CONTROLLED PUMPING TESTS

CONTENTS

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1.0 SCOPE AND APPLICATION

The most reliable and commonly used method of determining aquifer characteristics is by controlled aquifer pumping tests. Groundwater flow varies in space and time and depends on the hydraulic properties of the subsurface materials and the boundary conditions imposed on the groundwater system. Aquifer pumping tests provide results that are more representative of aquifer characteristics than those predicted by slug or bailer tests. Aquifer pumping tests, however, require a greater degree of activity and expense and are not always justified for all levels of investigation. As an example, slug tests may be acceptable at the reconnaissance level whereas aquifer pumping tests are usually performed as part of a feasibility study in support of designs for aquifer remediation.

Aquifer characteristics, which may be obtained from pumping tests, include hydraulic conductivity (K), transmissivity (T), specific yield (Sy) for unconfined aquifers, storage coefficient (S) for confined aquifers, and leakage coefficients if leaky confining beds are encountered. These parameters can be determined by graphical solutions and computer software programs. The purpose of this Standard Operating Procedure (SOP) is to outline the important considerations and protocol for conducting controlled aquifer pumping tests. Methods and analytical procedures used to process pumping test data begin with the selection of a conceptual model of the hydrogeological system. The choice of conceptual model and the type of testing that was performed determines which parameters will be estimated for the aquifer. The best approach is to select the simplest conceptual model that can be easily defended.

A Quality Assurance Project Plan (QAPP) in Uniform Federal Policy (UFP) format describing the project objectives must be prepared prior to deploying for a testing event. The field technician or field scientist needs to ensure that the methods used are adequate to satisfy the data quality objectives listed in the UFP-QAPP for a particular site.

The procedures in this SOP may be modified, dependent on site conditions, equipment limitations or other procedural limitations. In all instances, changes in the procedures employed must be documented on a Field Change Form and attached to the UFP-QAPP. These changes must be documented in the final deliverable.

2.0 METHOD SUMMARY

Adequate design and execution of an aquifer pumping test must involve considerable planning and attention to detail. The understanding of fundamental well hydraulics is necessary for a valid test design, and for the interpretation of data.

Prior to initiating an aquifer pumping test procedure, pre-pumping conditions need to be established. It is desirable to monitor pre-test (baseline) water levels at the test site for about one week prior to performing a pumping test. The baseline information allows for the determination of the barometric efficiency of the aquifer, as well as noting changes in head due to recharging or pumping in the area adjacent to the well. Prior to initiating an extended constant-rate pumping test, a step test is typically conducted to estimate the greatest flow rate that may be sustained by the pumping well.

After the pumping well has recovered from the step test and the predicted sustainable pumping rate has been identified, the constant-rate pumping test begins. At the beginning of the test, the discharge rate is set as quickly and accurately as possible. The water levels in the pumping well and any observation wells are recorded accordingly with a set schedule. Data are entered on the Pumping/Recovery Test Data Sheet (Appendix A) or stored on data-loggers for downloading to a computer. The duration of the test is determined by project needs and aquifer properties.

Following the pumping test, it is necessary to collect water level recovery measurements until the water level in the well has stabilized to at least 90 percent (%) of the pre-pumping level. Water level measurements can be collected indefinitely after the well has recovered to establish post-pumping baseline conditions. This is important if the pumping and recovery test extend beyond a week to establish long-term groundwater trends (i.e., is the water level trend rising or declining).

3.0 SAMPLE PRESERVATION, CONTAINERS, HANDLING, AND STORAGE

This section is not applicable to this SOP.

4.0 INTERFERENCES AND POTENTIAL PROBLEMS

Interferences and potential problems include atmospheric conditions, the impact of local potable wells, and compression of the aquifer due to trains, heavy traffic, etc.

