Description of the U.S. Geological Survey's slug-test at the Hallam Nuclear Facility — July to November 1994

An aquifer test agreement between the U.S. Department of Energy (USDOE) and the U.S. Geological Survey (USGS) was set up to log and measure the aquifer response in two observation wells, 1B and 4C at the Hallam Nuclear Facility, Hallam, Nebraska. Observation wells 1B and 4C are owned by the USDOE and were installed by HWS Technologies Inc. of Lincoln, Nebraska, in June 1993.

These observation wells were measured monthly from September 1993 to August 1994 by using a graduated steel tape. The accuracy of these water-level measurements is approximately ± 0.02 foot. Also well 1B contained a submersible pressure transducer to record hourly water-level data during this same period. During access of the wells, personnel wear clean disposable latex gloves, a hard hat, and safety glasses. Directly following each measurement the steel-tape was rinsed with deionized water and the effluent was disposed of in a 55-gallon drum.

For the aquifer tests, observation wells 1B and 4C had submersible pressure transducers installed to monitor water-level responses. These pressure transducers were connected to an electronic data logger (edl) to record the water levels, atmospheric pressure from a barometric pressure gauge, and rainfall data from a tipping-bucket rain gauge. The data recorded on each edl was downloaded onto a field computer during each site visit, processed in the field, and then stored on the USGS's Data General workstations upon return to the District Office.

Description of the aquifer slug-test

Four separate aquifer slug-tests were performed in two observation wells, 1B and 4C, located at the Hallam Nuclear Facility near Hallam, Nebraska. These aquifer tests followed the stabilization of water levels effected by collection of water-quality samples taken in July 1994. The 'slug' used for the tests consisted of either two cylindrical, concrete-filled submersible transducer weights, used in well 4C, or a 1-Liter disposable bailer filled with deionized water, used in well 1B, attached to a support string. The first aquifer slug-test was a 'slug-in' test. It consists of displacing a volume of water by insertion of a 'slug' into the water column within the well casing and monitoring the water-level response with a submersible pressure transducer. The second aquifer slug-test was a 'slug-out' test. It involved removing the same slug from the water column following the return to pretest conditions and monitoring the water-level response.

The aquifer tests consisted of installing one decontaminated, submersible pressure transducer into the well. After installation of the submersible pressure transducer the water-level reading to be recorded in the edl was set to zero and the measurement interval was set to 1 minute for the start of the test. Following this, the edl's recording was turned on and a slug was introduced into or removed from the water column. After approximately 15 minutes of data collection, the data was downloaded onto a field computer and plotted using available software provided by the edl manufacturer. Plotting ensured that the data was completely downloaded and no downloading errors were present. The measurement interval within the edl was then reset to record water levels every five minutes. Water-level data was then collected for 2 weeks or until the water level returned to near pretest levels.

The slug-in and slug-out tests were run consecutively before well development, July to August 1994, and after well development, October to November 1994, for a total of four tests per well. Between the predevelopment slug-out test and the postdevelopment slug-in test, each well was

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developed for 15 to 20 minutes using a surge-block technique. Surge-block technique entails introducing a surge-block into the water column within the well casing and agitating the well water for a number of minutes. It is most commonly used in low transmissivity wells and is supposed to remove the fine material from the screen as well as develop the well. The surge-block used was the same two cylindrical, concrete-filled submersible transducer weights used for the slug-in test in well 4C. However, decontamination procedures with deionized water was used before and after each well development.

Data collected during the aquifer tests were plotted in a graphics program and analyzed using the Cooper, and others (1967) method for slug-test analysis of a confined compressible aquifer. The aquifer analysis included plotting the data (H_t/H_0 versus log time from start of test). H_t is the value water level at any time t , and H_0 is the initial head value. This curve was then matched to the Cooper's type curves $F(\alpha, \beta)$ versus β for different values of α (Papadopoulos, and others, 1973).

Generally, well 1B responded more rapidly than did well 4C. Problems encountered during the test are as follows:

1. Barometric pressures probably influenced the water level responses during the predevelopment slug-out test in well 4C, August 2-17, 1994.
2. Well 1B had data collection problems during the postdevelopment slug-in test (edl battery failed), October 14-21, 1994.
3. Well 4C showed that water levels may not have completely recovered from the surge-block development — water levels responded in an opposite manner expected following well development, slug-in test October 14-21, 1994.

