Study uses remote sensing to monitor groundwater along river corridors in the Southwest

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Lush vegetation follows the path of the Virgin River as it cuts like a green ribbon across the desert of Washington County, Utah. Credit: MARC MAYES

Spend time in any of the world's great forests and you'll start seeing the trees as immense pillars holding the heavens aloft while firmly anchored in the earth. It's as much fact as sentiment. Trees really do link the ground to the sky by exchanging energy and matter between the soil and the atmosphere. Researchers believe that understanding this connection could provide both a wealth of scientific insight into ecosystems and practical applications that address challenges such as water resource conservation and management.

A recent study led by UC Santa Barbara's Marc Mayes investigates how patterns in tree water loss to the atmosphere, tracked with satellite imagery, relates to groundwater supplies. The results validate at landscape-wide scales ideas that scientists have proposed based on decades of research in labs and greenhouses. What's more, the techniques lend themselves to an accurate, efficient way of monitoring groundwater resources over large areas. The findings appear in the journal *Hydrological Processes*.

For all their diversity, most plants have a very simple game plan. Using energy from sunlight, they combine water from the ground with carbon dioxide from the air to produce sugars and oxygen. During photosynthesis, plants open small pores in their leaves to take in CO_2, which also allows water to escape. This process of water loss is called evapotranspiration—short for soil evaporation and plant transpiration—and it's essentially a transaction cost of transporting the ingredients for photosynthesis to the leaves where the process occurs.

Just like evaporating sweat cools down our own bodies, the evapotranspiration from the trees cools down the forest. With the proper understanding and technology, scientists can use thermal image data from satellites as well as manned and unmanned aircraft to understand the relationship between plants and groundwater: cooler temperatures correlate with more evapotranspiration.

"The core hypothesis of this paper is that you can use relationships between plant water use [as] measured by [satellite] image data, and climate data including air temperature and rainfall, to gauge the availability of, and changes in, groundwater resources," said Mayes, an Earth scientist and remote sensing expert based at the university's Earth Research Institute (ERI).

Mayes and his colleagues focused on the flora of dryland rivers—those in deserts and Mediterranean climates. Throughout these regions, many plants have evolved adaptations that minimize water loss, like slow growth, water retention or boom-bust lifecycles. However, plants that dominate river channels—species like sycamore, cottonwood and willows—evolved to take advantage of the surplus groundwater the habitat offers relative to the surrounding landscape.

"Rather than slowing down its water use when water becomes scarce, this vegetation will basically drink itself to death," Mayes said. This makes it a good window into conditions below the surface.

The team used satellite-based thermal imaging to look at temperatures across the San Pedro River corridor in southern Arizona. On cloud-free days the satellites can gather data on surface temperatures at high resolution over large areas of land. By comparing the temperatures along the river to those in nearby, more sparsely vegetated areas, the researchers were able to determine the extent of evapotranspiration along different parts of the river at different times. They found that it correlated with air temperature in water-rich environments and with rainfall in water-scarce environments.

The findings support recent advances in our understanding of plant water use. The hotter and drier the air, the stronger it pulls water from the leaves, and the more water the plant uses. Consequently, Mayes and his colleagues expected to see evapotranspiration vary with air temperature as long as the stream has abundant groundwater for the plants to draw on.

On the other hand, where groundwater is scarce, plants will close the openings on their leaves to avoid water loss; it's more important to avoid drying out than to take advantage of the extra sunshine on a warm day. As a result, evapotranspiration will correlate much more strongly with rainfall and streamflow, which increases the supply of water to trees through their roots.

Scientists had demonstrated the predictable effect of evapotranspiration in lowering surface temperatures in lab and small field experiments. However, this is the first study to demonstrate its impact over large areas. The technology that made this possible has matured only within the past five years.

"This remote sensing method shows great promise for identifying the relevant climatic versus other controls on tree growth and health, even within narrow bands of vegetation along rivers," said coauthor Michael Singer, a researcher at ERI and lead investigator on the project that funded Mayes' work.

In fact, these ecosystems are vitally important to the southwestern U.S. "Despite taking up about 2% of the landscape, over 90% of the biodiversity in the Southwest relies on these ecosystems," said coauthor Pamela Nagler, a research scientist at the U.S. Geological Survey's Southwest Biological Science Center.

The same techniques used in the paper could be applied to the perennial challenge of groundwater monitoring. In fact, this idea helped motivate the study in the first place. "It's very hard to monitor groundwater availability and change[s] in groundwater resources at the really local scales that matter," Mayes said. "We're talking about farmers' fields or river corridors downstream of new housing developments."

Monitoring wells are effective, but provide information only for one point on the map. What's more, they are expensive to drill and maintain. Flux towers can measure the exchange of gasses between the surface and the atmosphere, including water vapor. But they have similar drawbacks to wells in terms of cost and scale. Scientists and stakeholders want reliable, cost-effective methods to monitor aquifers that provide wide coverage at the same time as high resolution. It's a tall order.

While it may not be quite as precise as a well, remote thermal imaging from aircraft and satellites can check off all of these boxes. It offers wide coverage and high resolution using existing infrastructure. And although it works only along stream corridors, "an inordinate amount of agricultural land and human settlements in dry places ends up being where the water is, along stream paths," Mayes said.

The idea is to look for shifts in the relationships of evapotranspiration to climate variables over time. These changes will signal a switch between water-rich and water-poor conditions. "Detecting that signal over large areas could be a valuable early warning sign of depleting groundwater resources," Mayes said. The technique could inform monitoring and pragmatic decision-making on groundwater use.

This study is part of a larger Department of Defense (DOD) project aimed at understanding how vulnerable riverine habitats are to droughts on DOD bases in dryland regions of the U.S. "We are using multiple methods to understand when and why these plants become stressed due to lack of water," said Singer, the project's lead scientist. "[We hope] this new knowledge can support the management of these sensitive ecological biomes, particularly on military bases in dryland regions, where these pristine habitats support numerous threatened and endangered species."

Mayes added, "What's coming down the pipe is a whole ensemble of work looking at ecosystem responses to water scarcity and water stress across space and time that informs ways we both understand ecosystem response and also improve the monitoring."

More information: Marc Mayes et al. Climate sensitivity of water use by riparian woodlands at landscape scales, *Hydrological Processes* (2020). DOI: 10.1002/hyp.13942

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