5.0 EQUIPMENT/APPARATUS

The following equipment is required to perform a pump test:

- Fiberglass survey tape (subdivided into tenths of feet)
- Steel measuring tapes (subdivided into tenths of feet)
- Weighted tapes
- Submersible pump and control box
- Computer and pertinent software
- Submersible water pressure transducers with onboard data-loggers
- Water level indicators
- Barometric transducer or other recording instrument (for tests conducted in confined aquifers)
- Surface water and rainfall measuring devices
- Generator or other constant electrical power source
- Fuel container with fuel for the generator; on-site or delivered
- Electrical extension cords
- Heat shrink tubing
- Electrical tape
- Discharge pipe, hose, or tubing
- Foot-valve for discharge line (for recovery tests)
- Gate or globe valve, which is needed for step testing
- Flow meter
- 5-gallon bucket or 55-gallon steel drum (backup method for measuring flow; pumped water storage as needed)
- Water quality multi-parameter meter and calibration standards
- Flashlights and lanterns
- Watch or stopwatch with second hand
- Semi-log graph paper (if required)
- Water-proof ink pen and logbook
- Reference documents and calculator

6.0 REAGENTS

No chemical reagents are used for this procedure; however, decontamination solutions may be necessary. If decontamination of equipment is required, refer to the current version of ERT-PROC-2006 SOP, *Sampling Equipment Decontamination* and the site-specific UFP-QAPP.

7.0 PROCEDURES

7.1 Pumping Test Design

- The design of an aquifer pumping test depends on the hydrogeological environment and purpose of the test. The designer should determine pumping well location (areal and depth) and design, pumping rate, pump selection, location and depth of observation wells (well network), predicted test duration, discharge rate measurements and devices, water disposal or storage options, interval and method of water level measurements, and method of analyzing the collected test data.

- The duration of the test is determined by the needs of the project and properties of the aquifer. One simple test for determining adequacy of data is when the log-time versus drawdown for the most distant observation well begins to plot as a straight line on semi-log graph paper. There are several exceptions to this simple rule of thumb; therefore, it should be considered a minimum criterion. In general, longer tests produce results that are more definitive. A drawdown test duration of 24 to 72 hours is desirable, followed by a similar period of monitoring the recovery of water levels and if possible, extending the recovery period to collect post-pumping baseline data is recommended. Unconfined aquifers and partially penetrating wells may have shorter test durations. There is no need to continue the test if the water level becomes constant (asymptotic) with time. This normally indicates that a hydrogeologic boundary has been intercepted and that additional useful information will not be collected by continued pumping. It is important to remember that when plotting drawdown vs. time, delayed yield often occurs in unconfined aquifers.

- A pumping well should be located far enough away from hydraulic boundaries to permit recognition of drawdown trends before boundary conditions influence the data. To minimize the effect of stream, river or lake bed infiltration, it should be located at a distance equal to or exceeding the groundwater zone thickness from the possible boundary. However, if the intent is to induce recharge, then the pumping well should be located as close to the boundary as possible. The appropriate depth should be determined from exploratory boreholes or logs from nearby wells.

- The design of a pumping well depends on the hydrogeologic environment, the choice of conceptual model, and economics. Components to consider include well diameter, length and depth of the screened interval, and screen slot configuration.

- The pumping rate(s) should be sufficient to ensure the groundwater zone is stressed and that drawdown can be measured accurately. The water table in an unconfined zone **should not** be lowered by more than 25 %. This is the largest drawdown that can be corrected and analyzed with an analytical solution of the groundwater flow equation (Dawson and Istok, 1991). The pumping rate for tests conducted in confined zones should not readily dewater the pumping well. Well efficiency and an appropriate pumping rate for a constant discharge test can be determined by conducting a step-drawdown test.

7.2 Observation Wells

- Drawdown data can be recorded from both the pumping well and appropriately placed observation wells; however, the accuracy of the data taken from the pumping well is usually less reliable because of turbulence created by the pump. Thus, at least one observation well should be used when possible. Additionally, drawdown data from an observation well are required to accurately calculate the aquifer storage coefficient, whereas transmissivity values may be calculated on the basis of drawdown data taken from either the pumping well or observation well.

- Observation wells should be just large enough to allow accurate and rapid measurements of the water levels. Small-diameter wells are best because the volume of water contained in a large-diameter observation well may cause a time lag in drawdown changes particularly during the early stages of the test.

