Global warming could affect groundwater recharge

By Melanie Lenart

Less than a week after record streamflow filled the six-lane-highway sized Rillito River with churning brown water, barely a puddle remained visible in the Tucson stretch near River and Park. A logjam piled up against a bridge bore silent testimony to the late July flood, which seemed to have passed on (Figure 1). Actually, some of it had passed underground. Judging from previous events, remnants of the floodwaters continued to trickle toward the water table about 120 feet below the barely moist surface.

Groundwater reservoirs remain mysteriously out of sight, making fluctuations of these important sources of southwestern water difficult to measure. It's even more challenging to project how they might fare as climate changes with the ongoing global warming.

Recent research shows that groundwater replenishment in the Southwest depends largely on floods, especially winter floods. This, in turn, means the fate of El Niño and snow cover likely hold the key to how groundwater recharge rates will change as the climate warms. The fate of El Niño as climate continues to warm remains unclear. Snow cover changes are more predictable. The changes they will wreak on groundwater recharge is less predictable, but not encouraging.

Figure 1. Tucson resident Robert Segal stands by debris collected by supports of the First Avenue bridge where it crosses the Rillito River. The July 31 high waters that carried the logs had moved downstream or underground by August 5, when this picture was taken.

Short-term recharge

"The thing that really drives groundwater recharge are these large storm events," which typically occur in winter, explained John Hoffmann, brandishing a graph showing episodes of groundwater recharge along the Rillito from one of his studies. The U.S. Geological Survey hydrologist pointed to the boost in aquifer levels during the winter of 1998, when the Rillito flowed for a month straight.

"That sustained flow provided an opportunity for focused recharge," Hoffmann added during a conversation in his Tucson office that also included Stan Leake, a hydrologist who has considered how climate change might impact groundwater recharge processes. Like the 2006 flood, a 1999 summer flood during the study disappeared more quickly, providing less time for recharge (Figure 2).

Riverbeds focus recharge in space as well as time, Leake explained. Unlike most of the southwestern lowlands, riverbeds do not contain a layer of caliche. Composed of calcium carbonate—roughly the same material as concrete—caliche blocks the downward flow of water. Caliche forms when the carbonate in rainfall joins with the calcium in the soil, often combining as the water evaporates back up through the soil horizon.

Along with riverbeds, mountain fronts also serve as major recharge sites. The alluvial fans of sediment spreading across the foothills can soak up the melted snow streaming down from the peaks as well as the monsoonal rainfall of summer that the mountains help spur.
Just how much recharge occurs along mountain fronts versus in riverbeds depends on the region and the climate that year, noted James Hogan, the assistant director of SAHRA, a University of Arizona consortium of water researchers. His work in the San Pedro Basin of southeastern Arizona suggests the recharge occurring in riverbeds can range from zero, such as during a dry year like 2002, up to 40 percent during a year with a strong monsoon, such as 1999.

Like the oil and natural gas contributing to global warming, groundwater exists in the porous spaces of rocks and sediments. Also like these fossil fuels, groundwater may have moved into its belowground location thousands of years ago or more. That's why some geologists like to refer to it as "fossil water" and speak of "mining" groundwater. The latter refers to taking out more groundwater from an aquifer than can be recharged on average in the time frame considered.

Although the Southwest contains massive amounts of fossil water, mining

continued on page 4

Groundwater, continued

it can cause the ground to subside—a potential disaster from a homeowner's point of view. In Tucson, subsidence has caused three to four feet drops in some sections around the central area.

So far, the subsidence hasn't caused widespread damage to homes and roads—but it could in the future if water mining continues unabated, explained Tim Thomure, the lead hydrologist for the Tucson Water Department. That's why the department has been promoting the use of renewable water supplies to replace groundwater mining.

'Artificial' recharge

Along with surface water supplied by rivers, renewable sources can include the water that measurably replenishes the aquifer. In Tucson's case, it also includes some of the city's Colorado River allocations now deployed in the Avra Valley artificial recharge project. It's called artificial because the water source is not local precipitation. But the recharge project is helping officials and researchers better understand recharging processes, whatever the water source.

