# STANDARD OPERATING PROCEDURE

# Fourteen

# IN-SITU PERMEABILITY TESTING

**Modified from**
GUIDANCE FOR DESIGN, INSTALLATION AND OPERATION
OF GROUNDWATER EXTRACTION AND
PRODUCT RECOVERY SYSTEMS
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**1.0 Aquifer Testing**

Aquifer testing is necessary to estimate the hydraulic conductivity or transmissivity for plume capture calculations, RBCA modeling, etc. In some cases, the hydraulic conductivity tests conducted during the site investigation provide sufficient data. In other cases, a pumping test prior to remedial design may be necessary to accurately estimate the rate of groundwater pumping that is needed to capture the plume.

In some situations, aquifer testing techniques such as a slug tests, bail-down tests, and grain-size methods provide sufficiently accurate hydraulic conductivity estimates. However, these techniques may not be sufficiently accurate for design or modeling purposes.

The following is a list of aquifer tests in decreasing order of accuracy:

- Long duration (multi-day) constant rate pumping tests;
- Short duration (less than eight hours) step drawdown tests;
- Bail-down and slug tests; or
- Permeability calculations based on grain-size analysis.

Some suggested guidelines when testing aquifers include the following:

- A plume in sand or gravel that is hundreds of feet long and over 100 feet wide is a major groundwater extraction project; therefore, a pumping test is probably necessary.
- In silt and clay soils, a likely pumping rate is several gpm or less. A bail-down test from each well generally provides sufficient data for evaluating design, treatment, and/or disposal options. Although a pumping test more clearly defines an aquifer, it may be more cost effective to oversize the groundwater extraction/treatment system and delay a pumping test until after the system installation, provided that it is relatively inexpensive to oversize the groundwater treatment system.
- A pumping test is probably needed prior to designing groundwater extraction systems that are likely to produce more than 50 gpm, but is probably not necessary for systems that are likely to operate at less than 5 gpm. If the system is likely to produce between 5 and 50 gpm, designers should assess site-specific factors such as water disposal options, treatment needs, etc. to determine what level of accuracy is needed for an aquifer test.

A careful evaluation of the costs and benefits of a pumping test may be warranted. If a pumping test is not proposed at a site, the hydrogeologist should include an evaluation of the aquifer-testing data quality in the report to justify the exclusion of a pumping test. If a number of aquifer-testing results are available, the geometric mean of the results should be used to calculate the average hydraulic conductivity (Domenico and Schwartz, 1990; page 67). If multiple hydrogeologic units are present, designers should calculate the geometric mean for each hydrogeologic unit, not a single, overall site average. If some results have a higher degree of certainty, designers should **NOT** use the results that are less certain in the calculation.

Example: If both pumping test results and Hazen method results are available, the Hazen method results should not be used when calculating the geometric mean due to the higher level of uncertainty.

The groundwater discharged during an aquifer test or well development should be sampled and chemically analyzed for contaminants and other parameters that may affect the treatment system and/or disposal options.

Water that is produced as part of aquifer testing must be handled in accordance with Department requirements. Portable, low-volume air strippers or carbon filters may be used as treatment for water that is produced by pumping tests. Pre-approval is necessary by the Department's Surface Water Quality Program if discharging to a storm sewer or surface water body. In some cases, a publicly owned treatment works (POTW) will accept untreated pumping test water without significant costs. The POTW will probably require test results from the well prior to approving the discharge. The local POTW should be contacted to determine necessary analytical requirements.

Designers should evaluate the means and costs of water disposal when determining which aquifer characterization method to use.

## 1.1 Hydraulic Conductivity Estimates Based on Grain-Size Analysis

A mathematical determination of the hydraulic conductivity based on the grain size is rarely appropriate for designing a groundwater extraction system. A grain-size test may be used in unconsolidated material to corroborate other tests. The reasons for poor performance of this test include the following:

- There are a number of methods available (Shepherd, 1989, Masch and Denny, 1966, Hazen method described in Freeze and Cherry, 1979 and Fetter, 1988), but no single test is proven to be best under all conditions.

- Most methods are only applicable to sand. Note: The Hazen Method is only valid for a grain size of $0.1 < D_{10} < 3.0$ mm, the Masch and Denny method is limited to samples of unconsolidated sand.

