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Short-Term Energy Outlook Supplement: Drought Effects on California Electricity Generation and Western Power Markets

May 2022



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Summary

Over the last decade, California has experienced more frequent and intense drought conditions, and is currently in its third year of drought. Droughts limit water use in general and reduce hydropower in particular. Current drought conditions in the state potentially have a significant impact on power markets throughout the West, which could be different than in past years, given the state's accelerating growth in intermittent generating capacity and reliance on imports, which account for nearly **one-third** of California's power supply.

EIA's *Short-Term Energy Outlook* (STEO) forecasts for California hydroelectric generation currently rely on a simple econometric model that assumes monthly generation in the future will mimic average historical patterns. Because of the potential significant effects of changing water availability, in this Supplement to STEO we evaluate an alternative approach to modeling hydropower that explicitly includes hydrological variables and more precisely accounts for the impact of variable hydro conditions on forecasts for the California region. This STEO Supplement focuses on the critical June 1–September 30 period (when electricity demand increases) and uses detailed information about water and reservoir storage conditions to model the output of six major hydropower projects in California as a driver for overall hydroelectric generation in the California electricity supply region.

We used this approach to compare the effects of two model scenarios on electricity markets:

- Median case water conditions, defined as median water supply between 1980 and 2020
- Drought case water conditions, representing the current year as of April 1

In our Drought case, we found that California's summer hydroelectric share of generation mix was nearly halved, falling from 15% to 8%. To offset the reduction in hydroelectric generation, California purchases more electricity from neighboring markets and increases in-state natural gas generation, which rises from 45% in the Median case to 50% of total summer generation mix in the Drought case. In the Drought case, increased natural gas generation contributed to higher modeled wholesale electricity prices, as well as an increase in CO₂ emissions. The analysis in this STEO supplement focuses on the drought's effect on hydropower generation in California. Though the impact of drought on water-cooled thermal power plants was not explicitly modeled here, it is not expected to have a significant near-term effect on thermal generation in California.

Issues Overview

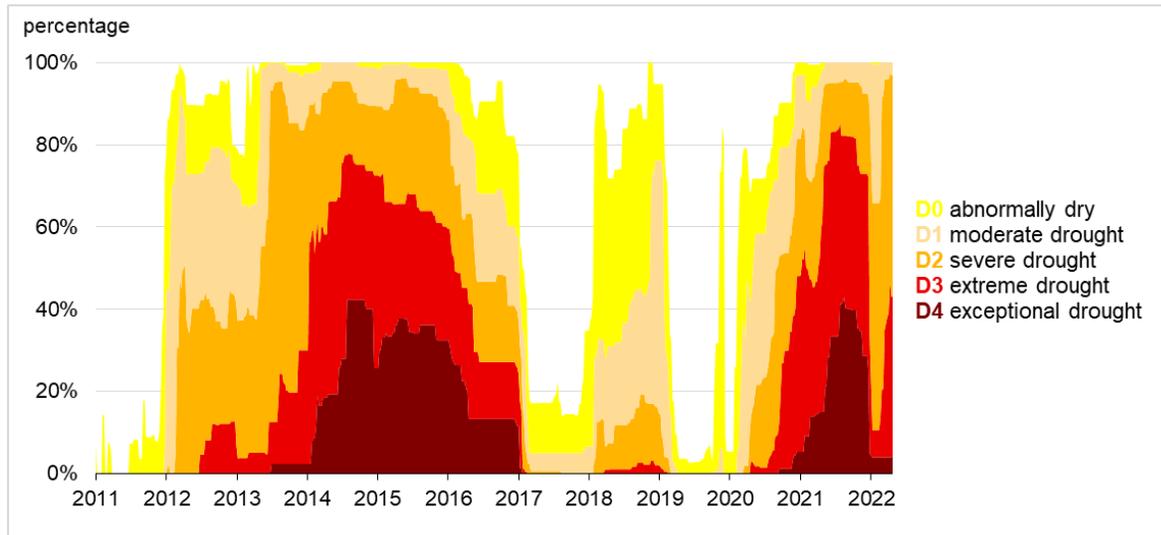
Relationship between drought conditions and hydroelectric generation

Drought conditions have intensified in California, although a few years have had higher-than-normal precipitation (Figure 1).¹ During the last extended drought period (2012–16), all of California experienced drought conditions for three consecutive years. Drought conditions ranged from

¹ Jeffrey Mount, Alvar Escrivá-Bou, and Gokce Sencan (Public Policy Institute of California), [Fact Sheet: Droughts in California](#), April 2021.

abnormally dry (coded as D0 by the National Drought Mitigation Center) to exceptional drought (D4). Code D0 drought impacts are mostly limited to farmers. Code D4 drought impacts include widespread crop and pasture losses as well as potential water emergencies affecting industry and the general population, given the reduced water supply in reservoirs and rivers. D4 is the most severe drought category, according to the National Drought Mitigation Center.

