SLUG TESTS

1.0 SCOPE AND APPLICABILITY

This procedure is applicable to determine the horizontal hydraulic conductivity of distinct geologic horizons under in-situ conditions. The hydraulic conductivity (K) is an important parameter for modeling the flow of groundwater in an aquifer.

These are standard (i.e. typically applicable) operating procedures which may be varied or changed as required, dependent upon site conditions, equipment limitations or limimtations imposed by the procedure. In all instances, the ultimate procedures employed should be documented and associated with the final report.

Mention of trade names or commercial products does not constitute U.S. Environmental Protection Agency (U.S. EPA) endorsement or recommendation for use.

2.0 METHOD SUMMARY

A slug test involves the instantaneous injection or withdrawal of a volume or slug of water or solid cylinder of known volume. This is accomplished by displacing a known volume of water from a well and measuring the artificial fluctuation of the groundwater level.

The primary advantages of using slug tests to estimate hydraulic conductivities are numerous. First, estimates can be made in-situ, thereby avoiding errors incurred in laboratory testing of disturbed soil samples. Second, tests can be performed quickly at relatively low costs because pumping and observation wells are not required. And lastly, the hydraulic conductivity of small discrete portions of an aquifer can be estimated (e.g., sand layers in a clay).

3.0 SAMPLE PRESERVATION, CONTAINERS, HANDLING AND STORAGE

This section is not applicable to this standard operating procedure (SOP).

4.0 INTERFERENCES AND POTENTIAL PROBLEMS

Limitations of slug testing include: 1) only the hydraulic conductivity of the area immediately surrounding the well is estimated which may not be representative of the average hydraulic conductivity of the area, and 2) the storage coefficient, S, usually cannot be determined by this method.

5.0 EQUIPMENT/APPARATUS

The following equipment is needed to perform slug tests. All equipment which comes in contact with the well should be decontaminated and tested prior to commencing field activities.

- C Tape measure (subdivided into tenths of feet)
- C Water pressure transducer
- C Electric water level indicator
- C Weighted tapes
- C Steel tape (subdivided into tenths of feet)
- C Electronic data-logger (if transducer method is used)
- C Stainless steel slug of a known volume
- C Watch or stopwatch with second hand
- C Semi-log graph paper (if required)
- C Water proof ink pen and logbook
- C Thermometer
- C Appropriate references and calculator
- C Electrical tape
- C 21X micrologger
- C Compact portable computer or equivalent with Grapher installed on the hard disk

6.0 REAGENTS

No chemical reagents are used in this procedure; however, decontamination solvents may be necessary. If decontamination of the slug or equipment is required, refer to the Sampling Equipment Decontamination SOP and the site specific work plan.

7.0 PROCEDURES

7.1 Field Procedures

The following general procedures may be used to collect and report slug test data. These procedures may be modified to reflect site specific conditions:

1. When the slug test is performed using an electronic data-logger and pressure transducer, all data will be stored internally or on computer diskettes or tape. The information will be transferred directly to the main computer and analyzed. A computer printout of the data shall be maintained in the files as documentation.

   If the slug test data is collected and recorded manually, the slug test data form (Figure 1, Appendix A) will be used to record observations. The slug test data form shall be completed as follows:

   - C Site ID - Identification number assigned to the site.
   - C Location ID - Identification of location being tested.
   - C Date - The date when the test data was collected in this order: year, month, day (e.g., 900131 for January 31, 1990).
   - C Slug volume (ft^3) - Manufacturers specification for the known volume or displacement of the slug device.
   - C Logger - identifies the company or person responsible for performing the field measurements.
   - C Test method - The slug device is either injected or lowered into the well or withdrawn or pulled-out from the monitor well. Check the method that is applicable to the test situation being run.
   - C Comments - Appropriate observations or information for which no other blanks are provided.
   - C Elapsed time (min) - Cumulative time readings from beginning of test to end of test, in minutes.
   - C Depth to water (ft) - Depth to water recorded in tenths of feet.

2. Decontaminate the transducer and cable.

3. Make initial water level measurements on monitor wells in an upgradient to downgradient sequence, if possible.

4. Before beginning the slug test, information will be recorded and entered into the electronic data-logger. The type of information may vary depending on the model used. When using different models, consult the operator's manual for the proper data entry sequence to be used.

5. Test wells from least contaminated to most contaminated, if possible.

6. Determine the static water level in the well by measuring the depth to water periodically for several minutes and taking the average of the readings.

7. Cover sharp edges of the well casing with duct tape to protect the transducer cables.

8. Install the transducer and cable in the well to a depth below the target drawdown estimated for the test but at least two feet from the bottom of the well. Be sure the depth of submergence is within the design range stamped on the transducer. Temporarily tape the transducer cable to the well to keep the transducer at a constant depth.

9. Connect the transducer cable to the electronic data-logger.

10. Enter the initial water level and transducer design range into the recording device according to manufacturers instructions (the transducer design range will be stamped on the side of the transducer). Record the initial water level on the recording device.

11. "Instantaneously" introduce or remove a

known volume or slug of water to the well. Another method is to introduce a solid cylinder of known volume to displace and raise the water level, allow the water level to restabilize and remove the cylinder. It is important to remove or add the volumes as quickly as possible because the analysis assumes an "instantaneous" change in volume is created in the well.

12. At the moment of volume addition or removal assigned time zero, measure and record the depth to water and the time at each reading. Depths should be measured to the nearest 0.01 foot. The number of depth-time measurements necessary to complete the test are variable. It is critical to make as many measurements as possible in the early part of the test. The number and intervals between measurements will be determined from earlier previous aquifer tests or evaluations.

