Spring Arriving Earlier *in Western Streams*

A summary of USGS Fact Sheet 2005-3018 *and selected articles from the* Watershed Management Council Networker, *Spring 2005.*

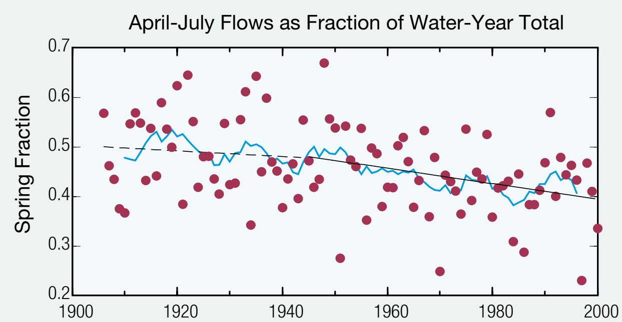
Mountain snow fields act as natural reservoirs for many western water-supply systems, storing water in snowpacks during winter when most precipitation falls, and releasing it into rivers during the warm season as they melt. As much as 75 percent of water supplies in the western United States are derived from snowmelt, thus, management of western rivers commonly is based on significant spring and early summer runoff to reservoirs and lowlands when water demands for irrigation are greatest. In the winter, water demands are low and the potential is high for storms to cause floods. This temporal separation between cool-season flood risks and warm-season runoff benefits is a fundamental assumption of water-resource management strategies. Thus recent trends toward diminished snowpack and earlier snowmelt threaten those finely tuned water-resource and flood-management systems and procedures.

Describing Streamflow Timing

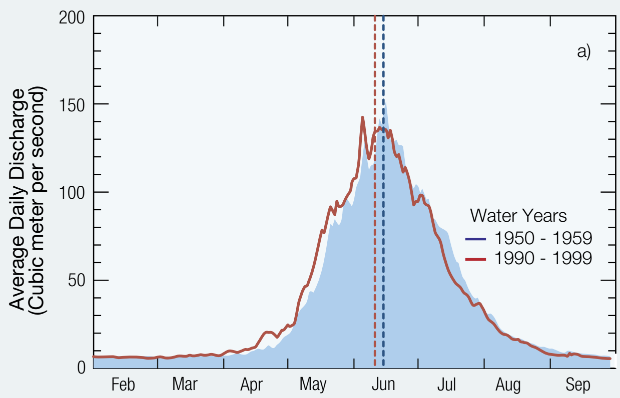
Streamflow timing can be described by different measures depending on data availability and the aspects of greatest concern. Roos (1991) and Dettinger and Cayan (1995) analyzed the fractions of annual streamflow that occur in the spring and early summer, which, in many water-resource systems, is the most readily stored and distributed for warm-season uses. Cayan and others (2001) characterized streamflow timing by the day of year when wintertime low-flow conditions rapidly transition to springtime high-flow conditions with the onset of warm-season snowmelt. These "spring-pulse dates" are important because they indicate the timing of snowmelt and the divide between winter and spring conditions. Stewart and others (2004) characterized streamflow timing according to the date by which roughly half of the streamflow for a year has passed. Such "center of volume" dates provide direct measures of overall streamflow timing based on runoff conditions throughout the year.

Earlier Flow Observed

Annual streamflow in most western rivers has come progressively earlier during the past several decades. The long-term tendency of springtime streamflow—that fraction of overall flow that occurs from April to July—to decline during the 20th century in the central and northern Sierra Nevada is shown above right as a fraction of overall flow. Regressions of data indicate no statistically significant trend until 1945, when a trend toward earlier streamflow begins. As the springtime fraction of yearly flows has declined, the winter fraction, especially in March, has increased, reflecting a regional trend toward warmer winters and springs since the mid-20th century.



April to July streamflow in eight major rivers of the western Sierra Nevada, California, as a fraction of the water-year (October through September) total streamflow. Dots indicate yearly values, blue curve is 9-year moving averages, dashed line is linear trend prior to 1945, and solid line is trend after 1945 (from USGS Fact Sheet 2005-3018).



