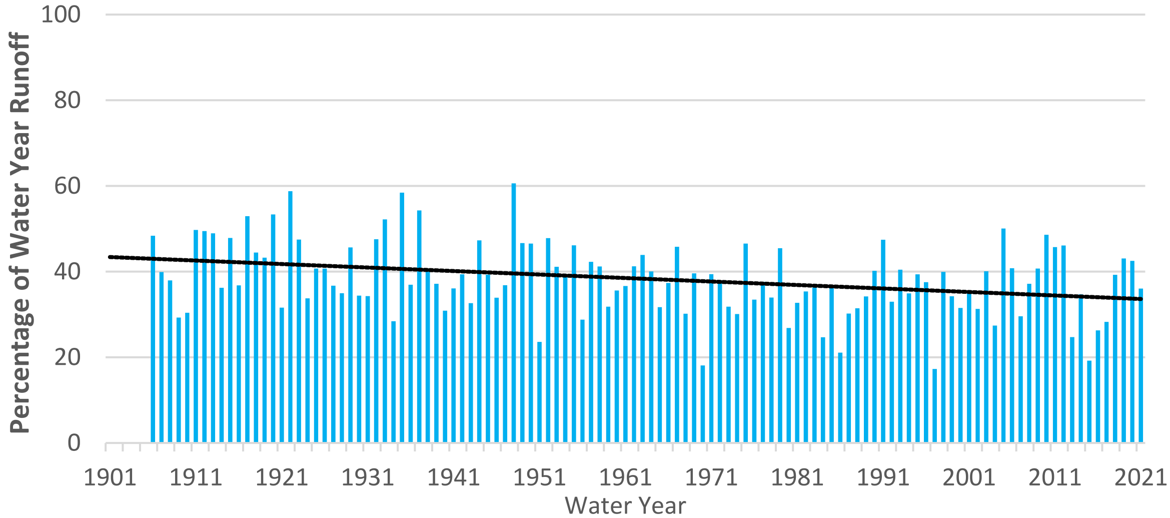
SNOWMELT RUNOFF

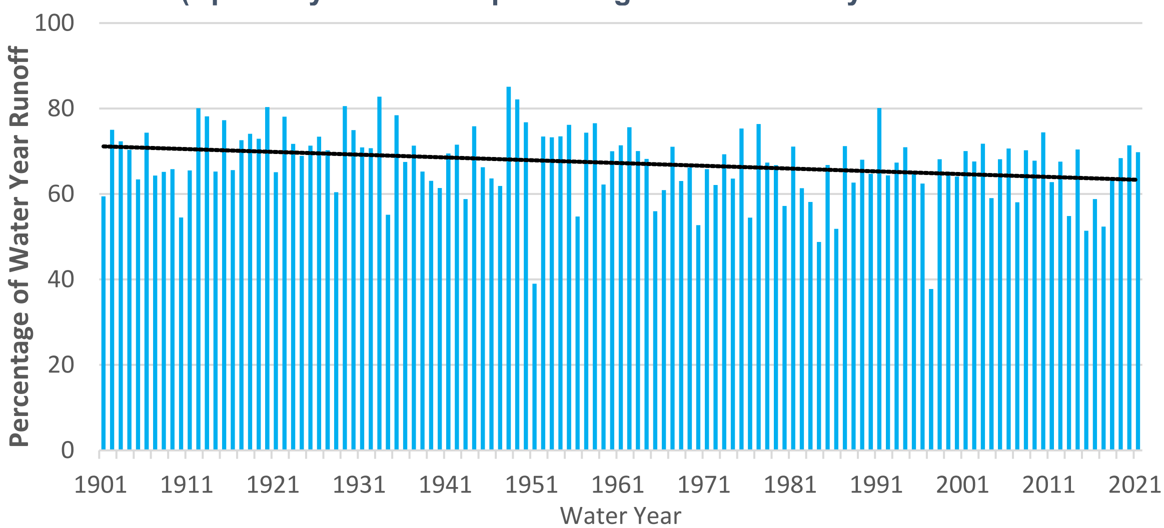
The fraction of snowmelt runoff from the Sierra Nevada into the Sacramento River and the San Joaquin River hydrologic regions between April and July relative to total year-round water runoff, while highly variable, has declined over the past century.

Figure 1. Sacramento River spring runoff (April-July runoff as a percentage of total water year runoff)



Source: DWR, 2022

Figure 2. San Joaquin River spring runoff (April-July runoff as a percentage of total water year runoff



Source: DWR 2022

What does the indicator show?