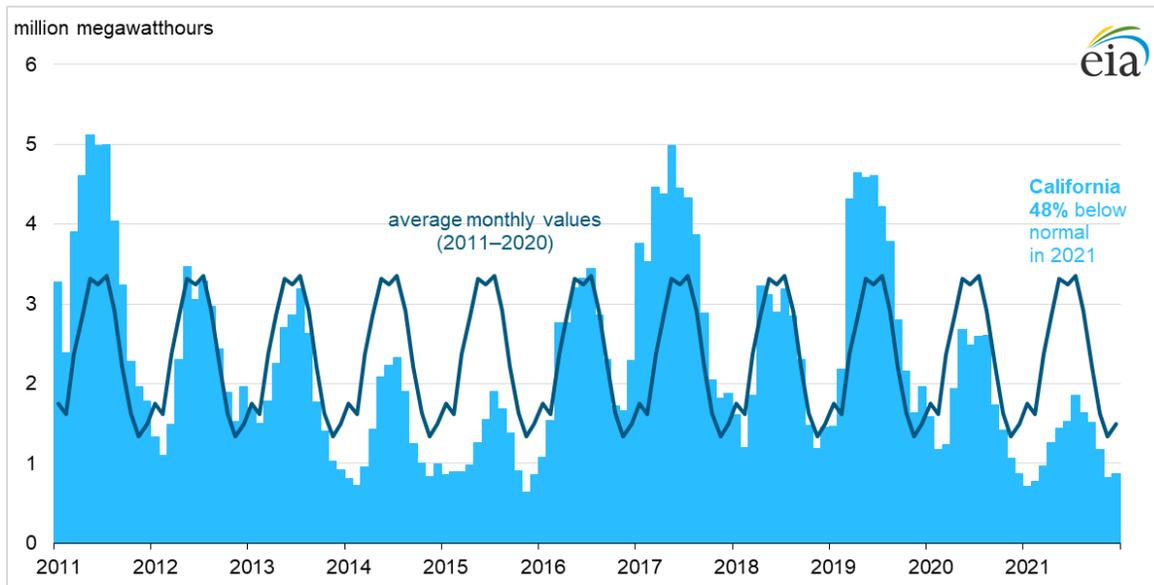
Figure 1. California-Nevada areas reporting drought conditions (January 2011–February 2022)



Data source: [U.S. Drought Monitor](#), jointly produced by the National Drought Mitigation Center (NDMC) at the University of Nebraska-Lincoln, the United States Department of Agriculture, and the National Oceanic and Atmospheric Administration. Graph courtesy of NDMC.

During 2017, above-normal precipitation significantly reduced drought severity, and exceptional drought conditions did not appear again until October 2020. For 2021 the entire state was under some level of drought. By August 2021, 41% of the state was classified experiencing exceptional drought (D4). Drought conditions throughout the West resulted in lower hydroelectric generation in 2021 across the western region. Hydroelectric generation in 2021 was 48% below the 10-year (2011-2020) average in California, (Figure 2).²

² U.S. Energy Information Administration, *Today in Energy*, “[Drought effects on hydroelectricity generation in western U.S. differed by region in 2021](#),” March 30, 2022.

Figure 2. Monthly hydroelectric generation, California (2011–2021)

Data source: U.S. Energy Information Administration, *Electric Power Monthly*

A comparison between Figure 1 and Figure 2 shows the relationship between drought conditions and hydroelectric generation. In 2011 and 2017, a small portion of California was abnormally dry. Most of the state experienced wet conditions resulting in greater-than-average California hydroelectric generation. On the other hand, in 2014, 2015, and 2021, drought conditions were severe, and the state's hydroelectric generation fell below average.

