Editorial
Volume 10:7, 2021

Irrigation and Drainage Systems Engineering

ISSN: 2168-9768 **Open Access**

Progressive Technique for Non-Invasive Tracking (Hydrological Strategies)

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Advances in hydrological research are based on innovative methods for determining the state and flow of water with high temporal and spatial resolution and covering a large area. The emergence of new measurement technologies has been and will continue to be an important driving force for analyzing hydrological processes and evaluating the capabilities of process-based models. Soil moisture is an important state variable because it controls the exchange of water and energy between the surface and the atmosphere. Information on soil moisture dynamics is also important for agricultural practice and management, as well as for a better understanding of biogeochemistry, vadose zones, and atmospheric processes. So far, soil moisture is mainly measured by in-situ electromagnetic soil moisture sensors in relatively small soil volumes. However, soil moisture shows strong field-scale spatial variability, and in-situ sensors do not cover these changes well. The latest developments in non-invasive measurement technologies, such as Cosmic Ray Neutron Detector (CRNP), GNSS (Global Navigation Satellite System) reflection measurement, ground microwave radiation measurement, gamma-ray monitoring and ground gravity measurement, allowing continuous non-invasive measurement of soil moisture.

The purpose of this research topic is to share the latest developments in CRNP-based technologies that detect neutron intensity fluctuations on the Earth's surface caused by high-energy particles from space and the distribution of hydrogen on the Earth's interior and on the ground to provide continuous non-invasive Soil moisture measurement. Dynamics from field to watershed scale. This research topic includes seven papers, which are briefly introduced as follows. Franz applies established data analysis methods to derive new CRNP data products: smoothing the time series of soil moisture, average landscape precipitation, and root zone soil moisture. The author has taken an important step by enhancing CRNS soil moisture data to provide value-added data products to stakeholders. The presented results can be used as a key step in applying CRNP data to practical applications. Jakobi uses the easy-to-use third-order Taylor expansion method to quantify the uncertainty in estimating soil moisture based on cosmic-ray neutron measurements. This method is particularly useful for neutron detector measurements, because the soil moisture estimates obtained with this method are usually more uncertain than those obtained with a fixed CRNP. Therefore, the proposed method has great potential in planning and evaluating rover experiments and finding an appropriate balance between measurement accuracy, aggregation, and the relative spatial resolution of the resulting soil moisture products. The author also published a companion article Corrigendum.

Bogena uses long-term CRNP measurements at the Pinios Hydrological Observatory (PHO) in Greece to test different methods of converting neutron count rate into snow characteristics. These methods include linear regression methods based on thermal neutrons and hyperthermic neutrons, standard N0 calibration functions, and physics-based calibration methods. They found that the N0 calibration function and physics-based calibration worked best, while the relationship between thermal neutrons and super-thermal neutrons was the worst. They concluded that the CRNP-based SWE (Snow Water Equivalent) determination is a potential alternative to the established method based on point observations of snow depth. Nasta compared data from CRNP and SoilNet wireless on-site sensor networks at two stations in the Arento basin in Italy. They found that the difference in data between the two types of sensors is related to the effect of CRNP's vertical measurement footprint over time. Furthermore, they showed that CRNP cannot capture well the bimodality of the soil moisture index (SMI) derived from SoilNet data, and the comparison of the SMI between two different test sites can be explained by soil texture or topographic characteristics. Finally, the author also derived field-scale water retention functions from CRNP and Soil Net data for the analysis of hydrological processes.

Weimar examined the key features of a neutron detector designed for CRNP applications. The author introduced a large-scale detector configuration by optimizing the thickness of the moderator and the size of the moderator housing space to increase the count rate. They also discussed the impact of non-neutron radiation and its impact on the overall signal quality. The new detection system achieves a much higher count rate than the usual system with a higher signal-to-noise ratio. Furthermore, lower relative statistical uncertainty leads to more accurate soil moisture measurements on a short time scale. González Sanchis compared the capacity of in situ soil sensors and CRNP to evaluate soil hydrodynamics as a key variable that reflects the effectiveness of forest management in semi-arid environments. For this reason, two test sites were established in Sierra Calderona, Spain, in regenerated Aleppo pine forests after a fire. They found that CRNP performed better in semi-arid conditions than in extreme drought conditions. Forest biomass and litter layers lead to an overestimation of soil moisture derived from CRNP. Both sensor systems can reproduce the transpiration of trees affected by soil moisture, environmental variables and thinning, while CRNP is affected by atmospheric forcing. Kohli proposes a new analytical method to estimate the response of neutrons to soil and air moisture. By comparing two MonteCarlo neutron transport simulations, URANOS and MCNP, their findings revealed a systematic deviation from the standard relationship between neutron count rate and soil moisture, especially in extremely dry conditions. The author also discussed the importance of detector-specific response functions, various modeling concepts, and atmospheric humidity. The new analytical relationship has been tested at two exemplary CRNP monitoring sites, and its performance is better than standard methods to date.

We believe that current advancements based on CRNP technology will improve the description of local-scale processes related to hydrological flow and changes in storage, which is important to reduce the large amount of uncertainty that still exists in the large-scale models used to predict soil hydrodynamics.

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Received 06 July 2021; **Accepted** 13 July 2021; **Published** 20 July 2021

How to cite this article: Shaik Hyderali. "Progressive Technique for Non-Invasive Tracking (Hydrological Strategies)." *Irrigat Drainage Sys Eng* 10 (2021): 278.