

Water Year 2004: Western Water Managers Feel the Heat

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This spring, a rare combination of exceptionally warm temperatures and near-record lack of precipitation in the western United States caused a rapid change in hydrologic conditions and an unexpectedly early onset of spring conditions.

With much of the western U.S. already in its fifth year of drought, an above-average western snowpack on 1 March 2004 provided hope for much-needed abundant runoff. Unfortunately, snowmelt began far earlier than anticipated, resulting in dramatic declines in seasonal spring-summer streamflow forecasts as the month proceeded, declines more rapid by some measures than ever before in the past 75 years. With reservoirs near historic lows, many water users have been hard pressed to deal with the continuing drought.

Dismayed by the prospects of yet another dry year, even after the best January snowpack since 1997, one local hydrologist (Randy Julander, U.S. Natural Resources Conservation Service, 8 April 2004) quipped that Utah “managed to snatch defeat from the jaws of victory once again,” as, it seemed, had much of the West.

Extremes like spring 2004 pose challenges to overtaxed western U.S. water supplies. Since 1950, the population of the western U.S. has more than tripled, environmental needs have become integral parts of water management operations, urban-rural demographics have changed, the cast of interests has diversified, and water law has evolved.

Water managers operate with a shrinking margin of error, facing increasingly complex and competing demands while trying to retain flexibility to adapt to hydroclimatic conditions. Fortunately, forecasters and water managers are now able to monitor hydrologic conditions with unprecedented speed, resolution, and coverage.

The abrupt cessation of winter storms, together with early spring snowmelt in spring 2004, highlights the new observational capabilities, and raises the question: are our environmental networks sufficient to serve resource management and

science needs to deal with difficult climate anomalies and trends?

Record-Breaking March Weather

Several real-time climate networks serve the natural resources and research communities in the western U.S. The National Weather Service (NWS) maintains a network of observers who measure temperature and precipitation at moderate to low elevations. The U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) operates a snow survey program that measures monthly high-elevation snow-water equivalents (SWE, the

water depth if the snow on the ground were melted) at 922 “snow courses.” The NRCS also measures temperature, precipitation, and SWE at 702 high-elevation SNOwpack TELemetry (SNOTEL) sites, supplemented in the Sierra Nevada by 90 sites operated by the state of California. The U.S. Geological Survey (USGS) and other federal, state, and local water agencies measure streamflow, groundwater, and reservoir storage. Each of these networks provided indications of the extreme spring conditions, and each provided its own unique perspective on the event.

A storm at the beginning of March brought the last significant moisture to the region until early April. The March precipitation deficiencies were widespread, with about three-quarters of the West receiving less than 50% of long-term averages. Some regions were particularly hard hit, with parts of Utah, Wyoming, Arizona, and Idaho receiving less than 5% of average.

