PRINCETON GEOSCIENCE, INC.

Technical Support to LSRP: Bedding Attitude Assessment Based on Multiple Lines of Evidence

LSRPs frequently face the difficult task of verifying protectiveness of remedies put in place years ago, prior to advances in scientific knowledge and remediation practice. In such situations, the LSRP must often apply new lines of inquiry to validate previous assumptions or low-resolution characterizations upon which the remedy was based. For sites in the Newark Basin, gamma logging of existing monitoring wells is an efficient way to accurately assess bedding attitude, a first step in review of the conceptual site model. Seemingly small errors in strike and dip can result in remedies that target or monitor the wrong zones in the rock. Properly interpreted, borehole geophysics is a tool that can be used to avoid, or detect and fix, such problems.

Background - During biennial review pursuant to New Jersey's Site Remediation Reform Act (SRRA), a Licensed Site Remediation Professional (LSRP) identified the need to reassess elements of a 1990s-era hydrogeologic characterization at a New Jersey Industrial Site Recovery Act (ISRA) site in the Newark Basin. A monitored natural attenuation (MNA) remedy was ongoing and a Classification Exception Area (CEA) was in place to address volatile organic compounds in bedrock groundwater. An offsite supply well was impacted by the same constituents, but this area was not being addressed by the MNA program or CEA based mostly on the project consultant's previous finding that there was no identified pathway connecting the site and the offsite supply well. Noting that hydrogeologic characterization and groundwater monitoring practice had advanced significantly since the time the remedy was put in place, the LSRP determined that an updated characterization was needed to support protectiveness assessment and if necessary, remedy modification, consistent with current site remediation practice.

Based on current New Jersey Department of Environmental Protection (NJDEP) guidance, the LSRP determined that a fundamental element of the reassessment was to evaluate the structural attitude (strike and dip) of bedding planes in the sedimentary bedrock, which hosts a leaky, multi-unit aquifer system (LMAS). At the LSRP's request, the project technical consultant and an outside expert had reviewed existing data including rock core logs, borehole geophysical logs and published geological maps, but were unable to arrive at a consistent understanding of bedding attitude sufficiently resolved to support systematic characterization of the bedrock flow system. The responsible party then hired Princeton Geoscience to review technical memoranda prepared by the project consultant and expert, and to develop an independent assessment of bedding attitude.

After reviewing project data and technical memoranda, Princeton Geoscience concluded that the existing data could not support accurate determination of bedding attitude. We developed and implemented a plan for assessing bedding attitude based upon three lines of evidence, including 1) area-wide structural evaluation via correlation of marker beds evident on natural gamma logs 2) inspection and analysis of features evident at a bedrock outcrop near the site, and 3) review and analysis of acoustic televiewer logging data collected during previous investigations.

Area-Wide Bedding Attitude Assessment based on Gamma Logging - To support the area-wide assessment, Princeton Geoscience used a combination of existing and newly acquired downhole geophysical logging data. Initially, we collected

natural gamma logs at six existing deep monitoring wells. The wells had been completed with PVC screen and riser, sand pack and grout, but as expected, the natural gamma response was not significantly affected by the well construction materials. Next, we digitized paper copies of analog-format natural gamma logs collected during previous investigations at six other locations. Data from all 12 logs were then processed electronically, to produce logs of equal scale and format, assisting correlation. A vertical succession of over 20 laterally extensive gamma markers was identified. The elevation of each marker unit was determined based on marker unit depths determined by log inspection and logging reference elevations. Marker elevations and the vertical separation of each marker unit were tabulated, to allow easy verification of the lateral continuity and parallelism of the surfaces described by each set of markers.