Water supply in 2022

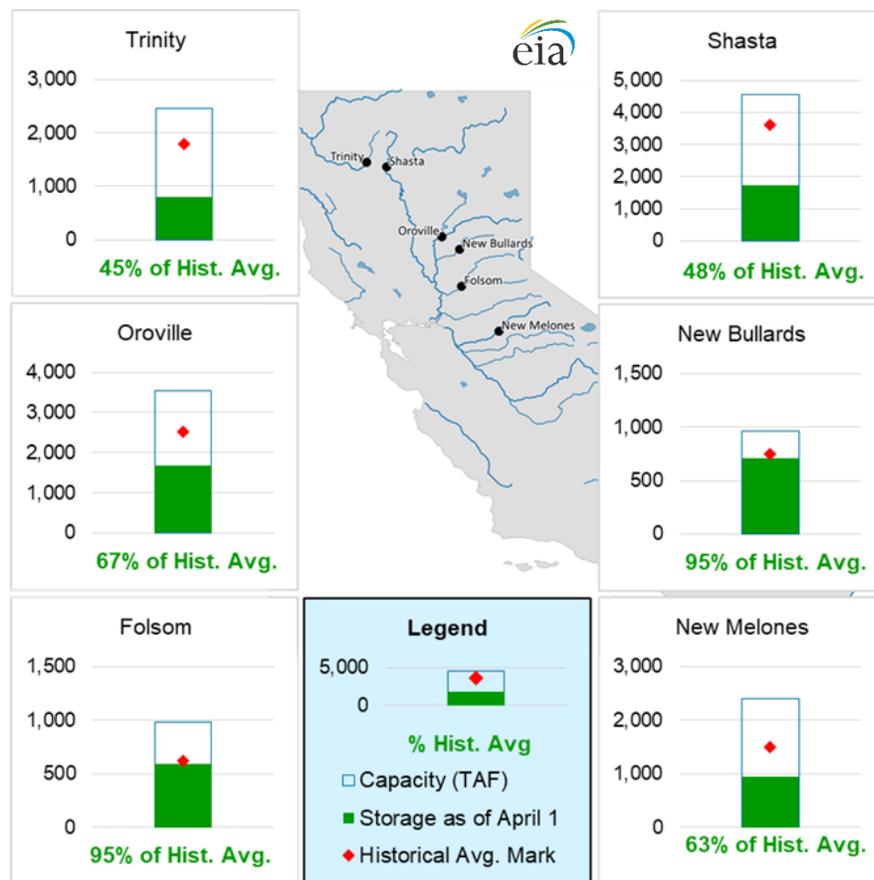
During the current water year, which began on October 1, 2021, and continues through September 30, 2022, California precipitation in the forms of rainfall and snow has been below normal. At the beginning of the water year, some daily rainfall record highs were set. But in January 2022, the trend was reversed when historically low rain and snow amounts were recorded from January through March. According to the [California Department of Water Resources](#), as of April 1, which is when snowpack typically reaches peak levels, snowpack in Northern California was 26% of the normal level, while Central and Southern California snowpacks were higher, each at 42% of the normal level. Less snow in the mountains means that as temperatures begin to warm in the spring, less snow will melt and flow into California's reservoirs.

In many years, less inflow into reservoirs as a result of dry conditions is partially offset by releases of stored reservoir water, mitigating reductions in hydroelectric generation due to drought conditions. In 2022, however, we do not expect that the effect of the drought will be eased by withdrawals from storage because some of California's largest reservoirs have below-average water storage levels. Many of California's reservoirs serve multiple purposes, and storage levels are managed over time primarily by releasing water to meet environmental, agricultural, and urban water objectives rather than for generating electricity.

Hydropower plants, unlike other types of power plants, have dual functions. Hydropower plants provide electricity and system reliability services to California’s electric grid, while also serving a key role in a very complex, integrated system that delivers water for environmental, agricultural, and urban demands. These demands vary within the state by sub-region and by water conditions and are often competing, creating the need to regularly rebalance the water supply primarily among environmental, agricultural, consumptive sectors, and, secondarily, the electricity sector.

Current reservoir storage is lower than the historical average at most [reservoirs](#) (Figure 3). On April 1, California’s two largest reservoirs, Lake Shasta and Lake Oroville, were 48% and 67% of historical average storage, respectively. Lake Shasta, which was completed in 1945, has only experienced one year, 1977, when the [reservoir storage was lower](#).

Figure 3. April 1, 2022 reservoir levels for California’s major hydropower plants



Data source: California Department of Water Resources, [Current Reservoir Conditions](#)

During drought years with lower-than-average storage levels, releasing water from storage increases the possibility that the reservoir water level will drop to a point at which hydroelectric generation is no longer feasible because the water level is lower than the point of entry into the facility. This situation occurred in late 2021 at Lake Oroville. During the summer of 2021, the Oroville reservoir was drained to the point that the adjacent hydropower plant, Edward C. Hyatt, had to go offline due to drought conditions for the first time since it started operations in the 1940s. California subsequently experienced a wet fall and early winter, enabling reservoir levels in Lake Oroville to [rise from 22% of total storage](#)

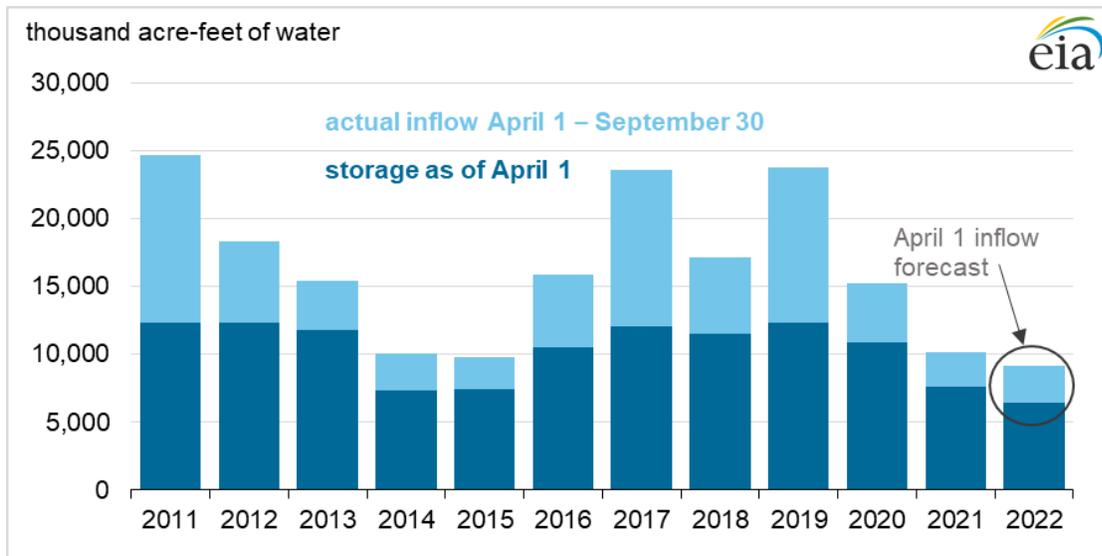
capacity in October 2021 to 39% by January 2022, when the Edward C. Hyatt hydropower plant resumed operations.

