The drawbacks to traditional NMR come from its dependence on a large magnetic field for high-resolution measurement, which can only come from heavy and costly permanent magnets that interfere with other instrumentation and require the work to be confined to a laboratory. Los Alamos scientist Sanna Sevanto and her colleagues have developed a radically different approach to measuring water uptake and transport in living plants that avoids permanent magnets entirely and relies on comparatively miniscule magnetic fields. An adaptation of ultra-low magnetic field technology pioneered at the Laboratory by scientists Michelle Espy and Michael Malone for medical magnetic resonance imaging (MRI), the new plant NMR system consists of an air-cored electromagnet operating at an ultra-low field strength (about a million times weaker than a conventional hospital MRI).

The setup provides a number of advantages over conventional NMR or other techniques. First, because it's an electromagnet—created basically by coiling an insulated current-carrying wire around the tree trunk—it is affordable, lightweight, and easily adapted to trees of different sizes. Second, because the magnetic field is so weak, the scientists can use other instruments in tandem, and the NMR electromagnet won't interfere. Third, it provides more complete data than the usual invasive techniques because it allows water measurement from the entire cross section of a tree. And last, because of the reduced interference, modest price tag, and small size, multiple systems can be set up within the same study area, or even on different parts of the same tree, which enables more comprehensive study of the drought response.

To test their setup, Sevanto and her colleagues did a variety of experiments in a greenhouse setting. They were able to distinguish rates of water transport clearly in four different types of trees, across a twenty-degree temperature range, during a two-month period of peak drought season. They also experimentally mimicked naturally occurring extreme conditions that alter trees' water content and were able to detect changes on a time scale as short as 30 minutes.

To confirm that the NMR measurement was actually measuring water transport through the plants' conduits and not the water inside the plants' cells, the scientists needed to validate the NMR findings with an imaging method. For this, the team conducted neutron imaging at the Los Alamos Neutron Science Center. Because it wasn't practical to bring whole trees into the facility, they used freshly cut branches, which can still transport water.

The branches were first given normal water and then switched to heavy water (H_2O in which the hydrogen atoms have an extra neutron) just before being placed in the neutron beam. Whereas normal water tends to stop neutrons from passing through the tree branch to detectors on the other side, heavy water does not. So as the normal water was displaced by the heavy water entering the tree branch, the images of the branch gradually changed from fairly dark (opaque to neutrons) to much more transparent. Conveniently, NMR can also distinguish between normal and heavy water, so the researchers conducted NMR simultaneously with the neutron imaging. By comparing neutron imaging and NMR data, they were able to conclude that the NMR technique was indeed capturing water transport within conduits, not water inside cells.

"There are two branches to what we're doing," explains Sevanto. "There's the new technology—developing low-field NMR to look at trees in nature—and then there's the new kinds of data we're getting. If we understand both things as thoroughly as possible, we will be able to combine the new technique and new data with others' studies and really improve the state of drought science moving forward." LDRD

—Eleanor Hutterer

From Cosmos to Canyons

HERE'S THE PROBLEM: YOU'VE GOT A NATURAL LANDSCAPE with the possibility of past exposure to chemical or nuclear contamination, and you want to keep a watchful eye for contaminants that could discharge to a major river system through storm-water runoff. It's a rugged, remote, and expansive region, with few roads and no electricity, and you're going to need to monitor it continuously, rain or shine, for years. How do you do it?

You could try to design from scratch a versatile network of a hundred or more low-power sensors that operate reliably in variable weather conditions using a robust data-transmission system to send the measurement data from remote locations without line of sight to any kind of receiver. Or you could call someone accustomed to handling that kind of thing.

That's how it went down when Armand Groffman and Steve Veenis, environmental science specialists from the Lab's Surface Water Program, met with Janette Frigo of the Laboratory's Space Data Science and Systems group. Groffman and Veenis wanted to monitor the storm-water runoff in the wide expanse of hills and canyons surrounding Los Alamos in a cost-effective manner, and Frigo knew just how to do it.

Frigo based her solution on radiofrequency transmission circuitry initially designed for networked Department of Defense surveillance satellites with many of the same design requirements as the storm-water samplers: transmission versatility to overcome line-of-sight issues, wide temperature range functionality, and extremely low power use. She set out to design and build field-deployable units that, in addition to being resilient against temperature swings and other weather extremes, could run on limited battery power for years on end and yet transmit more information farther than any comparable existing hardware.

"The easiest thing would have been to use satellite modems," says Frigo. "You measure something, send the information up to a commercial satellite on a subscription-based, pay-per-bit paradigm and then download it to your computer. We've had success with that approach in the past, but we couldn't use it here. With all the data we would be sending from every sampling location, the satellite uplink would cost a fortune in hardware and data subscription fees."

Alexandra Saari configures an automated storm-water sampling station in the Jemez mountains near Los Alamos.

Frigo and applied physics specialist Alexandra Saari opted for a multi-pronged alternative. First, they would design each sampling unit to operate in a low-power idle mode except when transmitting. Second, they would give each unit a smart processor that could analyze the raw measurement data locally, filtering for important events and compressing the data to limit the duration of power-consuming transmissions to less than one second. But these advances alone would not be sufficient to overcome the power demands and prohibitive cost of satellite-based communications.

Instead, the units were modified to transmit messages and alarms through local, low-power radio broadcasts. That meant each unit would be both sender and receiver, sampling station and relay station. In idle mode, the units would always be listening, allowing them to communicate with one another in a smart "mesh" network, intelligently taking turns passing data from one unit, or "node," to another until the data reaches a common base station. They would also automatically reroute signals around busy or damaged nodes as changing field conditions may require.

"There simply are no commercial off-the-shelf components that come close to meeting our needs in terms of cost, compactness, power use, data processing, transmission flexibility, and multi-hop mesh capability," says Saari. "So we had to design our own system." Indeed, the Los Alamos team now has more than 100 nodes operating in the surrounding canyon country, with each drawing power at a low enough rate that it can be accommodated by the sampler's 12-volt battery, trickle-charged by a solar panel. Ultimately, the mesh will be expanded to 150 nodes, although it could accommodate another 100 more.

"All we have to do to add a new node to the existing mesh is turn it on," Saari says. "And if a node goes down for some reason"—she identifies lightning, raging floodwaters, and even elk antlers as potential culprits—"its neighbors will automatically seek a new route home around the missing node." In addition, the nodes can be adapted to transmit and receive on different frequencies, should there ever be too much radio noise on a chosen frequency. This flexibility also allows them to operate within unusually narrow bandwidths, as required to obey regulations within controlled bandwidth environments, such as the region around Los Alamos National Laboratory.

Farther afield, Frigo and others had already deployed an earlier version of the sensor-transmitter technology to support data collection in other diverse environments. The sensor units are helping ranchers in Northern New Mexico keep tabs on moisture, wind, and soil conditions across their sweeping ranchlands. They're also recording and transmitting climate data from the northern reaches of Alaska and Sweden. It was the Los Alamos storm-water project, however, that advanced the system into a true self-forming, self-healing mesh network, allowing hundreds of nodes to coordinate reliably over mountainous terrain, from burning deserts to freezing icescapes. Perhaps that's not so crazy for a system that had its origins in the ultra-remote, alternately searing and freezing wilderness of outer space. LDRD

—Craig Tyler