UCDAVIS
Graduate Program of
Environmental Policy and Management

Policy Brief
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Climate change caused snow droughts in the Sierra Nevada will have implications to water supply

"Drought is fundamentally an imbalance between water supply and demand – both of which can be impacted by climate change."

- ***Ullrich, et al. (2018)***

Executive Summary

The future of California's climate is wetter, drier, and changing. Due to human caused climate change, California's climate is experiencing a shift from the relatively stable periods of the past. The shift will bring rising temperatures and increased variation in precipitation. Extreme heat and precipitation events, snowpack loss, and drier soils will lead to constraints to the current water management system in California which relies on healthy levels of snowpack accumulation to supply water to about 60% of people living in the state.

California leaders must understand the consequences climate change will have on water supply to successfully adapt to resilient water resource management strategies.

Background

The mountain snowpack, which makes up two-thirds of California's surface water supply, will experience a 48% to 65% loss from the historical April 1 average due to climate change, according to the California Department of Water Resources. This magnitude of variation in the Sierra Nevada snowpack will place further strain on the state's ability to provide water for all Californians, agriculture, industry, and the environment.

The basics: Human activities caused greenhouse gas emissions, like carbon dioxide, trap terrestrial radiation in the atmosphere causing an intensification of the greenhouse effect. The effect disrupts the Earth's mechanism by which it regulates climate, creating:

1. Climate sensitivity, referring to the change in surface temperature and

2. Climate feedbacks, which can amplify or minimize the effects of climate forcings, such as increasing greenhouse gas concentrations, and changes in albedo.

This climatic disruption leads to elevated temperatures and shifts in precipitation patterns and intensity, which lead to an increase frequency of:

1. Heat extremes,
2. Widespread wildfires,
3. Snowpack loss and,
4. Drought conditions.

Data Illustrates the Future of Sierra Nevada Snowpack:

"The Wet Becomes Wetter and The Dry Becomes Dryer" – ***Ullrich, et al. (2018)***

Modern modeling software is helping scientists understand how climate change will affect future snowpack levels and therefore water supply. By using historical climate data and specific climate change parameters, such as concentration levels of greenhouse gases, likely future scenarios can be inferred.

Studies have shown the direct consequences of climate change in the Sierra Nevada are:

1. Substantially higher temperatures
2. More frequent extreme heat days
3. Reduction in snow accumulations
4. Shortened snow season length
5. Precipitation extremes intensifying
6. Reduced soil moisture in higher elevations
7. Record-high forest loss.

Implications: Changes in temperature, precipitation, snowpack, and forest health in the

Sierra Nevada will have clear impacts to California's water resources. California leaders must understand the consequences of climate change on the state's hydroclimate to sustainably and adequately plan, manage, operate, and adapt to future water supply variations. The forethought will ensure California is prepared to serve the people and the ecosystems of the state in the face of incoming periods extreme droughts, floods, and temperatures.

Issue Analysis

Case Study: California's Drought of the Future

"California's drought of the future: A midcentury recreation of the exceptional conditions of 2012–2017", by Ullrich, et al (2018) examined the record-breaking 2012-2016 drought and simulated similar dynamical conditions 30-years into the future. (*See Further Reading 1*)

Temperature: As a response to human-caused *(anthropogenic)* warming, temperatures in the Sierra Nevada are expected to rise approximately 2.7 °F (1.5 °C) by mid-century.

Throughout the highest elevations, midcentury temperatures may reach to 3.6°F (2 °C).

Warmer temperatures will:

1. Change humidity and soil moisture, which will not be sufficient to buffer warm temperatures
2. Increase evapotranspiration,
3. Reduce snowpack, due to snow-albedo feedback, and
4. Increase in extreme temperature days, over 104 °F (40 °C).

The bottom line is, "Regions with more extreme temperatures days are not regions with the greatest increase in average temperature."

Precipitation: The Sierra Nevada will increase in, both mean and extreme, precipitation during the wet season, and increased drying during the summer season.

Snowfall: Decline in snow water equivalent (SWE) of snowpack occurs at all elevation of the Sierra Nevada, leading to more rainfall and less snowfall. Headwater regions will be affected, with peak SWE volumes reduced.

