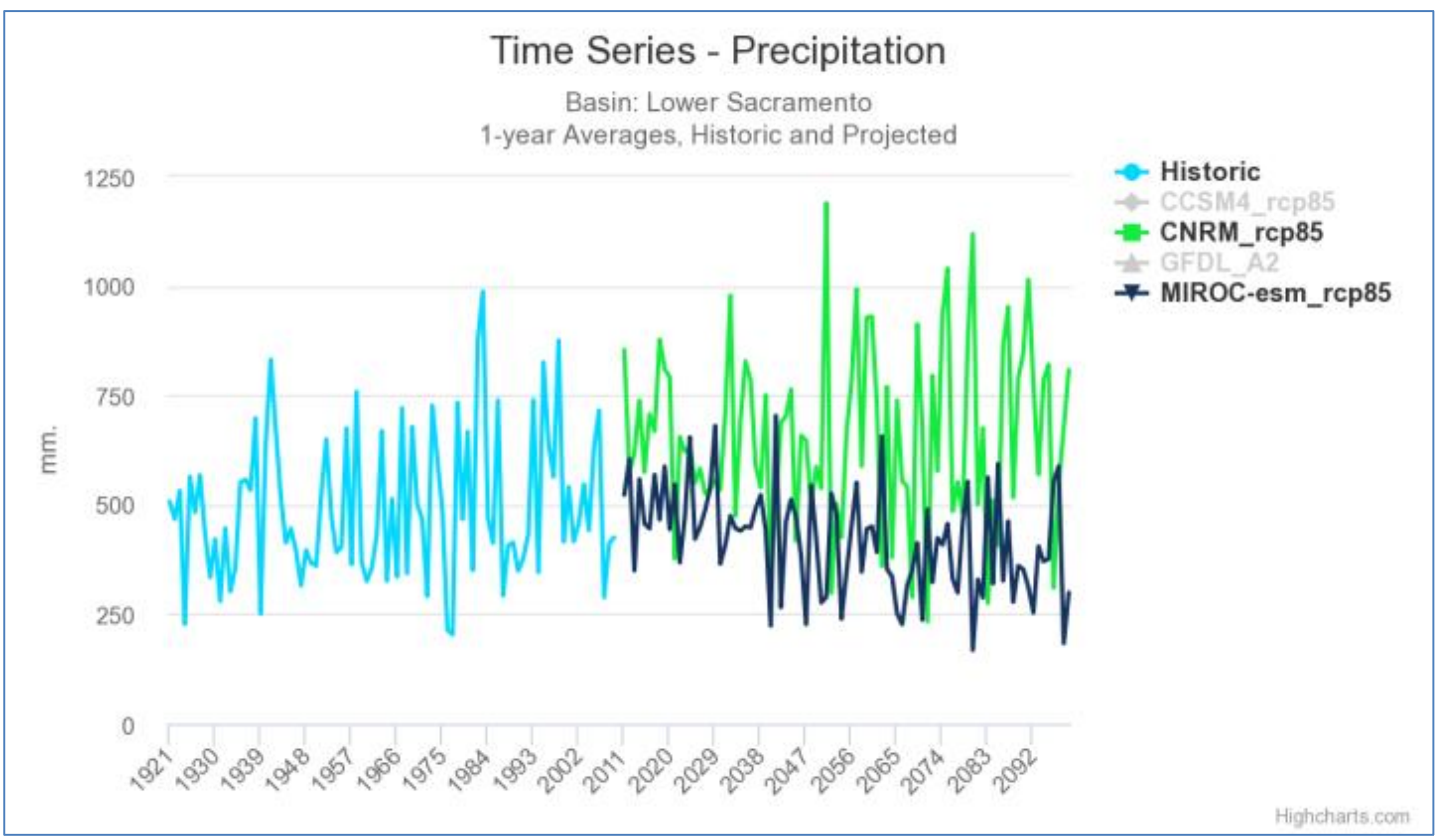
For California, overall winter precipitation is projected to decrease by 15%-30% by the year 2100, with reductions concentrated in the Central Valley and along the north Pacific Coast (Hayhoe et al. 2004, Cayan et al. 2009). Some areas in northern California may experience higher annual rainfall amounts and potentially larger storm events, but California as a whole, particularly southern California, are projected be 15 to 35% drier by 2100 (Cayan et al. 2009). Some projections suggest that annual precipitation may increase slightly in the Sacramento River Basin and decrease slightly in the San Joaquin River Basin by 2050 (Bureau of Reclamation 2015), and precipitation extremes may increase (Toreti et al. 2013). The southern portion of the Central Valley is more sensitive to precipitation and water availability changes due to its drier climate, although water from snowmelt may help buffer water shortages during the winter and spring (Kahara et al. 2012)

