The Development of Field Methods and Tools for Subsurface Characterization

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Virtually every hydrogeologic investigation requires information about the processes and properties affecting the flow of water in the subsurface. Whether the objective is estimation of the ease with which water flows through an aquifer, delineation of water-balance components, or some other task, hydrologists have devoted considerable effort to characterization of the shallow subsurface in pursuit of their goal. In this presentation, I will provide an overview of a decade-long program of data-driven research directed at the development of technology for the physical characterization of subsurface flow systems. The specific focus of this presentation will be on hydraulic testing methods developed for investigations at sites of groundwater contamination.

For more than a century, ground-water hydrologists have utilized pumping tests as a means to evaluate how an aquifer will respond to ground-water exploitation. These tests are commonly performed by pumping a well at a near constant rate, while measuring changes in water level at the pumped well and nearby observation wells. Although of great use for groundwater supply assessments, the large volumetric averages of hydraulic properties obtained with these tests may be of limited value for contaminant transport investigations. In that case, we need information about the fine-scale spatial variations in hydraulic conductivity (K) that are often a critical control on contaminant movement.

One commonly used method for obtaining information about spatial variations in K is the slug test. This approach involves changing the water level in a well in a near-instantaneous fashion and then tracking the water level as it recovers to its pre-test position. At the Kansas Geological Survey, we have developed new analytical models as well as practical guidelines for the design, performance, and analysis of slug tests in an effort to improve the quality of K estimates obtained with this method. Ultimately, however, the reliability of the information obtained from slug tests is highly dependent on conditions in the immediate vicinity of the test well. This near-well region is often disturbed as a result of well construction and development, so conditions may not be representative of the formation prior to well installation. Thus, in most cases, slug-test K estimates should be considered as lower bounds on the hydraulic conductivity of the undisturbed portions of the formation in the vicinity of the well. Although slug tests can be used to obtain vertical profiles of K for investigations at sites of groundwater contamination, it is an extremely time consuming process to use this approach in a high-resolution mode, particularly when one takes measures to reduce the impact of near-well disturbances.

In response to the limitations of the slug test and other commonly used approaches, increasing emphasis is being placed on the development of higher-resolution and higher-accuracy methods. We are currently working on two new direct-push tools for use in shallow unconsolidated formations. With direct-push technology, a tool or sensor is attached to the lower end of a string of steel rods and then advanced into unconsolidated sediments using hydraulic rams and a high-frequency percussion hammer. The new tools, the direct-push injection logger and the direct-push permeameter, have been specifically developed for obtaining high-resolution vertical profiles of K or a surrogate for it. The direct-push injection logger (DPIL, trade name - Hydraulic Profiling Tool) has a small circular screened port through which water is injected into the formation while pressure in the injection line is monitored. The tool is advanced as water is continuously injected at a rate of a few hundred mL/min. The injection-produced backpressure is measured every 1.5 cm during advancement to produce vertical profiles of injection backpressure. The ratio of the backpressure over the injection rate is a surrogate for hydraulic conductivity, so the obtained profiles are high-resolution records of relative variations in K with depth. Estimates of actual variations in K can be obtained with the direct-push permeameter (DPP). The DPP is a tool with a short cylindrical screen above which are two pressure transducer ports mounted on the tool at short distances from the screen. Tool advancement is suspended at depths at which K information is desired and a sequence of short-term injection tests (injection rate from 400-4000 mL/min) is performed. The injection-produced head responses are measured at the two pressure transducer ports and K is calculated using either analytical or numerical approaches. Unlike slug tests, K estimates from the DPP are relatively insensitive to formation disturbances in the immediate vicinity of the tool. In practice, the current configuration of the DPP can provide K profiles at a vertical resolution of 50 cm. Recently, the DPIL and DPP have been coupled into a single tool to produce profiles of vertical variations in K at the resolution of a few centimeters. Methods are currently under development for combining the results of direct-push profiling with high-resolution geophysical surveys to produce descriptions of lateral and vertical K variations on the site scale at a level of detail that has not previously been possible.

Scientists involved in the development of field methods should strive to ensure that their approaches are adopted by the practitioner community. Thus, the technology transfer phase of projects must not be neglected. Publications in scientific journal are an essential step for establishing the technical soundness of a particular method. These publications, however, should not be solely theoretical in nature; some should emphasize the important practical aspects of the approach and should be in outlets accessible to practicing professionals. Workshops and short courses for consultants and regulators are a critical component of the technology transfer effort, and should be heavily utilized. At the Kansas Geological Survey, we stress the transfer of our developed technology to the practitioner community and have used all of the above means to do so. Most recently, we have created laminated field guides that can be readily consulted in the field and office to ensure that the methods and guidelines that we have developed are applied in the most effective manner.