Comparison of mean daily streamflows in the Clark Fork Yellowstone River, Wyoming, during the 1950s and 1990s, with vertical lines marking center-of-volume dates (from USGS Fact Sheet 2005-3018).

Photo: Noah Molotch

Changes in daily streamflow of western rivers are illustrated at bottom left in a comparison of mean measured flows in the Clark Fork Yellowstone River, Wyoming, during the 1950s versus the 1990s. Overall river discharges in these decades were quite similar, with average flow of 27.8 cubic meters per second in the 1950s and 27.9 in the 1990s. In the 1990s, however, springtime flows were larger and late summer flows were smaller than in the 1950s. Thus, flow generally arrived earlier in the recent decade, with an average center-of-volume date about 4 days earlier in the 1990s than in the 1950s.

Change Widespread Across the West

The geographic extent of the trend toward earlier streamflow in snow-fed streams is shown in the figure below, with timing measured by the center-of-volume dates in rivers throughout western North America. The measurements indicate that flows in many western streams arrive one week to almost three weeks earlier now than in the mid-20th century.

This regional trend developed amid large year-to-year and basin-to-basin variations in both streamflow amount and timing. The variations are due to contrasts in topographies, precipitation patterns, and snow conditions among river basins. Despite the variations, over 90 percent of the stations with statistically significant trends have trended toward earlier runoff in western states. The average center-of-volume date for western rivers is about nine days earlier now than in the 1950s.

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Natural or Human-Induced Causes?

These trends in timing are most readily attributed to winter and spring warming, but that interpretation is complicated by recent variations in precipitation in some areas and by a broad trend toward slightly later precipitation. Causes of these long-term climatic trends remain uncertain. The observed streamflow timing and winter-spring warming trends are consistent with current projections of how greenhouse gases may affect western climates and hydrology; thus streamflow timing and trends may be attributed, in part, to global warming. The climate of the North Pacific Ocean basin, however, underwent a seemingly natural shift toward warmer conditions in the eastern Pacific and western Americas around 1977. This change was part of a multidecadal cycle of climate fluctuations in the region and has contributed, to an uncertain extent, to long-term climatic and hydrologic changes in the western states during the past 50 years. The cycle shifted back to a cool phase in 1999 but the reversal did not slow the trends toward warmer temperatures or earlier streamflows in most of the West.

Response to Future Conditions

Increasing concentrations of greenhouse gases in the atmosphere are expected to induce future climate changes beyond those caused by long-term climate variation. Modern climate models uniformly predict warmer temperatures in the West but show little consensus on how precipitation might change. Conservative values for warming and small precipitation changes modeled for the Sierra Nevada showed that even modest climate changes would cause substantial changes in extreme temperature episodes (fewer frosts and more heat waves); substantial reductions in spring snowpack, earlier snowmelt, greater winter runoff, and reduced spring and summer runoff; more winter flooding; and drier summer soils and vegetation with greater fire danger (Cayan and others, 2005).

In the lower reaches of many western watersheds, dams and levees control water movement. The Sacramento-San Joaquin Delta is one area likely to experience climate effects from two directions: increased wintertime flows and floods from upstream, and sea level rises below. Florsheim and Dettinger (2005) determined that the type of fluvial geomorphic changes that occur in the delta—such as erosion, flooding, sedimentation, and levee failures—will depend on how well existing infrastructure survives and what decisions are made about the timing, magnitude, and duration of flow releases from upstream reservoirs. However, the lower delta with its manmade infrastructure appears more vulnerable to climate variations now than under natural conditions.

