UNLOCKING SECRETS OF THE VADOSE ZONE

Researchers say this layer of soil holds keys to tracking water's every move

Editor's note: The stories in this issue of txH2O are examples of each stage of the research process, beginning with applied research, which is the application of science to solve practical problems. This story examines Dr. Binayak Mohanty and his team's investigation into the vadose zone to help solve issues related to global water management, agriculture, flood forecasting, climate prediction, weather, energy balance and contaminant transport.

When drought strikes, water planners, scientists and farmers alike look to surface water and groundwater supplies for answers. But what if the answer to drought prediction and mitigation isn't there? What if it's in a place few people have ever heard of?

That place is called the vadose zone—the layer of earth that lies between topsoil and groundwater—and it has some secrets to tell. Fortunately, a team of Texas A&M University scientists led by Dr. Binayak Mohanty is listening.

Mohanty, a professor in Texas A&M's Department of Biological and Agricultural Engineering, a Texas A&M AgriLife Research Faculty Fellow and a Texas A&M Engineering Experiment Station Faculty Fellow, has studied the vadose zone for years. He has enlisted postdoctoral and graduate student researchers from a variety of disciplines to work beside him. Their common objective is to examine, model, scale and understand what happens in this layer of soil, helping scientists all over the world better understand and predict not only drought, but a wide range of natural processes that impact both water quality and quantity.

What is the vadose zone?

Sayena Farid-Marandi collects ground-based soil moisture data for calibration/validation of remote sensing platforms in Oklahoma.

Also known as the critical or unsaturated zone, the vadose zone is the section of soil located above the water table.

"This zone is right under our feet, so whatever we do, it impacts the vadose zone," Mohanty said. "In layman's terms, it's soil."

The vadose zone could hold keys to everything from drought mitigation to how water contaminants move, to food production and flood prediction, but unfortunately it's not a simple place to understand, Mohanty said. Always changing and shifting, the zone is intrinsically dynamic because it's unsaturated.

"The critical aspect of the vadose zone is that it is not saturated," he said. "It is always in a dynamic mode, fluctuating between saturated and dry conditions. During times of heavy rainfall, it fully saturates, and during drought times, it becomes drier due to evaporation.

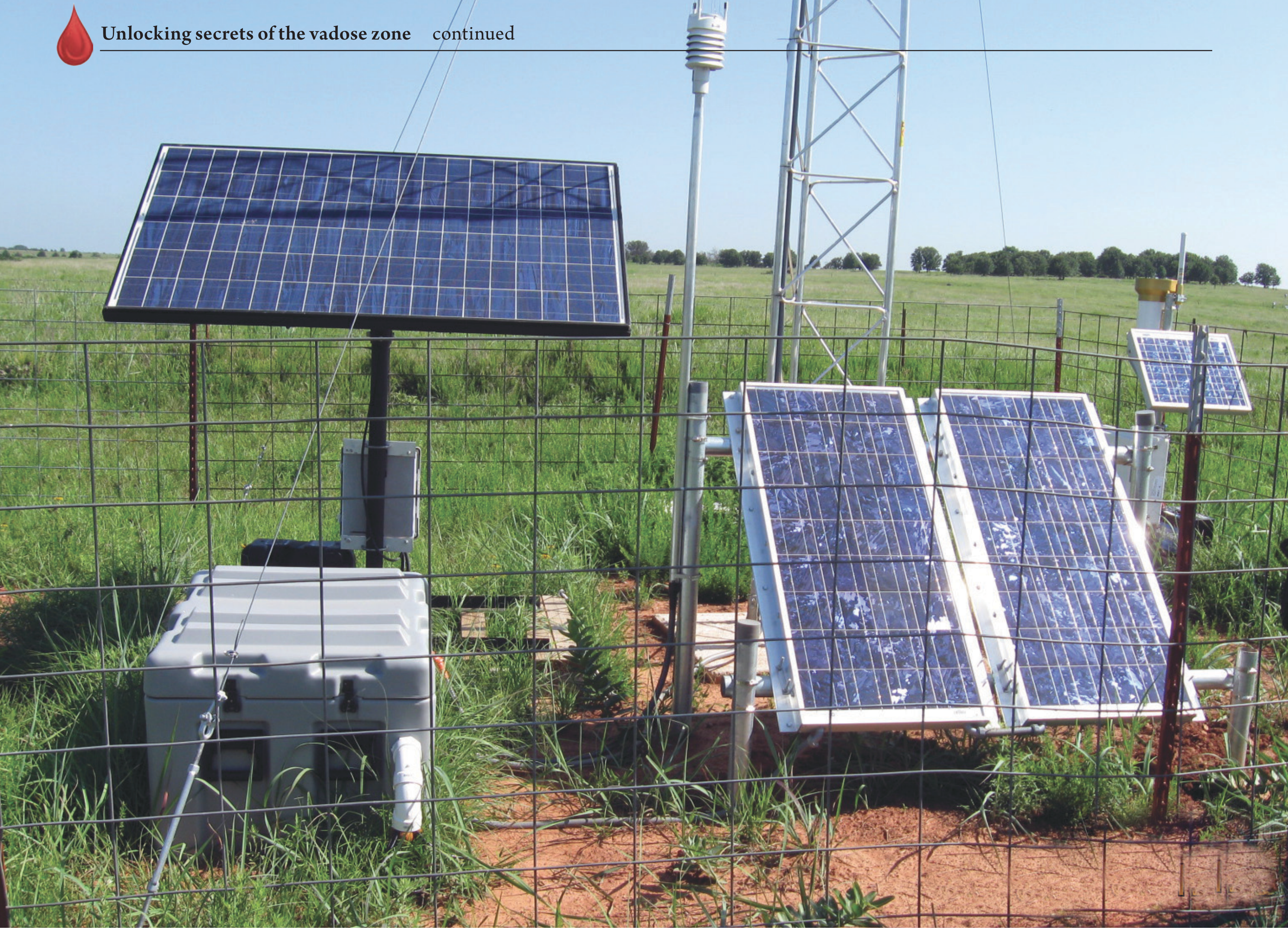
"The challenges are even more complex because you need to understand how those dynamics evolve under different variables—different locations, different hydro-climatic conditions, different types of crop cover, different types of soil and different types of landscape features."