Assumptions

Cooper and others (1967) state that an independent estimate of storativity, S , will help in the selection of which alpha curve to use. Dawson and Istok (1991) report that selection of α to within 1 to 2 orders of magnitude should be expected. However, an error of this magnitude for $\alpha < 10^{-5}$ can produce computed transmissivity errors of 30 percent.

Assumptions (modified from Dawson, K.J., and Istok, J.D., 1991, *Aquifer testing: design and analysis of pumping and slug tests*, p. 318):

- a) The aquifer is bounded above and below by confining layers.
- b) All layers are horizontal and extend infinitely in the radial direction.
- c) Initial head is horizontal and infinite.
- d) Aquifer is homogeneous and isotropic.
- e) Ground-water density and viscosity are constant.
- f) Ground-water flow can be described by Darcy's Law.
- g) Ground-water flow is horizontal and directed radially away from injection well.
- h) Injection well is screened over the entire saturated thickness of the aquifer.
- i) Instantaneous injection of volume, V .
- j) Head losses through the well screen are negligible.
- k) Aquifer is compressible and completely elastic.

Results

The results of the slug-tests show that the tests were not performed under ideal conditions. Barometric fluctuations in the highly confined system created anomalies in the curve (see slug-test out, well 4C, before development). Furthermore, the test results varied from test to test. Not only did the results vary before and after development, but the tests seemed to vary between slug-in and slug-out. I think that this could be attributed to the changing atmospheric conditions which occurred over the two week test interval (four week for both slug-in and slug-out) and the natural variation in the tests.

Well 1B - Data from the slug-tests in Well 1B show that the computed average hydraulic conductivity values, K , of 3.6×10^{-8} feet per second before development and 2.38×10^{-8} feet per second after development (postdevelopment slug-in test results were not used for calculations), 3.1×10^{-3} and 2.1×10^{-3} feet per day, respectively. No values of storativity or transmissivity were computed for this well.

Well 4C - Data from the slug-tests in Well 4C show that the computed average hydraulic conductivity values, K , of 2.11×10^{-8} feet per second before development (predevelopment slug-out test results were not used for calculations), and 2.14×10^{-8} feet per second after development, 1.82×10^{-3} and 1.84×10^{-3} feet per day, respectively. No values of storativity or transmissivity were computed for this well.

References

- Cooper, H.H., Bredehoeft, J.D., and Papadopoulos, I.S., 1967, Response of a finite-diameter well to an instantaneous charge of water: *Water Resources Res.*, v. 3, p. 263-69.
- Dawson, K.J., Istok, J.D., 1991, *Aquifer testing: design and analysis of pumping and slug tests*: Lewis Publishers, Chelsea, MI, 344 p.
- Papadopoulos, I.S., Bredehoeft, J.D., and Cooper, H.H., 1973, On the analysis of 'slug test' data: *Water Resources Res.*, v. 9, p. 1087-89.

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Aquifer Test Documentation — Slug Tests at the Hallam Nuclear Power Facility, Hallam, Nebraska

1. Description of test

Purpose: The purpose of the slug-in and slug-out aquifer tests is to determine the hydraulic characteristics, particularly the hydraulic conductivity, of the glacial till which underlies the former Hallam Nuclear Power Facility located one mile north of Hallam, Nebraska.

Date: Start — July 21, 1994 end — November 8, 1994

Test Procedures: The test procedures were to instantaneously insert or remove a slug of known volume into the water column in the well and to measure the water level with respect to time. The amount of time needed was dependent upon how long the water level took to return to a static or near static state. If the time involved was determined to be quite lengthy, e.g. several weeks in duration, then the test continued until the water level versus time curve seemed to match one of Cooper's type curves, $F(\alpha, \beta)$ versus β (Cooper, Bredehoeft, and Papadopulos, 1967).

Method of Analysis: Cooper's method, after Cooper, and others, 1967. Cooper's type curves, $F(\alpha, \beta)$ versus β for different values of α .

Unique features: The hydrogeologic unit underlying this site is generally considered to be a confining or leaky confining unit due to its low permeability. It consists of glacially derived clays with minor amounts of fine to medium sand. Because of the low permeability of this unit, the time for the water level to return to equilibrium after the slug insertion or removal can be on the order of weeks.

Well development was performed after the first two (slug-in and slug-out) tests and prior to the second set. The development entailed taking a surge-block (two 0.92-foot by 0.1-foot cylinders filled with sand) and agitating the water within the well for 15 to 20 minutes. The idea being to clean out some of the fine materials that could have been present within the well screen since the installation of the well.