- When observation wells are too close to the pumping well, drawdown readings may be affected by the stratification of the aquifer. For unconfined aquifers, observation wells should be placed no farther than 50 to 300 feet from the pumping well. For thick confined aquifers that are considerably stratified (or fractured), observation wells should be placed within 300 to 700 feet of the pumping well. However, existing aquifer conditions may warrant the use of closer or more distant observation wells. Locating observation wells too far away from the pumping well is not a good practice because 1) the pumping test must be continued for a longer time period in order to produce sufficient drawdowns at the most distant points, and 2) small measurement errors may be a significant percentage of the total drawdown in the observation well. In addition, boundary effects may not be noticed.

- Screens for observation wells should typically be installed at approximately the same stratigraphic interval as the central portion of the screen in the pumping well. While fully-penetrating wells are generally desirable, most observation wells are constructed with screens ranging from five to 25 feet in length due to economics. Depending on the project's data quality objectives, the amount of funding available or the level of detail required, a number of additional observation wells can also be terminated in strata above or below the one tapped by the pumped well to assess if any hydraulic interconnection exists between the formations. Naturally, the response of these observation wells to pumping may be delayed significantly, depending on the degree of hydraulic connection.

- The appropriate number of observation wells depends upon the amount of information desired and upon the funds available for the test program. The data obtained by measuring the drawdown at a single location beyond the pumped well permit calculation of the average hydraulic conductivity, transmissivity, and storage coefficient of the aquifer. If two or more observation wells are placed at different distances, the test data can be analyzed by studying both the time-drawdown and the distance-drawdown relationships. Using both analytical methods provides greater assurance that the calculated transmissivity and storage coefficient values are correct. It is usually advantageous to have as many observation wells as conditions allow because the hydraulic conductivity may vary in one or more directions away from the pumping well (as can be the case for fractured bedrock formations). Observation wells placed in a circle or on different rays around the pumping well will reveal the directions of anisotropy.

7.3 Initial Preparation

1. Determine the extent of the testing effort, the testing methods to be employed, and the types and amounts of equipment and supplies needed.

2. Obtain necessary testing and monitoring equipment.

3. Decontaminate or pre-clean equipment and ensure that it is in working order.

4. Prepare scheduling and coordinate with staff, clients, and regulatory agency, if appropriate.

5. Perform a general site survey prior to site entry in accordance with the site-specific Health and Safety Plan (HASP).

6. Identify and mark all monitoring locations.

7.4 Field Preparation

1. Review the site work plan and UFP-QAPP, and become familiar with information on the wells to be tested.

2. Check and ensure the proper operation of all field equipment. Ensure the electronic data-logger(s) is fully charged, if appropriate. If multiple data loggers are used in a well network ensure each data logger is synchronized. Specialized transducers and computer software can be used to simplify the synchronization of the transducers. Test pressure transducers and the electronic data-logger using a container of water. Always bring additional transducers in case of malfunctions.

3. Assemble a sufficient number of Pumping/Recovery Test Datasheets (Figure 1, Appendix A) to complete the field assignment with spares.

4. The pumping well should be properly developed prior to testing per the current version of ERT-PROC-2045 SOP, *Monitoring Well Development*.

5. An orifice, weir, flow meter, container or other type of water measuring device to accurately measure and monitor the discharge from the pumping well will be used.

6. Sufficient pipe to transport the discharge from the pumping well to an area beyond the expected cone of depression is required. Water discharged during the pumping test must be conducted away from the pumping well in a downgradient direction and at a sufficient distance (300 to 600 feet away) to eliminate recharge of this water to the aquifer. If the aquifer is confined or if it can be otherwise demonstrated that discharged water will not recharge the aquifer being tested, a more convenient method of discharge can be used. If it is anticipated that discharged water will create flooding, erosion and/or turbidity, then the water must be directed to a holding area and released in a controlled manner to prevent such problems.

   Note: Conducting a pumping test in contaminated groundwater may require treatment, special handling, or a discharge permit before the water can be discharged.

