Rocky Mountain
Remediation Services, L.L.C.
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PROCEDURE

SLUG TESTING

Procedure No. RMRS/OPS-PRO.107
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Manager, Water Operations/Waste Operations Div. Date

USE CATEGORY 2

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1.0 PURPOSE

This document contains general guidelines for performing slug tests in monitoring wells and piezometers for the purpose of obtaining water level response data used to determine hydraulic conductivity values. This procedure can be used to support the development of, and be used in conjunction with, work plans involving the collection of single well hydraulic conductivity data at individual project sites. The testing procedures selected will depend on individual well conditions and project objectives.

2.0 SCOPE

This document, which supercedes Procedure No. GW.04, applies to all RMRS personnel and subcontractors conducting work at the Rocky Flats Environmental Technology Site (RFETS).

Slug testing will be conducted in wells where estimates of hydraulic conductivity are required for hydrologic characterization and groundwater remediation design activities. Slug test results are also useful for assessing long-term well performance for groundwater sampling and potential well abandonment and replacement. Slug testing will normally be conducted in wells completed in geologic formations having a low to moderate hydraulic conductivity.

3.0 REQUIREMENTS

The following sections identify the personnel qualifications and equipment for performing slug tests.

3.1 Personnel Qualifications

Personnel performing slug test procedures will be geologists, hydrogeologists, engineers, or field technicians with an appropriate amount of field experience or on-the-job training under supervision of a qualified person. The training requirements for this procedure will be identified in the project-specific health and safety plan or work plan.

3.2 Equipment

The following basic equipment is required, where applicable, according to the project-specific work plan or other appropriate work document:

- Field log book and slug test data forms (Form PRO.107A or PRO.107B)
- Water level indicator.
- Hermit Environmental Data Logger, Model SE1000B, or equivalent with pressure transducer.
- Stainless steel slug, sized appropriately for expected well casing diameter, water column thickness, and desired excess head.
- Cable for slug or bailer.
- Bailer (bail-down tests only).
- IBM-compatible lap top computer for data retrieval (optional).
- Engineer's tape.

4.0 INSTRUCTIONS

Falling and rising slug tests shall be performed by "instantaneously" introducing a solid slug into or removing a solid slug from the water column in piezometers or monitoring wells. Slug tests will not be performed simultaneously in adjacent piezometers (those within 50 feet vertically or horizontally), in order to prevent potential interference that could compromise data quality.

4.1 Pretest Data Recording

Complete a Slug Test Data Form (Form PRO.107A for manually recorded water level data, or form PRO.107B for electronically recorded data; see Section 5.0 –Records) before conducting each test. Obtain the following information in the field or from existing well logs before each slug test and record it on the appropriate Slug Test Data Form.

- Well location and well number
- Casing diameter (check in field)
- Borehole diameter
- Location of surveyed measuring point
- Total casing depth (check in field)
- Static water level, Ho (prior to introducing slug) (measure in field)
- Screen depth and interval
- Location of gravel pack
- Lithology of screened interval

For electronically recorded data, complete Form PRO.107B using the Excel 5.0 spreadsheet template provided in filename WELL_SG2.ANL.

4.2 Field Procedures For Slug Testing

4.2.1 *Slug Injection Test Field Procedures*

An excess head, large enough to provide meaningful data for slug test analysis, will be created in each piezometer or well tested during the slug injection test. Select a slug size that will provide a maximum amount of displacement in the well to be tested, while ensuring that the slug will remain submerged for the duration of the test. Decontaminate all equipment and cables before use at each well, according to SOP OPS-PRO.127, General Equipment Decontamination.

Measure the static water level in accordance with SOP PRO.105, Water Level Measurements in Wells and Piezometers. The measuring point shall be the survey point where the surface elevation was measured, otherwise the point of reference will be the rim of the top of casing. Record water levels to the nearest 0.01 foot.
Determine the total casing depth with a weighted measuring tape or with a water level indicator.

Measure water levels during the slug test with a Hermit Environmental Data Logger, Model SE1000B, or a similar measuring device. Keep the manufacturer's operation manual for the measuring device available in the field for reference. Using the operation manual, select the appropriate transducer probe for the piezometer or well to be tested.

The instruments, and the appropriate calibration procedures for each, that will be used to measure both the static water levels and the water levels during the slug test are described in SOP PRO.105, Water Level Measurements in Wells and Piezometers.

