Nuclear Magnetic Resonance Geophysics For High Resolution Site Characterization, CSM Refinement, and Remedial Design Optimization

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Background. Many traditional site investigation methods have been replaced in recent years by high-resolution site characterization tools that are designed for deployment using direct push boring advancement techniques, but there are penetration depth and other practical limitations to those technologies. Nuclear Magnetic Resonance (NMR) geophysical tools are now available for near surface and shallow aquifer characterization using technologies first developed for use in the oil and gas industry. NMR logging provides high-resolution quantification of porosity (both mobile and bound water fractions) and hydraulic conductivity, and can detect and quantify multi-phase saturations of certain LNAPLs. NMR data can be acquired through non-metallic (PVC) casing using existing well infrastructure eliminating the need for additional invasive borings required with other technologies. NMR is a proven technology that offers significant benefits at railroad facilities and remediation sites, by obtaining high-resolution data of critical aquifer properties required for conceptual site models and for remedial system design and optimization, particularly at legacy sites where additional lines of evidence are needed to achieve site closure.

Innovations and Methods. Traditional oil field NMR logging tools were designed for deep, subsurface exploration of petroleum reservoirs and were not suited for near-surface investigations due to cost and scale issues associated with data acquisition. As patents for those tools expired, new tools have been developed that are designed and sized for near-surface aquifer characterization. NMR detects fluid-filled pore space using magnetic fields that excite polar hydrogen molecules present in water. The response of hydrogen molecules to the oscillating magnetic field results in an NMR signal that can be detected by the tool. Primary properties that can be logged in great detail from the NMR signal include total porosity, pore size distribution, and hydraulic conductivity which is estimated using well-established empirical formulas. Fluid diffusivity is fairly constant in water, but varies with differences in viscosity that are often characteristic of certain hydrocarbons. Differences in diffusivity detected by NMR can be used to detect and quantify multi-phase saturations in the pore space, such as NAPL saturation.

Successes and Lessons Learned. Case studies will be presented that demonstrate the viability of using NMR technology for near-surface investigations, and showcase the use of NMR to refine site conceptual models. A critical benefit of this logging method is the ability to deploy in existing monitoring wells and determine formation properties in both the screened and unscreened intervals. This greatly reduces the cost, safety concerns, and time required to install additional borings or wells. The studies will include applications in both unconsolidated and bedrock aquifers. Continuous, high-resolution vertical profiles of total porosity, mobile, capillary bound and clay bound porosity fractions, and hydraulic conductivity collected from existing PVC-cased monitoring wells will demonstrate how NMR data can be used to develop a robust CSM, provide input to groundwater flow models, and help optimize groundwater extraction wells and remediation systems. Examples of LNAPL saturation detection and quantification will also be presented.