GWPD 17—Conducting an Instantaneous Change in Head (Slug) Test with a Mechanical Slug and Submersible Pressure Transducer

VERSION: 2010.1

PURPOSE: To obtain data from which an estimate of hydraulic conductivity of an aquifer can be calculated.

During a slug test the water level in a well is changed rapidly, and the rate of water-level response to that change is measured. From these data, an estimate of hydraulic conductivity can be calculated using appropriate analytical methods (for example, Ferris and Knowles, 1963).

A slug test requires a rapid ("instantaneous") water-level change and measurement of the water-level response at high frequency. A rapid change in water level can be induced in many ways, including injecting or withdrawing water, increasing or decreasing air pressure in the well casing, or adding a mechanical device like a plastic rod to displace water. The water-level changes can be measured with many methods, including steel tape, electric tape, air line, wireline/float, and submersible pressure transducers.

One of the most common methods in use is displacement of water with a mechanical slug, measurement of water levels with a submersible pressure transducer, and recording water levels with a data logger. This method combines ease of use, accuracy, and rapidity of water-level measurement. This document describes the mechanical slug/pressure transducer method. This technical procedure can be used with slight modifications if other approaches are used to instantaneously change the water level or measure water-level change.

Materials and Instruments

1. Tools or key to open the well.
2. Field notebook; Pencil or pen, blue or black ink. Strike-through, date, and initial errors; no erasures.
3. Well-construction diagram.
4. Data logger and submersible pressure transducer. A 10-pound-per-square-inch (psi) pressure transducer commonly is used for slug tests because it combines adequate accuracy with an acceptable range of measurement.
5. Slug of polyvinyl chloride (PVC) or other relatively inert material (fig. 1). A slug of solid PVC (fig. 1*C*) is ideal because PVC caps (fig. 1*A*) can catch the well casing during insertion, and PVC plugs (fig. 1*B*) can come loose during the rapid removal of the slug.

   Select the largest diameter and length of slug that will fit in the well without disturbing the transducer. The slug should have a displacement that will provide an adequate change in water level. The slug should displace enough water to provide a measurable change in water level, but not so large as to significantly increase the saturated thickness of the aquifer, disturb the transducer, or affect the speed at which one can raise or lower the slug. A water-level rise between 0.5 and 3 feet (ft) often is adequate. In low permeability formations, a smaller displacement will take less time for full recovery. In high permeability formations (1 to 100 ft per day), a larger displacement is desirable and practical. This usually can be generated with a slug diameter about 1 inch less than the well diameter and a length of 3 ft or more (lengths greater than 5 ft are awkward to handle in the field). Tables 1 and 2, respectively, provide theoretical displacement volumes for various slugs and volumes necessary for specific water-level changes.
6. Nylon cord or other strong line of sufficient length to reach below the water level in order to secure the slug.
7. Wooden rod, or 2 by 4 to secure the slug line.
8. Tripod or other device to support the slug line (optional).
9. Bungee cord or other device to secure the transducer cable and support line.
10. Water level measuring device (steel or electric tape).
11. Appropriate decontamination equipment, if necessary.
12. Field computer (optional).
13. Stopwatch (optional).

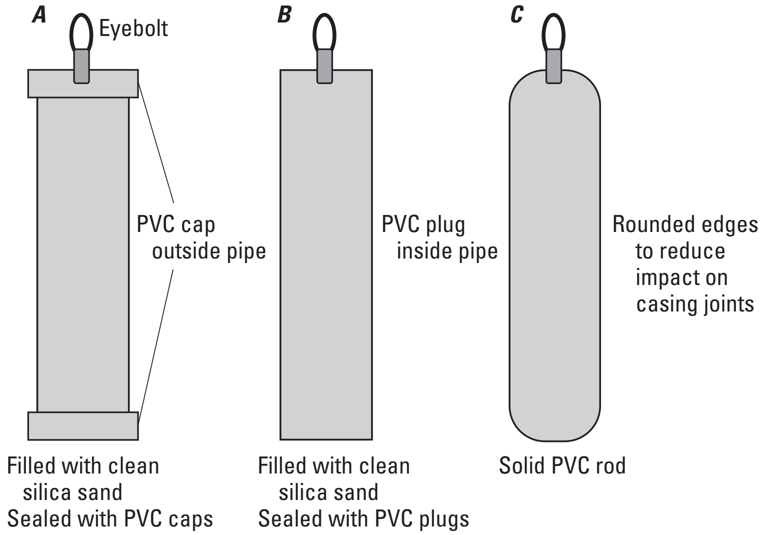

Figure 1. Polyvinyl chloride (PVC) plastic slug. *A*, Solid 2-inch PVC pipe with external cap. *B*, Solid 2-inch PVC pipe with internal plug. *C*, Solid 2-inch PVC rod.