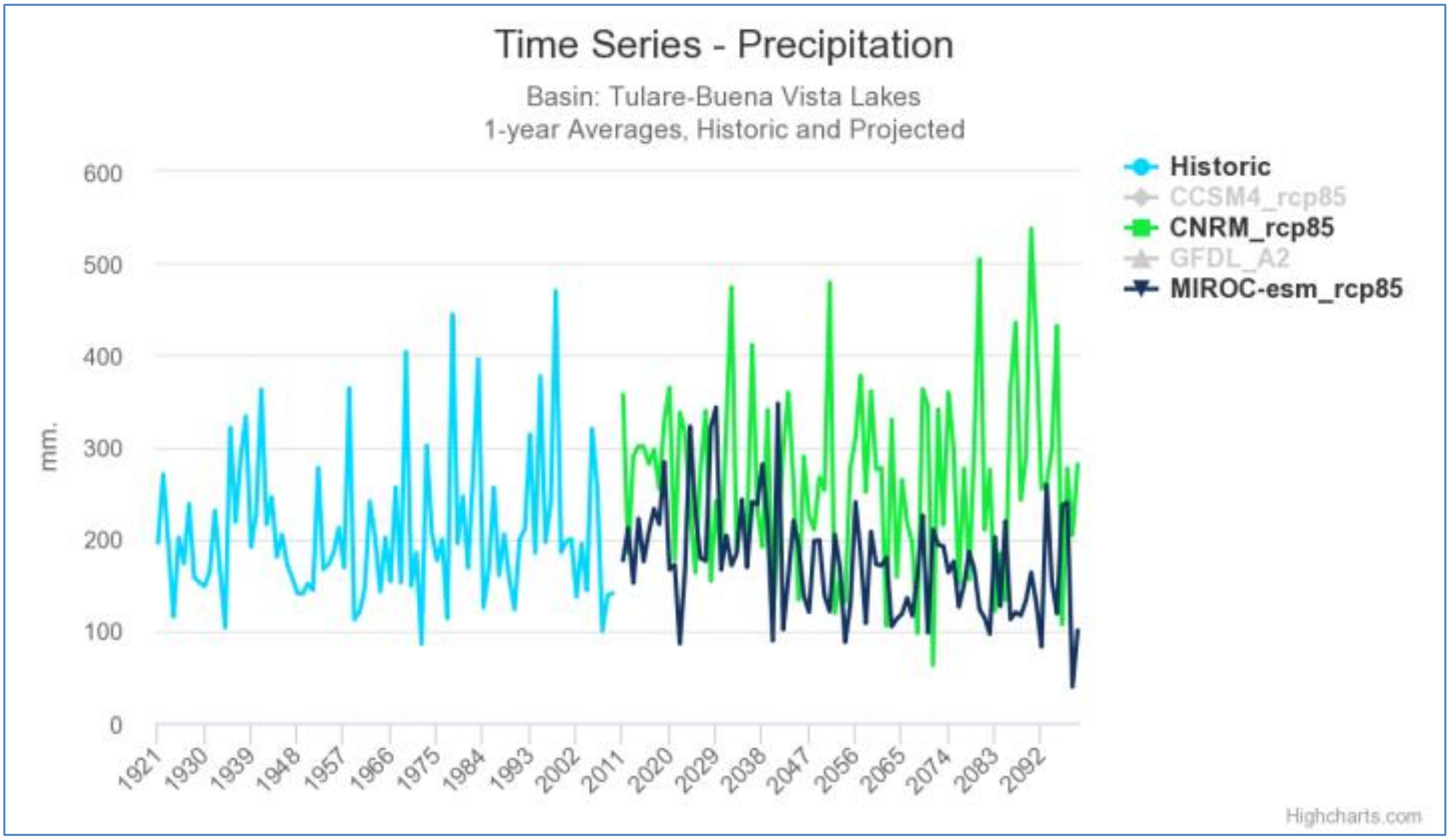
In addition to potential changes in average rainfall, models project changes in precipitation patterns, such as increased variability (Hunsaker et al. 2014) and an increase in frequency of intense storms and shifts in seasonality (Dettinger 2011).

Regardless of changes in precipitation, warmer temperatures are expected to increase evapotranspiration and cause drier conditions (Cook et al. 2015). Models with both more and less overall precipitation for California indicate an increase in climatic water deficit (Flint et. al. 2013).



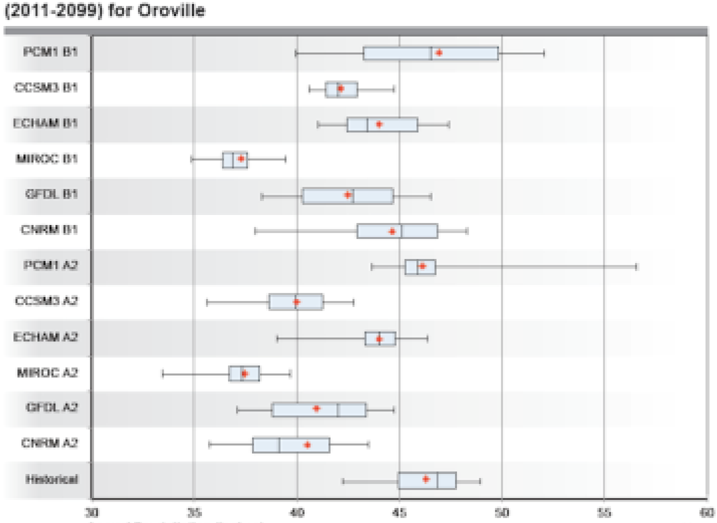
Above: Historical and modeled future precipitation for the Middle San Joaquin-Lower Hydrologic Basin using a 30-year running average, showing overall trends and comparing four models using high greenhouse gas scenarios. Data source: 2014 CA Basin Characterization Model access using the California Climate and Hydrology Change Graphs.



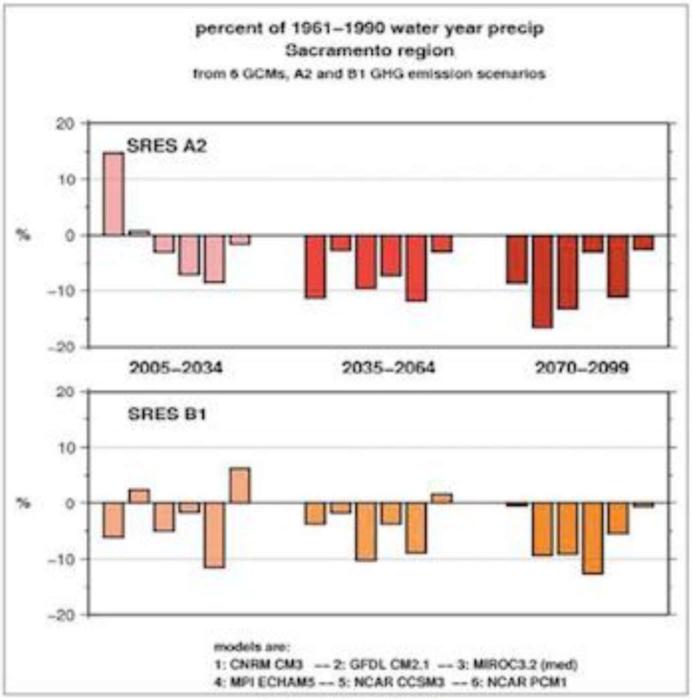


Above: Annual average historical and projected precipitation for the Lower Sacramento and Tulare-Buena Vista Lakes hydrologic units, showing a wet (CNRM) and a dry (MIROC-esm) model. Data source: 2014 Basin Characterization Model graphed using the California Climate and Hydrology Change Graphs tool on the Climate Commons.

Figure 5-3 Variation in 30-Year Running Average precipitation for Historical Record (1915-2003) and Alternative Scenarios of Future Simulated Climate (2011-2099) for Oroville



Above: Precipitation projections from the California Water Plan Update 2013.



Source: Cayan et al. 2009

Above: Projected change in Sacramento region precipitation, using five GCMs with A2 and B1 scenarios. Graph from the Bay Delta Conservation Plan.