Set the transducer probe in the piezometer at the appropriate depth as determined by the sensitivity of the transducer, height of the water column in the well, and length of the slug to be introduced into the piezometer. Fasten the probe cable to the outside of the piezometer casing. Initially, set the transducer probe pressure readout (reference level) to zero while the probe is in the water. Check the depth to water (from static water level to transducer probe) on the data logger with the known depth of submergence to verify that the probe is working properly. Then, reference the probe to the appropriate datum. Perform a pre-run checkout test by setting the data logger to the appropriate parameters (as outlined in the operation manual), initiating recording of measurements on the data logger, and raising and lowering the transducer probe in the well to simulate water level changes. Continue the measurements of the changing water levels for 10 minutes. Then, review the data to verify that equipment is operating properly.

After completion of this initial pre-run checkout, lower the solid slug into the well so that the bottom of the slug is about 2 to 3 feet above the initial static water level.

Set the water level recording interval to the logarithmic mode. The frequency of measurement will be approximately as follows:

Elapsed Time (after lowering slug)	Log Sample Interval
0-2 sec.	0.2 sec.
2-20 sec.	1.0 sec.
20-120 sec.	3.0 sec.
2-10 min.	5.0 sec.
10-100 min.	2 min.
100-1000 min.	10 min.
E3-1E4 min.	100 min.

Record water level with the data logger immediately before introducing the slug.

Then, quickly lower the slug so that it is positioned 1 to 2 feet below the static water level and above the transducer probe. If there is insufficient water to completely submerge the slug, immerse the slug as fully as possible without disturbing the transducer probe. Keep the transducer probe stationary during and after the process of lowering the solid slug. Continue the test until sufficient water level data for analysis is collected, usually when water levels return to within 10 percent of the initial displacement length. Additional recovery time may be required for slug tests conducted in wells where the static water level occurs within the screened interval and the initial displacement length is affected by filter pack material.

Periodically check the water level in the piezometer or well with the water level indicator to verify that the data logger is functioning properly. The time required to complete the test will depend upon the hydraulic conductivity of the surrounding formation.

Upon completion of the test, electronically transfer data from the data logger to a temporary file using software and instructions provided in the manufacturer's operation manual. Then transfer the test data to Form PRO.107B for documentation and analysis.

Alternatively, a water level indicator may be used to measure water levels in piezometers or wells that are expected to exhibit slow pressure falloff (as indicated by well development records). Changes in water levels are expected to be slow enough that a sufficient number of water level measurements can be recorded manually using the water level indicator. Use Form PRO.107A for manually recorded water level data.

4.2.2 *Slug Withdrawal Test Field Procedures*

The withdrawal test is set up similar to the injection test, except that the head differential is created by removing a slug from the well rather than adding a slug to the well. This test is normally conducted following the completion of a slug injection test, after the water level has returned to its original static level. The withdrawal test provides a useful check of injection test results and may yield a more appropriate hydraulic conductivity value in certain circumstances.

For withdrawal tests that follow injection tests, reset the data logger and perform a pre-run checkout test, as described in section 4.2.1. Set the water level recording interval to the logarithmic mode. Remove the slug from the water column as rapidly as possible while taking care not to lift the pressure transducer cable and probe. Begin recording water levels with the data logger and continue the test until sufficient data is collected for analysis (see section 4.2.1).

Analysis methods for slug withdrawal testing are similar to those used for slug injection testing.

4.2.3 *Bail-Down Test Field Procedures*

The bail-down test is set up similar to the withdrawal test except that the head differential is created by removing water from the well using a bailer instead of a slug.

Lower the pressure transducer probe to a depth where it will not be disturbed (or will be only minimally disturbed) by the bailer when it is lowered into the well. Follow all pre-test procedures in section 3.1.

Using a decontaminated bailer, begin to remove water from the well. Remove water as quickly as possible, taking care not to disturb the transducer or spill water. Bailed water should be handled the same as well development water. How much water is removed depends upon the well: more water must be removed from wells that recharge quickly. Usually 2 to 3 feet of head differential is adequate to perform a test.

Begin the test immediately after removing the required volume of water.

Data analysis uses methods similar to those used for slug testing.

