Quantifying Riparian Evapotranspiration

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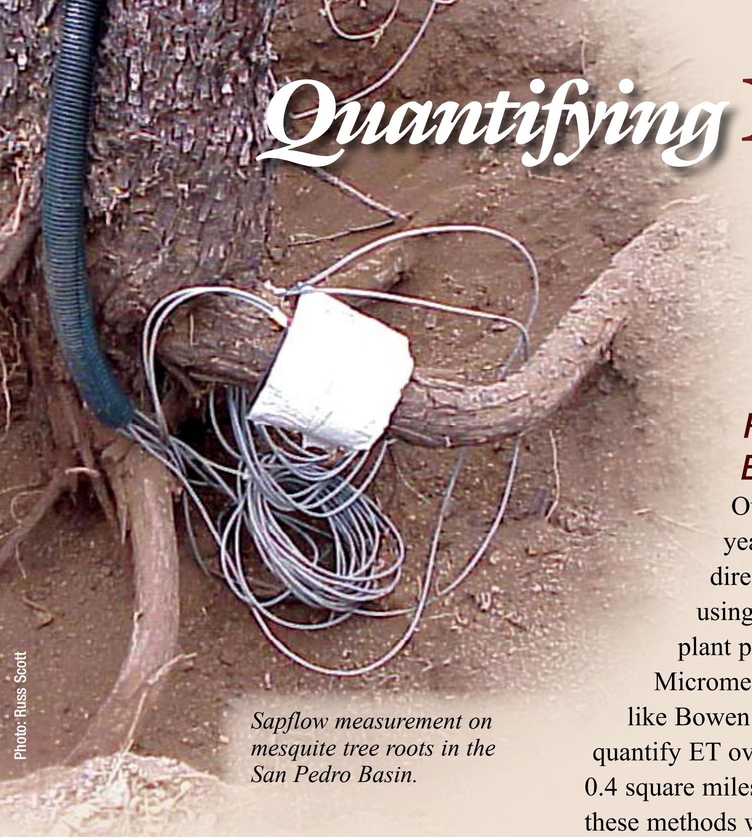

Sapflow measurement on mesquite tree roots in the San Pedro Basin.

Photo: Russ Scott

Riparian corridors are hot spots of biological activity and provide valuable habitat, supporting significant biodiversity in semiarid regions such as the southwestern United States. Yet rural and urban developments increasingly are impacting the vitality of riparian areas by changing land use, diverting water, and lowering the water table. The San Pedro River in southeastern Arizona is a good example of such a situation. Population growth and the resulting increase in groundwater pumping in the Upper San Pedro Basin have created concern that the water table may fall below the rooting zone of the riparian vegetation, leading to abrupt changes in many ecosystems.

A multidisciplinary group of government scientists and university researchers has been working to better understand the hydrological functioning of riparian systems in the Southwest, particularly the quantification of riparian evapotranspiration (ET). Groundwater modeling studies have long shown that water use by riparian vegetation is an important component of the basin water balance. Yet because the quantification of ET was based on indirect techniques like streamflow data or by untested empirical approaches, its magnitude was highly uncertain.

Refining Riparian ET Measurements

Our focus over the last 10 years has been on making direct measurements of ET using micrometeorological and plant physiological techniques. Micrometeorological techniques like Bowen ratio or eddy covariance quantify ET over an area of around 0.2 to 0.4 square miles, so measurements using these methods were made in carefully chosen sites with uniform stands of vegetation, like the floodplain grasslands and mesquite shrublands and woodlands along the San Pedro. Shrublands and grasslands along the old alluvial terraces were found to have similar annual ET rates of around 24 to 28 inches per year, while the more mature and dense mesquite woodlands typically have annual rates greater than 28 inches (Scott and others, 2006a; Williams and Scott, in press). This represents significant groundwater use: ET *in excess* of precipitation, as annual rainfall totals have ranged from only about 10 to 12 inches. On a leaf-area basis alone, mesquite transpiration is considerably higher than that of grass. This finding has management implications because mesquite are readily expanding into grassland areas, which likely has resulted or will result in increasing groundwater use for the whole riparian system (Scott and others, 2006b). These investigations also revealed that grasses can only access groundwater at depths of 11 feet or less, but the deeper-rooted trees access groundwater at depths greater than 36 feet.