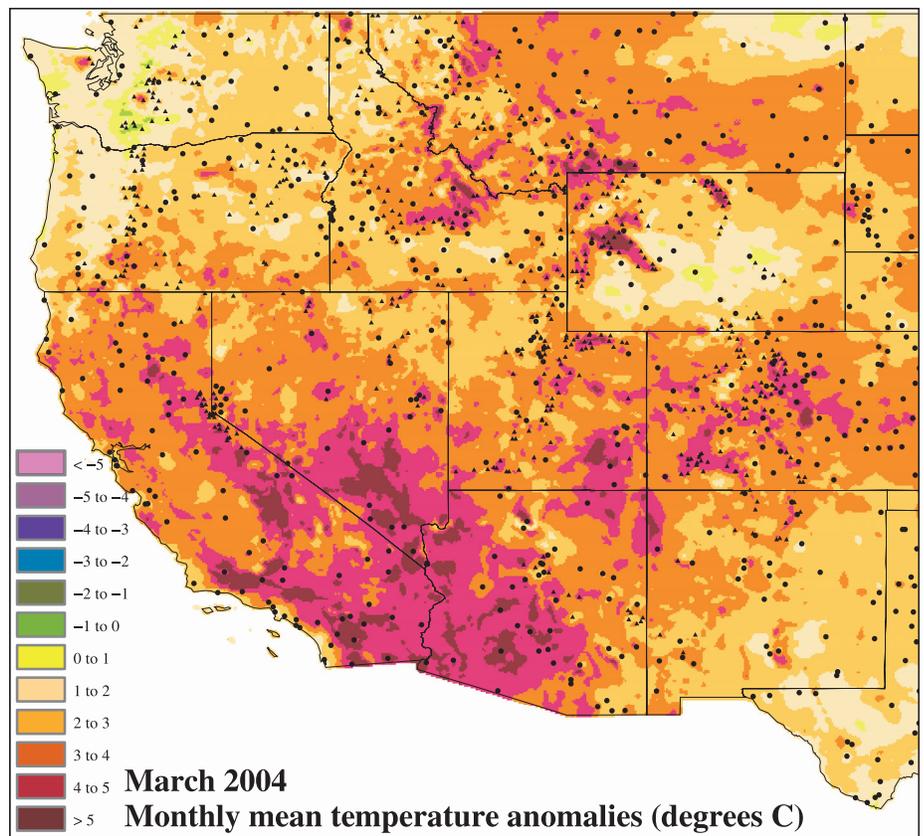


Fig. 1. March 2004 observed monthly mean temperature anomalies in degrees Celsius. NRCS SNOTEL sites are shown as triangles, and NWS sites are shown as circles. Contours are derived using the PRISM system (<http://www.ocs.orst.edu/prism/>).

March normally contributes 12–15% of the annual precipitation in the intermountain western U.S. (<http://www.wrcc.dri.edu/pcpn/west.frac.mar.gif>). So without normal spring snowpack gains, water supply prospects diminished rapidly.

On the basis of provisional NWS data, March 2004 tied with 1956 and 1969 as third driest years for the 11 westernmost continental states as a whole, behind 1914 and 1965 (tied). Grand Junction, Colorado, tied for the driest March in 104 years, and Billings, Montana, fell below a 110-year record set during the 1936 drought. At higher altitudes, 75 of the 389 NRCS SNOTEL sites outside Alaska with 20 or more years of data set or tied records for the driest March on record.

As much as a year earlier, the NWS Climate Prediction Center forecasted a higher-than-normal chance of a warm spring, but no one anticipated such record temperatures. Monthly temperatures across half of the region exceeded normals by +3°C, and at many sites by +4° to +5°C (Figure 1). The southwestern U.S. (Colorado, New Mexico, Arizona, and Utah) experienced the warmest March, as a region, in at least 110 years, and a number of cities broke previous March temperature records by large margins. Death Valley, California, surpassed the 37.8°C (100°F) mark by 20 March (with a temperature of 38.3°C), 7 days prior to the previous earliest recorded 37.8°C temperature, and the next day reached 38.9°C. Phoenix, Arizona, broke or tied at least 17 temperature records between 11 March and 31 March. Among several other records, Sacramento, California, experienced 14 consecutive March days over 26.7°C (80°F); the previous record was 4 days, in March 2002. These temperatures drove energy demands to unseasonably high levels so that, by 29 March, state power officials issued an unusually early Stage One electrical-supply alert in southern California.

Snowpack Responses

Warm temperatures and lack of precipitation are a perfect combination to deplete snowpacks (Table 1). On the basis of provisional data, west-wide declines in SWE from March to April 2004 far outstripped any in the past 70 years, including the nearest competitor, 1972. Even though, in some places, decreases in the percentages of normal SWE were due to lack of new snow, in most places they resulted from the unprecedented snowmelt in 2004. For example, for the first time since measurements began in 1932, less SWE was measured at the Bear Creek snow course in northeastern Nevada on 1 April than on 1 March. One of the oldest snow courses, the Central Sierra Snow Laboratory in Nevada, measured its largest March to April SWE drop in 95 years. Over 25% of the snow measurement sites more than 20 years old reported record deterioration of conditions in March (Figure 2).

