

Sampling Method/Media: Constant Rate Pumping Test / Groundwater	Title: Standard Operating Procedure for Constant Rate Pumping Test
Revision No: Original Revision Date: 24 November, 2020	Reference No: SOP-E2-11 Parent Document: BC Field Sampling Manual – Part E2
1. Introduction and Scope This Standard Operating Procedure (SOP) provides operating guidelines and instruction for performing a constant rate pumping and recovery test. This SOP provides a field procedure for estimating hydraulic conductivity over a large area (i.e., within an aquifer) which can also be used to estimate hydrogeologic parameters such as storativity or specific yield, and aquifer boundary conditions. The procedures within this SOP are completed on water supply wells, dewatering wells, injection wells, and contaminant capture wells, and can also be applied to properly designed and developed monitoring wells. This SOP forms part of the British Columbia Field Sampling Manual (BCFSM). Additional information on constant rate pump testing is provided in Part E2 – Groundwater, which must be used in conjunction with the information provided in this SOP. Further information regarding monitoring wells and testing 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. Constant rate pump testing, sampling and monitoring conducted for regulatory purposes within the provincial jurisdiction of BC must be carried out with consideration to the WSA, the GPR, 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 Constant Rate Pump Testing A constant rate pump test is conducted by pumping a well at a constant rate while monitoring the drawdown occurring in the well and in nearby observation wells which are chosen based on aquifer properties and site-specific features. At the conclusion of pumping, the recovery of water levels is measured in the pumping well and the observation wells. Numerous analytical solutions are available to analyze both drawdown and recovery which can be used to provide estimates of transmissivity, specific yield (in unconfined conditions) and specific storage (in confined conditions). This test can be conducted using variable rates however, a constant rate is most commonly used and is the subject of this SOP. Pump tests provide estimates of hydraulic conductivity over a much larger aquifer volume than single well response tests. Hydraulic properties measured over greater spatial scales can differ by up to an order of magnitude or more, with pump tests commonly yielding the higher estimates as more preferential flowpaths are incorporated at larger scales and there is less susceptibility to skin effects or other well inefficiencies.	

4. Quality Control

- Ensure field 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. Re-check the equipment once in the field.
- Ensure that data logger records are complete and satisfactory before leaving for the field.
- All material entering the borehole (pumps, water level probes, and transducers) 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 a sufficiently long period of time (several hours for low-permeability media).
- Ensure that field notes (including appropriate 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:

- Control box and pump: usually provided by a Water Well Driller or Pump Contractor, the control box should ideally include a Variable Frequency Drive (VFD) to protect the pump from adverse motor conditions.
- Power supply and fuel: usually provided by a Water Well Driller or Pump Contractor, includes a generator, equipped with outlets that will allow the pump controller to be plugged in, and extra fuel for the generator if required. An electrician might be required.
- Water level kit: this may include a sonic well sounder, electric water level probe, or pressure transducer and barometric data logger (including direct read cables, laptop, required software, and aircraft cable and attachment).
- Discharge system: including adequate discharge piping, in-line flow meter and/or circular orifice weir, calibrated bucket (5 gallon) and stopwatch.
- Sampling kit: this may include flow-through cells, multi-parameter probe, laboratory supplied sample containers, filters, preservatives, Chain-of-Custody form and Custody Seals.
- 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.

6. Test Considerations

- 1) Store generator fuels in a safe location.
- 2) Pressure transducers while time-saving can make field practitioners complacent. The transducer should be tested and calibrated before the program. Software error, cable breakage, pressure sensor failure and drift, and sensor reader failure are common.
- 3) In-line flow meters and totalizers can become plugged with low amounts of sediment. If this occurs alternate flow rate measurement including orifice tube, weir box, calibrated buckets *etc.* will be needed.
- 4) If safe, ensure a sealed well has a vent so water level can respond to pumping, note that some wells are sealed for safety considerations, never attempt to vent a sealed well without the well operator on-site.
- 5) It may be necessary to have a water well installer present to adjust or repair pump equipment if it is damaged.

- 6) This SOP does not review methods to diagnose the type of well response from the constant rate drawdown data. A detailed review can be found in Renard et al. (2009).
- 7) The estimation of aquifer storativity from pumping well drawdown data can be influenced by parameters other than storativity and is therefore typically not reported.
- 8) Depending on the purpose of the test, and nature of test results a more complex analytical technique may be required to correctly analyze the data. Methods to complete more detailed analyses are contained in the references provided. Kruseman and de Ridder, 1992 provide particularly detailed methods for a range of settings.

