Long-term Monitoring of Hydrological Changes in the Near Surface Via Surface NMR and Borehole NMR

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Nuclear magnetic resonance (NMR) measurements provide direct detection of water, and are also sensitive to the pore scale environment in which the water resides. Hence, NMR measurements hold potential to monitor changes in the water content and/or pore scale environment in the near subsurface.

In this work, we demonstrate the feasibility of using newly developed borehole and surface based NMR instruments to monitor relatively long term changes in water content and pore structure. First we demonstrate the use of surface NMR to monitor water infiltrating the ground at an aquifer storage and recovery (ASR) facility near Tucson Arizona. Surface NMR measurements were performed in a recharge basin at regular intervals over a 7 week period, including before, during and after a managed infiltration event. The resulting time-lapse surface NMR images, shown in Figure 1, show the progress of the initial wetting front and provide quantified measurements of water content and its distribution in depth and pore sizes over time. The resulting data set can be further analyzed to estimate the initial infiltration rate, saturation vs. depth and time, and possibly hydraulic conductivity as a function of saturation.

We also demonstrate the feasibility of using borehole NMR measurements to monitor biofilm growth and iron redox state changes associated with subsurface remediation processes. Low field laboratory NMR measurements were performed at the same sample scale and field strength (250 kHz) of a newly developed borehole NMR logging tool. The laboratory NMR measurements demonstrated that biofilm growth and health can be detected and monitored as significant reduction in the T2 relaxation rates of a sample. This was demonstrated using both engineered and natural soil samples, including natural soil samples with high magnetic susceptibility. Another set of laboratory NMR measurements confirmed that redox changes in naturally occurring iron, which are a by-product of certain bio-remediation strategies for heavy metals, can be detected and monitored via changes in the NMR T2 relaxation and diffusion relaxation rates.

Finally, we demonstrated the feasibility of using borehole NMR to monitor the construction and effect of development of groundwater production wells. (Development refers to the practice of intensively pumping water from a well in order to remove fines from the adjacent formation, and hence increase production yield of the well.) Borehole NMR measurements were performed repeatedly, on newly installed wells, before development, and after one or more stages of development. The repeat NMR logs show significant and monotonically increasing T2 relaxation rates, as a result of each stage of development. This technique could conceivably be applied to monitor changes in older wells and direct redevelopment efforts.

In addition to these applications, surface and borehole NMR methods could conceivably be applied to monitor other existing and emerging subsurface monitoring applications, including: the monitoring of CO2 sequestration via displacement of water and/or formation of precipitates in the target formation, and the monitoring of fluid content and pore-scale properties in formations subjected to in-situ mining or petroleum extraction.

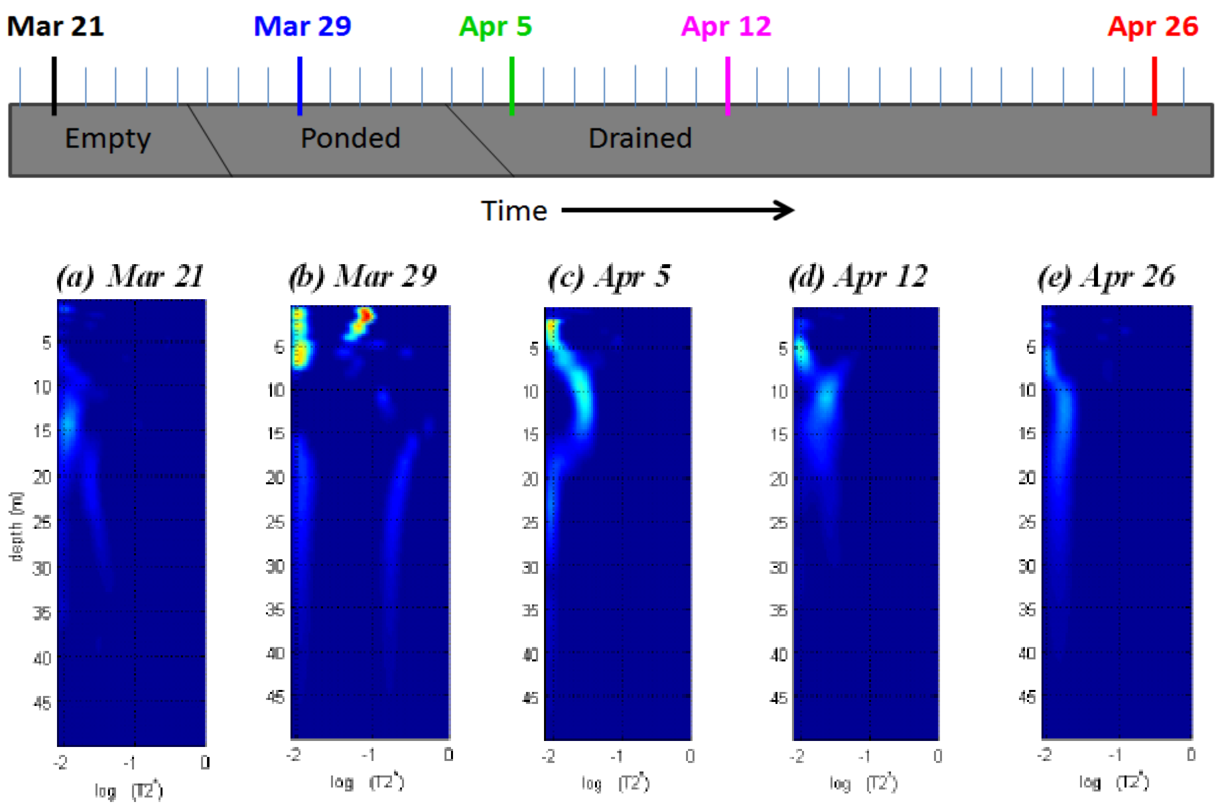

Figure 1: Surface NMR inversion for SAVSARP ASR recharge experiments. The results show water content vs depth and in different pore sizes at different stages of the infiltration experiment.

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