California has a Mediterranean climate,³ with wet winters and dry summers. While winter precipitation creates most of California’s water supply, precipitation ranges from strong atmospheric rivers with large masses of precipitation to periods of drought. Due to the precipitation uncertainty and because water releases from reservoirs occur year round, hydrologists create water inflow forecasts daily for the remainder of the water year to assist water managers in water release decision-making. Their water supply forecasts capture existing conditions and future weather. Because most of the rain and snow for the water year has typically fallen by April 1, the potential water supply that is available for summer releases, when California is dry and the demand for water increases, is largely set by that date.

The 2022 water year has had lower-than-average precipitation and lower-than-average storage reservoir levels, so California’s water supply is likely to be the lowest since 2011. Estimated water supply for California is comprised of two components (Figure 4):

- Reservoir storage as of April 1
- Inflow, which includes the water from melting snow and precipitation falling from April 1 through the end of the water year on September 30

Figure 4. Water supply at major California reservoirs, March 31 storage and April through September inflow



Data source: Storage data from the [California Data Exchange Center](#) and inflow forecast from the [California Nevada River Forecast Center](#)

Notes: Data include storage and inflow data for Trinity, Shasta, Oroville, New Bullards Bar, Folsom, and New Melones reservoirs. An **acre-foot** is the volume of water that will cover an area of one acre to a depth of one foot.

³ Kauffman, Eric. California Department of Fish and Game. "Climate and Topography," in: *Atlas of the Biodiversity of California—Climate and Topography*, October 2003. .

We calculated an April 1 total water supply using forecast April through September inflow and the April 1 storage totals at six key California storage reservoirs:

- Trinity Lake
- Shasta Lake
- Lake Oroville
- Folsom
- New Bullards Bar Reservoir
- New Melones Lake

For the 2022 water year, we used the median [inflow forecast](#) developed by the [California Nevada River Forecast Center](#) (CNRFC) to represent the expected amount of additional inflow into reservoirs from melting snow and future precipitation from April through September.

Changes in California's electricity portfolio

California's forecast water supply for 2022 is similar to the water supply in 2015, and both water years were preceded by a dry year. As a result, 2015 is useful as a reference year for our current summer California hydropower forecast. However, California's generating capacity mix has changed since 2015. In addition, the [Western Energy Imbalance Market](#) (WEIM), which is a voluntary real-time energy market grew from 3 participants in 2015 to 19 participants in May of 2022. WEIM now covers large portions of the western power market. Because of the changes in California's generating portfolio and the growth in the WEIM real-time energy market, the 2022 drought response will likely be different from 2015.

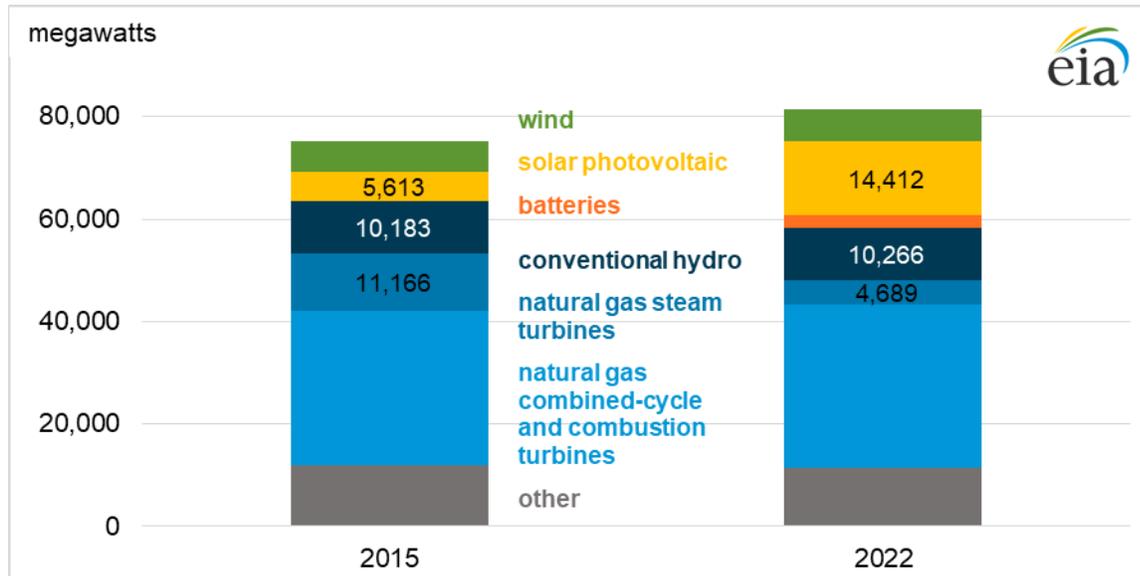
In recent years, California has shifted toward more solar and wind energy resources for electric power generation and away from natural gas power plants. Since 2015, 58% of steam turbine natural gas units have been retired, or 6,500 megawatts (MW). Solar capacity, on the other hand, has increased by 8,800 MW (157%) since 2015. The increase in intermittent renewable generating capacity and the decrease in dispatchable resources (whose generation can ramp up or down to meet changes in system needs) means that fewer conventional power plants are available to meet greater system needs. To mitigate this situation, California has added significant battery storage capacity, growing from 11 MW in 2015 to 2,300 MW at the beginning of 2022. Batteries can provide system support to meet rapid changes in load and generation when renewables generate more or less than expected.⁴ Even with California's battery capacity additions, however, the total share of dispatchable resources is lower in 2022 (Figure 5).