Drought and Aridity

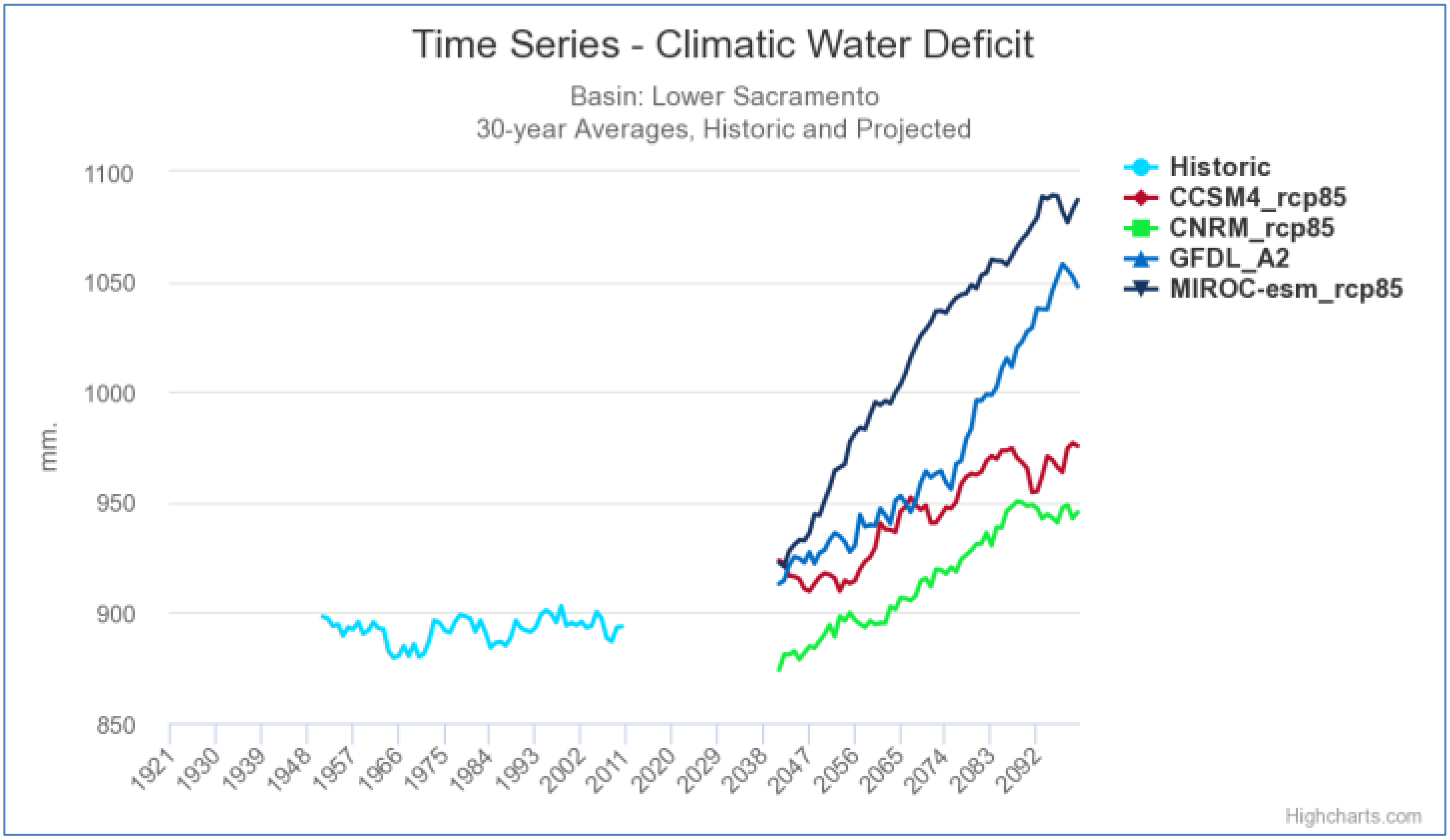
Compared to the preceding century, drought years in California have occurred twice as often in the last 20 years (Diffenbaugh et al. 2015). Additionally, the recent drought (2012-2014) has been the most severe drought on record in the Central Valley (Williams et al. 2015), with record accumulated moisture deficits driven by high temperatures and reduced, but not unprecedented, precipitation (Griffin & Anchukaitis 2014; Williams et al. 2015). Recent studies have found that anthropogenic warming has substantially increased the overall likelihood of extreme California droughts, including decadal and multi-decadal events (Cook et al. 2015; Diffenbaugh et al. 2015; Williams et al. 2015).

Comparatively, the frequency and severity of drought is expected to increase due to climate change over the next century (Hayhoe et al. 2004; Cook et al. 2015; Diffenbaugh et al. 2015; Williams et al. 2015). Diffenbaugh et al. (2015) and Mann and Glieck (2015) show that the increasing co-occurrence of dry years with warm years raises the risk of drought regardless of a trend in precipitation itself, highlighting the critical role of elevated temperatures in altering water availability and increasing overall drought intensity and impact.

The impacts of drought are expected to increase as warming temperatures exacerbate dry conditions in years with low precipitation, causing more severe droughts than have previously been observed (Cook et al. 2015; Diffenbaugh et al. 2015).

Overall aridity is expected to increase across California, concurrent with warming temperatures. Yearly average climatic water deficit, a measure of potential water demand by plants that is unmet by soil moisture, is projected to increase steadily. Beyond the year 2030 the 10-year average consistently exceeds the historical extreme. Precipitation and soil moisture patterns influence the distribution and species composition of vegetation types and habitats across the study region. Future water demand is expected to increase as climate changes interact with expanding urban populations (Dept. of Water Resources, 2013).

Read more about Drought and Climate Change.



Above: Yearly Climatic Water Deficit for the Lower Sacramento Basin showing four models, using a 30-year running average Data source: 2014 CA Basin Characterization Model graphed using the California Climate and Hydrology Graphs, Climate Commons 2015 tool on the Climate Commons.

Sierra Nevada Snowpack, Snowmelt, and Runoff

Snowmelt from mountainous areas surrounding the Central Valley plays a large part in water storage and supply, releasing meltwater gradually to recharge aquifers and flow downstream into the Central Valley (Knowles & Cayan 2002; Scanlon et al. 2012; California Rice Commission 2013). As one of the primary sources of water for irrigation and wetland management throughout the Central Valley (Domagalski et al. 2000; Scanlon et al. 2012), reduced snowpack could lead to summer water shortages and altered streamflow patterns (Miller et al. 2001; Knowles & Cayan 2002; Kiparsky & Gleick 2003; Vicuna et al. 2007).

