

ANALYSIS OF FLOWING FLUID-ELECTRIC-CONDUCTIVITY LOGS UNDER NONIDEAL CONDITIONS

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RESEARCH OBJECTIVES

In the study of flow and transport in the subsurface, knowledge of flow zones and their hydraulic properties is essential. Coring and geophysical methods in boreholes drilled deep into the rock may be able to identify the fractures themselves, but they are unlikely to provide information on fracture flow properties. Straddle-packer pump-testing yields fracture flow properties, but is very time-consuming. Flow-logging techniques are an attractive alternative—they are sensitive to fracture flow and are efficient to deploy in the field.

The flowing fluid-electric-conductivity (FFEC) logging method provides information on the depths, salinities, transmissivities, and pressure heads of individual conductive features intercepted by a borehole, without the need of specialized probes. The method has been successfully applied to deep boreholes in granitic formations. This summary presents the application of the method to two zones in a 1,000 m borehole in sedimentary rock at Horonobe, Japan. The data sets involve a number of complications, such as variable well diameter, free water table decline in the well, periods of time with unknown pumping rate, and effects of drilling mud. Our objective is to determine whether the method is robust enough to use under these nonideal conditions.

APPROACH

The FFEC logging method involves the replacement of wellbore water by de-ionized water, followed by pumping at a constant rate, during which a series of fluid electric conductivity logs are taken. The logs can be analyzed to identify depth locations of inflow, and evaluate inflow rate and electric conductivity (salinity) of the fluid at each inflow point. When the method is repeated with two or more pumping rates, a combined analysis of the multi-rate data allows an efficient means of also determining transmissivity values of all inflow points, as well as their inherent (so-called far-field) pressure heads.

For each of the two zones logged in the 1,000 m wellbore, three sets of logs were collected using different pumping rates, each set measured over a period of about one day (Figure 1). To analyze the data, we apply various techniques that have been developed for analyzing FFEC logs: direct-fitting, mass-integral, and the multi-rate method mentioned above.



ACCOMPLISHMENTS

In spite of complications associated with the tests, analysis of the data is able to identify 44 hydraulically conducting fractures distributed over the depth interval 150–775 m below ground surface with resolution of about 0.2 m. The salinities (in FEC), and transmissivities and pressure heads (in dimensionless form) of these 44 features are obtained and found to vary significantly among one another. These results are compared

with data from eight packer tests with packer intervals of 10–80 m, which were conducted in this borehole over the same depth interval. They are found to be consistent with these independent packer-test data, thus demonstrating the robustness of the FFEC logging method under non-ideal conditions.

SIGNIFICANCE OF FINDINGS

FFEC logging provides an efficient, affordable means of characterizing the hydraulically conductive features intersecting a borehole, with high vertical resolution and without the need of specialized probes. Such information is valuable for characterization of regional groundwater flow, design of nuclear waste storage facilities, remediation of subsurface contamination, and a host of other problems. Moreover, it can be very useful in conjunction with other subsurface site-characterization activities, such as providing high-resolution monitoring during a tracer test, or providing ground truth at boreholes for crosshole geophysical imaging methods.

RELATED PUBLICATIONS

Doughty, C., C.-F. Tsang, K. Hatanaka, S. Yabuuchi and H. Kurikami, Application of direct-fitting, mass-integral, and multi-rate methods to analysis of flowing fluid electric conductivity logs from Horonobe, Japan. LBNL-63307. Water Resour. Res. (in press), July 2007.

ACKNOWLEDGMENTS

This work is supported by the Nuclear Waste Management Organization of Japan (NUMO) and the Japan Atomic Energy Agency (JAEA), through a bi-national agreement between JAEA and the U.S. Department of Energy (DOE), and conducted at Berkeley Lab under DOE Contract No. DE-AC02-05CH1123.

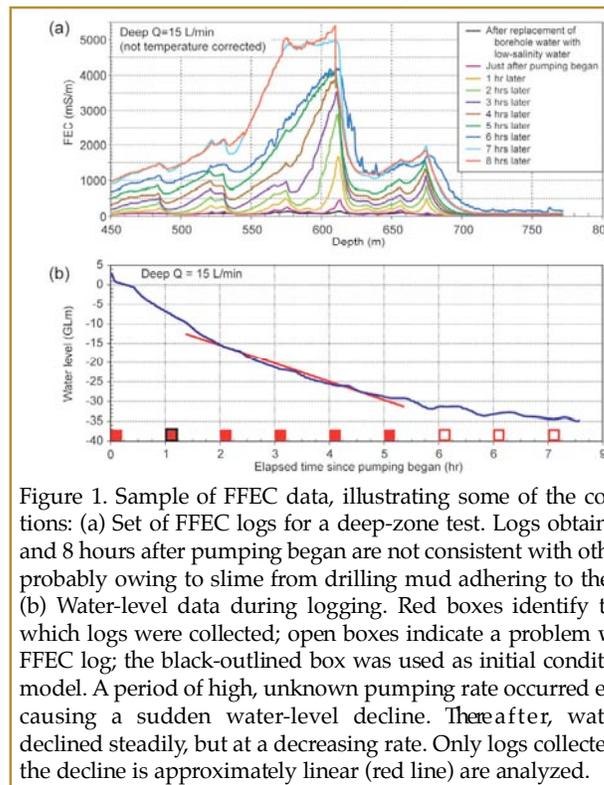


Figure 1. Sample of FFEC data, illustrating some of the complications: (a) Set of FFEC logs for a deep-zone test. Logs obtained 6, 7, and 8 hours after pumping began are not consistent with other logs, probably owing to slime from drilling mud adhering to the probe; (b) Water-level data during logging. Red boxes identify times at which logs were collected; open boxes indicate a problem with the FFEC log; the black-outlined box was used as initial conditions for model. A period of high, unknown pumping rate occurred early on, causing a sudden water-level decline. Thereafter, water-level declined steadily, but at a decreasing rate. Only logs collected while the decline is approximately linear (red line) are analyzed.