In addition, hydroelectric plants, which are also well suited for ramping up and down to offset changes in renewable energy, will likely provide less of this operational flexibility this summer than in 2015 due to lower reservoir storage levels and less water flow into reservoirs. Partially offsetting the reduction in this operational flexibility is the accelerated growth of the WEIM. While WEIM began in 2014, over half of the WEIM entities began participating in the past two years, and WEIM's broad footprint adds both load diversity and variable energy resource diversity. WEIM's market characteristics also make it well suited for integrating more intermittent resource energy into the grid. The market solves for every five-minute interval, enabling a west-wide market solution to the intra-hour, generation variability of

⁴ U.S. Energy Information Administration, [Battery Storage in the United States: An Update on Market Trends](#), August 2021.

intermittent resources and system load. In addition, because all participants submit offers into this automated market, WEIM provides a structure for solving each five-minute interval with lower cost resources. We expect that WEIM, given its expansion since 2015, will moderate the impact of drought conditions on the California electricity market and possible changes in emission levels this summer.

Figure 5. California generating capacity



Data source: U.S. Energy Information Administration, *Preliminary Monthly Electric Generator Inventory*

Methodology

In the analysis for this STEO Supplement, we evaluated an alternative approach to modeling hydropower that we plan to use in future STEO forecasts. This alternative approach reflects the effects of low water supply levels caused by persistent drought and other water demands on hydroelectric generation. The alternative modeling directly includes hydrological variables to more precisely account for drought conditions in our forecasts for California's electricity generation.

The STEO electricity model currently uses econometric equations for most regions including California that estimate the monthly average capacity factor of hydroelectric generators, then combine these capacity factors with expected capacity to forecast regional generation. For the May STEO, we made adjustments to the econometric-based forecast for California hydropower generation so that June–September generation totals 7 million megawatthours (MWh), similar to the modeled results from the Drought case in this Supplement.

The one exception is the Northwest electricity supply region. For that region, the econometric equation for hydroelectric generation uses the water supply forecast from the [Northwestern River Forecast Center](#) for the Dalles Dam as an explanatory variable for region's average capacity factors. We have found the operation patterns of the Dalles Dam to be well correlated with hydroelectric generation for the entire Northwest region.

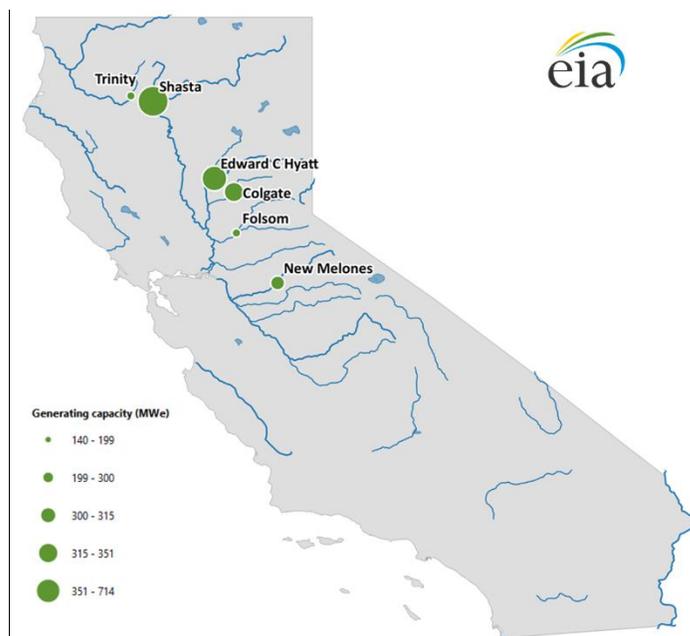
The sustained drought in the western United States has demonstrated that precipitation and snowpack conditions can vary significantly from normal conditions and that hydroelectric operations are affected not just by current water conditions but also reservoir storage levels.

