Monitoring snowpack and forecasting streamflows in the Southwest

By Zack Guido

It came in a caravan of white. Since mid-January, a trail of storms crossed the mountains and deserts of the Southwest, leaving the Verde River, Upper Salt River, Upper Gila River basin, and the Little Colorado River basins blanketed in snow.

The large snowpack bodes well for spring river flows in the Southwest. Forecasts for all major rivers in the upper reaches of their watersheds in Arizona and most upper basins in New Mexico suggest at least a 50 percent chance that spring streamflows will be more than 150 percent of average—good news for reservoirs such as the San Carlos Reservoir, which was nearly empty at the beginning of 2010.

Streamflow forecasting is the principal reason why the Natural Resources Conservation Service (NRCS) monitors nearly 2,000 stations and focal points around the West using automated snow telemetry (SNOTEL) stations and manual measurements. These forecasts are integrated into management to help water managers, for example, decide how much water to dole out to irrigation districts and the amount to release from reservoirs. The importance of the forecasts merits a closer look at how snowpack is measured and monitored and how streamflows are forecasted.

Snow Monitoring

Near the summit of Mormon Mountain outside Flagstaff, Ariz., a large rubber pillow filled with anti-freeze is spread on the bare ground. When snow accumulates, sensors inside the pillow measure the weight and calculate the water content in the snow, often called snow water equivalent, or SWE. A nearby pole supports weather devices that monitor air temperature and solar radiation, among other climate variables, and a rain gauge measures the precipitation.

Seven hundred automated SNOTEL systems like the Mormon Mountain station pepper the high country in the West. Each hour the stations transmit radio waves that bounce off the ionized wake of micro-meteorites, dust-size particles that constantly disintegrate in the upper atmosphere. Several NRCS hubs in the West receive the data, administer quality control, and release the information for public consumption.

In Arizona and New Mexico, about 40 SNOTEL stations have been established where snows often accumulate. Most are situated in remote places at elevations between 8,000 and 9,000 feet. The NRCS installed these stations in Arizona beginning in late 1970s.

"Most stations are located in meadows or open areas and near the crests of ridges separating watersheds," said Dino De Simone, Water Supply Specialist for the NRCS. Sites are often on north aspects; if they were

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Figure 1. The Beaver Spring SNOTEL site is located in northeastern Arizona near the border with New Mexico. Most SNOTEL and snow course sites are located at high elevations and in clearings where tree canopy does not obstruct precipitation. A typical station contains a rain gauge (the rusty-looking feature in the photograph), solar panels, weather sensors, and a snow pillow (outlined by the three visible poles in the foreground). Photograph courtesy of Dino De Simon, NRCS.

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placed on the southern slopes that receive the brunt of the winter sun they wouldn't be measuring much snow in Arizona.

The value of snow surveys was recognized long before engineers discovered how to reflect radio waves off cosmic dust. In the mid-1930s sites were selected for manual measurements. Surveyors skied or snow-shoed into the remote sites, called snow courses, to collect data about twice a month. Many of these snow courses are still operational today and account for about 60 percent of the 1,950 automated and manual monitoring sites in the West, including Alaska.

Snow course sites have the same characteristics as SNOTEL—they sit near basin divides, at high elevation, and away from the tree canopy—and the SWE and snow depth measurements at snow courses are made at six locations in a 50-foot transect. They have one major drawback, however: they are periodic, made only when someone visits the site, so weeks can pass without insight into the snowpack conditions. In that time, intense storms can dump copious snow or rain, or a warm spell can cause rapid melting that elevates flood risk.

New Mexico has 23 SNOTEL and 39 snow courses (Figure 2). Arizona has 21 and 23 respectively, including the newest station, which was installed in October in the Four Corners region of Arizona. SNOTEL stations have made data collection easier and more rapid, but snow courses remain vital.

"We still want to have manual measurements to help ground-truth the SNOTEL data," De Simone said. "When we install a new station we often locate them near a snow course. If the measurements are similar over a five-year period, the snow course site isn't necessary."

Automated SNOTEL stations are high tech compared to the old fashion stations.

