Using ground-penetrating radar to observe hidden underground water processes

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To meet the needs of a growing population and to provide it with a higher quality of life, increasing pressures are being placed on the environment through the development of agriculture, industry, and infrastructures.

Soil erosion, groundwater depletion, salinization, and pollution have been recognized for decades as major threats to ecosystems and human health. More recently, the progressive substitution of fossil fuels with biofuels for energy production have been recognized as potential threats to water resources and sustained agricultural productivity.

The top part of the earth between the surface and the water table is called the vadose zone. The vadose zone mediates many of the processes that govern water resources and quality, such as the partition of precipitation into infiltration and runoff, groundwater recharge, contaminant transport, plant growth, evaporation, and energy exchanges between the earth's surface and its atmosphere. It also determines soil organic carbon sequestration and carbon-cycle feedbacks, which could substantially affect climate change.

The vadose zone's inherent spatial variability and inaccessibility make direct observation of the important belowground (termed "subsurface") processes difficult. Conventional soil sampling is destructive, laborious, expensive, and may not be representative of the actual variability over space and time. In a societal context where the development of sustainable and optimal environmental management strategies has become a priority, there is a strong prerequisite for the development of noninvasive characterization and monitoring techniques of the vadose zone.

In particular, approaches integrating water movement, geological, and physical principles (called hydrogeophysics) applied at relevant scales are required to appraise dynamic belowground phenomena and to develop optimal sustainability, exploitation, and remediation strategies.

Among existing geophysical techniques, ground-penetrating radar (GPR) technology is of particular interest for providing high-resolution subsurface images and specifically addressing water-related questions. GPR is based on the transmission and reception of electromagnetic waves into the ground, whose propagation velocity and signal strength is determined by the soil electromagnetic properties and spatial distribution. As the electric permittivity of water overwhelms the permittivity of other soil components, the presence of water in the soil principally governs GPR wave propagation. Therefore, GPR-derived dielectric permittivity is usually used as surrogate measure for soil water content.

In the areas of unsaturated zone hydrology and water resources, GPR has been used to identify soil layering, locate water tables, follow wetting front movement, estimate soil water content, assist in subsurface hydraulic parameter identification, assess soil salinity, and support the monitoring of contaminants.

The February 2008 issue of *Vadose Zone Journal* includes a special section that presents recent research advances and applications of GPR in hydrogeophysics. The studies presented deal with a wide range of surface and borehole GPR applications, including GPR sensitivity to contaminant plumes, new methods for soil water content determination, three-dimensional imaging of the subsurface, time-lapse monitoring of hydrodynamic events and processing techniques for soil hydraulic properties estimation, and joint interpretation of GPR data with other sources of information.

“GPR has known a rapid development over the last decade,” notes Sébastien Lambot, who organized the special issue. “Yet, several challenges must still be overcome before we can benefit from the full potential of GPR. In particular, more exact GPR modeling procedures together with the integration of other sources of information, such as other sensors or process knowledge, are required to maximize quantitative and qualitative information retrieval capabilities of GPR. Once this is achieved, GPR will be established as a powerful tool to support the understanding of the vadose zone hydrological processes and the development of optimal environmental and agricultural management strategies for our soil and water resources.”

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