7. The discharge pipe must have a gate valve to control the pumping rate.

8. Determine if there is an outlet or port near the wellhead for sampling and water quality determination (if required).

7.5 Pre-Test Monitoring

Water Levels and Barometric Pressure: It is necessary to monitor pre-test water levels at the test site prior to the performance of the aquifer stress test. One week of pre-test monitoring is suggested. This can be accomplished by using continuous-recording devices such as pressure transducers. This information allows the determination of the barometric efficiency of the aquifer when barometric records are available. The barometric efficiency of each well involved in the test should be determined if unvented pressure transducers are utilized. It also helps determine if the aquifer is experiencing an increase or decrease in head with time due to recharge or pumping in the nearby area, or diurnal effects of evapotranspiration. Changes in barometric pressure are recorded during the test (preferably with an on-site instrument) in order to correct water levels for any possible fluctuations, which may occur due to changing atmospheric conditions. Pre-test water level trends are projected for the duration of the test. These trends and/or barometric changes are used to "correct" water levels during the test so they are representative of the hydraulic response of the aquifer due to pumping of the test well.

Rainfall Measurements: Rainfall should be measured to the nearest 0.01 inch and recorded daily at or near the site for about one week preceding the pumping test, during the test, and during the recovery period. A log of weather conditions during this period should also be kept (e.g., barometric pressure recorded on the same schedule as rainfall). Weather station data available from within a reasonable distance of the test site can be utilized. Current year precipitation records should be compared to historic precipitation in order to determine if conditions at the time of the pumping test are wetter or drier than normal.

Surface Water Measurements: Fluctuations in surface water stages (or stream flow) for all surface waters within 500 feet of the pumping well should be measured to the nearest 0.01 foot. Weirs, staff gages, stilling wells, nested piezometers, etc. can be used for obtaining measurements. Weir flow or similar measurements should be conducted for small streams. The vertical elevation of a fixed reference point on each observation well should be established to the nearest 0.01 foot. Measurements from nearby surface water bodies should be obtained and recorded at least once daily for about one week prior to the start of the test and at least twice per log cycle after the first ten minutes of the test, for the duration of the test. Measurements should be made more frequently if surface water levels are changing rapidly. If tidal influence is suspected, the measurements should be recorded every 15 minutes for one week prior to the start of the test. The degree and nature of hydraulic connection with any surface water bodies must be quantified.

Survey Locations
Survey the horizontal distance between each observation point (e.g., pumping and observation wells, stream gage, weir, etc.) and the pumping well should be measured to the nearest 0.1 foot.

7.6 Single Well Pumping Tests

A single well test involves pumping at a 'variable' or 'constant' rate and measuring changes in water levels in the pumped well during pumping and recovery. Single well pumping tests can be used to determine transmissivity, hydraulic conductivity, and yield of a groundwater zone. They are also conducted to determine well loss and optimizing pumping rate and pump setting for multi-well constant-rate tests. Single well tests are often used when water level recovery is too rapid for slug tests and no observation wells or piezometers are available. Single well tests generally will not identify impermeable boundaries, recharge boundaries, or interconnection between other groundwater/surface water sources unless these conditions exist in very close proximity to the well being tested.

7.7 Step Tests

A step test or step drawdown test is a type of single well test that is used to establish the short-term relationship between yield and drawdown for the well being tested. It consists of pumping the well in a sequence of different (variable) pumping rates, for relatively short periods (the whole sequence can usually be completed in a day). There are many different ways to perform a step test, but the most common practice is as follows:

- Start with a low pumping rate and increase the rate with each successive step, without switching off the pump between steps.
- Aim for four or five steps in total, with the pumping rates roughly spread equally between the minimum and maximum rates.
- All steps should be of the same length in time. The duration of each step generally should be a minimum of 60 minutes and should be long enough such that drawdown vs. time data, as plotted on semi-logarithmic paper (with time on the log scale), falls on a straight line. Common step periods range between 60 and 120 minutes.
- The pumping rate for the final step should be at or beyond the intended operational pumping rate when the well is fully operational. Of course, this depends on whether the pump being used for the step test is capable of that pumping rate.

