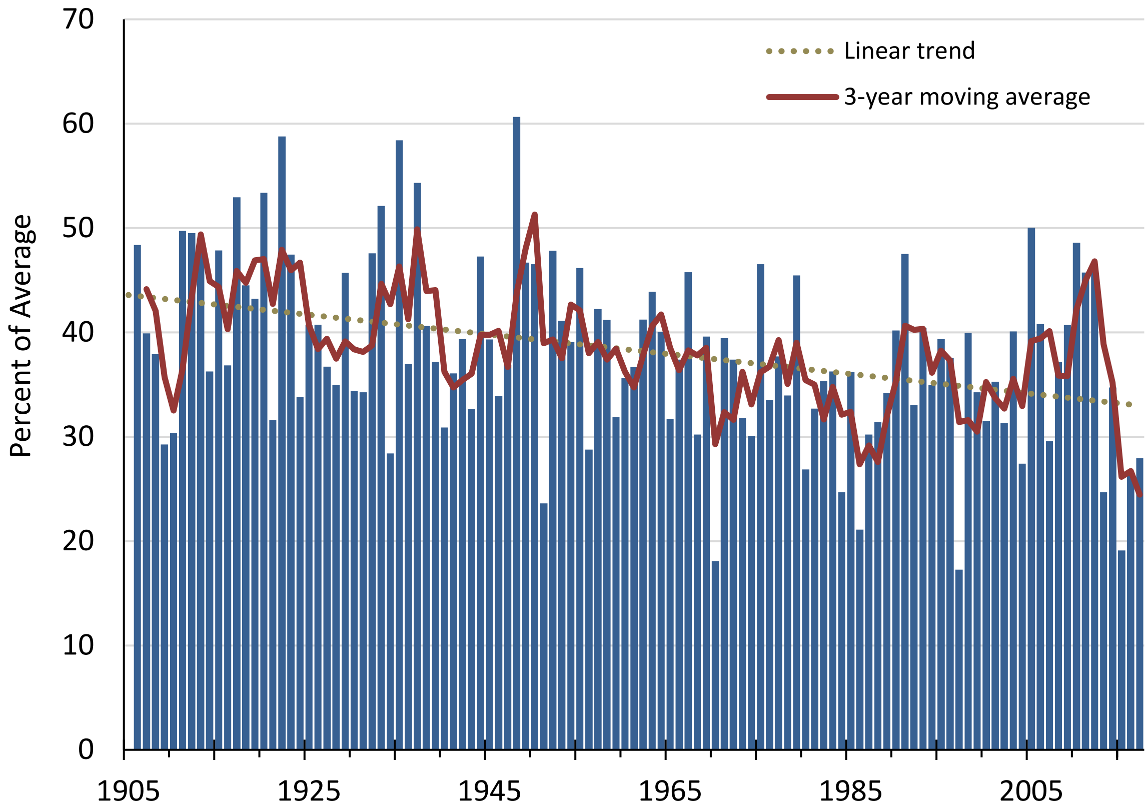
SNOWMELT RUNOFF

The fraction of snowmelt runoff into the Sacramento River between April and July relative to total year-round water runoff has declined over the past century.

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



Source: DWR (2016), updated 2017

What does the indicator show?

Since 1906, the fraction of annual unimpaired snowmelt runoff that flows into the Sacramento River between April and July ("spring") has decreased by about nine percent. Figure 1 shows this spring fraction as the percentage of total runoff for the entire water year, the period from October through the following September. The 2015 water year had the third lowest percentage of spring runoff on record (the lowest snowpack on record also occurred in 2015). This decreased runoff was especially evident after 1950. There is no significant trend in total water year runoff into the Sacramento River (not shown), just a change in the timing of runoff.

