Utilizing azimuthal seismic first-arrival tomography (ASFT), time-lapse electrical-resistivity tomography (TLERT), and other geophysical methods for the detection and characterization of physical controls on hydrologic transport

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The Oak Ridge Integrated Field Research Challenge (ORIFRC) project was established to study the various biogeochemical processes involved in the remediation as well as natural attenuation of a large contaminant plume that is extant in the vicinity of the S-3 Pond area. The site in general consists of three hydrostratigraphic units: (1) a clayey saprolite, (2) a transition zone, and (3) more competent Nolichucky Shale bedrock. The saprolite is clayey, low permeability, typically between 3 and 10 m thick, and has some remnant fracturing. The transition zone includes an irregular region with higher permeability and contaminant transport than either the saprolite or bedrock, due to a combination of high fracture density and lower clay content. The primary fracture sets yield a strong degree of horizontal hydrologic anisotropy. The transition zone can have a hydraulic conductivity as high as 1×10^{-3} to 1×10^{-2} cm/s, where the saprolite and bedrock zones typically have hydraulic conductivities between 1×10^{-4} and 10^{-7} cm/s. Ground water flow is oriented predominantly along geological strike (i.e., bedding planes). The underlying Nolichucky Shale bedrock is highly fractured, with a large degree of horizontal hydrologic anisotropy, but yields much lower conductivities than the transition zone. We have utilized three main techniques for characterizing groundwater movement and physical controls on transport associated with these three hydrostratigraphic units.

First, we demonstrate azimuthal seismic first-arrival tomography (ASFT) as a novel technique for identifying and quantifying the horizontal anisotropy of the three layers present at the ORIFRC. The methodology involves acquisition of seismic first-arrival tomography profiles at 10° intervals rotated around a central point. The resultant tomograms are converted from XZ plane cross-sections to XY plane polar plots. Initial azimuthal velocity maps show an increase in seismic anisotropy with depth, correlating well with the three principle hydrostratigraphic units. Seismic data have been collected at a second site, and in conjunction with pump test and tracer data, we establish a correlation between observed seismic anisotropy and observed hydrologic anisotropy to establish an intermediary relationship between the two types of datasets.

Second, time-lapse surface and crosshole electrical resistivity tomography (TLERT) data, collected over a course of a year in conjunction with aqueous geochemical and rainfall data, are used to examine the impact of recharge on subsurface contamination near the S-3 ponds in response to vertical anisotropy in unsaturated flow. The data suggest that subsurface hydrogeological zonation plays a critical role in plume transient behavior.

Finally, we utilize a combination of traditional seismic first-arrival tomography, deep borehole core analysis, and additional shallow boreholes to identify a spatially confined along-strike fast-flow path, that exceeds fast-flow rates elsewhere in the transition zone. This flow path—initially identified as a low-seismic-velocity zone with continuity down hydrologic gradient and along strike of the S-3 ponds—has been correlated with regions of deepened weathering in the Nolichucky Shale associated with increased limestone composition, resulting in a thicker and more hydraulically conductive zone within the transition zone layer.