Table 1. Slug displacement volume, in cubic feet, for a specific slug diameter and length.

Slug length (feet)	Slug diameter (inches)						
	1	1.5	2	2.5	3	3.5	4
2	0.011	0.025	0.044	0.068	0.098	0.134	0.175
3	0.016	0.037	0.065	0.102	0.147	0.200	0.262
4	0.022	0.049	0.087	0.136	0.196	0.267	0.349
5	0.027	0.061	0.109	0.170	0.245	0.334	0.436
6	0.033	0.074	0.131	0.205	0.295	0.401	0.524

Table 2. Volume of water, in cubic feet, required to raise the water level a prescribed distance within a specific well diameter.

Well diameter (inches)	0.3-foot rise	0.5-foot rise	1-foot rise	1.5-foot rise	2-foot rise	3-foot rise
2	0.007	0.011	0.022	0.033	0.044	0.065
3	0.015	0.025	0.049	0.074	0.098	0.147
4	0.026	0.044	0.087	0.131	0.175	0.262
6	0.059	0.098	0.196	0.295	0.393	0.589
8	0.105	0.175	0.349	0.524	0.698	1.047
10	0.164	0.273	0.545	0.818	1.091	1.636

Data Accuracy and Limitations

1. The accuracy of a slug test is a function of many factors, including well construction, field procedures, and analysis method. Rapidly changing the water level in a well can be done by submerging an object (slug) in the water, causing the water level to rise instantaneously. Displaced water will move from the well to the geologic formation until the hydraulic head falls to the original static or equilibrium level. This is called a falling head test or “slug in test.” After the water level reaches equilibrium, quickly removing the slug causes the water level to fall instantaneously. Water will move from the formation into the well until the hydraulic head returns to the equilibrium level. This is called a rising head test, “slug-out test,” or bailer test. Because the early-time data for these tests are most important for the subsequent analysis, the data logger should begin collecting data just before the slug is submerged or removed from the well. The initial time can be adjusted during analysis, but the logger must be collecting data at a frequency of at least several samples per second when the water level begins to change. After the first minute or two of data collection, the sampling interval can be increased. Data loggers designed for aquifer tests and slug tests frequently have internal programs that allow for rapid data collection at early time and gradual increase of the sampling interval over time (a logarithmic time scale).

2. Some transducers have more rapid recording rates than others. If the slug test is being done in a formation of high hydraulic conductivity, select a transducer that can transmit at very small time increments (tenths of a second).

3. Due to the accuracy limitations of slug tests, results should be reported to one significant figure.

Advantages

1. Potentially contaminated water requiring special disposal is not removed from the well.

2. The slug test can be conducted quickly and is therefore relatively inexpensive.

3. Only one well is needed for the test (no need for other observation wells), and a pump is not required.

4. Because the slug-test data to be analyzed for an estimate of hydraulic conductivity are collected within a few minutes of the test initiation, this technique can be used near pumped wells or where well interference is expected, as long as the expected water-level changes occur slowly in comparison to the time for which the slug-test data will be analyzed.

Disadvantages

1. The collected data represent only a small volume of aquifer material near the tested well.

2. The test may be influenced by the well filter pack, skin effects, or poor well development.

Assumptions

1. Operator is familiar with the operation of data loggers and submersible pressure transducers. The data logger/transducer can measure and record at a high frequency (less than or equal to one second in highly transmissive formations).

2. The well is free of obstructions which might hinder water-level measurement or introduction or removal of the mechanical slug.

3. The water level is easily accessible from the surface (within approximately 100 ft) and is within the length of the transducer cable.

4. Column of water in the well is long enough to cover the transducer and the slug.

5. The well is properly constructed and developed.

6. Well construction details such as well depth, screen length, borehole radius, filter pack, and well radius are known.

7. The hydraulic conductivity of the aquifer is not extremely low. A slug test is an acceptable method in low-permeability formations, but a transducer may not be necessary in this situation. The water level in the well should recover within minutes or hours for this procedure.