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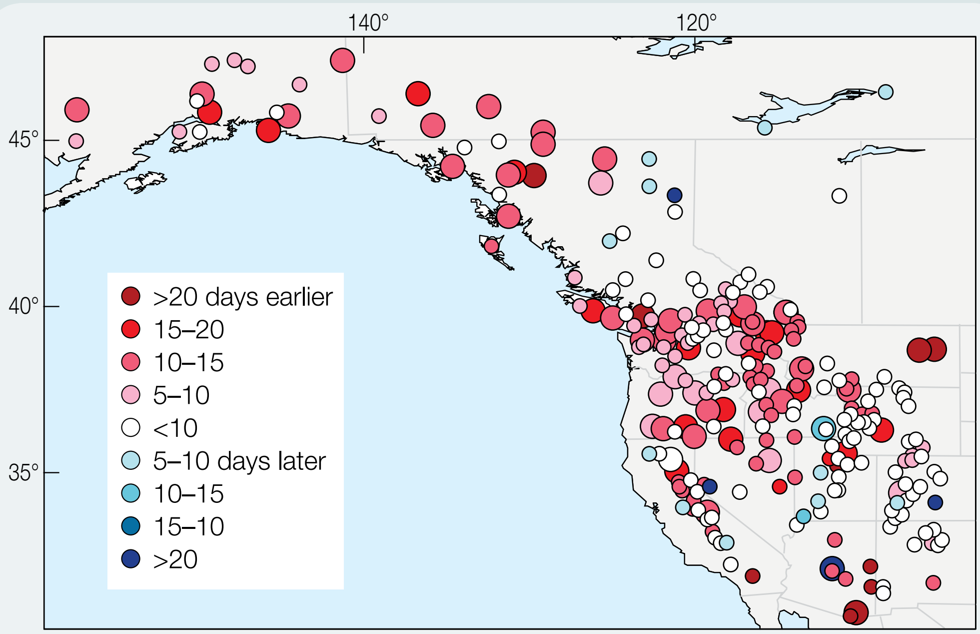

Trends in centers of volume of yearly streamflow hydrographs in rivers throughout western North America, based on U.S. Geological Survey streamgauges in the United States and an equivalent Canadian streamflow network. Large circles indicate sites with trends that differ significantly from zero at a 90-percent confidence level; small circles are not confidently identified (from USGS Fact Sheet 2005-3018).

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streamflow with reconstructed streamflow to recreate a likely temperature and precipitation record to represent the paleoclimate record. Our goal was to develop a new reconstruction of streamflows that was similar to the tree-ring-derived reconstruction in terms of: 1) duration, 2) average streamflow, and 3) overall frequency of extreme flows.

Our approach was to select several years from the observed record in which the annual streamflow closely matched that of a single year in a 400-year reconstructed streamflow record developed by Woodhouse. From this subset of years, we used a random selection process, placing the greatest weight on the closest match, but allowing for some variability, to determine the "selected" year from the observed record that would serve as the analog for the particular year from the paleo record. The process was repeated for each year of the paleo record.

The result is an ensemble of data from the observed record that approximates the volume of total annual streamflow and variability of the paleo record, but that contains temperature and precipitation data which can be used to approximately recreate paleoclimate conditions.

The monthly temperature and precipitation values will next be used as input parameters for the Snowmelt-Runoff (SRM; Martinec et al., 1994) and WATBAL (Rosenzweig et al., 2004) models to produce new "modeled" streamflows for Boulder Creek. SRM simulates and forecasts daily streamflow in mountainous basins where snowmelt is a major runoff component, and WATBAL is an integrated water balance model developed for climate change impact assessment of river basin runoff. Changes in temperature and precipitation from climate models for the central Rocky Mountains will be combined with the new paleoclimate temperature and precipitation data set. This will produce estimates of the conditions that would be experienced under a warmer climate with changes in average precipitation, but also one with more variability than in the recent record.

This approach will allow water managers to use the paleoclimate record and climate change models jointly to evaluate the risks from both climate change and climate variability together, providing an improved tool for water resources planning. In other words, water managers can examine what would happen if past droughts happen again, but this time under warmer conditions consistent with climate change.

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What To Do?

Trends that have natural origins may well reverse themselves, but if they are driven by manmade influences on the climate system, streamflow timing may continue to change. If present trends continue, the natural reservoirs provided by western snowfields will become progressively less useful for water-resources management, flood risks may change in unpredictable ways, and many mountain landscapes will experience increasingly severe summer-drought conditions.

Given the potential for large impacts of climate change on water resources, water management policies that promote flexibility and resilience will be needed to accommodate potential warming impacts, although they remain uncertain. Equally important, continued and enhanced streamflow monitoring and analysis of western snow-fed rivers will be needed to determine the precise natural and human-induced causes, and the likely future, of these western streamflow-timing trends.

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