In this STEO Supplement, we present the results of our alternative modeling approach that focuses on using detailed information about water conditions in the California electricity supply region, where the current drought has significantly affected hydroelectric generation. Specifically, we focus on the operation of six major hydropower projects in California (Figure 6):

- Edward C. Hyatt Powerplant at Lake Oroville
- New Melones Powerplant at New Melones Lake
- Shasta Powerplant at Shasta Lake
- Trinity Powerplant at Trinity Lake
- Folsom Powerplant at Folsom Lake
- Colgate Powerplant at New Bullards Bar Reservoir

These six projects accounted for 22% of total California hydroelectric generation in the previous five years (2017-2021).

Figure 6. Selected major California hydropower plants



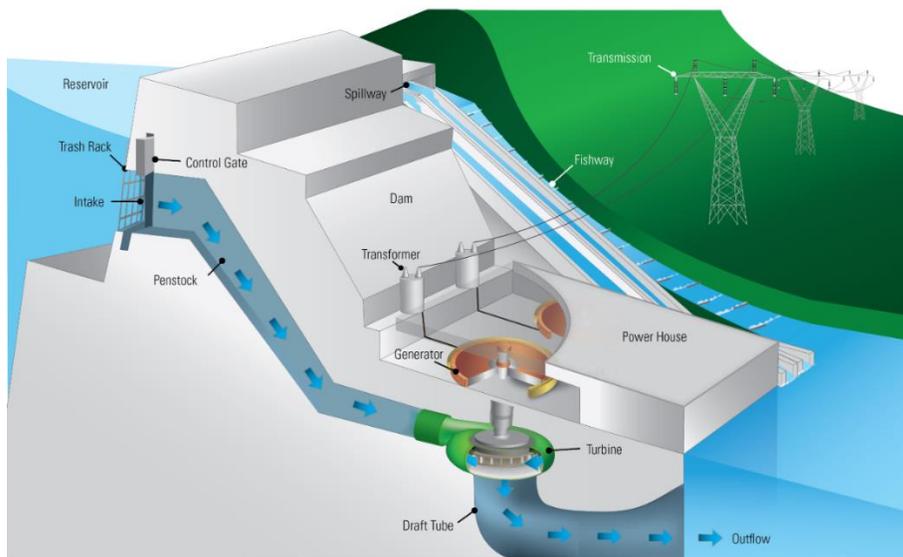
Data source: U.S. Energy Information Administration, [Preliminary Monthly Electric Generator Inventory](#)

With hydroelectric power plants, flowing or falling water turns a turbine, which turns a generator and creates electricity. For hydropower projects that obtain their energy from falling water, such as the ones that we have modeled, two main factors determine the maximum amount of power. The first is the volume of water flow and the second is the head, which is measured by the distance that the water falls from the reservoir surface to the turbines (Figure 7).

We develop detailed generation forecasts for each of these six hydropower plants using water supply forecasts from the [California-Nevada River Forecast Center](#) and reservoir storage data from the [California Data Exchange Center](#). The UPLAN production cost model component of the Short Term Integrated Forecasting System that we use for developing the STEO electricity supply forecasts includes a feature for incorporating natural inflow to each project along with initial reservoir inventory. The UPLAN model then uses this information (along with project characteristics such as minimum and maximum outflow limits, reservoir capacity, head height, and power efficiency) to produce forecasts of hourly generation from each hydropower project. Input assumptions for all other aspects of electricity supply in the region are based on forecasts published in the April 2022 STEO.

The aggregated monthly generation forecasts for these selected hydropower units are then used to help develop estimated average monthly capacity factors for the remaining hydroelectric power plants in the California region, based on the historical correlation of generation between the two sets of hydroelectric generators.