> *Along the Upper San Pedro, mesquite groundwater use was the dominant component of total riparian water use.*

In riparian plant communities like the long, narrow cottonwood galleries or stands of seepwillow (a dominant understory plant along the river) that were not amenable to micrometeorological techniques, sap-flow sensors were deployed in our studies to quantify water flow in roots, branches, and stems of the dominant plant types (see sidebar at right). This technique was used in combination with plant surveys of total sap wood area and canopy cover to determine transpiration. Cottonwood and willow forests along a perennial flow reach (depth to groundwater ranging from 3 to 7 feet) had the highest water use with rates exceeding 37 inches for a growing season. Cottonwoods along an intermittent reach of the river where the depth to groundwater ranged from 10 to 13 feet were more water stressed and used only about 20 inches over the same time period (Gazal and others, 2006). Transpiration rates for seepwillow were about 31 inches, similar to the cottonwood overstory despite the reduced atmospheric demand of the understory environment (Scott and others, 2006a).

Scaling Up from Site to Reach

Two approaches were used to scale up the site-based measurements to obtain total riparian vegetation water use along entire reaches of the San Pedro. The first used a detailed vegetation map and the second used vegetation indices and surface temperature from satellites to provide spatially explicit data.

Vegetation mapping: Detailed vegetation maps were used to quantify the total

The Water-Banking Mesquites

One of the most fascinating results of our research was the the discovery of "hydraulic redistribution" by mesquite, or the transfer of soil water via plant roots in response to water potential gradients. Growing evidence suggests this process is prevalent in any ecosystem that contains plants with roots that span moisture potential gradients. Hultine and others (2004) discovered that riparian mesquites have the ability to redistribute near-surface soil moisture to the deeper vadose zone throughout the entire year (see chart at right). Measured nighttime sap flow in a mesquite taproot was upward before the monsoon onset, but became downward when the surface soil was moist, and sap in lateral roots moved toward the stem. Moisture redistribution followed the moisture potential gradient with upward "lifting" of deep vadose zone moisture or groundwater during the dry season and downward descent of precipitation during times of abundant surface moisture. In this way, they found that mesquite can "store" rainfall deeper in the vadose zone, away from scavenging understory plant roots and bare soil evaporation processes, and then later use this moisture to support transpiration. We are currently examining the ecohydrological significance of this process in nonriparian mesquites; preliminary results suggest it plays a pivotal role in their successful expansion into grassland ecosystems.

Reference

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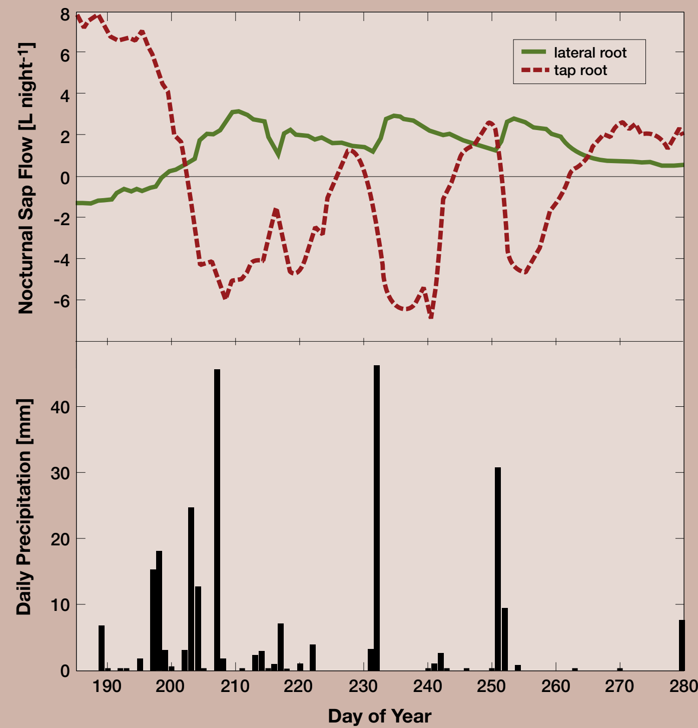