The fraction of annual unimpaired snowmelt runoff that flows into the Sacramento River and the San Joaquin River between April and July ("spring") has decreased by about eight and seven percent per century, respectively, while showing large year-to-year variability. Figures 1 and 2 show this spring fraction as a percentage of total runoff for the entire water year, the period from October through the following September. In the Sacramento River, three of the last ten years ranked among the ten lowest in the percentage of total water year runoff occurring in the spring: 2015, 2013 and 2016 were third, seventh and eighth lowest, respectively. In the San Joaquin River, two of the last ten years had among the lowest in percentage of total runoff in the spring (2015 and 2017 were ranked fourth and sixth lowest, respectively); notably, 2015 recorded the lowest, and 2017 the fifth highest, spring runoff volumes. The 2015 water year also saw the lowest snowpack on record. There is no significant trend in total water year runoff into either river, just a change in the timing: i.e., an increasingly larger proportion of runoff occurring earlier in the spring.

Average values for the percentage of runoff in the spring are higher for the “snow-dominated” San Joaquin River, compared to the “rain-dominated” Sacramento River – about two-thirds and one-third of the total water year runoff, respectively (DWR 2021). This difference is explained further in *What factors influence this indicator?*

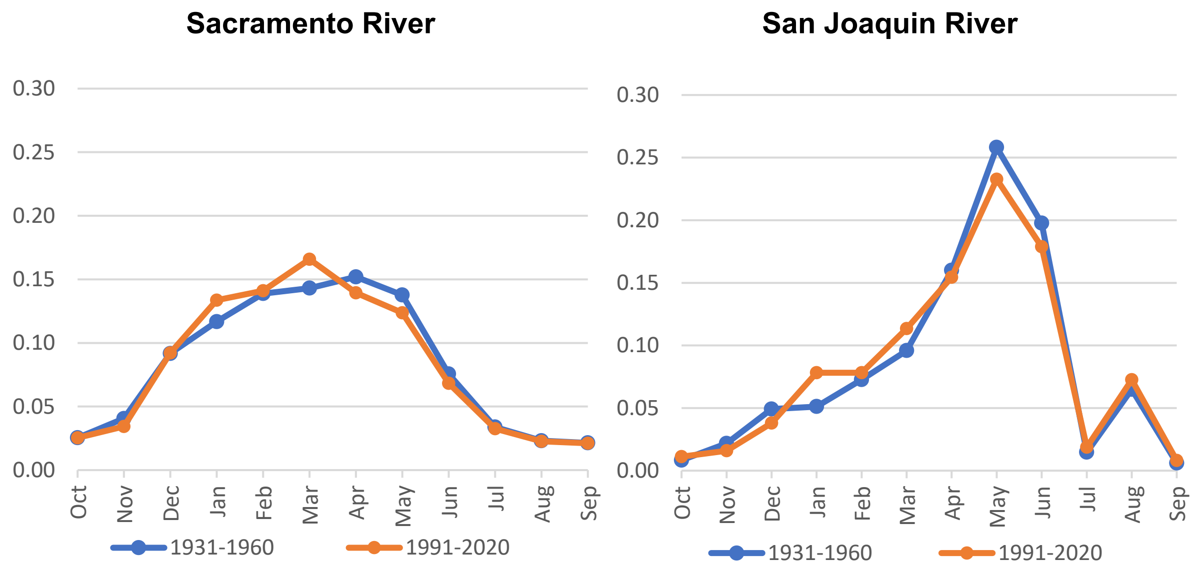
Why is this indicator important?

The Sacramento River and the San Joaquin River, the two largest river systems in California, serve as the major sources of water for the state. Snowmelt runoff into streams and rivers supplies water to meet human needs and to support ecosystems. In the Sierra Nevada and southern Cascade Mountains, snow accumulates from October through March (see *Snow-water content* indicator), preserving much of California’s water supply in cold storage. As temperatures warm in the spring and there is more daylight and solar radiation, the snowpack melts, releasing runoff, typically from April through July.

Spring runoff averages around 14.1 million acre feet (18 billion cubic meters) water, which is about 35 percent of the usable annual supply for agriculture and urban needs (Roos and Anderson, 2006; DWR, 2021). Spring runoff data, along with related snowpack information, are used for water supply and flood forecasting. (Forecasts of seasonal runoff are published weekly by the Department of Water Resources in Bulletin 120.