7. Procedures

- 1) *Authorization:* Obtain authorization from the landowner for site access, if needed, as well as any temporary discharge permits if required. The following should be considered and decided on prior to arrival at the site:
 - a. test design and preparation,
 - b. equipment (including selection of pump and generator, pressure transducers with compatible rating with expected drawdown, water level probe),
 - c. test duration (generally between 1 and 72 hours, but longer is sometimes required),
 - d. discharge rate (typically the rate at which the well has been designed to pump during operations, or a rate determined during a step-drawdown test, if completed),
 - e. number of observation wells required including the distance from the test well,
 - f. estimate of the expected drawdown (ensure this does not dewater the aquifer/pump), estimated radius of influence (ensure observation wells if needed fall within this area, [see Equation 1 or 2 from Sara, 2003]).

Equation 1 (unconfined aquifer):
$$R = \sqrt{\frac{12t}{Sy}} \sqrt{\frac{QK}{\pi}}$$

Equation 2 (confined aquifer):
$$R = \sqrt{\frac{12t}{S}} \sqrt{\frac{QK}{\pi}}$$

Where:

R radius of influence (m),
t projected pumping time (s),
Q pumping rate (m³/s),
K hydraulic conductivity (m/s),
Sy specific yield (unitless); and,
S storativity (unitless)

- 2) *Well survey:* Measure the distance between the pumping well and observation wells to be used during the test. Confirm completion details and that well casing elevations have not been altered. A field survey of well locations and elevations may be required within a defined radius surrounding the test location, if available data is inadequate.
- 3) *Pretest Monitoring:* Measure the static water level in the pump well and any wells within the anticipated radius of influence that may be used as observation wells. If scheduling permits, this can be achieved by installing a pressure transducer in the test well(s) for a period of time prior to the pumping test (a few days is ideal but not mandatory). Monitoring of water levels located outside the radius of influence may be required in certain conditions to remove effects related to external factors during pumping.
- 4) *Test and synchronize water level transducers:* The transducers should be tested and all watches and

transducers should be synchronized.

- 5) *Install the pump and transducers:* For a confined aquifer, install the pump above the top of the screen or aquifer (whichever is shallower). For an unconfined aquifer, install the pump at 2/3 of the saturated depth (or shallower if local *regulations* require). For a shallow well, install the pump above the screen to maximize available drawdown during testing. Install a check valve on the discharge pipe above the pump. If the discharge line runs directly to a tank or stream ensure an air break exists so that a siphon is not created when the pump is shut down. Install a barometric data logger with the same measurement frequency. Barometric data loggers should be protected from wind and freezing conditions; ideally located in an uncapped observation well at a depth above the water level.
- 6) *Setup the discharge system:* Run the discharge line to the discharge location, install an in-line flow meter and totalizer (highly recommended). Make sure a gate valve (recommended) or ball valve is available to allow the control of discharge during the test by maintaining some back pressure on the discharge line. The discharge rate during the constant rate test should be maintained within $\pm 5\%$ of the target value. The discharge location should be approved, downgradient from the pumping well and at a suitable distance from the pumping well if the discharge may infiltrate back into a monitored unit during the test (i.e., unconfined shallow aquifers).
- 7) *Prepare field notes:* Using the Aquifer Test Field Form, make sure required well information and transducer information is recorded prior to starting the test.
- 8) *Begin the constant rate pumping test:* The test should be started at a defined time (e.g., 10:00 AM) so that all observations are relative to the same start time.
- 9) *Measure water level:* Collect manual water level measurements at the pumping well based on the time-frequency recommended in Table 1. Please note the times are for guidance only; more frequent measurements may be required depending on the setting. Manual water level measurements in observation wells should be made at a similar frequency however this may not be possible during the first 30 minutes of the test. Manual water levels should be measured in key wells, even if pressure transducers were installed, for backup data.

Table 1: Manual water level measurement frequency

Time duration after pump started/stopped (mins)	Monitoring frequency
0-10	Every minute
10-30	Every 5 mins
30-90	Every 30 mins
90-720 (12 hours)	Every 60 mins (1 hour)
720-1,440 (24 hours)	Every 120 mins (2 hours)
720-2,160 (36 hours)	Every 240 mins (4 hours)
2,160-2,880 (48 hours)	Every 360 mins (6 hours)
2,880-4,320 (72 hours)	Every 480 mins (8 hours)
After 4,320 minutes (72 hours)	Every 720 mins (12 hours)

- 10) *Measure and maintain discharge rate:* Fluctuations in discharge rates are most likely to occur at the start of the test when drawdown is rapid. Therefore, it is recommended to check the flow rate, and make adjustments if needed, once every ten minutes for the first 60 minutes of the pumping test. The discharge rate and total volume discharged should be recorded periodically through the remainder of the test.
- 11) *Confirm water quality parameters:* During the test, water quality parameters including pH, temperature, and electrical conductivity, at a minimum, should be monitored. Measurement of additional field parameters might be required depending on the site and the scope (e.g., chloride and turbidity are sometimes measured). If at any time the water quality parameters indicate the groundwater discharge does not meet local surface water quality requirements (i.e., pH or chloride are outside acceptable limits), the test may be required to stop.