Impacts on Water Resources

As snow melted, streamflow rose dramatically and much earlier than usual. To determine

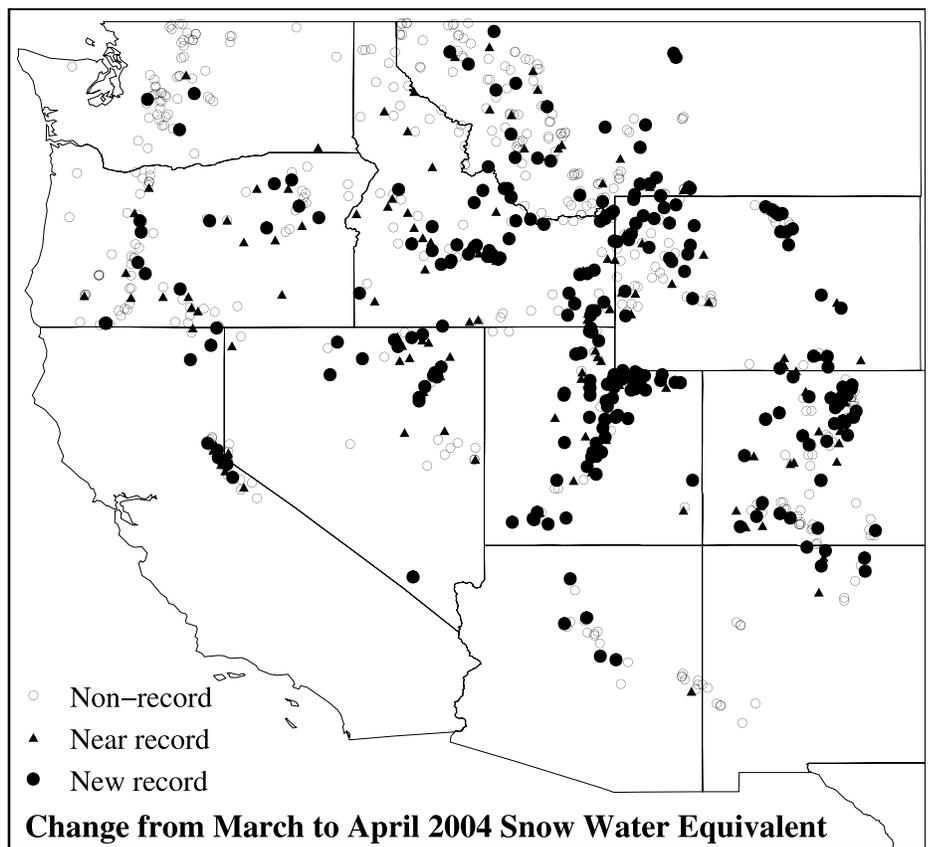


Fig. 2. The 1 March to 1 April 2004 change in SWE at NRCS snow course and SNOTEL sites. Sites that set new records for the greatest decrease or smallest increase are shown as filled circles. Sites that had the second largest change on record are shown as filled triangles, and all remaining sites are shown as hollow circles.

how much earlier, the spring-pulse dates for the 2004 onset of springtime high streamflows were determined from USGS flow data (updates of Slack and Landwehr [1992] at 95 stream gauges, by an abbreviated version of Cayan *et al.*'s [2001] algorithm, using a shorter winter-spring season to allow onsets to be identified with less than a full year's data). The spring-pulse dates are the dates on which accumulated departures of streamflow from season's average reach their minima, which historically are the dates when streamflow begins to increase most rapidly.

The pattern of earlier-than-normal snowmelt pulse dates in 2004 (Figure 3) was remarkable for its coherence and magnitude. Streamflow at 92 of 95 gauges rose to springtime rates earlier than expected, arriving as many as 20–30 days before the 1950–1999 averages. Snowmelt discharge in 70 streams began between 6 and 10 March, with the first major outbreak of spring warming. Spring-pulses in 2004 were among the earliest in the past 50 years in a large majority of rivers; e.g., spring-pulse dates in 2004 were in the earliest historical quintile in 87% of the rivers (inset, Figure 3), whereas the largest previous percentage in any year had been 70%.