13. Continue measuring and recording depth-time measurements until the water level returns to equilibrium conditions or a sufficient number of readings have been made to clearly show a trend on a semi-log plot of time versus depth.

14. Retrieve slug (if applicable).

Note: The time required for a slug test to be completed is a function of the volume of the slug, the hydraulic conductivity of the formation and the type of well completion. The slug volume should be large enough that a sufficient number of water level measurements can be made before the water level returns to equilibrium conditions. The length of the test may range from less than a minute to several hours.

If the well is to be used as a monitoring well, precautions should be taken that the wells are not contaminated by material introduced into the well. If water is added to the monitoring well, it should be from an uncontaminated source and transported in a clean container. Bailers or measuring devices should be cleaned prior to the test. If tests are performed on more than one monitor well, care must be taken to avoid cross contamination of the wells.

Slug tests shall be conducted on relatively undisturbed wells. If a test is conducted on a well that has recently been pumped for water sampling purposes, the measured water level must be within 0.1 foot of the water level prior to sampling. At least one week should elapse between the drilling of a well and the performance of a slug test.

7.2 Post Operation Procedures

When using an electronic data-logger use the following procedure:

1. Stop logging sequence.
2. Print data.
3. Send data to computer by telephone.
4. Save memory and disconnect battery at the end of the day's activities.
5. Review field forms for completeness.

8.0 CALCULATIONS

The simplest interpretation of piezometer recovery is that of Hvorslev (1951). The analysis assumes a homogenous, isotropic medium in which soil and water are incompressible. Hvorslev's expression for hydraulic conductivity (K) is:

$$K = \frac{r^2 \ln (L/R)}{2 L T_0} \quad for\ L/R > 8$$

where:

K	=	hydraulic conductivity [ft/sec]
r	=	casing radius [ft]
L	=	length of open screen (or borehole) [ft]
R	=	filter pack (borehole) radius [ft]
T_0	=	Basic Time Lag [sec]; value of t on semi-logarithmic plot of $H-h/H-H_0$ vs. t, where $H-h/H-H_0 = 0.37$
H	=	initial water level prior to removal of slug
H_0	=	water level at t = 0
h	=	recorded water level at t > 0

(Hvorslev, 1951; Freeze and Cherry, 1979)

The Bower and Rice method is also commonly used for K calculations. However, it is much more time consuming than the Hvorslev method. Refer to Freeze and Cherry or Applied Hydrogeology (Fetter) for a discussion of these methods.

9.0 QUALITY ASSURANCE/ QUALITY CONTROL

The following general quality assurance procedures apply:

1. All data must be documented on standard Chain of Custody records, field data sheets, or within personal/site logbooks.

2. All instrumentation must be operated in accordance with operating instructions as supplied by the manufacturer, unless otherwise specified in the work plan. Equipment checkout and calibration activities must occur prior to sampling/operation, and they must be documented.

The following specific quality assurance activity will apply:

1. Each well should be tested at least twice in order to compare results.

10.0 DATA VALIDATION

This section is not applicable to this SOP.

11.0 HEALTH AND SAFETY

When working with potential hazardouse materials, follow U.S. EPA, OSHA and corporate health and safety procedures.

12.0 REFERENCES

Bower, H., 1978. Groundwater Hydrology, McGraw-Hill Book Company, New York, New York.

Bower, H., and R.C. Rice, 1980. "A Slug Test for Determining the Hydraulic Properties of Tight Formations", Water Resources Research, Vol. 16, No. 1 pp. 233-238.

Cooper, Jr. H.H., J.D., Bredehoeft, and S.S. Papadopulos, 1967. "Response of a Finite-Diameter Well to an Instantaneous Charge of Water", Water Resources Research, Vol. 13, No. 1.

DOI (U.S. Department of the Interior), Ground Water Manual, U.S. Government Printing Office, New York, New York, Washington, D.C.

Earlougher, R.C., 1977. Advances in Well Test Analysis, Society of Petroleum Engineers of AIME.

Ferris, J.G., and D.B., Knowles, 1954. "The Slug Test for Estimating Transmissivity", U.S. Geological Survey Ground Water Note 26.

Freeze, R. Allen and John A. Cherry, 1979. Groundwater, Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Hvorslev, 1951. "Time Lag and Soil Permeability in Ground Water Observations", Bulletin No. 36, U.S. Army Corps of Engineers p. 50.

Johnson Division, UOP, Inc., 1966. Ground Water and Wells, Johnson Division, UOP, Inc., St. Paul, Minnesota.

Lohman, S.W., 1982. "Ground Water Hydraulics", U.S. Geological Survey, Paper 708, p. 70.

Neuman, S.P., 1972. "Theory of Flow in Unconfined Aquifers Considering Delayed Response of the Water Table", Water Resources Research, Vol. 8, No. 4, p. 1031.

Papadopulos, S.S., J.D., Bredehoeft, H.H., Cooper, Jr., 1973. "On the Analysis of Slug Test Data", Water Resources Research, Vol. 9, No. 4.

Todd, David K., 1980. Ground Water Hydrology, 2nd ed. John Wiley & Sons.

APPENDIX A

Slug Test Data Form

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FIGURE 1. Slug Test Data Form

DATE: _____

SITE ID: _____ SLUG VOLUME (ft^3): _____

LOCATION ID: _____ LOGGER: _____

TEST METHOD: __ SLUG INJECTION __ SLUG WITHDRAWAL

COMMENTS: _____

Time Beginning of Test #1 _____ Time Beginning of Test #2 _____

Time End of Test #1 _____ Time End of Test #2 _____

ELAPSED TIME (MIN)	DEPTH TO WATER (FT)	ELAPSED TIME (MIN)	DEPTH TO WATER (FT)