- The samples that are collected for grain-size analysis are from very small discrete locations. Often, only one to three samples are tested; therefore, only a few discrete parts of the site are used to estimate the overall site hydraulic conductivity and transmissivity.

- Some methods disregard soil density, porosity, grain roundness, etc.

- Only groundwater flow through primary porosity in soil is evaluated in a grain-size test, if there is flow-through secondary porosity — such as fractures in till — the conventional tests are invalid.

- The tests are not appropriate for bedrock.

## 1.2 Bail-Down and Slug Tests

Bail-down or slug tests provide better hydraulic conductivity estimates than grain-size analyses.

**Note:** For purposes of this document, a bail-down test is a test that instantaneously extracts or withdraws a volume of water or a slug from the well, and a slug test is a test that instantaneously injects a solid slug into the well.

Slug tests are best conducted in piezometers or monitoring wells that are **not** screened across the water table. A slug test in a water table well will force water into the unsaturated filter pack and possibly the unsaturated native soils, increasing the length of submerged screen. Changing the length of the submerged screen during the test, makes the test invalid (Bouwer, 1989).

Most general hydrogeology texts describe these tests and provide a number of references. Selected references include Cooper, et. al. (1967), Bouwer and Rice (1976), and Bouwer (1989); there also are many other articles on these tests in various publications.

Bail-down or slug tests may not provide the most accurate results for the following reasons:

- Only the part of the aquifer immediately adjacent to the filter pack and screen is evaluated.

- When testing water-table wells, only the uppermost part of the aquifer is tested. More representative results are obtained from wells, which reflect an overall average of the aquifer.

- If tests are conducted using piezometers, they only test a very small part of the aquifer in the vertical dimension because piezometer screens are usually only 5 feet long and the sand pack is 7 to 8 feet long.

- If there is flow in secondary porosity channels, the wells may not intersect the channels or fractures and would only evaluate the primary permeability. If a fracture is intersected by the well, the interpretation could also be inaccurate because the assumptions in the conventional methods are violated (Karasaki,1988).

- If the wells are not adequately developed, they will not yield meaningful results. Smearing of the bore-hole during drilling will cause the well to reflect an artificially low permeability.

**Note:** Because wells that are not properly developed typically do not provide accurate hydraulic conductivity estimates with slug or bail-down tests, these wells should be redeveloped prior to aquifer testing.

- Highly permeable aquifers often yield artificially low estimates with slug/bail-down tests because the injection/extraction rate relative to the rate of the induced inflow/outflow from the aquifer is not instantaneous.

- If the filter pack is less permeable than the native soil, the calculated hydraulic conductivity is artificially low because the test measures the hydraulic conductivity of the filter pack. A screen slot size that is too small can also limit the groundwater flow into a well lowering the hydraulic conductivity estimate in highly-permeable aquifers.

### 1.3 Pumping Tests

A pumping test extracts groundwater at a constant rate for a number of hours, and a step drawdown test varies the pumping rate over time. These tests are used to calculate the aquifer transmissivity and specific yield or storage coefficient. Most general hydrogeology texts cover the basics of pumping tests; Kruseman and de Ridder (1990) is an excellent reference.

In some cases, an additional monitoring well or aquifer-test well is necessary to perform a pumping test. A pumping test can be performed in an aquifer-test well constructed for the pumping test, a groundwater extraction well, or an oversized (4-inch) monitoring well. An aquifer-test well should be evaluated for entrance velocity (Driscoll, 1986) prior to installing the well. A wire wrapped screen may be necessary in highly permeable aquifers to reduce entrance velocity. In this case incrustation due to a high entrance velocity is not an issue because of limited pumping duration, but flow restriction through too small a slot size could occur.

A longer well screen than normally used for a monitoring well may also be necessary to achieve the desired drawdown and flow rate during the pumping test. If the aquifer-test well is upgradient of the source and within the same geologic unit, it may produce clean water. Disposing of clean water from a pumping test is much easier than contaminated water. This may be a factor when planning the duration and pumping rate for a test.

General considerations for pumping tests include the following:

- A method that accounts for partial penetration and/or unconfined conditions is appropriate in most aquifer-decontamination projects. During a pumping test, the groundwater below a partially penetrating extraction well is relatively stagnant and does not "flow" during the test, therefore, this portion of the aquifer is not "tested" during the pumping test. Methods that assume a fully penetrating well could result in a transmissivity estimate that is artificially low.