Dry conditions and rapid snowmelt significantly affected water resource forecasts. NRCS and NWS hydrologists produce seasonal water supply outlooks each spring from snowpack observations, soil moisture deficits, and climate trends. Between 1 March and 1 April, streamflow

forecasts for the Columbia River at The Dalles and the Colorado River inflow to Lake Powell were reduced by the second-largest amounts in the past 63 and 58 years, respectively. Never before had the Pacific Northwest and intermountain western U.S. simultaneously suffered such large drops in forecasts. In southern Utah, forecasts were reduced by over 60% of their long-term averages.

As the spring progressed, outlooks for many areas continued to worsen; e.g., sites in Idaho reported record lows for combined March–April precipitation. California approached record high temperatures again in late April. April–July 2004 Colorado River inflows to Lake Powell were 46% of normal, making 2000–2004 the first instance of five consecutive years with less than 50% of average flow since modern records began in 1922. Other regions, however, traded one extreme for another; Wesner Springs, New Mexico, recorded 14.7 cm (5.8 inches) of precipitation on 2–3 April from a storm also credited with what may have been the 100-year flood near Carlsbad, New Mexico, on Dark Canyon Draw.

Real-Time Climate Monitoring

March 2004 provides an important test of monitoring networks in the western U.S. Only 30 years ago, snow measurements were made about once per month. Water supply forecasts reached many users 2 weeks after that. Because

resource managers hate being taken by surprise, especially at vulnerable and sensitive times of the year, those informational delays carried intolerable risks.

Since then, the automated NRCS SNOTEL and California snow-instrumentation networks, as well as the NRCS Soil Climate Analysis Network (SCAN), have been developed to report real-time watershed conditions to forecasters and users. Hydrologists are often able to provide users with weekly updates to official supply forecasts. From the weekly updates and their own interpretations of publicly available data streams, users now can anticipate forecast changes and react rapidly at a time of year when major financial outlays are made.

More recently still, even speedier and more widespread dissemination of observations has become possible through the Applied Climate Information System (ACIS), a joint effort by the NOAA Regional Climate Centers, NWS, and NCDC that ingests observations from 2000–3000 NWS stations daily and generates maps of temperatures and precipitation at a variety of timescales, current through yesterday (<http://hprcc.unl.edu/products/current.html>). Modernization of the NWS cooperative network into the planned National Cooperative Mesonet, and the associated Integrated Surface Observing System (ISOS), should greatly improve access times and spatial densities of available data. Similarly, streamflow measurements from over 6000 USGS gauging stations now are available in real time (<http://water.usgs.gov/waterwatch/>). All of these systems were used to track March 2004 hydroclimatic anomalies, separately and through portals like the National Drought Monitor.

Thus, present networks are quick to address the most immediate operational concerns; however, a number of environmental variables that will be important for understanding and predicting changes in western watersheds are less well observed and understood. Surface radiation balances are not measured routinely, although they are strong drivers of snowmelt. Wind, humidity, and soil moisture are rarely measured at high altitudes. Snow and precipitation are measured at index sites but are not monitored widely enough to determine how precipitation is delivered and stored across altitude zones.

Lessons for the Future

The early onset of spring in March 2004 must be thought of as an extreme event because of the short duration of the warming involved and the rapidity with which it laid waste to seasonal water supply prospects. Warm temperatures and low precipitation totals caused significant departures from the normal cycles of snow accumulation and melt. From a longer perspective, though, the unusually early snowmelt in March 2004 is another in the series of early springs that have become increasingly common [Cayan et al., 2001]. Spring snowmelt has advanced by 1–3 weeks [Stewart et al., 2004], and associated spring snow accumulations have