"Your key point is you have to get through the surface—your top 10 to 20 feet," Thomure explained during a recent interview. Once it filters down that far, it should be safe from evaporation, as long as plants can't reach it. Then it has time to move around pockets of clay or other impermeable barriers on its long journey to the water table, which can take a year at the Avra Valley site. The artificial recharge project is highlighting another value of floods. Floods tend to scour channels, clearing out debris and organic matter from the riverbed. In the artificial recharge arena, officials must find ways to mimic the cleansing action of floods or clogged pores can impede their efforts.

Without floods, an impenetrable layer of mud or algae can build up on the channel bottom. Scouring the riverbed with heavy equipment can help, but creates potential erosion problems. Where the recharge source involves wastewater effluent, the high nitrogen levels boost algae growth so much that workers have to allow the sediments to dry out every day or two.

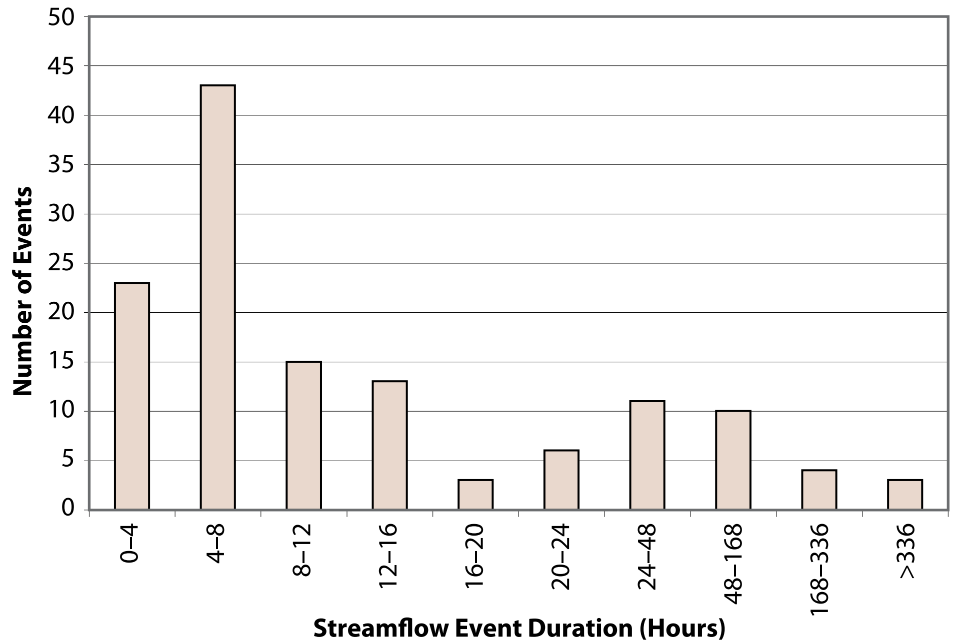

Figure 2. The number of hours during which waters soaked the Rillito River, an ephemeral stream, rarely lasted more than a day (24 hours) between 1990 and 2002 at USGS site 9485700. Graphic adapted from a figure published in the August 5, 2006, issue of *Water Resources Research* (Volume 42, number 8, page W08405-7).

Long-term recharge

To consider the long-term flow of groundwater, researchers favor using isotopes. For the past 15 years, University of Arizona (UA) geologist Christopher Eastoe has been employing isotopes from carbon, oxygen, hydrogen, and sulfur along with tritium to explore the sources and flow patterns of groundwater in the Tucson Basin.

Using equipment at the UA campus, Eastoe can compare chemical patterns in groundwater patterns to those in rainfall. For instance, the ratio of slightly heavier oxygen atoms—known as isotopes in this context—to the more common variety can reveal whether their H_2O source fell during summer or winter.

This chemical detective work has allowed him to identify groundwater signatures that point to their sources—in space as well as time. His paper on the topic, along with others including one on James Hogan's research mentioned above, can be found in the book *Groundwater Recharge in a Desert Environment* (American Geophysical Union, 2004).

Winter storms rule

Eastoe's work over the years, with others, has highlighted the importance of winter precipitation for groundwater recharge.

"We have almost no influence of summer rain in the (Tucson) basin regarding recharge," judging from the isotopic signature in the top 600 feet of the water table, Eastoe said in November. This fits with the observations that winter storms tend to be larger and linger longer on the landscape, while summer storms tend to come in flashier local events and evaporate quickly.

continued on page 5

Groundwater, continued

"To the extent that you keep the water in the river for three months rather than three days, there's far more potential for recharge," noted Katharine Jacobs, executive director of the Arizona Water Institute.