  Driscoll (1986) indicates that partial penetration effects are minimized at a distance (from the extraction well) that is twice the aquifer thickness. Therefore, methods based on fully penetrating wells (including the Jacob straight line method) can be used on data from monitoring wells that are a significant distance from the extraction well. If the Jacob straight line method is used, the calculated u value should be less than 0.05 (Driscoll, 1986).

  N. Boulton and S. Neuman have each published a number of articles about aquifer testing in unconfined conditions. Fetter (1988) lists a number of references related to aquifer testing (pages 209 to 21) including most of those by Boulton and Neuman.

- The classic pumping test for a water-table aquifer is a 72-hour test. Confined aquifers may need a 24-hour test. At some small sites, a low-capacity test (less than 10 gpm) for a shorter period of time (8 to 24 hours) may be sufficient.

  The length of the pumping test may need to be modified if the hydrogeologist conducting the pumping test determines that a different length of time for the test is necessary, based on initial test data. If early test data suggests that the drawdown in an unconfined aquifer has stabilized, the pumping test should continue long enough to ascertain that a delayed yield or slow drainage effect is not influencing the interpretation.

- Water-level measurements should be collected at all available measuring points. Even distant points that are outside the radius of influence provide data on background water-level fluctuations during the test.

  > **Note:** Hydrogeologists should collect water and product level measurements in wells with floating product. However, wells with floating product should not be used for pumping test evaluation, unless there is a shortage of wells at the site. Because the

dynamics of multi-phase fluid flow into and out of a well with floating product may introduce error, these monitoring wells may provide misleading results. If wells with floating product are used, the density of the product should be estimated to calculate the equivalent head in the well.

- In all cases, recovery data for a pumping test is collected and evaluated, especially at the groundwater extraction well.

- Casing storage can influence early drawdown data in large-diameter wells that are installed in relatively impermeable aquifers. See Kruseman and de Ridder (1990) and/or Driscoll (1986).

In some cases, a short step-drawdown test is a viable alternative to a full-scale pumping test. Small-diameter electric submersible pumps that fit in 2-inch wells that can be used for step-drawdown tests are available. If a 4-inch monitoring well is used at the site, a higher capacity step-drawdown test can be conducted.

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## 1.4 References


Cooper, H.H, Bredehoeft, J.D., and Papadopulos, I.S. 1967. Response of a Finite Diameter Well to an Instantaneous Charge of Water. *Water Resources Research.* Volume 3, Number 1, pages 263 to 269.

Bouwer, H. and Rice, R.C. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers with Completely or Partially Penetrating Wells. *Water Resources Research.* Volume 12, pages 423 to 428.

Bouwer, H. 1989. The Bouwer and Rice Slug Test - An Update. *Ground Water*, Volume 27, Number 3, Pages 304 to 309.

Domenico, P.A. and Schwartz, F.W. 1990. *Physical and Chemical Hydrogeology*. John Wiley and Sons, Inc. New York, New York.

Driscoll, F.G. 1986. *Groundwater and Wells*, Second Edition. Johnson Division, St. Paul, Minnesota.

Fetter, C.W. 1988. *Applied Hydrogeology*, Second Edition. Merrill Publishing Company, Columbus, Ohio.

Fetter, C.W. 1993. *Contaminant Hydrogeology*. Macmillan Publishing Company, New York, New York.

Freeze, R.A. and Cherry, J.A. 1979. *Groundwater*. Prentice Hall Inc., Englewood Cliffs, NJ.

Karasaki, K., Long, J.C.S., and Witherspoon, P.A. 1988. Analytical Models of Slug Tests. *Water Resources Research*, Volume 24, Number 1, pages 115 to 126.

Kruseman, G.P. and de Ridder, N.A., 1990. *Analysis and Evaluation of Pumping Test Data*, Second Edition. International Institute for Land Reclamation and improvement, Wageningen, The Netherlands.

Masch, F.D. and K.J. Denny. 1966. Grain Size Distribution and its effect on the permeability of unconsolidated sand. *Water Resources Research*, Volume 2, Number 4, pages 665 to 677.