| Sampling Method/Media: **Bedrock Packer Permeability Testing / Groundwater** | Title: **Standard Operating Procedure for Bedrock Packer Permeability Testing** |
|---|---|
| **Revision No: Original**<br>**Revision Date: 24 November, 2020** | **Reference No: SOP-E2-09**<br>**Parent Document: BC Field Sampling Manual – Part E2** |

## 1. Introduction and Scope

This Standard Operating Procedure (SOP) provides operating guidelines and instruction for performing in situ permeability testing of bedrock boreholes using inflatable packers. This SOP provides a field procedure for estimating the hydraulic conductivity of discrete zones within a borehole via the constant head or falling head test methods; analytical procedures are given by Hvorslev (1951). The procedures within this SOP are applicable to bedrock of moderate to high hydraulic conductivity (greater than $10^{-8}$ m/s) and may be used for either single (bottom of borehole) or double (straddle zone) packer tests. Refer to ASTM D4630 for field and analytical procedures of testing low-permeability (hydraulic conductivity less than $10^{-8}$ m/s) bedrock.

This SOP forms part of the British Columbia Field Sampling Manual (BCFSM). Additional information on step-drawdown pump testing is provided in Part E2 – Groundwater, which must be used in conjunction with the information provided in this SOP. Further guidance regarding groundwater is provided in the Water Sustainability Act (WSA) and the Groundwater Protection Regulation (GPR) which are available at:

https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/laws-rules/groundwater-protection-regulation.

The Environmental Management Act (EMA), the Contaminated Sites Regulation (CSR) and associated guidance documents provide information specific to groundwater monitoring wells installed to investigate and remediate contaminated sites; these documents are available at:

https://www2.gov.bc.ca/gov/content/environment/air-land-water/site-remediation/contaminated-sites.

Groundwater well installations, sampling, monitoring and decommissioning conducted for regulatory purposes within the provincial jurisdiction of BC must be carried out with consideration to the WSA, the GPR, the EMA, and the CSR, all as applicable, Part E2 of the BC Field Sampling Manual, and this document.

## 2. Document Control

This Standard Operating Procedure (SOP) is a controlled document. Document control provides a measure of assurance that the specifications and guidance it provides are based on current information that has been scrutinized by a qualified reviewer/s. Controlled documents are reviewed within a five year life cycle. Please ensure that the revision date listed in the header of this document does not exceed five years.

## 3. Principle of Bedrock Packer Permeability Testing

Bedrock permeability testing involves isolating a discrete zone of the borehole between either two mechanical or inflatable packers (when testing is completed after borehole advancement) or between one packer and the bottom of the hole (when testing is completed during borehole advancement). Water is introduced into rods that pass through the top packer, either by pumping at a fixed pressure (constant head) or by filling the rods rapidly and allowing them to drain (falling head). In the constant head test, conditions near the borehole rapidly approach steady-state due to the very low storage of water in fractured bedrock, and the water inflow rate is a function of the injection pressure and the hydraulic conductivity of the rock within the test interval. In the falling head test, the water level response is a function of water storage within the rods and the hydraulic conductivity of the rock within the test interval.

A falling head test is typically conducted first on a test interval. Should the response be too rapid to accurately measure, the water level is allowed to stabilize and a constant head test can be conducted. An advantage of this method is that a profile of hydraulic conductivity can be obtained relatively rapidly. Disadvantages are that low permeability zones cannot be accurately tested using the constant head method unless a very precise measurement of injection volumes can be made, while the falling head test may require considerable time for testing. Also, the testing introduces water into the rock which may interfere with future sample collection.

## 4. Quality Control

- Ensure that all instruments (flow meters, pressure gauges, water level probes, transducers, etc.) are functioning and properly calibrated before starting and that all required information is recorded in the field.
- The manufacturer's recommendations for minimum packer inflation pressure and maximum injection pressure must be followed to ensure that leakage around packers and hydraulic fracturing of rock are minimized.
- The injection rods should be properly joined using Teflon® tape to prevent hydraulic leaks.
- Ensure that any material entering the borehole (packers, injection rods, water level probes and transducers) is clean. Materials must be fully decontaminated prior to use if working on a site where groundwater contamination may be present; a three-bucket rinse using a phosphate-free detergent solution, tap water and deionized water is recommended.
- Data must be collected at sufficiently frequent intervals. Pressure transducers may be required for permeable media and/or for low-permeability media requiring several hours to complete.
- Ensure that field notes and field forms are legible, recorded in ink where possible and complete.
- Retain all field notes to ensure information reported is accurate and defensible.