Figure 7. Key factors in hydropower plant design

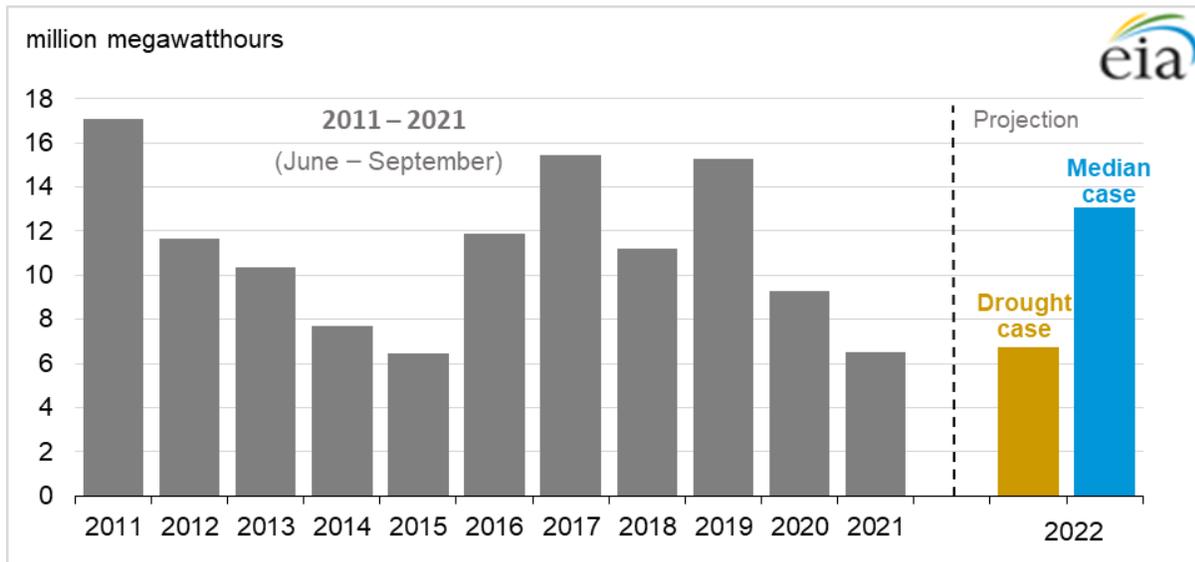


Source: U.S. Department of Energy, [Office of Energy Efficiency & Renewable Energy](#)

Findings

By comparing the results from the two scenarios, we have estimated the effect that drought conditions in California will have in the state and on the western power market. Our analysis shows that the reduction in hydroelectric generation will alter the generation mix in California, resulting in an increase in wholesale power prices in the West and higher carbon emissions.

Figure 8. Historical and forecast summer hydroelectric generation in California, Median case versus Drought case, (June–September, 2011-2022)



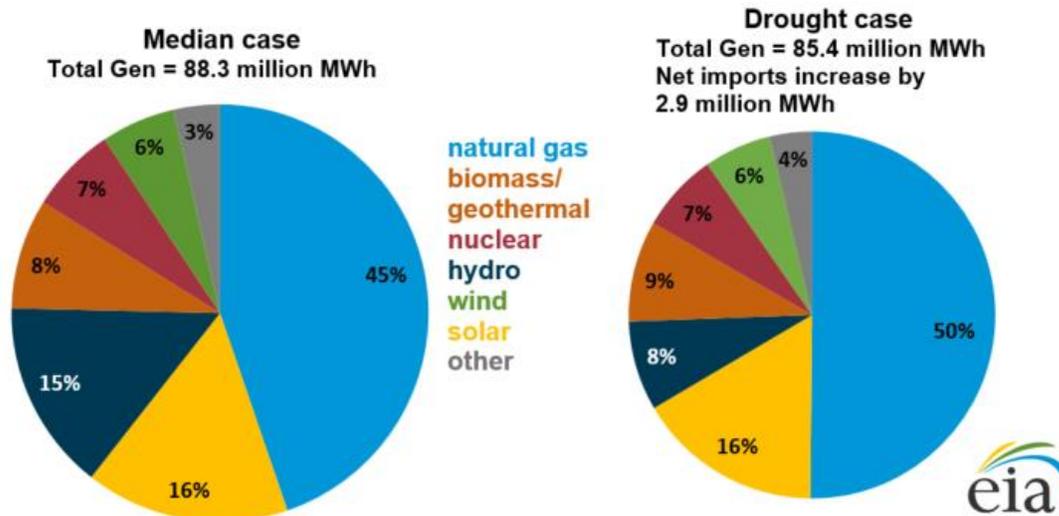
Data source: U.S. Energy Information Administration, [Form EIA-923 data](#) and Short-Term Integrated Forecasting System

We found that California’s total summer hydroelectric generation (from June to September) in 2022 would fall from 13 million MWh in the Median case to 7 million MWh in the Drought case, a 48% drop in hydroelectric generation and comparable to generation in 2015 (Figure 8). As a result, hydroelectric generation’s share of total summer generation falls from 15% in the Median case to 8% in the Drought case (Figure 9).

The replacement power to make up for the reduced hydroelectric generation is about evenly divided between an increase in out-of-state market purchases and in-state natural gas generation. In-state natural gas generation in the Drought case is 8% higher than the Median Case, with the natural gas share of generation rising from 45% to 50% of total summer generation to make up for the reduced share from hydropower.

Given identical load between the two cases, the additional rise in natural gas generation in California leaves 2.9 million MWh to be made up by imported power. Although California already makes out-of-state market purchases to meet one-third of its electricity demand, WEIM provides another opportunity to import electricity. The real-time nature of WEIM matches well with California’s greater need for resources that can respond quickly to the within-the-hour-generation variability characteristic of solar and wind resources.