2. Description of the site hydrogeologic characteristics

Keech (1962) reports that the surficial sediments in the Hallam area are predominately unconsolidated glacial deposits of Pleistocene age overlain by loess deposits. These glacial deposits are generally fine grained sediments in the upper half and sand and gravel in the lower half. The fine grained deposits are very compact, can contain localized sand and gravel lenses, and can be 100 to 200 feet thick. The total thickness of the unconsolidated deposits can reach a maximum of slightly more than 400 feet. Underlying the unconsolidated surficial deposits are limestone and shale bedrock sequences of Permian age. These bedrock deposits are not considered sufficiently permeable enough to serve as aquifers. The sand and gravel deposits of the unconsolidated units are considered to be the local aquifer.

Wells: Two monitoring wells were used during the aquifer tests. Both wells are comprised of schedule 40, 2-inch diameter poly-vinylchloride (PVC) casing with .01 slot PVC installed in May 1993.

OBS1B — Well is 50 feet total depth below land surface

—> 39-foot plain casing; 10-foot 0.01 slot schedule 40, 2-inch screen; 1-foot sump.

Concrete seal 0-1 foot, Bentonite grout 1-34 feet, and silica sand 34-50 feet

OBS4C — Well is 75 feet total depth below land surface

—> 64-foot plain casing; 10-foot 0.01 slot schedule 40, 1-inch screen; 1-foot sump.

Concrete seal 0-3 feet, Bentonite grout 3-59 feet, and silica sand 59-75 feet.

3. Water-level hydrographs

Enclosed — Plots of water-level hydrographs, barometric pressure, and slug tests (4 each per well); slug-test in and slug-test out (predevelopment) and slug-test in and slug-test out (post-development).

4. Description of methods and computations

Cooper, Bredehoeft, and Papadopoulos (1967) method for slug tests in a confined compressible aquifer.

Equation:

$$\frac{H_w}{H_o} = F(\alpha, \beta)$$

$$F(\alpha, \beta) = \left(\frac{8\alpha}{\pi^2}\right) \int_0^{\infty} \frac{\exp\left(-\beta \frac{y^2}{\alpha}\right)}{y \Delta y} dy$$

Assumptions (modified from Dawson, K.J., and Istok, J.D., 1991, Aquifer testing: design and analysis of pumping and slug tests, p. 318):

- a) The aquifer is bounded above and below by confining layers.
- b) All layers are horizontal and extend infinitely in the radial direction.
- c) Initial head is horizontal and infinite.
- d) Aquifer is homogeneous and isotropic.
- e) Ground-water density and viscosity are constant.
- f) Ground-water flow can be described by Darcy's Law.
- g) Ground-water flow is horizontal and directed radially away from injection well.
- h) Injection well is screened over the entire saturated thickness of the aquifer.
- i) Instantaneous injection of volume, V.
- j) Head losses through the well screen are negligible.
- k) Aquifer is compressible and completely elastic.

5. Plots of observed data

Enclosed

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SLUGTEST - IN
BEFORE DEVELOPMENT
JULY 21-30, 1994
WELL 1B, SHELDON STATION
HALLAM, NEBRASKA

SLUGTEST - OUT
BEFORE DEVELOPMENT
AUGUST 2-10, 1994
WELL 1B, SHELDON STATION
HALLAM, NEBRASKA

SLUGTEST - IN
AFTER DEVELOPMENT
OCTOBER 14-21, 1994
WELL 1B, SHELDON STATION
HALLAM, NEBRASKA

SLUGTEST - OUT
AFTER DEVELOPMENT
OCTOBER 14-21, 1994
WELL 1B, SHELDON STATION
HALLAM, NEBRASKA

SLUGTEST - IN
BEFORE DEVELOPMENT
JULY 19 TO AUGUST 2, 1994
WELL 4C, SHELDON STATION
HALLAM, NEBRASKA

SLUGTEST - OUT
BEFORE DEVELOPMENT
AUGUST 2-17, 1994
WELL 4C, SHELDON STATION
HALLAM, NEBRASKA

WATER-LEVEL CHANGE, IN FEET

TIME SINCE START OF TEST, IN MINUTES

SLUGTEST - IN
AFTER DEVELOPMENT
OCTOBER 14-21, 1994
WELL 4C, SHELDON STATION
HALLAM, NEBRASKA

SLUGTEST - OUT
AFTER DEVELOPMENT
NOVEMBER 3-11, 1994
WELL 4C, SHELDON STATION
HALLAM, NEBRASKA