Instructions

1. Confirm well identification with well-construction diagram.

2. Measure the total depth of the well (see GWPD 11).

3. Measure the water level in the well (see GWPD 1 or GWPD 4). This should be repeated at the end of the test for long duration slug tests. The column of water in the well should be long enough to cover the transducer and the slug.

4. Document the static water level, well diameter, well depth, and screened interval in field notebook. The diameter of the hole, nature of filter pack, and type of screen also are documented, if known.

5. Place the transducer in the well below the level at which the slug will be submerged, but not so low that the range of transducer might be exceeded at the highest anticipated water level. Secure the transducer in place. The transducer should not move during the test.

6. Measure (estimate) the maximum length of slug line that will be used. This length should allow the slug to completely submerge, about 1 ft below water surface.

7. Allow the transducer to adjust to the new pressure and temperature following manufacturer's guidance. This also provides time for the water level to recover prior to the test.

8. If needed, set up a tripod or some other device from which the slug can be lowered and raised in the well. Lower the clean, decontaminated slug to a point just above the water level and secure it in place. Take care not to move or kink the transducer line (fig. 2*A*). A simple approach of securing the slug is to tie a loop of cord that would hold the slug about 1 ft above the water surface and then tie off a second loop at the length of cord required for the entire slug to submerge. Put both of these loops over a rod or a wooden 2 by 4 that can rest across the top of the well casing.

9. Prepare the data logger. The data logger should be set to record data as frequently as possible during the first minutes of the test, and it can be set to record less frequently during later time. Recording in seconds on a logarithmic time scale meets this objective.

10. Establish a starting water level for the transducer and data logger. Data analysis is based on the change in water level rather than a comparison to a standard datum. The transducer starting water level can be set to zero, a value equal to the head of water above the transducer, or any other value.

Slug In Test

11. Begin the test by starting the data logger and nearly simultaneously submerging the slug quickly but gently into the water to minimize disturbance at the water surface or movement of the transducer cable (fig. 2*B*). Secure the slug cord to the wooden rod to maintain its position below the water level.

12. After 1 minute and periodically thereafter, check the status of the water-level reading with the data logger/transducer or with a water-level measuring tape.

13. When the water level is equal to the initial water level, or when readings change less than 0.01 ft per 10 minutes, stop the test. This is the end of the falling head, or slug in test. You are now ready to begin the rising head, or slug out test.

Slug Out Test

14. Establish a starting water level for the transducer and data logger. Data analysis is based on the change in water level rather than a comparison to a standard datum. The transducer starting water level can be set to zero, a value equal to the head of water above the transducer, or any other value.

15. Prepare the data logger. The data logger should be set to record data as frequently as possible during the first minutes of the test, and it can be set to record less frequently during later time. Recording in seconds on a logarithmic time scale meets this objective.

16. Begin the test by starting the data logger and nearly simultaneously withdrawing the slug quickly but gently from the water to minimize disturbance at the water surface or movement of the transducer cable. The slug need not be withdrawn completely out of the well, but should