Much of the state’s flood protection and water supply infrastructure was designed to capture high volumes during winter storms to prevent flooding. In the spring, as much streamflow as possible is captured and stored in reservoirs to be delivered for multiple uses during the drier summer and fall months. This infrastructure was designed and optimized for historical conditions. Changing patterns of spring runoff, such as in the timing of peak monthly runoff, can strain the current water management system, requiring adjustments in water storage and flood strategies. In the last 30 years, peak runoff has shifted earlier by a month on the Sacramento River (March instead of April), compared to earlier years in the record (1931-1960); no such shift occurred in the San Joaquin River (see Figure 3).

Figure 3. Monthly average runoff: historical (1931-1960) vs. current (1991-2020)



Source: DWR, 2022

A comparison between historical and current 30-year averages of the fraction of total water year runoff that occurs each month shows peak runoff occurring earlier in recent years in the Sacramento River, while the San Joaquin River is largely unchanged.

The earlier onset of spring runoff generally results in less available water in warmer months for domestic and agricultural uses, hydroelectric power production, recreation and other uses. This results in lower soil moisture, which could stress vegetation, lead to tree deaths (see *Forest tree mortality* indicator), and increase wildfire risk (see *Wildfires* indicator). Changes in the amount and the timing of snowmelt runoff can alter streamflow and impair cold water habitats, particularly for salmonid fishes (Roos, 2000; Halofsky, 2021). Runoff during rain-on-snow events – when rain falls on existing snowpack – has been associated with mass erosion of slopes, damage to riparian zones, and downstream flooding (Li et al., 2019). Past warming has been shown to increase early season runoff in the Sierras by about 30 percent, thus increasing runoff-driven flood risk (Huang et al., 2018).

What factors influence this indicator?

Lower water volumes of spring snowmelt runoff compared to the rest of the water year indicate warmer winter temperatures or early onset of warm springtime temperatures. With warmer winter temperatures, a greater proportion of precipitation occurs as rain, and snow falls and accumulates at higher elevations than in the past. Higher elevations of the snow line mean reduced snowpack and runoff in the spring.

Increased winter snowmelt was found to be highly sensitive to temperature in 34 percent of snow monitoring stations across western North America (Musselman et al., 2021). In the Sierra Nevada, the peak snow mass and snowmelt shifted earlier over the past 30 years, as daily maximum temperatures increased in March and April (Kapnick and Hall, 2010). Years of “snow drought” – defined as anomalously low snow-water content (Cooper et al., 2016) –between 1951 and 2017 originated and evolved in various ways in the northern Sierra Nevada (Hatchett and McEvoy, 2018), including from extreme early season precipitation, frequent rain-on-snow events, lower fractions of precipitation falling as snow, and midwinter peak runoff events. These conditions are generally associated with earlier snowmelt runoff.

The characteristics of a watershed affect changes in runoff. Because they are located at lower elevations, the Sacramento River watersheds are more vulnerable to reduced snowpack than the San Joaquin River watersheds. A study of projected changes in runoff in the 21st century found that the rain-dominated Sacramento watersheds will experience earlier and increased amounts of peak runoff; in contrast, in the snow-dominated San Joaquin watersheds, runoff peak timing and amounts are projected to remain relatively unchanged (He et al., 2019; He et al., 2020).

Technical Considerations

Data characteristics

Runoff for the Sacramento River system is the sum of the estimated unimpaired runoff of the Sacramento River and its major tributaries, the Feather, Yuba, and American Rivers. “Unimpaired” runoff refers to the amounts of water produced in a stream unaltered by upstream diversions, storage, or by export or import of water to or from other basins. The California Cooperative Snow Surveys Program of the California Department of Water Resources (DWR) collects the data. Runoff forecasts are made systematically, based on historical relationships between the volume of April through July runoff and the measured snow water content, precipitation, and runoff in the preceding months (Roos, 1992).

Related snowpack information is used to predict how much spring runoff to expect for water supply purposes. Each spring, about 50 agencies, including the United States Departments of Agriculture and Interior, pool their efforts in collecting snow data at about 260 snow courses throughout California. A snow course is a transect along which snow depth and water equivalent observations are made, usually at ten points. The snow courses are located throughout the state from the Kern River in the south to Surprise Valley in the north. Courses range in elevation from 4,350 feet in the Mokelumne River Basin to 11,450 feet in the San Joaquin River Basin.

Since the relationships of runoff to precipitation, snow, and other hydrologic variables are natural, it is preferable to work with unimpaired runoff. To get unimpaired runoff, measured flow amounts have to be adjusted to remove the effect of infrastructure or water management operations such as reservoirs, diversions, or imports (Roos, 1992). The water supply forecasting procedures are based on multiple linear regression equations, which relate snow, precipitation, and previous runoff terms to April-July unimpaired runoff.