Setting Pumping Rates: On the day before the step test, experiment with different valve settings that will produce the required pumping rates for each step. Manually-operated gate or globe valves are commonly used, and these are operated by a screw handle. Fully close the valve and then open it to the fully open position, counting the number of turns of the handle that are made between fully closed and fully open. Experiment with opening the valve with different numbers of turns (from the fully closed position) to achieve the different pumping rates for the steps and make a note of the results.

Step Test Procedure: Assuming the water level in the well is at rest (or static), all equipment is ready, and people have been assigned their tasks, the procedure for conducting a step test is as follows:

1. Open the valve to the setting for the first step (determined by prior experiment, as described above) and switch the pump on, starting a stopwatch at the same time (note: there will be a slight lag until the pump reaches full power). Do not keep changing the valve setting to achieve a particular pumping rate (e.g., a round number). Rather, aim for an approximate rate and measure the actual rate.

2. Measure the water level in the well every 30 seconds for the first 10 minutes, then every minute until 30 minutes have elapsed, then every 5 minutes until the end of the step (the length of each step having been decided during the test preparations). If a planned time for a water level

reading is missed, then write down the actual time the reading was taken. Record all the readings and times in a logbook or on a standard form.

Manual measurements of water levels will be in accordance with ERT-PROC-2043 SOP, *Manual Fluid Level Measurements.* Alternatively, if a pressure transducer (with data logging capability) is used to record water levels, then set the measurement schedule to "log" mode (measurements are very closely spaced at the start of the test and get further apart on a logarithmically decaying schedule as the test progresses).

3. Measure the pumping rate soon after the start of the step, and then at intervals during the step (every 15 minutes is reasonable). If there is a noticeable change in the rate of increase of drawdown or if the pump sounds different, then measure the pumping rate at those times as well. If the pumping rate changes significantly (by more than 10%), then adjust the valve setting to maintain as steady a pumping rate as possible throughout the step. Be careful not to overcompensate the valve adjustments.

4. At the end of Step 1, open the valve further, to the setting for Step 2. Note the time (or restart the stopwatch) and repeat the procedures for measuring water levels and pumping rates as stated above in paragraphs numbered 2 and 3).

5. Repeat the procedure for subsequent steps, progressively increasing the pumping rate for each step.

6. At the end of the final step, switch the pump off, note the time (or restart the stopwatch), and measure the water-level recovery at the same measurement intervals as for measuring the drawdown in each step (see paragraph numbered 2). Continue for at least the length of one step, and ideally for much longer, until the water-level approaches the pre-test level.

References detailing the mechanics of step tests include Kruseman and de Ridder (2000), Driscoll (1986), Dawson and Istok (1991), and Batu (1998). Refer to Section 12.0 of this SOP for these references.

7.8 Constant-Rate Tests

Constant-rate tests can involve either a single well (i.e., the pumping well) or multiple wells (pumping well with observation wells). The procedures for carrying out a constant-rate test are very similar to a step test, except that only one pumping rate is used during a constant-rate test.

- Before the test begins, verify that water levels in the pumping well and near-field observation wells (if any) are static.

- At the beginning of the test, set the discharge as quickly and accurately as possible. Ideally, the pumping rate during the test should not vary by more than 5%.

- If water levels are recorded manually in the pumping well and observation wells, they should be collected according to the following schedules:

TABLE 1. Time Intervals for Measuring Drawdown in the Pumping Well

Elapsed Time Since Start or Stop of Test (Minutes)	Interval Between Measurements (Minutes)
0-10	0.5-1.0
10-15	1
15-60	5
60-300	30
300-1440	60
1440-termination	480

TABLE 2. Time Intervals for Measuring Drawdown in Observation Wells

Elapsed Time Since Start or Stop of Test (Minutes)	Interval Between Measurements (Minutes)
0-60	2
60-120	5
120-240	10
240-360	30
300-1440	60
1440-termination	480

Alternatively, if pressure transducers (with data logging capability) are used to record water levels, then all should be set to begin recording at the same time (i.e., when the pump is turned on). The same measurement schedule should be applied to all transducers (set to "log" mode). Ideally, the pre-test monitoring would be followed by a step drawdown test, followed by the constant flow rate aquifer pumping test. The transducers should record the entire series of events.