Figure 9. Forecast June–September 2022 California generation mix, Median case versus Drought case
million megawatthours (MWh) and percentage



Data source: U.S. Energy Information Administration, Short-Term Integrated Forecasting System

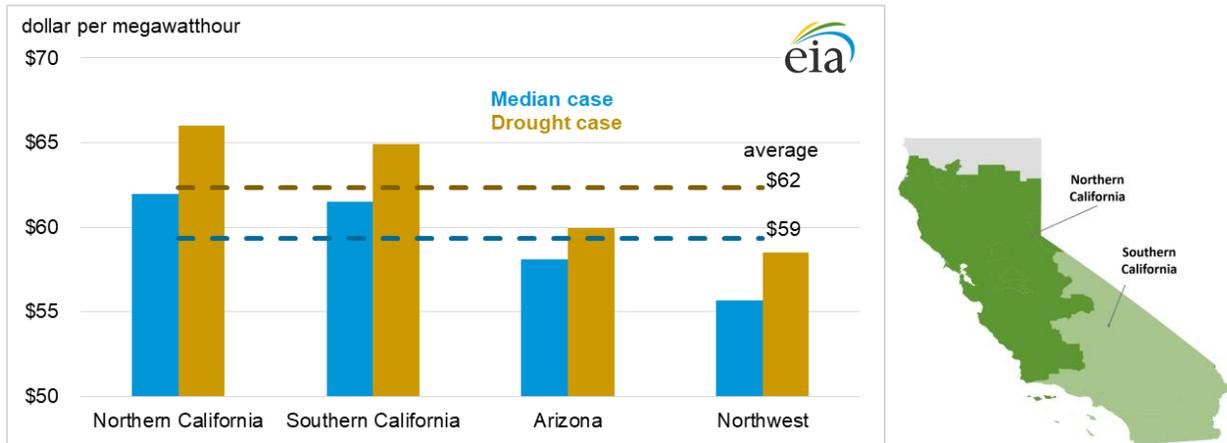
Wholesale power price impact

Because the potential generation from low-cost energy sources such as hydropower is limited under drought conditions, wholesale electricity prices are affected when higher cost resources are dispatched to make up for the difference.

Our analysis showed that all summer electricity prices in California increase under a drought scenario. The California power market is divided into two large regions along a north-south axis, (see inset Figure 10): Northern California (which includes the NP-15 region), and Southern California (which includes the SP-15 region). Replacing low-cost hydroelectric power necessitates a shift to more expensive natural gas generators and out-of-state power suppliers. As a result, on-peak prices in Northern California, where most of California hydroelectric plants are located, increased by 7% relative to the Median case, while Southern California on-peak prices are 5% higher (Figure 10).

From our analysis, we also found that prices in the neighboring power markets, Arizona and the Northwest, increased in the Drought case as well. Summer on-peak prices increased by 5% in the Northwest and 3% in Arizona. We forecast higher prices in neighboring power markets because less available hydropower in California means California will need to import more electricity into the state from neighboring regions, which puts pressure on power supplies in those markets. Although Arizona and Nevada are also experiencing drought conditions, we did not include the effect of drought outside of California in this analysis. If we had included other regions, price increases in Southern California and Arizona would have been higher. We also did not include potential demand response to the higher prices in California or elsewhere in the West. Such demand response could lower the need for replacement power and resulting price impacts.

Figure 10. Forecast impact on summer 2022 wholesale electricity price by power market region, on-peak Median case versus Drought case, (June–September)

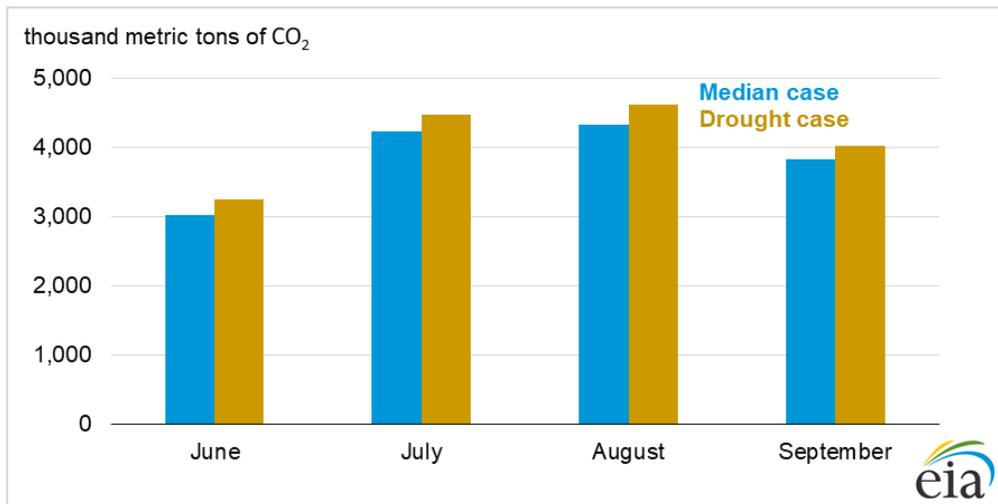


Data source: U.S. Energy Information Administration, Short-Term Integrated Forecasting System

CO₂ emissions impact

As a result of the forecast greater use of natural gas generation in the Drought case, we expect CO₂ emissions attributable to California’s summer electric demand to be 6% higher than in the Median case, representing an additional 978,000 tons of CO₂ (Figure 11). In the Drought case, CO₂ emissions in the Southern California area increase by 8% during the summer, and CO₂ emissions increase by 4% in Northern California during those same months, compared with the Median case.

Figure 11. Forecast impact on summer 2022 California CO₂ emissions by month, Median case versus Drought case, (June–September)



Data source: U.S. Energy Information Administration, Short-Term Integrated Forecasting System