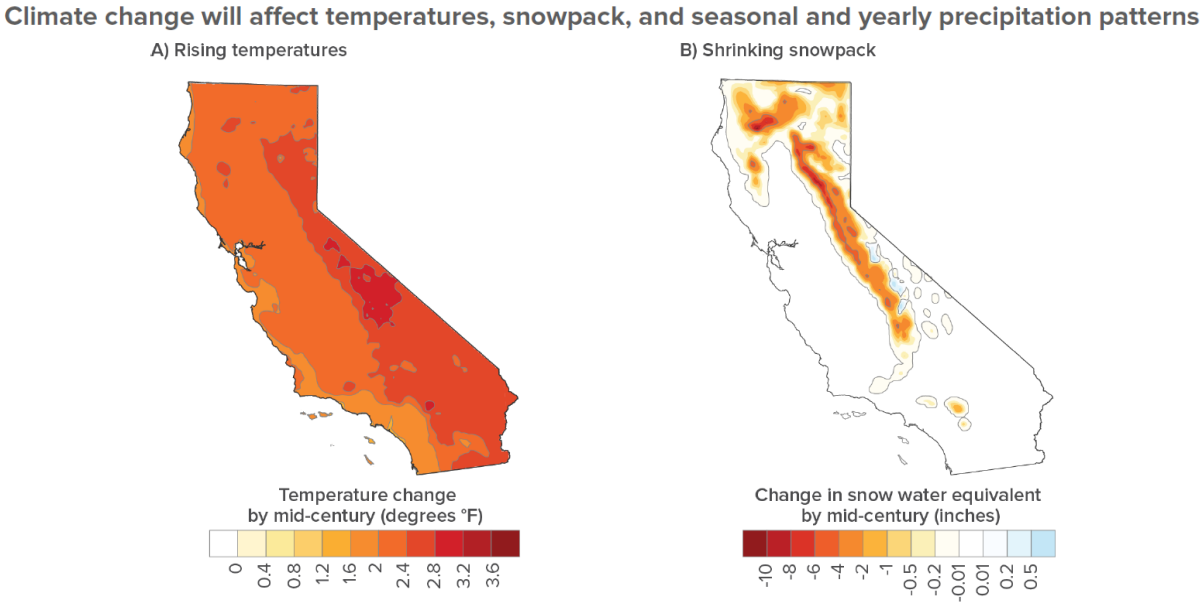

Figure 1: Panel A shows average temperature increases relative to the 2012–16 drought for a similar drought in midcentury (2042–46). Panel B shows the decline in snowpack relative to 2017 for a similar wet year in midcentury (2047). (Source: Public Policy Institute of California)

Case Study: Snowpack Depletion in Tuolumne County, Central Sierra Nevada
(*See Further Reading 2*)

Tuolumne County is a key water resource rich region of the state, located in the Central Sierra Nevada, which provides water to the San Francisco Bay Area, through the Tuolumne River, and the Central Valley, through the Stanislaus River.

From 1955 until 2020, in 63 years, the April 1 annual average snowpack of all the Sierra Nevada declined by 19%, according to the Environmental Protection Agency. However, the change has not been uniform, with the northern region showing most of the decline and the southern Sierra Nevada, a higher elevation region, showing a slight increase in snowpack.

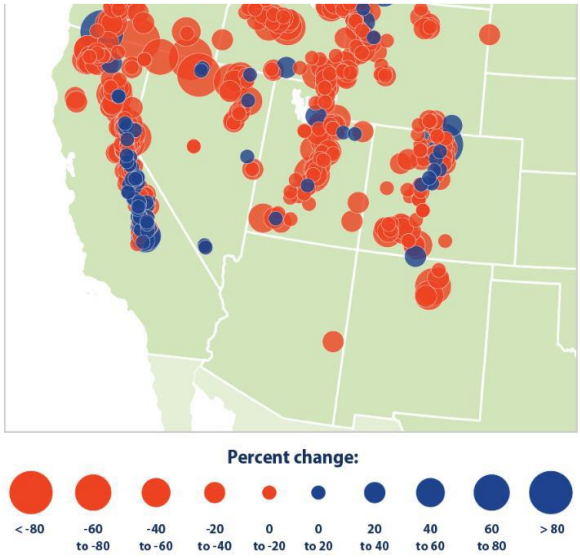

Figure 2 Trends in April snowpack in the Western United States, 1955 - 2020. (Source: EPA)

Time series data of Tuolumne County, from Cal-Adapt, shows:

1. **Maximum average temperatures** rose in both medium (RCP 4.5) and high (RCP 8.5) greenhouse gas emissions scenarios.
2. **Snow Water Equivalent (SWE)** declined in both medium and high emission scenarios.
3. **Annual Stream Flow** for both the Stanislaus and Tuolumne declined under a medium emission scenario. However, under a high emission scenario streamflow both rivers increased in stream flow. The trend relates to the concept of "wet becomes wetter," where soaring temperatures disallow snowfall and therefore a trend toward rain instead of snow arises.

A similar analysis can be produced throughout all of California's counties or district boundaries to assess the impacts of temperature, SWE, and streamflow will have on water supply availability and reliability.

Policy Recommendations

To adapting to incoming climatic variation due to climate change California leader must:
(*See Further Reading 3*)

1. **Update current water resource management** methods and infrastructure operations using weather forecasting technology which accounts for incoming climatic variation to safeguard communities from floods, store water for drought, and protect freshwater ecosystems.
2. **Intergrade the water grid**, surface and groundwater, to promote resilience toward a more volatile climate.
3. **Invest strategically** to rehabilitate outdated infrastructure and restore natural environmental protection mechanisms
4. **Provide a reliable source of funding** to continue long-term investment for climate adaptation and mitigation.

Further reading

1. Ullrich, P. A., Xu, Z., Rhoades, A. M., Dettinger, M. D., Mount, J. F., Jones, A. D., & Vahmani, P. (2018). California's drought of the future: A midcentury recreation of the exceptional conditions of 2012–2017. Earth's Future, 6, 1568– 1587
2. Diana C. Giraldo (2022) Snowpack Depletion in the Tuolumne County, Central Sierra Region: Trends of the last century and a look into the future. HYD 243
3. Jeffrey Mount, Daniel Swain, and Paul Ullrich (2019). Climate Change and California's Water. Public Policy Institute of California

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