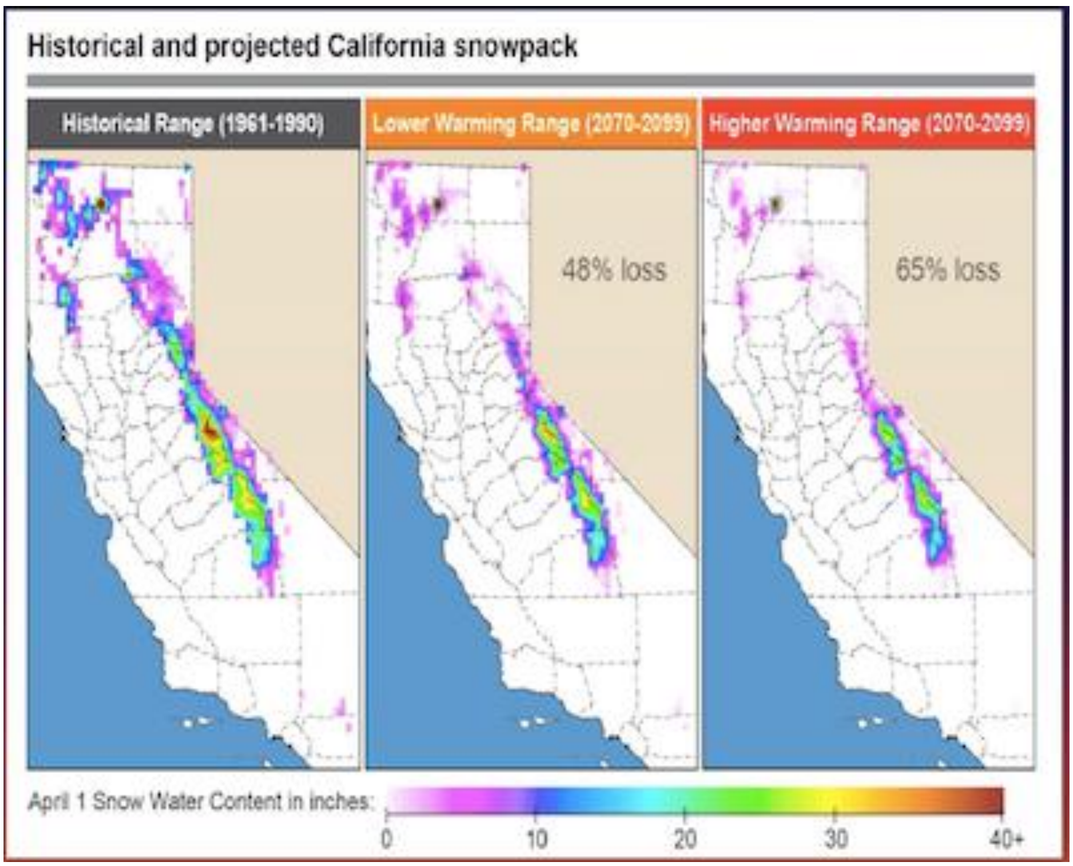
The timing of springtime snowmelt in the Sierra Nevada is controlled by air temperature and has been earlier in recent years (Dept. of Water Resources 2013). Regardless of the amount of precipitation, less is likely to fall as snow, and snowpack will not maintain the water supply as long into the dry season as at present. Warmer temperatures have already resulted in reduced snowpack, greater proportions of rainfall compared to snowfall, increased rain-on-snow events, and earlier snowmelt in many areas of the western U.S., with the biggest changes observed in rivers with low-elevation headwaters (Regonda et al. 2005; McCabe & Clark 2005).

Warmer temperatures are already leading to earlier spring snowmelt and peak flows in the Sierra Nevada (Hayhoe et al. 2004; Stewart et al. 2005; Thorne et al. 2015), changing the timing and amount of water available in regions that receive much of their water from snowmelt (Moser et al. 2009; Yarnell et al. 2010; Thorne et al. 2015). In the Sacramento and San Joaquin basins, April-July runoff volume has decreased over the last 100 years by 23% and 19% respectively, reflecting earlier timing of peak flows (Anderson et al. 2008).

Earlier snowmelt accelerates the release of water from the snowpack, leading to earlier and higher peak flows, followed by reduced summer flows and longer periods of summer drought (Yarnell et al. 2010). Higher peak flows are likely to increase spring flooding (Jackson et al. 2011), which requires larger releases of stored water from reservoirs in order to meet flood control requirements (Kiparsky & Gleick 2003; Anderson et al. 2008). This results in a net loss of spring runoff that is normally stored, and decreases water availability for the summer growing season and post-harvest flooding practices (Anderson et al. 2008).

The timing of peak monthly runoff is projected to continue to shift earlier in the year, further constraining water management by reducing the ability to refill reservoirs after the flood season has passed. Instead of the snowmelt providing runoff during the dry spring and summer, it will be greatest during cool seasons when demand for water is less and the desire for flood control space behind dams is greatest, and there will be less runoff in warm seasons when demands for water are high and likely to increase with warming temperatures. Dam releases provide a cold water supply that will be increasingly needed to counter the effects of climate change on native fishes (Dept. of Water Resources 2013).

A reduction in snowpack in the Sierra Nevada Mountains combined with earlier runoff and reduced spring and summer stream flows will likely affect surface water supplies, decreasing water availability for the summer growing season and post-harvest flooding practices (Anderson et al. 2008) and shift reliance to groundwater resources for water for 85% of California's population in the Central Valley (Hayhoe et al. 2004).



Above: Projected April 1 snow water equivalent 2070-2099, from Pierce and Cayan, 2012 in the California Water Plan (2013).

Snowpack and runoff projection summary:

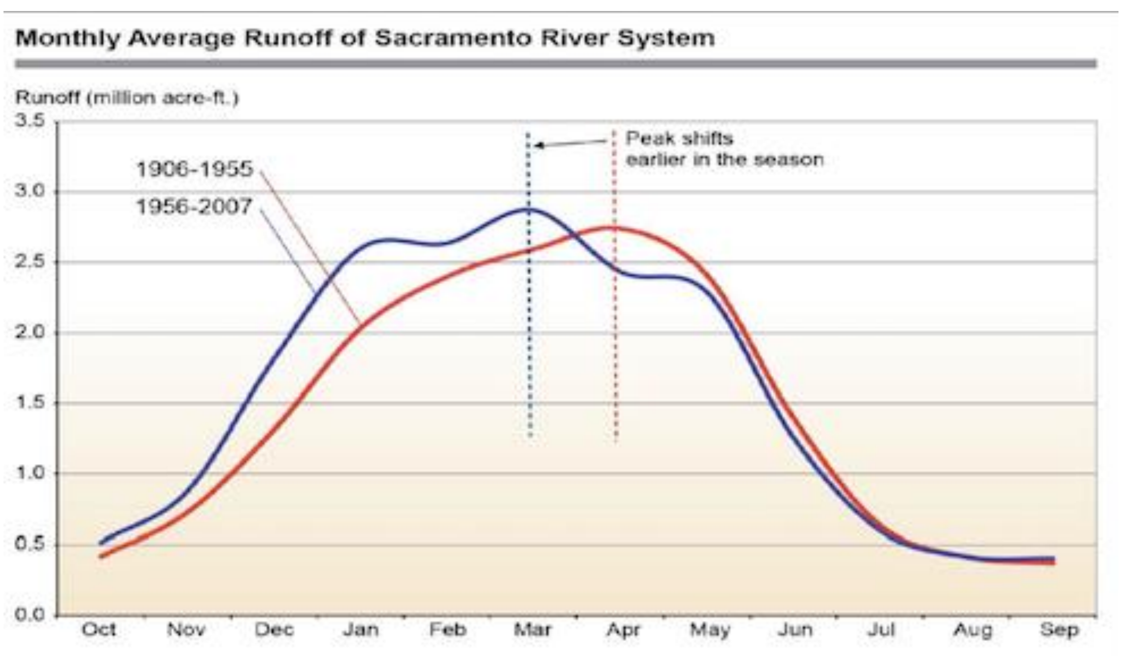
- 30-40% reduction in snow water equivalent across the Sierras by mid-century
- 65% less snowpack by end of century
- Earlier snowmelt runoff
- Changing stream flows and water temperatures
- 15-20% lower soil moisture

