The Integration of Logging and Surface NMR
for Mapping Spatial Variation in Hydraulic Conductivity

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Throughout the U.S., various levels of government are faced with the challenge of remediating, managing and monitoring sites at which there are high levels of subsurface contamination that pose threats to human populations and natural ecosystems. Essential to the long-term responsible stewardship of these sites, is the ability to characterize, in a cost-effective way, the spatial variation in the subsurface properties that govern the fate and transport of miscible and immiscible, organic and inorganic, contaminants.

Of interest in our research is the development of a new approach to measuring and mapping hydraulic conductivity K in the saturated zone of the near-surface (top ~100 m) in a way that 1) minimizes the impact on the natural environment and/or human health and safety concerns, 2) is economic, 3) is reliable. The methodology we propose is motivated by very recent technological advancements, and the commercial availability of systems designed make proton nuclear magnetic resonance (NMR) measurements in the near-surface region. These systems include NMR logging in shallow boreholes, with direct-push (DP) systems, and noninvasively from Earth's surface using surface NMR (SNMR).

Our methodology: We first "calibrate" the transform that allows us to estimate K from logging NMR data using the NMR parameter T_2 and K, both measured in a shallow borehole or with a DP system. This provides a site-specific logging NMR-K transform. We then acquire SNMR data, which provides a depth profile of the NMR parameter T_2*, which is related to, but not equivalent to T_2. The availability of T_2 and T_2* data allows us to translate the site-specific logging NMR-K transform to the surface NMR measurement regime. We then use surface NMR as the primary means for measuring and mapping K over wide areas in the vicinity of the site-specific calibration(s). We use the data acquired during the calibration step to estimate the uncertainty in the surface NMR K estimates.

We demonstrate the proposed methodology using NMR data acquired at the GEMS research site in Kansas. Measurements were made of the NMR parameter T_2 in shallow boreholes; available were K measurements made using a multi-level slug test. Measurements were also made of both T_2 and K using a DP system. All NMR and K measurements were used to determine the transform that could be used to best estimate K from the logging NMR data. Specifically we determined the optimal values for the empirical constants in the Schlumberger-Doll Research (SDR) equation. We evaluated the accuracy of our predictions of K with increasing distance from the calibration site. SNMR data were compared to the logging and DP NMR data and a transform developed that account for the differences in the physics controlling the logging T_2 and SNMR T_2* measurements. We find that the average values of K derived from NMR after the surface/logging transform are in close agreement with the average values of K determined from direct measurements.