Tracking water to mitigate drought

The water cycle is a basic concept often taught to young children—in Texas' state curriculum it's covered in second grade—but a clear understanding of precisely how and where water moves is not nearly so elementary.

Employing physics, hydrology, remote sensing, geographical information systems (GIS) and a host of other techniques, the research team maps out its understanding of this dynamic and complicated part of the earth. Mohanty's ultimate goal is to use the collected data to quantify the processes happening in the vadose zone.

"We're trying to unravel the complexity of the vadose zone and how the water migrates through it," Mohanty said. "The vadose zone is also very important to weather feedback: Basically, the land and atmosphere interact to create local weather conditions, and much of the water in the vadose zone goes back to the atmosphere. The water in the vadose zone controls these dynamics by acting as a switch that determines how much water from rainfall flows into streams and how much penetrates the earth and reaches the groundwater. So, the amount of the water that's in the vadose zone is important to weather and climate forecast models." ⇨



Above: The research group uses soil moisture and land atmosphere interaction monitoring networks to collect data.

That water's movement depends on the variables in the environment, so Mohanty's team studies areas with various soil types, conditions, landscape attributes and features—including complex typographies, catchments and watersheds.

"How does rainfall migrate on the ground and send water into the vadose zone?" he asked. "We look into that process, describe the differential flow, try to innovatively model it and then develop more sophisticated, process-based models for near-surface water that other scientists can use.

Because the water that resides in the vadose zone dictates how much water is available for plants, understanding the zone is critical to mitigating drought. Mohanty said that the different kinds of drought—hydrological, agricultural and climatological—are all tied to the vadose zone. "When we have conditions of little precipitation and high amounts of evaporation from the vadose zone, this results in permanent wilting of plants, or agricultural drought," he said.

Hydrological drought entails a reduction in streamflow, Mohanty said, and climatological drought is reduced precipitation. Vadose zone hydrologists focus mainly on hydrological and agricultural drought. His team aims to provide the information needed to optimize water resources and at least reduce the impact of drought by minimizing runoff and maximizing crop productivity.

"Drought is such a natural calamity—it damages not only local conditions and the livelihoods of so many farmers, but it also affects the global economy," Mohanty said. "Unfortunately, drought is going to be happening more and more, and the basic reason is because the water cycle and available water resources are changing."

Climate change, misuse or over-use of available water resources, agricultural practices and urbanization are some of the reasons for those changes, Mohanty said.

Left: The vadose zone research group, including (front row, left to right) Dr. Binayak Mohanty, Bhavna Arora, Champa Joshi, and Nandita Gaur; (middle row, left to right) Yongchul Shin, Dipankar Dwivedi, and Jun Wang; (top row, left to right) Raghavendra Jana, Zhenlei Yang, Sayena Farid-Marandi, and Jonggun Kim; is a multidisciplinary team.

Right: Mohanty's team uses soil core extractions for soil water retention and hydraulic conductivity measurements.

"One of the biggest scientific challenges facing Texas right now is that we don't have a widespread, concerted effort to observe and develop a scientific understanding of the critical zone. We're trying to bring this to Texas."