Stream Flow and Temperatures

Total annual water year runoff has increased for the Sacramento River basins and decreased for the San Joaquin River basins, but both areas experienced decreases in spring runoff, which has declined by 9% for the Sacramento River system and by 7% for the San Joaquin River system in the 20th century (Hunsaker et al. 2014). Spring snowmelt has shifted earlier in the year and peak surface water flows from associated runoff has shifted from April to March (California Resources Agency, 2013.)

Streamflow will likely be impacted by reduced snowpack and more rapid snowmelt runoff, which could manifest in decreases in mean annual flow, especially during the summer months (Knowles & Cayan 2002; Miller et al. 2003; Medellín-Azuara et al. 2007; Vicuna et al. 2008). Although earlier snowmelt may lead to higher peak flows in many cases, drastically reduced snowpack may ultimately lower the magnitude of spring flows. Projections from a suite of model emissions scenarios show a decrease in California's average streamflow from April to October, with the greatest drop in June and July (Schramm and Loehman. 2012). Modeling shows that a temperature increase of 7°F (4°C) and a 20% increase in precipitation could increase winter runoff by 75% and decrease the summer runoff by 49% (Schramm and Loehman. 2012). Stream discharge is projected to increase by 30–90% for the Northern Sierra Nevada and 50–100% for Southern Sierra by end of century (Das et al. 2013). Projections of streamflow in the latter half of the 21st century yield "critically dry" water years 8% more often than in 1951–2000 in the Sacramento Valley and 32% more often in the San Joaquin Valley (Null and Viers, 2013). Stream channels are highly sensitive to changes in flow regimes, which drive sediment transport, channel migration, floodplain access or accretion, the development of riparian zones, and instream bedload quality (Poff et al. 1997; Stromberg et al. 2007; Perry et al. 2012; Wohl et al. 2015).

Earlier snowmelt and drought contribute to low flow conditions and associated elevated water temperatures (Yarnell et al. 2010). Water temperatures may increase by 1.6°C for each 2°C rise in air temperature, with most of the warming occurring during the spring months (Null et al. 2013).



Above: Monthly average runoff of Sacramento River System, from the [California Water Plan (2013)]

Storms and Flooding

An analysis of climate change projections for California indicates that although the average intensity of atmospheric river (AR) events does not increase, there may occur more years with many AR events and occasional events that are much stronger than historical ones. Moreover, the length of the season over which AR events may occur is predicted to increase. These changes to the patterns of AR events may result in more frequent and more severe floods in California (Dettinger 2011). Hydrological models project larger and more frequent winter floods as rain-on-snow events and winter snowmelt become more common in the headwaters (Hamlet & Lettenmaier 2007).

Models suggest that flooding may become more intense on the western slopes of the Sierra Nevada mountains, which feed Central Valley streams and rivers. Regardless of precipitation projections all models project that by end of century, and discharges from the Northern Sierra Nevada with 50-year return periods increase by 30–90% compared to historical values. Corresponding flood flows from the Southern Sierra increase by 50–100%. (Das et al., 2013). Higher peak flows from earlier and more rapid snowmelt are likely to increase spring flooding (Jackson et al. 2011).

More intense summer monsoon rainstorms and more frequent winter frontal rainstorms in the monsoon region would likely increase flooding in monsoon-dominated rivers (Vivoni et al. 2009).