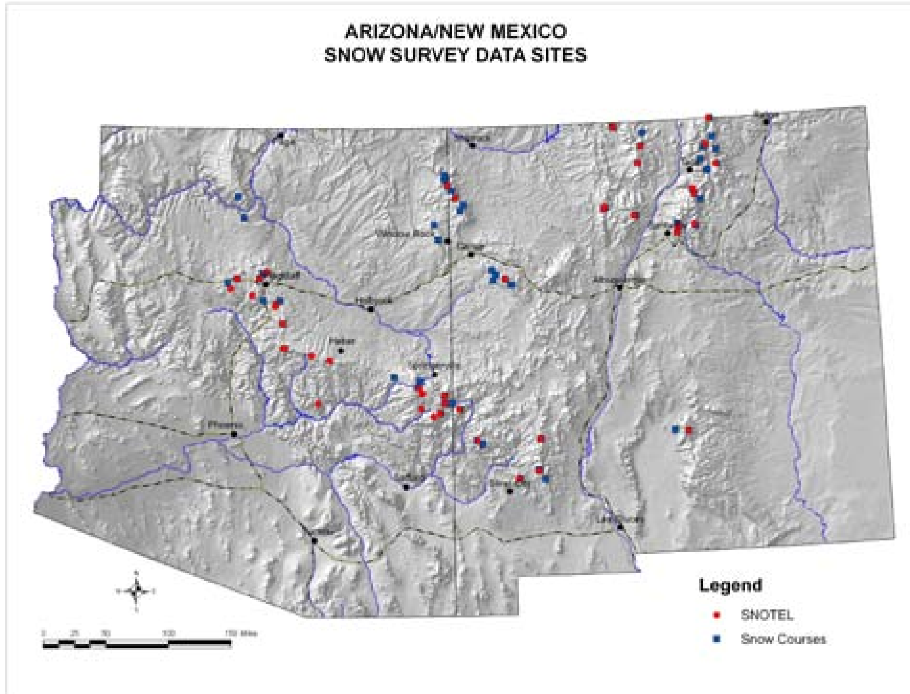

Figure 2. There are 21 SNOTEL stations and 23 snow courses in Arizona, while New Mexico tallies 23 and 39, respectively. Map courtesy of Dino De Simon, NRCS.

The basic SNOTEL station provides snowpack, water content, snow depth, precipitation, and air temperature data. The more sophisticated SNOTEL stations also are equipped to measure soil moisture and temperature at various depths.

The data generated by SNOTEL and snow course measurements are used by researchers, state climatologists, and fire and forest managers. The greatest value of the information, however, is found in the streamflow forecasts that are built on the snow measurements. These forecasts are used by irrigation districts and for reservoir operation, domestic water use, power generation, and flood control.

Streamflow forecasting

Most of the usable water in the western states originates as mountain snowfall. This snowfall accumulates during winter and spring, several months before the snow melts and appears as streamflow. Because the runoff from snow is delayed, estimates of snowmelt runoff can be made in advance.

In Arizona, forecasts from spring streamflow are made every two weeks between January 1 and April 1. Forecasts are issued once a month and continue through May 1 for New Mexico and through June 1 for the Upper Colorado River Basin states, where snow tends to linger on the landscape.

The NRCS bases its streamflow forecasts on a statistical model that uses historical relationships between SWE at a given date, total precipitation since the water year began on October 1, and the spring streamflow. A linear relationship between these three variables allows estimates of spring runoff to be computed as long as the SWE and total accumulated precipitation is measured.

The model works well in snow-dominated systems like the Upper Colorado River Basin, said Angus Goodbody, forecast hydrologist for the NRCS. But forecasting for Arizona and southern portions of New Mexico is challenging because a

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single large precipitation event can swamp the winter totals, and temperatures at higher elevations often can be above the freezing point, melting snow before spring arrives.

"We deal with the trickiness in Arizona by forecasting streamflows every two weeks, which allows us to see big storms approaching," said Goodbody.

But, he said, the statistical model prevents early winter forecasts from projecting high spring streamflows generated by extremely wet winters, like this year. Even though forecasters knew El Niño increased the likelihood of big storms, the streamflow forecasts were low in the beginning of the winter, said Goodbody.

Forecasts of spring runoff at the beginning of the winter, for example, can give a broad brush new of what to expect, Goodbody said. Most of the error in long-lead forecasts comes from one unknown variable—future weather—and forecasters will never be able to hone in on a specific streamflow forecast number until weather forecasting improves, he continued.

Forecasts become more accurate as the winter unfolds and more of the total precipitation has fallen. In snow-dominated basins like those in the upper Colorado River, measurements of SWE and total precipitation since October 1 made on April 1 can explain 80–90 percent of the expected streamflow in June. The other 10–20 percent comes from the whims of the weather.

The NRCS is not the only organization in the business of streamflow forecasting. The National Weather Service has 13 River Forecast Centers (RFC) in the U.S. that also issue forecasts. For the Colorado River basin, the RFC uses a similar statistical approach as the NRCS but also incorporates a hydrologic model. These two groups generate independent forecasts, discuss each together, and then issue one official forecast after reconciling the differences, if any.

Is the drought over?

For the 2009–10 winter, all of the major river basins monitored by SNOTEL stations in Arizona had more than twice the average snowfall as of March 15. It's a similar story in central and southern New Mexico; stations in the Mimbres watershed, which drains the southwestern corner of the state, posted more than three times the average snowfall.

After one of the driest monsoon seasons on record, the constant stream of winter storms improved or expunged short-term drought conditions in the region, leaving some to wonder if the drought is over.

"It's hard to argue that short-term drought is not over in many parts of the Southwest," said Mike Crimmins, a climate science extension specialist for the University of Arizona and affiliate of the Climate Assessment for the Southwest (CLIMAS).

Rain and snow since about December 1 will help moisten the deep soils, which will dampen fire risk in the spring. Rivers will swell in the spring, and extra water will flush through the system in some basins with reservoirs near full capacity. This will likely inject more water into aquifers, although how much is anyone's guess. Trees and winter vegetation also will flourish.

There are caveats, however. The winter storms bypassed the Upper Colorado River Basin; as a result, forecasts suggest that spring streamflow into Lake Powell will be around 67 percent of average.

In addition, it is difficult to assess the effects of one season's drought on the following season. The dry monsoon season, for example, likely caused grasses to release fewer seeds. There is a chance that even with an average monsoon season in 2010, pastures will be less robust because fewer seeds germinated. Another nuance is that the ecosystem of the Southwest is primed for seasonal rain. If it comes, all is green. If it doesn't, drought recurs.

"Drought comes and goes rapidly," Crimmins said. By the time summer rolls around, most of the wet winter will be a distant memory.