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Structural contour maps corresponding to markers at three stratigraphic horizons were prepared using electronic contouring software, applying triangulation with linear interpolation. These maps showed uniformly planar sedimentary bedding with a consistent northwesterly dip throughout the 800' x 1500' area investigated. The contours are evenly spaced and consist of essentially straight lines, with less than one degree of change in contour line orientation across the area investigated. The three stratigraphic horizons exhibited identical structure, as strike directions indicated by the structural contours varied by only 0.5°, and calculated dip differed by only 0.2° between the three depths mapped. The uppermost of the three markers mapped was encountered at the largest number of well locations because some wells were too shallow to intersect the deeper markers. Therefore, the uppermost gamma marker provided the best measure of bedding attitude. Because the vertical resolution of the gamma logging was about one foot and the locations logged were horizontally separated by hundreds to greater than 1000 feet, bedding attitude thus determined was accurately defined to within about 0.5° of strike and about 0.1° of dip.

Gamma markers identified at the site were also compared with features evident on a gamma log Princeton Geoscience constructed from data for the NSF-funded Newark Basin Coring Project (NBCP) "Rutgers" core hole site, located about 10 miles from of the project site. Princeton Geoscience was able to correlate markers between these sites and thereby 1) identify the stratigraphic position of several Members of the Passaic Formation rocks underlying the site and 2) demonstrate the expected lateral continuity of the markers over great distances.

Structural Measurements at Bedrock Outcrop - A published geologic map showed measured values of bedding attitude at an outcrop near the site, and projected gray-bed units observed at the outcrop along a presumed strike direction away from the outcrop. The limited data portrayed on the map were only partly consistent with bedding attitude determined via the area-wide gamma logging. To clarify this apparent discrepancy and to provide a second line of evidence for the bedding attitude assessment, Princeton Geoscience collected strike and dip measurements at 12 locations along the 500-foot long outcrop and determined the basal elevations of three gray-bed units via GIS processing of publically available Lidar data. The strike and dip values were plotted on a stereonet, deriving an average value for the measurements and graphically representing the closely grouped range of values recorded. The average bedding attitude measured at outcrop corresponded closely to the site-wide value determined based upon structural contours to gamma markers (i.e., strike was within 2.5° and dip was within 0.2°). Based upon elevations of the gray-bed units and projection along the line of strike, we were able to correlate the lowermost gray-bed observed in the outcrop with a shallow gamma anomaly at one well location. The other gray-bed units observed at the outcrop were located further up in the geologic section and did not intersect any of the wells onsite.

Review and Analysis of Acoustic Televiewer Data - Prior review of two ATV logs collected at the site had simply included presentation of "tadpole plots" and a stereonet showing all interpreted fractures. Princeton Geoscience conducted additional review and analysis of the ATV data, to provide a third line of evidence for the bedding attitude assessment. Initially, the data set was reduced to those planar features within the expected ranges of bedding strike and dip, specifically, those within 20° of the area-wide strike and within 4° of the area-wide dip determined from gamma logging. This selection also bracketed the ranges of strike and dip values represented on the published geological map for the area near the site. The strike and dip values for the reduced data set were then plotted on a stereonet, deriving an average value and graphically representing the closely grouped range of measurements recorded. The average bedding attitude determined from the ATV data was close to the site-wide value determined based upon structural contours to gamma markers (i.e., strike was within 2.5° and dip was within 2.2°).

Conclusions - The primary assessment achieved via gamma log correlation showed that sedimentary bedding is planar throughout the area investigated, exhibiting a uniform area-wide strike and dip. Structural contour maps prepared for three separate gamma markers showed no significant differences in contour line orientation or spacing, confirming that bedding attitude does not vary with depth. Bedding attitude was accurately determined based on the area-wide assessment.

Structural measurements at the outcrop and review of the ATV logging data support the findings of the primary assessment. The average strike and dip values calculated via these supporting assessments correspond closely to, and corroborate, the area-wide value determined based on the gamma log analysis.

The investigative approach made use of all existing data and the additional logging utilized previously installed wells as an investigative resource. Multiple lines of evidence support a reliable understanding of bedding attitude. With this fundamental evaluation complete, the LSRP and project consultant can now move forward with other dependent elements of the site hydrogeologic reassessment, consistent with NJDEP guidance and the current state of site remediation practice.