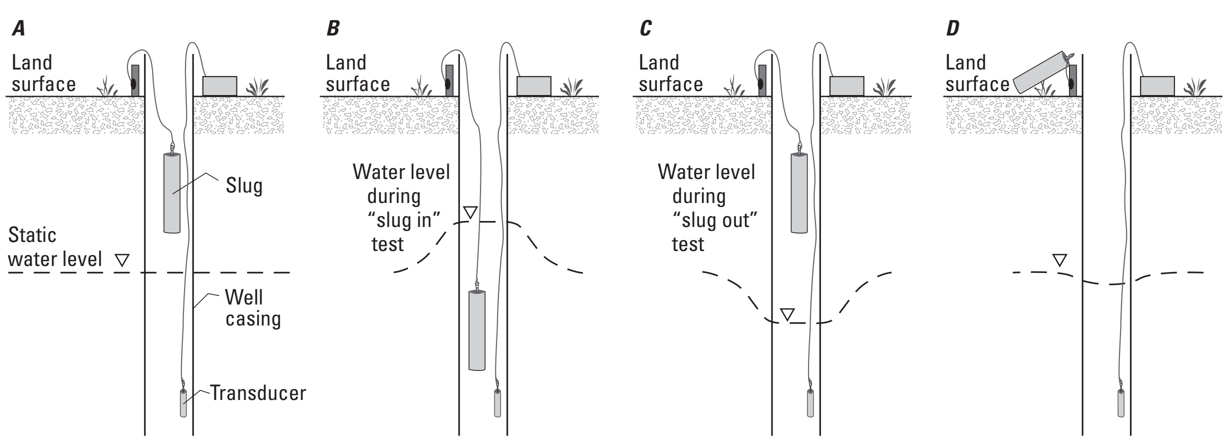

Figure 2. Well diagram with polyvinyl chloride (PVC) plastic slug (*A*) poised just above the water level for falling head or slug in test, (*B*) submerged below the water level for falling head or slug in test, (*C*) removed just above the water level for rising head or slug out test, and (*D*) removed from the well for rising head or slug out test.

be out of the water (fig. 2*C* or 2*D*). Secure the slug cord to the wooden rod to maintain its position above the water level.

17. After 1 minute and periodically thereafter, check the status of the water-level reading with the data logger/transducer or with a measuring tape.

18. When the water level is equal to the initial water level, or when readings change less than 0.01 ft per 10 minutes, stop the test. This is the end of the rising head, or slug out test.

19. Review the data for completeness and accuracy. This can be done on the data logger or on a field computer (preferred). Optionally, the test can be analyzed in the field on a field computer using aquifer test software.

20. Repeat the entire procedure at least once as time permits, so two complete sets of falling and rising head test data are collected (four tests).

Data Recording

1. All calibration and maintenance data associated with the data logger, steel or electric tape, and submersible pressure transducer are recorded in calibration and maintenance equipment logbooks.

2. Complete a field report with date, time, well identifier, type of test (rising or falling head), composition and dimensions (or volume) of the slug, and the name of data files. (Use site ID or well name, date, and year in the file name: for example, 424531077564201.19960101, or Well8.19960101).

3. Data are downloaded to an office computer for processing. Results are interpreted and submitted for Bureau approval. Original data are stored in the office aquifer test archive, and result is recorded on the Ground-Water Site Inventory form (fig. 3, Form 9-1904-D1).

FORM NO. 9-1904-D1
Revised January 2010, NWIS 4.9

Coded by ____________________ File Code ____________________

Checked by ____________________ Date ____________________

Entered by ____________________ Regional approval date ____________________

U.S DEPT. OF THE INTERIOR
GEOLOGICAL SURVEY

GROUNDWATER SITE INVENTORY
Hydraulics Data

AGENCY CODE (C4) [ ] SITE ID (C1) [ ]

RECORD TYPE (C744) [H Y D R] RECORD SEQUENCE NO. (C790) [ ]

HYDRAULIC UNIT IDENTIFIER (C100) [ ] DEPTH TO TOP OF INTERVAL (C101) [ ] . [ ] DEPTH TO BOTTOM OF INTERVAL (C102) [ ] . [ ]

HYDRAULICS UNIT TYPE (C103) [A C]
A – aquifer, C – confining unit

REMARKS - Method of determining hydraulics data (C104)
[ ]

HYDRAULICS SOURCE AGENCY (C305) [ ] WEB-READY FLAG (C874) [Y C P L]
Y – ready to display, C – condi-tional, P – propri-etary, L – local use only

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RECORD TYPE (C746) [C O E F] SEQUENCE NO. OF PARENT RECORD (C99) [ ] RECORD SEQUENCE NO. (C106) [ ]

TRANSMISSIVITY(C107) [ ]

HORIZONTAL CONDUCTIVITY (C108) [ ] . [ ] VERTICAL CONDUCTIVITY (C109) [ ] . [ ]

STORAGE COEFFICIENT (C110) . [ ] LEAKANCE (C111) [ ] . [ ]

DIFFUSIVITY (C112) [ ] SPECIFIC STORAGE (C113) . [ ]

BAROMETRIC EFFICIENCY (Percent) (C271) [ ] POROSITY (C306) . [ ]

WEB-READY FLAG (C875) [Y C P L]
Y – ready to display, C – condi-tional, P – propri-etary, L – local use only

Figure 3. Groundwater Site Inventory for Hydraulics Data, Form 9-1404-D1.

Procedures References

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