Understanding contaminant transport

This fundamental understanding of soil and the vadose zone is not only key to managing water, reducing the risk of drought and flood, and improving agricultural lands and ecosystems—it can also enable scientists to better track environmental pollutants that are harmful to ecosystems and groundwater supplies. Examining mechanics of contaminant transport is a part of the team's research.

"The vadose zone contributes to (understanding) contaminant transport," Mohanty said. "If you apply pesticides or fertilizers on the land surface or store any municipal or industrial contaminants, for example, in some containers below the ground, those chemicals cannot move until the water in the vadose zone carries them. The transport of these chemicals in the vadose zone eventually moves them into aquifers or into groundwater supplies."

Mohanty said that the team looks at how different chemicals interact and create different oxides or combinations in the soil and eventually either migrate to the groundwater system or become stabilized in the vadose zone. How contaminants move depends on soil type and hydrology and whether the contaminants were preexisting or caused by humans.

"Understanding how they're transported is very important for the contaminant removal processes," he said.

High nitrate levels in groundwater are one such contaminant that Mohanty's team studies. Nitrates existing in groundwater can cause health ⇨

problems in certain groups, such as pregnant women, Mohanty said. The team is examining how water becomes contaminated by nitrates and how contaminant levels can be reduced in Texas' water supplies.

Another project that the team is currently working on involves developing multiple conceptual models of how contaminants are transported in the vadose zone, and this knowledge is important to the military as well as the energy industry and regulators, he said. The team has also analyzed landfill sites and worked to understand contaminant transport in such sites.

"Whatever chemicals are left in the ground, they eventually leak into the groundwater," Mohanty said. "So, if we can at least understand how the contaminants move over time, then we can develop alternative strategies to minimize those negative impacts."

Because the vadose zone is critical to so many global applications, the team conducts research that can be developed on the global scale and then applied locally.

Studying soil from space

State-of-the-art remote-sensing techniques have been developed over the last several decades, with new satellites launching every year, Mohanty said. This wealth of new technology opens doors to expanding research in ways that were previously limited. The team has used data from many different satellite programs, including data from NASA, such as the Advanced Microwave Scanning Radiometer (AMSR-E).

"Instead of digging a hole in everyone's backyard, now we can efficiently collect remotely sensed data from satellites," Mohanty said. The team acquires soil moisture data from programs, such as NASA's upcoming SMAP (Soil Moisture Active-Passive) satellite, and then analyzes it and develops techniques to incorporate the remotely sensed data into predictive hydrology and climate models.

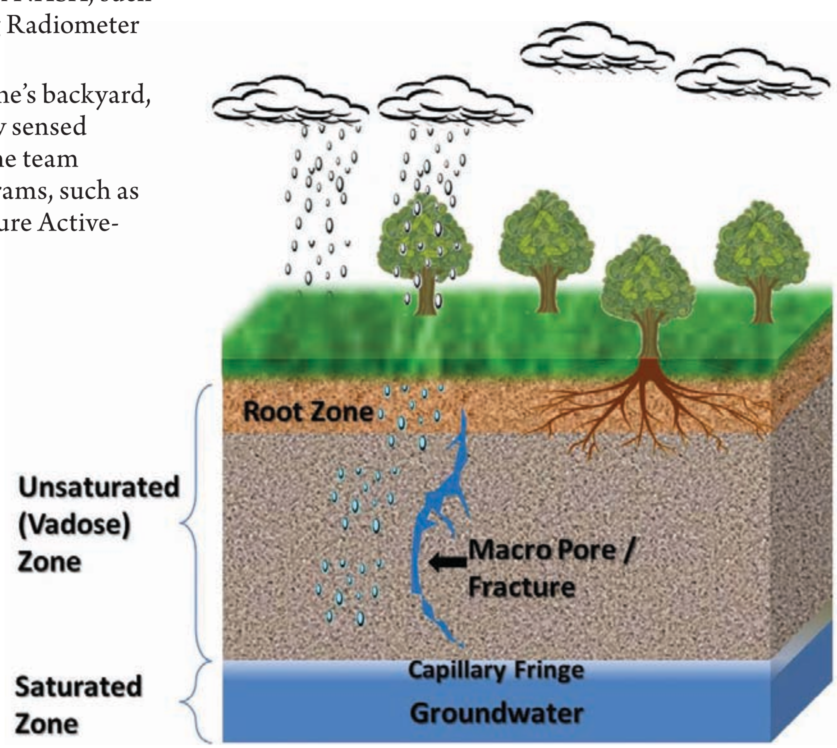
"Traditionally, people identified soil properties using local, ground-collected soil information, but with these new technologies and satellites, we can generate and populate findings on a global scale," he said. "This enables us to get soil hydraulic parameter data that is timeless and useful in many applications."