12) *Obtain water samples:* Water quality sampling can be completed throughout the constant rate test and obtained using the following general procedure. The methodology, timing, number of samples to be taken, and required analyses is dependent on the scope and objective of the project. The collection of water samples from potable water wells is strictly regulated; therefore, the sampling method used should be consistent with those prescribed by the local regulator. Refer to the relevant SOP for detailed descriptions of how to obtain water samples for specific analyses.

13) Water samples should be collected as close to the pumping well as possible, preferably prior to any storage tank and treatment system. Adjacent to the wellhead would be ideal for sampling; however, this may not be possible depending on location, accessibility and age/state of pumping equipment. Although not ideal, other sampling locations may be at the base of the pressure tank or sink faucet. If the sample is acquired from a tap or hydrant, any aerator or filter should be removed and the orifice should be swabbed inside and out using a 70% ethanol solution.

The decision of when to collect a sample(s) can be based on time since pumping began, stabilization of groundwater parameters, or once a pre-determined well volume has been purged. The staff should confirm with the PM which method is appropriate dependent upon project objectives (e.g., health-based investigations are normally sampled as soon as pumping begins, whereas aquifer investigations may be sampled after a longer duration of pumping).

Once the pre-determined criteria for pumping duration have been fulfilled groundwater samples can be acquired. Representative groundwater samples should be collected in laboratory supplied bottles, filtered and preserved if required, kept cool and out of sunlight until they are delivered to an accredited laboratory within specified hold times.

Industry standard quality assurance and quality control (QA/QC) protocols should be utilized during water sampling. The number and type of QC samples submitted will depend on the QA/QC objectives of the project. A blind duplicate can be collected to demonstrate that competent sampling procedures were deployed and to gauge the accuracy of the analytical test's conducted on the sample. Other QC samples include trip blanks (handling), equipment blanks (equipment) and field blanks (atmospheric contamination). These blanks are analyzed to demonstrate that these sampling components did not influence the analytical results. At a minimum, 10% of the groundwater samples will include a blind duplicate.

14) *Recovery test:* Once the pumping test has been run to completion (reaches the required time limit) the pump is shut down and the recovery test begins. The water level recovery in the pumping and observation wells is monitored manually using the frequencies as described in Table 1. Again, manual water level records from observation wells during the first 30 minutes of recovery may not be possible. Water level recovery in the wells should be monitored manually and via transducers until (in order of preference); the water level in the source well recovers to 95% of the pretest level, or the same amount of time as the constant rate test was run (i.e., 24-hour pumping = 24-hour recovery), or to a time agreed upon by the client.

15) *Review the data:* Data should be reviewed prior to leaving the site to ensure it is sufficient.

8. References

1. Agarwal, R. G., 1980. A New Method to Account for Producing Time Effects when Drawdown Type Curves are Used to Analyze Pressure Build-up and Other Test Data. Presented at the 1980 Society of Petroleum Engineers Annual Technical Conference and Exhibition, Sept. 21-24, 1980, Dallas. SPE Paper 9289.
2. ASTM D4043-17, 2017. Standard Guide for Selection of Aquifer Test Method in Determining Hydraulic Properties by Well Techniques, ASTM International, West Conshohocken, PA.
3. Cooper, J.R. and Jacob, C.E., 1946. A Generalized Graphical Method for Evaluating Formation Constants and Summarizing Well-Field History. Trans. Amer. Geophys. Union, 27, pp. 526-534.

4. Hantush, M.S., 1964. Hydraulic in wells. In: V.T. Chow (editor). Advance in hydrosience, Vol. I pp. 281-432. Academic Press, New York and London.
5. Kruseman, G.P. and de Ridder, N.A., 1992. Analysis and Evaluation of Pumping Test Data, Second Edition, Publication 47, International Institute for Land Reclamation and Improvement, P.O. Box 45, 6700 AA Wageningen, The Netherlands.
6. Renard, P., Glenz, D., and Mejias, M., 2009. Understanding diagnostic plots for well-test interpretation. Hydrogeology Journal, 17: 589-600.
7. Sara, M.N., 2003. Site Assessment and Remediation Handbook 2nd ed., CRC Press.
8. Sterrett, R.J., 2007. Groundwater and Wells 3rd Edition. New Brighton. Minnesota: Johnson Screens, A Weatherford Company.
9. Theis, C.V., 1935. The relation between the Lowering of the Piezometric Surface and the Rate and Duration of Discharge of a Well using Groundwater Storage. Trans. Amer. Geophys. Union, 2, pp. 519-524.
10. Walton, W.C., 1962. Selected Analytical Methods for Well and Aquifer Evaluation. Illinois State Water Survey Bull., No. 49, 81 pp.
11. Weight, W.D., 2008. Hydrogeology Field Manual, Second Edition, McGraw-Hill Companies, Inc.

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Approval