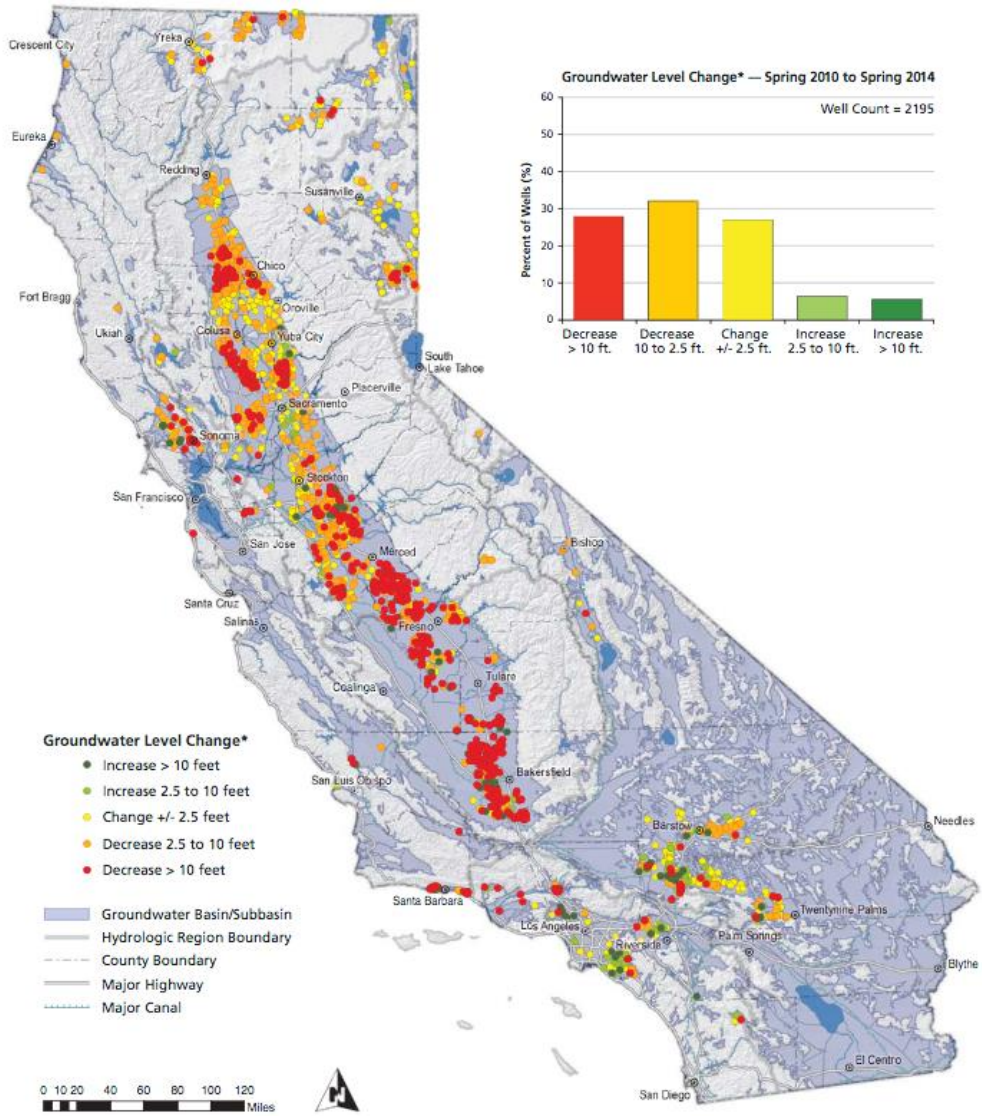
Groundwater

Population growth, expansion of agricultural practices, allocation of water to environmental resources and restrictions to protect threatened species all have contributed to either increased water demand or decreased availability of surface water supplies in California. In response, many water users pump groundwater to offset the reduction in surface water supply.

Groundwater depletion, which occurs when water demand through pumpage exceeds water supply through recharge, was estimated to be approximately 140 cubic km [60 km 3 from the 1860s to 1961 and 80 cubic km from 1962 to 2003, representing about 14% of estimated groundwater in storage before irrigation (1,000 cubic km). Groundwater depletion in the Central Valley occurs mostly in the Tulare basin and primarily during droughts when surface water and allocations are scarce (Scanlon et. al., 2012). Severe drought in 2014 resulted in a lack of adequate surface water supplies, forcing many water users to increase groundwater pumping. During the last two decades, more agricultural lands have been converted from annual crops to permanent vine and tree crops resulting in water demand hardening. Permanent crops require irrigation during the drought, while in the past many acres of annual crops were left idle through drought years.

These factors have resulted in further decline in groundwater levels and storage in the Central Valley from the 2010 levels. Recent increases in groundwater pumping have resulted in renewed land subsidence in some areas and initiated new areas of land subsidence in others.

Climate change, resulting in reduced snowpack and possibly reduced precipitation in the Central Valley region, will exacerbate the water supply and demand imbalance, putting additional pressure on the region's groundwater resources (Dept. of Water Resources, 2015).

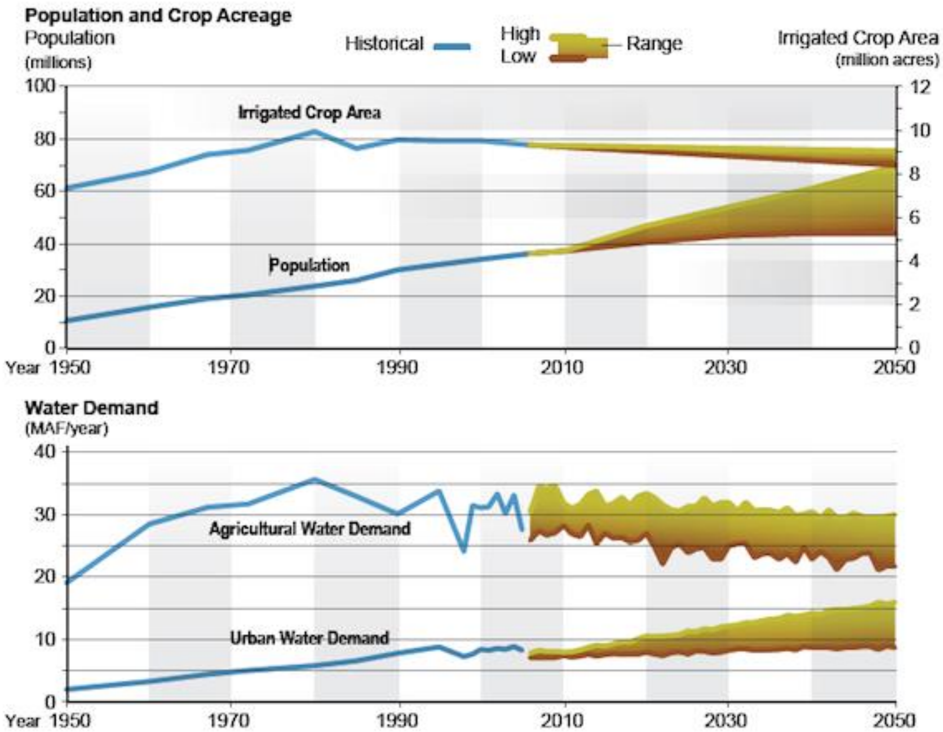


Above: Groundwater level change determined from water level measurements in wells. Map and chart based on available data from the DWR Water Data Library as of 11/08/2014. From the California Department of Water Resources Groundwater Sustainability Program Draft Strategic Plan, 2015.

Agriculture and Urban Land and Water Use

Future water demand is affected by a number of growth and land use factors, such as population growth, planting decisions by farmers, and size and type of urban landscapes. For the California Water Plan, the UPlan model was used to estimate a year 2050 urban footprint under the scenarios of alternative population growth and development density.

Models project an increase in human population with associated increases in urban water demand and reductions in irrigated agricultural acreage and agricultural water demand.



Above: Crop Acreage and Population, Agricultural and Urban Water Demand Projections from the California Water Plan.

Phenology

In the last few decades, spring bloom dates of lilac and honeysuckle have trended toward earlier occurrence in western North America, signaling an earlier onset of the spring season. Between the 1950 and 2000, bloom dates and spring pulses occurred 5–10 days earlier in the last half of the study period. This corresponds to a spring 1–3°C (1.8°-5.4°F) temperature increase over western North America since the 1970 (Schramm and Loehman. 2012).

Fire

Fire is a natural part of California's Mediterranean climate and plays an important role in its ecosystems, however, wildfire intensity and frequency has the potential to increase as a result of the current climate trends (van Mantgem et. al., 2013). Extreme cases of hotter and drier summers, with little precipitation throughout the year could drastically alter the fire regime and impact the ecosystems of California and the Central Valley. Urban growth, particularly in a more sprawling pattern with its associated larger wildland-urban interface, is an important factor in determining wildfire frequency (Bryant and Westerling, 2012).