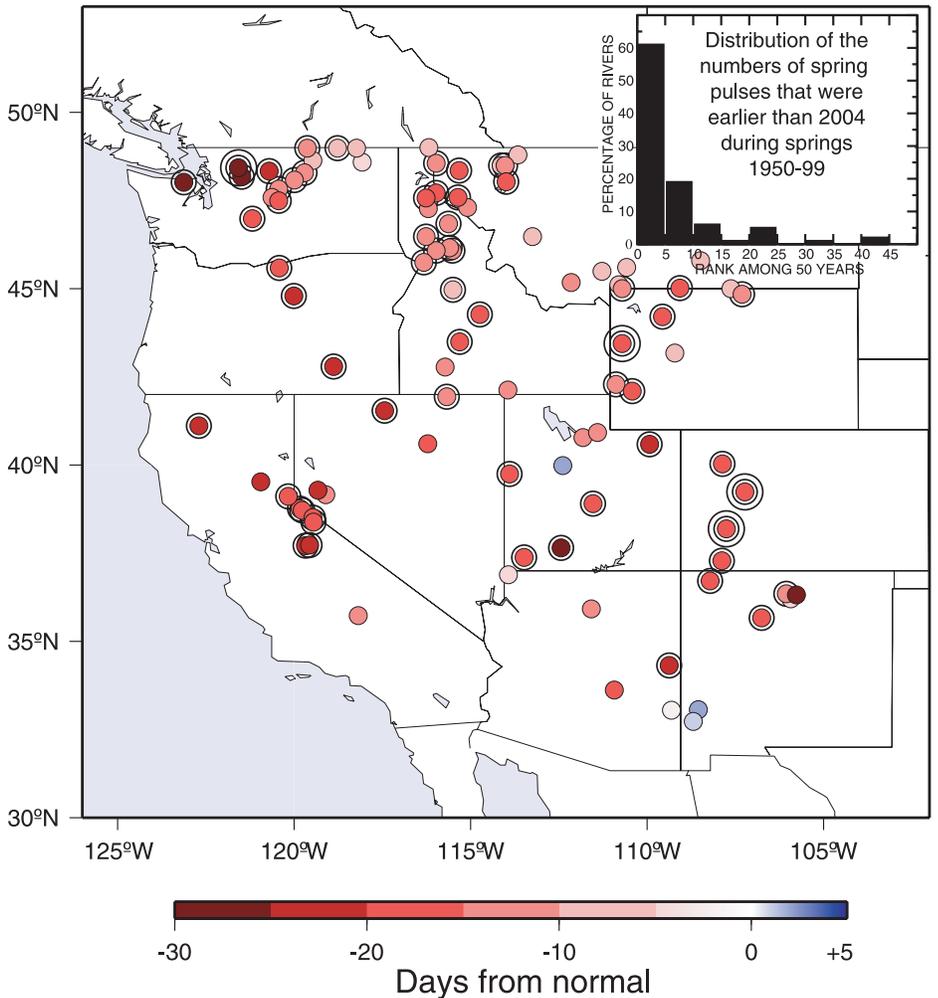


Fig. 3. Date anomalies of the first major snowmelt pulse during spring 2004. Dot color indicates the number of days before or after normal that the spring pulses began: a single circle around a dot indicates that the 2004 value was among the earliest five on record; and a double circle indicates that the site set a new record. Inset shows the distribution of the numbers of spring-pulse dates that were earlier than 2004 at each river.

diminished substantially [Mote, 2003], over most of western North America since the 1970s. Thus, March 2004 may be a harbinger of even more extreme changes to come, and such episodes need to be closely monitored and understood. Only a continuing commitment to long-term, stable hydroclimatic observations in the mountains of western North America will allow us to determine whether the frequency and character of such extremes are changing.

References

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 Mote, P.W. (2003), Trends in snow water equivalent in the Pacific Northwest and their climatic causes, *Geophys. Res. Lett.*, 30(12), 1601.
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Table 1. Summary of Mountain Snowpack (Snow Water Equivalent) Changes Between 1 March and 1 April 2004.

State/Area	Statewide % of Average, 1 March 2004	Statewide % of Average, 1 April 2004	Statewide % of Average, Change
Arizona	74	22	-51
Sierra/Tahoe	113	70	-35
Colorado	90	64	-26
Idaho	105	81	-25
Montana	93	78	-16
Nevada	118	64	-54
New Mexico	80	37	-43
Oregon	126	96	-30
Utah	109	70	-39
Washington	93	86	-7
Wyoming	91	71	-19

Author Information

Thomas Pagano and Phil Pasteris, National Water and Climate Center, NRCS-USDA, Portland, Ore.; Michael Dettinger and Daniel Cayan, USGS, Scripps Institution of Oceanography, La Jolla, Calif.; and Kelly Redmond, Western Regional Climate Center, Desert Research Institute, Reno, Nev.