Scaling data makes it globally relevant

Mohanty said the group is continually working to specifically understand the zone's underlying processes and then model the dynamics of soil moisture at multiple scales, using various ground, air and space techniques.

"To address all of the complexity of the vadose zone, we look into very fundamental processes and then scale them," Mohanty said. "From the scale of pores, where the water lies, we scale the data all the way to larger fields where crops grow, farther up in the hierarchy to the watershed scale, where the water creates surface runoff, and then eventually all the way to the regional, continental and even global scale.

"We cannot do this using only one technique, so we assimilate data from various platforms, such as ground-level measurements at the finest scale and remote sensing measurements up to the watershed,



regional and continental scales. So in addition to ground techniques, we also use airborne sensors and space-borne sensors to understand and unravel the processes of soil moisture in the vadose zone.

"We have discovered how to scale up and scale down these data sets that come from different sensors at different scales. For example, if you have data collected at the local scale, can you scale it up to the watershed scale or visa-versa? Now we can."

Because upscaling and downscaling are some of the research group's major focuses, they have learned how to scale remote sensing data down to local fields so that farmers can apply techniques for water management or drought prediction. Conversely, their ground-sensing data can be scaled up to the regional scale for hydroclimatic applications, Mohanty said. They use simple data to describe complex processes.

"Our findings are not just site-specific; more general findings can be transferred and adapted to any place in the world," Mohanty said.

The right team and the right technology

Mohanty's team combines these diverse technologies with people from diverse fields of expertise to convert data into new, innovative models for forecasting drought, managing water better and minimizing water loss. The group includes researchers in engineering, biological sciences, chemistry, geology, mathematics and physics, together analyzing the full range of soil parameters, which are nonlinear and not easy to model, Mohanty said.

"Our job is to provide these fundamental understandings of soil moisture to state officials, farmers or Extension professionals and give them tools such as models and data sets to use for various applications," Mohanty said. "We also develop a lot of new statistical techniques that enable us to better analyze these kinds of data sets."

Thanks to funding from the National Science Foundation, NASA, U.S. Geological Survey, U.S. Department of Energy, National Institute of Environmental Health and other state and federal agencies, Mohanty's group has continually produced new findings about the vadose zone.

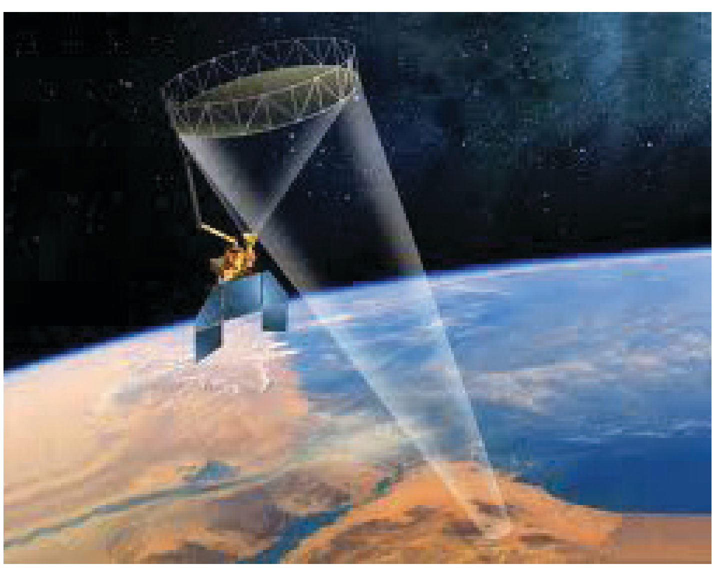
"With that funding, we've completed over 25 projects in the last 10 years," he said. "We are continually striving to improve our predictive skills of the water cycle in the vadose zone under different types of conditions."

How can the vadose zone help us right now?

In hydrology, soil moisture is known as the "gate keeper," Mohanty said. And that's why his team works so hard to link together so many different disciplines and processes—because understanding soil moisture in the vadose zone has important, global implications for natural resources.

"The vadose zone is important to all extreme events that happen in hydrology. And from all angles—everything from agriculture to weather to hydrology and energy balance, the vadose zone affects it all. From food security to water security, it has large implications that we cannot ignore."

For more information, see Mohanty's research group website: *vadosezone.tamu.edu*.



Left photo: Illustration of NASA's upcoming SMAP (Soil Moisture Active Passive) satellite, used by the team to acquire soil moisture data.

Right photo: Vadose zone research group students collect samples during soil moisture field campaigns for calibrating and validating satellite based remote sensors.