Major rivers in the forecasting program include the Trinity, Pit, McCloud, Sacramento, Feather, Yuba, American, Cosumnes, Mokelumne, Stanislaus, Tuolumne, Merced, San Joaquin, Kings, Kaweah, Tule, Kern, Truckee, East and West Carson, East and West Walker, and Owens.

Strengths and limitations of the data

River runoff data have been collected for over a century for many monitoring sites. Stream flow data exist for most of the major Sierra Nevada watersheds because of California's dependence on their spring runoff for water resources and the need for flood forecasting. The April to July unimpaired flow information represents spring rainfall, snowmelt, as adjusted for upstream reservoir storage calculated depletions, and diversions into or out from the river basin. Raw data are collected through water flow monitoring procedures and used along with the other variables in a model to calculate the unimpaired runoff of each watershed.

Over the years, instrumentation has changed and generally improved; some monitoring sites have been moved short distances to different locations. The physical shape of the streambed can affect accuracy of flow measurements at monitoring sites, but most foothill sites are quite stable.

OEHHA acknowledges the expert contribution of the following to this report:

Sean de Guzman, P.E.
California Department of Water Resources
sean.deguzman@water.ca.gov

Michael L. Anderson, Ph.D., P.E.
Michael.L.Anderson@water.ca.gov

Elissa Lynn
elissa.lynn@water.ca.gov

Peter Coombe
peter.coombe@water.ca.gov

Benjamin Hatchett, Ph.D.
Western Regional Climate Center
Benjamin.Hatchett@dri.edu

References:

DWR (2021). California Department of Water Resources:Hydroclimate Report, Water Year 2020. Office of the State Climatologist. August 2021.

DWR (2022). Chronological Reconstructed Sacramento and San Joaquin Valley Water Year Hydrologic Classification Indices. Data provided by Peter Coombe and Sean de Guzman, California Department of Water Resources.

Halofsky JE (2021). Chapter 2: Climate Change Effects in the Sierra Nevada. In: *Climate change vulnerability and adaptation for infrastructure and recreation in the Sierra Nevada*. Halofsky JE, Peterson DL, Buluc LY, Ko JM (Eds). General Technical Reports PSW-GTR-2xx. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. Albany, CA.

He M, Anderson M, Schwarz A, Das T, Lynn E, et al. (2019). Potential Changes in Runoff of California's Major Water Supply Watersheds in the 21st Century. *Water* **11**(8): 1651.

Huang X, Hall AD and Berg N ((2018). Anthropogenic warming impacts on today's Sierra Nevada snowpack and flood risk. *Geophysical Research Letters* **45**: 6215–6222.

Kang S, Zhang Y, Qian Y and Wang H (2020). A review of black carbon in snow and ice and its impact on the cryosphere. Earth-Science Reviews **210**: 103346.

Kapnick S and Hall A (2010). Observed Climate–Snowpack Relationships in California and their Implications for the Future. *Journal of Climate* **23**: 3446–3456.

Li D, Lettenmaier DP, Margulis SA and Andreadis K (2019). The role of rain-on-snow in flooding over the conterminous United States. *Water Resources Research* **55**: 8492–8513.

Mantua NJ and Hare SR (2002). The pacific decadal oscillation. *Journal of Oceanography* **58**(1): 35-44.

Mote PW, Li S, Lettenmaier DP. et al. (2018). Dramatic declines in snowpack in the western US. *npj Climate and Atmospheric Science* **1**: 2.

Musselman KN, Addor N, Vano JA and Molotch NP (2021). Winter melt trends portend widespread declines in snow water resources. *Nature Climate Change* **11**: 418–424.

NPS (2017). National Park Service: Hydrology, Yosemite National Park. Retrieved August 2017.

Roos M (1992). Water Supply Forecasting Technical Workshop. California Department of Water Resources.

Roos M (2000). *Possible Effects of Global Warming on California Water or More Worries for the Water Engineer*. W. E. F. Water Law and Policy Briefing. Department of Water Resources. San Diego, CA.

Roos M and Anderson M (2006). Monitoring monthly hydrologic data to detect climate change in California. *Third Annual Climate Change Research Conference*. Sacramento, CA.

Waliser D, Kim J, Xue Y, Chao Y, Elderling A, et al. (2011). Simulating cold season snowpack: Impacts of snow albedo and multi-layer snow physics. *Climatic Change* **109**: 95–117.