- During a pumping test, the following data must be recorded accurately on the test data form (Appendix A):

  - Site ID - A number assigned to identify a specific site.

  - Well ID - Identification or location of the well in which water level measurements are being taken.

  - Distance from Pumped Well - Distance of the observation well from the pumping well (feet).

  - Logger - The name of the company conducting the pumping test (if a subcontractor is used).

  - Test Start Date - The date when the pumping test began.

  - Test Start Time - Start time, using a 24-hour clock.

  - Static Water Level (Test Start) - Depth to water, in feet and tenths of feet, in the pumping well and observation wells at the beginning of the pumping test.

- Elapsed Time (min) - Time of measurement record, continuously from time 0.00 (start of test), recorded in minutes.

- Depth to Water (ft.) - Depth to water, in feet and tenths of feet, in the pumping well and observation wells at the time of the water level measurement (Tables 1 and 2).

- Pumping Rate (gal/min) - The flow rate as measured from an orifice, weir, flow meter, container or other type of water measuring device.

- Test End Date - The date when the pumping test was completed.

- Test End Time - End time, using a 24-hour clock.

- Static Water Level (Test End) - Depth to water, in feet and tenths of feet, in the pumping well and observation wells at the end of the pumping test.

- Average Pumping Rate - Summation of all entries recorded in the Pumping Rate (gal/min) column divided by the total number of Pumping Rate (gal/min) readings.

- Measurement Methods - Type of instrument used to measure depth-to-water (this may include electric water level indicators, pressure transducers, etc.).

- Comments - Appropriate observations or information that has not been recorded elsewhere, including notes on sampling.

If there is a problem during the test, such as an interruption to the power supply or a pump failure, then use judgment, depending on when the problem occurs and how long it is likely to last. For example, if something goes wrong in the first few minutes, wait for the water level to recover and start again. If the failure occurs well into the test and can be solved quickly, just restart the pump and carry on. If it is going to take a long time to solve, it may be better to allow full recovery of the water level (or levels) and start again. For long constant-rate tests, it is especially important to ensure there is an adequate fuel supply for the generators to last the planned duration of the test.

7.9 Recovery Tests

The recovery (or residual drawdown) test is not strictly a pumping test because it involves monitoring the recovery of the water level after the pump has been switched off. This test has already been referenced in the final stages of the procedures for undertaking step tests and constant-rate tests. A section has been devoted to recovery tests because recovery data are not always given the attention they deserve.

Recovery tests are valuable for a number of reasons:

- For very little extra effort, they provide a useful check on the aquifer characteristics derived from pumping tests (i.e., just extending the monitoring period after the pump has been switched off).

- The start of the test is relatively ‘clean’. In practice, the start of a constant-rate test, for example, rarely achieves a clean jump from no pumping to the chosen pumping rate.

- Similarly, recovery tests smooth out small changes in the pumping rate that occurred during the pumping phase, and there is no problem with well losses from turbulent flow. This results in more reliable estimates of aquifer properties when the recovery data are analyzed.

- Recovery tests represent a good option for testing operational wells that have already been pumping at a constant-rate for extended periods. In these cases, the recovery test can be performed when the pumps are first switched off, followed by a constant discharge test when the pumps are switched back on again.

Ideally, the duration of the recovery test should be as long as is necessary for the water to return to its original level, which, theoretically, would be as long as the duration of the pumping phase of the test program. In practice, however, the recovery test is often shorter, partly for reasons of cost. It should not be too short however, because as described in relation to the constant-rate test, the data from the early part of the test are affected by well storage. If the data from the constant-rate test have been roughly plotted in the field on semi-log graph paper, this will give some idea of the length of time before the data become useful for calculating transmissivity (i.e., when it falls on a straight line).