Although Eastoe is still pulling together other research, preliminary results indicate the tendency for winter precipitation to drive groundwater recharge probably holds for many basins throughout the Southwest. He noted that graduate researcher Arun Wahi's work shows the telltale signs of winter-dominated groundwater inputs even in the basin underlying the San Pedro River, where monsoon rain comprises about two-thirds of precipitation in a typical year.

USGS hydrologist Don Pool's research also supports the interpretation that winter storms drive recharge. He found the high-flow events that are good for recharge were more likely to occur during El Niño events at the three stretches he considered: the San Pedro River at Charleston and Tucson's Rillito and Sabino creeks (*Water Resources Research*, November 2005). La Niña conditions almost always meant low winter/spring river flows. However, about a third of the remaining years corresponded to years with high waters on at least one of the rivers.

El Niño years tend to boost winter and spring rainfall in the Southwest, with little direct impact on summer and fall precipitation. During El Niño events, warm water drifts to the eastern side of the Pacific Ocean Basin, often pulling the jet stream south into saguaro territory. During La Niña years, cooler eastern Pacific temperatures help create a ridge that deflects the jet stream and its associated rainfall.

Impacts of changing climate

El Niño events have become more frequent and pronounced since the mid-1970s, although a lengthy La Niña event from 1998–2002 helped provoke the southwestern drought. Global warming accelerated during the same three decades, but climatologists are reluctant to use this as evidence that El Niño events will dominate future climate.

El Niño can fall into decades-long patterns from other causes besides global warming, as evidence from past climates show (*Southwest Climate Outlook*, January 2006). Computer models considering how this crucial pattern might shift with additional warming show a wide array of results (*Advances in Geosciences*, 2006). Scientists disagree on exactly how the ocean fluctuates from El Niño to La Niña and back, much less on how the mechanisms behind the fluctuations will change as oceans warm (*International Journal of Climatology*, April 2006).

The fluctuations, which affect precipitation patterns throughout the world, depend on differences in temperature between the western and eastern Pacific, not merely the temperatures themselves. While it's straightforward to project an upward climb in overall temperatures for both land and sea, it's more challenging to predict how the dynamics will play out.

The fate of snow cover, on the other hand, is easier to project because it relates directly to the warming. As temperatures rise, snowline creeps up the mountaintops. Snow cover shrinks in time, too, as warm temperatures extend their reach forward into autumn and backwards into spring.

Already researchers have been documenting a trend for more precipitation falling as rain rather than snow over the past half century throughout much of the West (*Journal of Climate*, September 2006). These changes are bringing a documented shift forward in time for the peak river flow that comes with spring thaw (*Journal of Climate*, April 2005). This has some researchers worried about the fate of groundwater recharge.

"As we change toward more rain away from snow, that has the potential to decrease the amount of recharge," Leake said. In higher mountain ranges of the Southwest, the melting of snow creates steady springtime river flows that recharge aquifers in the valleys below, he added.

USGS researcher Michael Dettinger expressed similar thoughts. "As the snowline retreats to cover smaller and smaller areas, and as the snowpack itself declines because of more rain and less snow and more intermittent melting… it seems really likely that recharge will decline in many parts of the Southwest," he said during a telephone conversation.

Warming temperatures also can turn some winter storms into the flashier events usually associated with the Southwest summer. He recalled a May 2005 storm around California's Yosemite Valley. Warm temperatures allowed the rain to cover a much larger area than typical for that time of year, with snowfall limited to elevations above about 10,000 feet. As a result of the extensive area involved, a mere one inch of rainfall resulted in a flashy valley-wide flood.

Floods like this can provide some recharge, much as the here-and-gone Rillito flood this summer did. But it's unlikely to provide the same groundwater boost as it would have if the same amount of precipitation had fallen as snow and then melted over time, feeding rivers for months on end. If winter storms start acting like summer storms, groundwater aquifers could pay the price.

Melanie Lenart is a postdoctoral research associate with the Climate Assessment for the Southwest (CLIMAS). The SWCO feature article archive can be accessed at the following link: http://www.ispe.arizona.edu/climas/forecasts/swarticles.html