Vegetation

Climate modeling shows southern California shrublands, including Chaparral and coastal sage, moving to higher elevations with cooler climates and greater precipitation in response to rising temperatures and reduced precipitation in their current environments. Non-native grasses are projected to increase in shrublands, which, along with increased wildfire frequency, may substantially reduce their range and proficiency (Schramm and Loehman. 2012). By the end of the 21st century (2070–2099), cattle grazing forage production is projected to decline dramatically, ranging from a 14%-58% decline in annual mean production across a range of models and emissions scenarios (Shaw et. al., 2011). If fire events become longer and more severe, the distribution and abundance of dominant plant species may shift significantly, with species that are sensitive to fire declining while other species may benefit (McKenzie et al. 2004).

Warmer winter temperatures may lead to an increase in occurrences of forest diseases such as pitch canker, which are limited by low temperatures and are more successful when attacking drought-stressed trees. Pitch canker has been known to affect trees such as Monterey pine (Pinus radiate). Warming may also increase habitat quality for Phytophthora cinnamomi in northern California. This disease affects the root and stem-base of a wide range of broad-leaved and coniferous species. ([Kliejunas et al. 2009]).

Modeling by Gardali et al. (2011) indicates that grassland habitat in the Sacramento Valley may decline 1-20% by 2070 due to warmer winter temperatures and variable precipitation, leading to overall drier conditions. Modeling for the San Joaquin Valley indicates similar trends, with a 6-11% loss of grassland habitat by 2070 (PRBO Conservation Science 2011). A more recent assessment looking at both warmer/wetter and warmer/drier conditions under high and low emissions scenarios project that 52-84% of current grassland habitat in California will remain climatically suitable by the end of the century (2070-2099). The eastern edge of the Central Valley, particularly in the southern portion of the study region, is projected to become climatically unsuitable under drier conditions, while under wetter conditions, large portions of the northern Central Valley may become unsuitable (Thorne et al. 2016).

Regional climate modeling by Kueppers et al. (2005) indicates that climatically suitable blue oak and valley oak habitat may contract considerably and shift northward by the end of the century (2080-2099) due to warmer temperatures and declines in growing season (April-August) precipitation, contributing to high soil moisture deficits. Under a "business-as-usual" emissions scenario, blue oak is projected to have only 59% of current range size available, and valley oak, only 54% (Kueppers et al. 2005). Thorne et al. (2016) project that 24-59% of current California foothill and valley forests and woodlands will not be climatically suitable by the end of the century, particularly along the eastern margin and northern half of the study area.

Bibliography

California Climate Change Center. 2012. Our Changing Climate 2012; Vulnerability & Adaptation to the Increasing Risks from Climate Change. A Summary Report on the Third Assessment from the California Climate Change Center in California. California Energy Commission.

Anderson, J., F. Chung, M. Anderson, L. Brekke, D. Easton, M. Ejeta, R. Peterson, and R. Snyder. 2008. Progress on incorporating climate change into management of California's water resources. Climatic Change 87:91–108.

Bryant, B. P., and A. L. Westerling. 2012. Scenarios to Evaluate Long-Term Wildfire Risk in California: New Methods for Considering Links Between Changing Demography, Land Use, and Climate. California Energy Commission.

Bureau of Reclamation. 2015. Sacramento and San Joaquin Basins study, report to Congress 2015. U.S. Department of the Interior, Bureau of Reclamation, Mid Pacific Region. Prepared by CH2M Hill.
California Climate Change Center. 2006. Our changing climate: Assessing the risks to California. California Energy Commission, Sacramento, CA.

California Climate Change Center. 2012. Our Changing Climate 2012; Vulnerability & Adaptation to the Increasing Risks from Climate Change. A Summary Report on the Third Assessment from the California Climate Change Center in California. California Energy Commission.

California Department of Water Resources. 2015. Groundwater Sustainability Program, Draft Strategic Plan. Page 32. Department of Water Resources, State of California.

California Resources Agency. 2013. California Water Plan Update 2013. http://www.water.ca.gov/waterplan/cwpu2013/final/index.cfm.

California Rice Commission. 2013. Rice-specific groundwater assessment report. Prepared for Central Valley Regional Water Quality Control Board. California Rice Commission.

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.

Cayan, D., M. Tyree, D. Pierce, and T. Das. 2012. Climate Change and Sea Level Rise Scenarios for California Vulnerability and Adaptation Assessment. California Energy Commission.

Cook, B. I., T. R. Ault, and J. E. Smerdon. 2015. Unprecedented 21st century drought risk in the American Southwest and Central Plains. Science Advances 1:e1400082.

Das, T., E. P. Maurer, D. W. Pierce, M. D. Dettinger, and D. R. Cayan. 2013. Increases in flood magnitudes in California under warming climates. Journal of Hydrology 501:101–110.

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

Diffenbaugh, N. S., D. L. Swain, and D. Touma. 2015. Anthropogenic warming has increased drought risk in California. Proceedings of the National Academy of Sciences 112:3931–3936.

Flint, L. E., A. L. Flint, J. H. Thorne, and R. Boynton. 2013. Fine-scale hydrologic modeling for regional landscape applications: the California Basin Characterization Model development and performance. Ecological Processes 2:25.

Gardali, T., C. Howell, N. Seavy, W. D. Shuford, and D. Stralberg. 2011. Projected Effects of Climate Change in California: Ecoregional Summaries Emphasizing Consequences for Wildlife. Point Blue Conservation Science.

Griffin, D., and K. J. Anchukaitis. 2014. How unusual is the 2012–2014 California drought? Geophysical Research Letters 41:9017–9023.

Hamlet, A. F., and D. P. Lettenmaier. 2007. Effects of 20th century warming and climate variability on flood risk in the western U.S. Water Resources Research 43:W06427.

Hayhoe, K., D. R. Cayan, C. B. Field, P. C. Frumhoff, E. P. Maurer, N. L. Miller, S. C. Moser, S. H. Schneider, K. Nicholas, E. E. Cleland, L. Dale, R. Drapek, R. M. Hanemann, L. S. Kalkstein, J. Lenihan, C. K. Lunch, R. P. Neilson, S. C. Sheridan, J. H. Verville, K. N. Cahill, E. E. Cleland, L. Dale, R. Drapek, R. M. Hanemann, L. S. Kalkstein, J. Lenihan, C. K. Lunch, R. P. Neilson, S. C. Sheridan, and J. H. Verville. 2004. Emissions pathways, climate change, and impacts on California. Proceedings of the National Academy of Sciences 101:12422–12427.

Hunsaker, C. T., J. W. Long, D. B. Herbst, J. W. Long, L. Quinn-Davidson, and C. N. Skinner. 2014. Watershed and stream ecosystems. Pages 265–322. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA.