(Top) Total nighttime sap flow of the taproot and a lateral root of a mesquite tree, calculated from half-hourly measurements between 8 p.m. and 5:30 a.m. Negative values represent reverse flow (away from the crown). A significant negative correlation is observed between nocturnal sap flow in the taproot and in the lateral root ($R^2 = 0.85$, $P < 0.0001$). (Bottom) Daily precipitation totals at the field site during the study. Adapted from Hultine and others (2004).

area of the different riparian vegetation communities and then multiply these areas by their respective estimates of ET obtained from the micrometeorological or sap flow measurements (Goodrich and others, 2000; Scott and others, 2006a). Riparian groundwater use in 2003 for a 30-mile reach along the San Pedro River from the international boundary to the USGS stream-gauging station near Tombstone was calculated to be about 7,300 to 9,000 acre-feet (around 9 to 11 million cubic meters) per year. For the entire Sierra Vista subwatershed, estimates were 25 to 57 percent greater than the amount determined by the Arizona Department of Water Resources based solely on stream gauge information. Mesquite groundwater use was the dominant component of total riparian water use (58 percent), owing to its high abundance, followed by cottonwood-willow, open water, sacaton, and tamarisk.

Satellite data: More recently, a second approach to scaling up site-based measurements has been to connect satellite measurements of surface temperature and vegetation greenness with multiple years of site-specific ET data in a statistical modeling framework (Scott, 2007). Because the satellite data have spatial resolution of about 800 feet and temporal resolution of every 16 days since the year 2000, multiyear ET estimates, which implicitly account for the spatial heterogeneity of the vegetation functioning, were possible over the entire basin. Annual riparian

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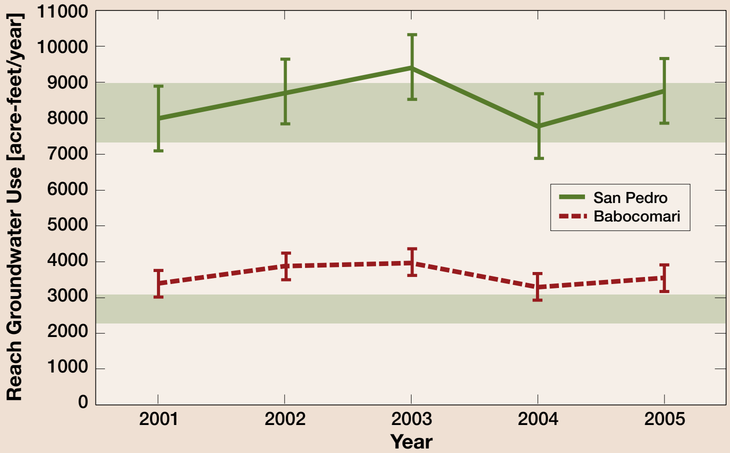
groundwater use from 2001 to 2005 within the subwatershed was nearly constant over the study period despite an ongoing drought, indicating that the vegetation's access to groundwater has so far buffered it against meteorological drought (see figure, right). For the same reach of the San Pedro, the annual amounts determined by this new approach range from 7,800 to 9,400 acre-feet (9.6 million to 11.6 million cubic meters), within the range of values determined by Scott and others (2006a) for 2003. However, because of the larger estimates for groundwater use for the main tributary of the San Pedro, the Babocomari, watershed totals were close to or exceeded the upper end of the range of previous estimates.



2001-2005 reach-level riparian groundwater use (ET in excess of precipitation) along the San Pedro and Babocomari rivers in the Sierra Vista subwatershed. The ranges of estimates determined by Scott and others (2006) for 2003 are indicated by the shaded regions.

This work has been supported by the USDA-ARS, SAHRA, and the Upper San Pedro Partnership. Our scope has also broadened to involve researchers of the Rio Grande and Colorado River basins so that generalized methods can be developed with broad application.

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