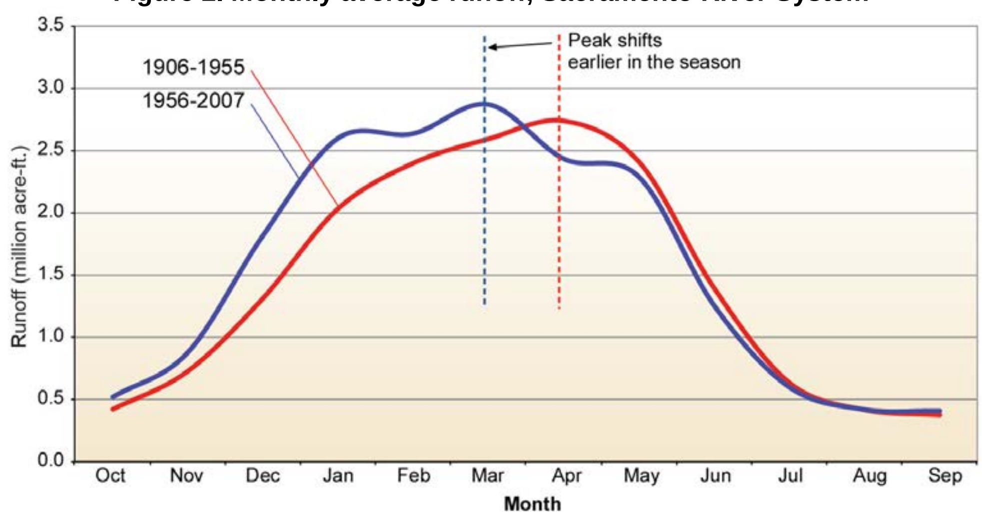
Why is this indicator important?

In the Sierra Nevada and southern Cascade Mountains, snow accumulates from October to March. The snowpack preserves much of California's water supply in cold storage. Less snowpack accumulates when winter temperatures are warmer because more precipitation falls as rain instead of snow. As temperatures warm in the spring, water stored in snowpack is released as snowmelt runoff, typically from April through July.

Source: NPS, 2017

Spring runoff averages around 15 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). Spring runoff data, along with related snow pack information, are used for water supply and flood forecasting. Much of the state's flood protection and water supply infrastructure was designed to capture the slow spring runoff and deliver it during the drier summer and fall months. This infrastructure was designed and optimized for historical conditions. As shown in Figure 2, the timing of peak monthly runoff had shifted earlier by nearly a month in 1956-2007 (blue line), compared to 1906-1955 (red line), indicating an earlier onset of springtime temperatures. This shift in timing strains the current water management system. As the climate continues to change, water storage, and flood strategies may also have to change.

Figure 2. Monthly average runoff, Sacramento River System



DWR, 2015

With less spring runoff, less water is available during the summer to meet the state's water needs, including domestic and agricultural uses, hydroelectric power production, and recreation. Reduced runoff impacts ecosystems, leading to impaired cold water habitat for salmonid fishes (Roos, 2000), tree deaths (see *Forest tree mortality* indicator), and increased wildfires (see *Wildfires* indicator). Precipitation in the form of rain instead of snow may increase flood risk and impact snow-related recreation.

What factors influence this indicator?

Lower water volumes of spring snowmelt runoff compared to the rest of the water year may indicate warmer winter temperatures or unusually early 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 snow pack and flows from watersheds in the spring.

Spring runoff from mountain snowmelt has declined throughout California:

River Runoff	***% Decline in the 20th Century***
Sacramento River system*	9
San Joaquin River system	6
Kings	6
Kern	8
Mokelumne	7
Trinity	8
Truckee	13
Carson and Walker	5

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** includes the Sacramento River and its major tributaries, the Feather, Yuba, and American Rivers.*

Other possible factors, such as the Pacific Decadal Oscillation (PDO) and air pollution, probably contribute to the patterns observed. The PDO is a pattern of Pacific climate variability that shifts phases on at least an interdecadal time scale, usually 20 to 30 years. It is detected as warm or cool surface waters in the Pacific Ocean, which in turn impact coastal and inland climate in Washington, Oregon and Northern California (Mantua and Hare, 2002). There appears to be a PDO effect concurrent with decreasing spring snowmelt percentages due to warming temperatures.

Technical Considerations

<u>Data Characteristics</u>

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). The snow surveys program began in 1929.

Related snow pack 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 270 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 man-made works, 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 Sacramento, Feather, Yuba, American, San Joaquin, Merced, Tuolumne, Stanislaus, and Kings on the western slopes of the Sierra; the Truckee, Walker, Carson and Owens on the eastern slopes; the Kern at the south end of the Sierra; and the Trinity in the North Coast.

Strengths and Limitations of the Data

River runoff data have been collected for almost 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.

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