Jackson, L. E., S. M. Wheeler, A. D. Hollander, A. T. O'Geen, B. S. Orlove, J. Six, D. A. Sumner, F. Santos-Martin, J. B. Kramer, W. R. Horwath, R. E. Howitt, and T. P. Tomich. 2011. Case study on potential agricultural responses to climate change in a California landscape. Climatic Change 109:407–427.

Kahara, S. N., W. G. Duffy, R. DiGaudio, and R. Records. 2012. Climate, management and habitat associations of avian fauna in restored wetlands of California's Central Valley, USA. Diversity 4:396–418.

Kiparsky, M., and P. H. Gleick. 2003. Climate change and California water resources: A survey and summary of the literature. Pacific Institute for Studies in Development, Environment, and Security, Oakland, CA.

Kliejunas, J. T., B. W. Geils, J. Micales Glaeser, E. M. Goheen, P. Hennon, M.-S. Kim, H. Kope, J. Stone, R. Sturrock, and S. J. Frankel. (n.d.). Review of literature on climate change and forest diseases of western North America. Page 54. General Technical Report (GTR), USDA Forest Service, Pacific Southwest Research Station.

Knowles, N., and D. R. Cayan. 2002. Potential effects of global warming on the Sacramento/San Joaquin watershed and the San Francisco estuary. Geophysical Research Letters 29:1891.

Kueppers, L. M., M. A. Snyder, L. C. Sloan, E. S. Zavaleta, and B. Fulfrost. 2005. Modeled regional climate change and California endemic oak ranges. Proceedings of the National Academy of Sciences of the United States of America 102:16281–16286.

Mann, M. E., and P. H. Gleick. 2015. Climate change and California drought in the 21st century. Proceedings of the National Academy of Sciences 112:3858–3859.

van Mantgem, P. J., J. C. B. Nesmith, M. Keifer, E. E. Knapp, A. Flint, and L. Flint. 2013. Climatic stress increases forest fire severity across the western United States. Ecology Letters 16:1151–1156.
McCabe, G. J., and M. P. Clark. 2005. Trends and variability in snowmelt runoff in the western United States. Journal of Hydrometeorology 6:476–482.

McKenzie, D., Z. Gedalof, D. L. Peterson, and P. Mote. 2004. Climatic Change, Wildfire, and Conservation. Conservation Biology 18:890–902.

Medellín-Azuara, J., J. J. Harou, M. A. Olivares, K. Madani, J. R. Lund, R. E. Howitt, S. K. Tanaka, M. W. Jenkins, and T. Zhu. 2007. Adaptability and adaptations of California's water supply system to dry climate warming. Climatic Change 87:75–90.

Miller, N. L., K. E. Bashford, and E. Strem. 2003. Potential impacts of climate change on California hydrology. JAWRA Journal of the American Water Resources Association 39:771–784.

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 Energy Commission, PIER Energy-Related Environmental Research.

Null, S. E., and J. H. Viers. 2013. In bad waters: Water year classification in nonstationary climates. Water Resources Research 49:1137–1148.

Null, S. E., J. H. Viers, M. L. Deas, S. K. Tanaka, and J. F. Mount. 2013. Stream temperature sensitivity to climate warming in California's Sierra Nevada: impacts to coldwater habitat. Climatic Change 116:149–170.

Perry, L. G., D. C. Andersen, L. V. Reynolds, S. M. Nelson, and P. B. Shafroth. 2012. Vulnerability of riparian ecosystems to elevated CO_2 and climate change in arid and semiarid western North America. Global Change Biology 18:821–842.

Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks, and J. C. Stromberg. 1997. The natural flow regime. BioScience 47:769–784.

Regonda, S. K., B. Rajagopalan, M. Clark, and J. Pitlick. 2005. Seasonal cycle shifts in hydroclimatology over the western United States. Journal of Climate 18:372–384.

Scanlon, B. R., C. C. Faunt, L. Longuevergne, R. C. Reedy, W. M. Alley, V. L. McGuire, and P. B. McMahon. 2012. Groundwater depletion and sustainability of irrigation in the US High Plains and Central Valley. Proceedings of the National Academy of Sciences 109:9320–9325.

Schramm, A. and R. Loehman. 2012. Understanding the Science of Climate Change Talking Points – Impacts to the Pacific Coast. National Park Service, Fort Collins, CO.

Shaw, M. R., L. Pendleton, D. Cameron, B. Morris, D. Bachelet, K. Klausmeyer, J. MacKenzie, D. Conklin, G. Bratman, J. Lenihan, E. Haunreiter, C. Daly, and P. Roehrdanz. 2011. The impact of climate change on California's ecosystem services. Climatic Change 109:465–484.

Stromberg, J. C., V. B. Beauchamp, M. D. Dixon, S. J. Lite, and C. Paradzick. 2007. Importance of low-flow and high-flow characteristics to restoration of riparian vegetation along rivers in arid south-western United States. Freshwater Biology 52:651–679.

Thorne, K. M., G. M. MacDonald, R. F. Ambrose, K. J. Buffington, C. M. Freeman, C. N. Janousek, L. N. Brown, J. R. Holmquist, G. R. Guntenspergen, K. W. Powelson, P. L. Barnard, and J. Y. Takekawa. 2016. Effects of climate change on tidal marshes along a latitudinal gradient in California. Page 87. USGS Numbered Series, U.S. Geological Survey, Reston, VA.

Toreti, A., P. Naveau, M. Zampieri, A. Schindler, E. Scoccimarro, E. Xoplaki, H. A. Dijkstra, S. Gualdi, and J. Luterbacher. 2013. Projections of global changes in precipitation extremes from Coupled Model Intercomparison Project Phase 5 models. Geophysical Research Letters 40:4887–4892.

Vivoni, E. R., C. A. Aragón, L. Malczynski, and V. C. Tidwell. 2009. Semiarid watershed response in central New Mexico and its sensitivity to climate variability and change. Hydrol. Earth Syst. Sci. 13:715–733.

Williams, A. P., R. Seager, J. T. Abatzoglou, B. I. Cook, J. E. Smerdon, and E. R. Cook. 2015. Contribution of anthropogenic warming to California drought during 2012-2014. Geophysical Research Letters in press:1–10.

Wohl, E., B. P. Bledsoe, R. B. Jacobson, N. L. Poff, S. L. Rathburn, D. M. Walters, and A. C. Wilcox. 2015. The natural sediment regime in rivers: broadening the foundation for ecosystem management. BioScience 65:358–371.

Yarnell, S. M., J. H. Viers, and J. F. Mount. 2010. Ecology and management of the spring snowmelt recession. BioScience 60:114–127.