## 5. Recommended Equipment and Materials

Field equipment should include the following:

- Inflatable packer(s) (either pneumatic or mechanical),
- Perforated spacer rod for straddle zone tests,
- Metal rods for lowering packer(s) into position,
- Air supply,
- Hose,
- Clean Water supply,
- Pressure regulator and gauge for inflating pneumatic packers,
- Electric water level probe,
- Site plan and borehole logs if available,
- Watch, stopwatch or other device to record elapsed time during the test,
- Field book/forms to record test details and measurements,
- Decontamination equipment (i.e., three bucket rinse, phosphate-free detergent, tap water and deionized water) if working on a site where contaminated groundwater is known or suspected,
- Falling Head Test:
  - Pressure transducer or electronic water level probe of suitable diameter for inserting packer rods
- Constant head test:
  - Pressure gauge for measuring injection pressure or pressure transducer,
  - Flow rate measuring device (volumetric tank or flow meter); and,
  - Thermometer (thermistor).

## 6. Procedures

1) *Following drilling*, flush the borehole with clean water to remove cuttings. Allow water level to stabilize.
2) *Measure the depth to static water level* at the beginning of the day to provide an initial estimate of the well's

static water level for test calculation purposes.

3) *Record all required information* including the date, borehole location, borehole details, test interval and methodology in a field book or appropriate test form.
4) *Determine the Minimum Packer Inflation Pressure:* Lower the packers to the desired test depth and inflate to pressure $P = (1.42\frac{psi}{m}) \cdot d \cdot \sin\theta + 25psi$ where $d$ is the depth to the test interval in metres and $\vartheta$ is the inclination of the borehole to the horizontal (vertical = 90 degrees). This provides at least 25 psi inflation over static pressure.
5) *Monitor the water level in the rods three times over a ten minute period* to establish a trend in pre-test water levels. Record the time of each reading. Wait for the water level and/or pressure and temperature to equilibrate. This condition is referred to as "shut-in".
6) *Complete a Falling Head Test:* Rapidly fill the rods at time zero, then monitor water level versus time. Initial readings should be taken at 15 second intervals; subsequent measurements can be taken at longer time intervals if the drop in water level is slow. If time permits, monitor until 70% to 90% of recovery has taken place. If response is slow, monitor until a minimum of 30% recovery has occurred. If the test is monitored for less than 30% recovery, an accurate estimate of hydraulic conductivity cannot be made, but an upper bound of hydraulic conductivity can be provided.
7) *If the response of the water level was too rapid* to obtain at least three reliable readings prior to full recovery, a constant head test should be undertaken.
8) *Determine the Maximum Injection Pressure for the Constant Head Test:* The maximum injection pressure $P_{max}$ to be used in the constant head test is calculated using $P_{max} = (1.42\frac{psi}{m}) \cdot 1.5 \cdot d \cdot \sin\theta$ where $d$ is the distance in meters from the test interval to the pressure gauge location, measured along the borehole inclination $\vartheta$. Use of this maximum injection pressure ensures that pressures in the test zone will not exceed the effective stress at that depth.
9) *Complete the Constant Head Test:* Begin injecting clean water into the packer rods, venting as much air as possible. Set an initial injection pressure at the minimum pressure that can accurately be maintained and measured on the pressure gauge (typically 5 psi or if measurable 5% shut-in pressure). Maintain constant injection pressure for five minutes, then measure the injection rate over three successive time intervals. Time intervals should be a minimum of one minute, but may need to be longer for accurate flow measurement, depending on the measurement system and the flow rate. Continue injection until the injection rate is constant over three successive time intervals (i.e., when steady state conditions are achieved, typically less than 2 to 3% change over 2 to 3 minutes).
10) *Increase the injection pressure to approximately half way* between the initial and maximum injection pressures [($P_{max}$+5 psi)/2], then measure the new injection rate until a constant rate is measured over three successive time intervals.
11) *Increase the injection rate* to the maximum injection pressure $P_{max}$, then repeat step (10).
12) *Terminate the test*, decontaminate the equipment as required, and raise or lower the packer(s) to the next selected test interval (if applicable) and repeat.

## 7. References


1. Hvorslev, M.J., 1951. *Time Lag and Soil Permeability in Ground-Water Observations.* Bull. No. 36, Waterways Exper. Sta. Corps of Engrs, U.S. Army, Vicksburg, Mississippi, pp. 1-50.
2. ASTM D4630-96 (2008), Standard Test Method for Determining Transmissivity and Storage Coefficient of Low-Permeability Rocks by In Situ Measurements Using the Constant Head Injection Test, ASTM International (Withdrawn 2017), West Conshohocken, PA.
3. ASTM D4044 / D4044M-15, 2015. Standard Test Method for (Field Procedure) for Instantaneous Change in Head (Slug) Tests for Determining Hydraulic Properties of Aquifers, ASTM International, West Conshohocken, PA.
4. Doe, T., J. Osnes, M. Kenrick, J. Geier and S. Warner, 1987. "Design of well testing programs for waste disposal in crystalline rock." *Proceedings, 6th Congress of the International Society for Rock Mechanics*,

Montreal, Canada.

5. Priest S.D., 1993. *Discontinuity Analysis for Rock Engineering*, Chapman & Hall.

**Revision History: 0.0 (New document)**

**Approval**