4.3 Slug Test Method of Analysis

Analyze the slug test data using an appropriate analytical method. Appropriate methods include but are not limited to Bouwer and Rice (1976), Hvorslev (1951), and Cooper, Bredehoeft, and Papadopulos (1967). The Ramey et al. (1975) method has been used for previous test analyses at RFETS. Excel 5.0 spreadsheet templates are available for the analytical methods of Bouwer and Rice (1976), and Horslev (1951) (filename WELL_SG2.ANL), and for the analytical method of Ramey et al. (1975) (filename WELL_SG.RMY).

5.0 RECORDS

Document the information required by this SOP on the Slug Test Data Forms (Form PRO.107A or PRO.107B). Borehole dimensions and other information required on this form can be found on applicable borehole log sheets.

Use of field logbooks to supplement the data form documentation is optional. Logbooks may be used to describe field conditions, instrument readings, and other event specific information.

6.0 REFERENCES

6.1 Source References

The following references were reviewed before this procedure was written:

Bouwer, H. and R. C. Rice, 1976, A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers with Completely or Partially Penetrating Wells, *Water Resources Research,* Vol. 12, No. 3, pp. 423-428.

Cooper, H. H., Jr., J. D. Bredehoeft, and I. S. Papadopulos, 1967, Response of a Finite Diameter Well to an Instantaneous Charge of Water. *Water Resources Research*, 3(1).

Hvorslev, M. J., 1951, *Time Lag and Soil Permeability in Groundwater Observations*, Bulletin No. 36, Waterways Experiment Station, Corps of Engineers, Vicksburg, Miss.

Ramey, Jr., H. J., R. G. Agarwal and I. Martin, 1975, Analysis of Slug Test or DST Flow Period Data, *J. Can. Pet. Tech.*, p. 37-42.

6.2 Internal References

Related SOPs cross-referenced by this SOP are these:

SOP RMRS/OPS-PRO.127, General Equipment Decontamination

SOP RMRS/OPS-PRO.105, Water Level Measurements in Wells and Piezometers

APPENDIX PRO.107A

SLUG TEST DATA FORM (MANUAL INPUT)

FORM PRO.107A
SLUG TEST DATA FORM (MANUAL INPUT)

Location _____ Name _____
Borehole No. _____ Groundwater Elevation Before Test (Ho) _____
Test Date/Time _____ Total Casing Depth _____
Measuring Point _____ Borehole Diameter _____
Type of Test _____ Casing Diameter _____
Transducer Probe Serial No. _____ Screened Interval _____
Datalogger Test Run No. _____ Sand Pack Interval _____
(include time and date for identification purposes)

Lithology Tested _____

Actual Time	Elapsed Time	Depth to Water from Top of Casing (ft)	H Excess Head (ft)	H/Ho

Actual Time	Elapsed Time	Depth to Water from Top of Casing (ft)	H Excess Head (ft)	H/Ho

FORM PRO.107B

SLUG TEST DATA FORM (ELECTRONIC INPUT)

FORM PRO.107B

SLUG TEST DATA FORM (ELECTRONIC INPUT)

Well No.			
Test Type	(Falling Head/Rising Head)		
Method	(Displacement/Bailed)		
Test date			
Well diameter			inches
Casing diameter			inches
Total depth of borehole			feet below ground surface
Lithology of screemed interval			(Bedrock =1,Alluvium =2)
Depth to bedrock			feet below top of casing (fbtc)
Screened interval	**Top**		feet below top of casing (fbtc)
	Bottom		feet below top of casing (fbtc)
Sand pack interval	**Top**		feet below top of casing (fbtc)
	Bottom		feet below top of casing (fbtc)
Water level before test (static)			feet below top of casing (fbtc)
Is the interval confined or unconfined		unconfined	Treat as unconfined
Water level immediately after slug			feet below to of casing (fbtc)
Length of water column above top of sand pack			feet
Effective saturated thickness of aquifer			feet
Length tested			feet
Effective casing radius			inches

Time (minutes)	Reading (fbtc)	Elapsed time (mins)	Residual Head (feet)
		0.000	Test Type?

Time (minutes)	Reading (fbtc)	Elapsed time (mins)	Residual Head (feet)
		0.000	Test Type?

Time (minutes)	Reading (fbtc)	Elapsed time (mins)	Residual Head (feet)
		0.000	Test Type?

Time (minutes)	Reading (fbtc)	Elapsed time (mins)	Residual Head (feet)
		0.000	Test Type?