The pump should not be removed from the borehole while the recovery test is taking place, because the sudden removal of the submerged volume of the pump and discharge pipe will cause a sudden change in the water level in the well. For a similar reason, there must be a non-return valve (i.e., check or foot-valve) at the base of the discharge pipe, near the pump. In the absence of a foot-valve, when the pump is switched off, water within the pipe will flow back down into the well, causing a sudden change in the water level. Unless the foot-valve can be opened from the surface, the discharge pipe will be full of water, and therefore heavy, when it is removed from the well. Thus, it may not always be practical to carry out a recovery test. Note: A separate cord or cable should be attached to the pump in the event that it becomes detached from the discharge pipe during removal from the well.

Recovery Test Procedure: The procedure for undertaking a recovery test is as follows:

1. Switch the pump off and start a stopwatch at the same time.

2. Measure water levels in the pumping well and any observation wells or the same schedule as for the start of the constant-rate test (Table 1 and 2). Alternatively, if pressure transducers (with data logging capability) are used to record water levels, then all should be set to begin recording at the same time (i.e., when the pump is shut off). The same measurement schedule should be applied to all transducers (set to "log" mode).

7.10 Post-Test Operation

The following activities shall be performed after completion of testing activities:

1. Decontaminate and/or dispose of equipment as per the current version of ERT-PROC-2006 SOP, *Sampling Equipment Decontamination*.

2. When using an electronic data-logger, use the following procedures.

- Stop logging sequence.
- Print and/or save data and disconnect battery at the end of the day's activities.

3. Replace testing equipment in storage containers.

4. Check sampling equipment and supplies. Repair or replace all broken or damaged equipment.

5. Review field forms for completeness.

6. Interpret pumping/recovery test field results.

7.11 Common Mistakes

The most common mistakes associated with controlled pumping tests include the following:

- Not finding out in advance whether there is access through the wellhead for the monitoring equipment or for a temporary pump. If a pumping well is constructed specifically for the test, a separate small diameter spy (or witness) well should be installed outside the pumping well within the same borehole.

- Choosing the wrong-sized pump for the test. Too small, and it may not be capable of imposing sufficient drawdown. Too big, and the pump may run dry.

- Not installing the pump deep enough in the well so that the pump runs dry before the test is finished. (Note: submersible pumps require upward vertical flow in the casing to cool the motor; therefore, it is desirable to set the pump above the well screen. If the submersible pump is set within the screen interval a pump shroud or a pump with a short motor that does not require a shroud is recommended).

- Installing the pump too deep in the well so that there is insufficient space between the pump intake and the base of the borehole.

- Insufficient fuel available (if a generator is being used) so that the test is interrupted.

- No spare batteries for the water level indicators and other monitoring equipment.

- Not performing an initial step test.

- Discharging water too close to the well being tested so that it recirculates back into the well.

- Not performing pre-test monitoring. (Water levels being influenced by other abstractions, tides, or heavy rainfall during the test, making test interpretation very difficult.)

- Conducting the test at the wrong time of year (conditions too wet or too dry).

- Different people using different measuring datum so that water-level results are not consistent.

- Forgetting to bring essential equipment to a remote site or taking equipment that has not been tested or is not functioning correctly.

- Not familiarizing oneself with the equipment in advance (not knowing how to operate it correctly).
- No foot-valve installed at the base of the discharge pipe or line, thus affecting the recovery-test results.

7.12 Pumping Test Selection

A guide for selecting pumping tests is summarized in Table 3, below. The table gathers all the important information in one place and thus serves as a quick reference guide.

TABLE 3. Guide for Selecting Pumping Tests

Type of Test	Parameters Derived from Test	Typical Duration	Test Limitations
Step Test	• Specific drawdown. • Specific capacity. • Qualitative assessment of well performance (yield vs. drawdown). • Pumping rate for constant-rate test.	1 day	• Must be able to vary the pumping rate. • Not very good at predicting long-term aquifer behavior.
Constant-Rate Test (single & multi-well)	• Aquifer transmissivity. • Specific yield or storage coefficient, if observation wells are used. • Qualitative assessment of ability to maintain the planned yield.	From 1 or 2 days up to 1 or 2 weeks. 3 days is typical.	• Difficult to keep the pumping rate constant. • Aquifer parameters may be different in wet season compared to dry season. • Must have a good discharge system.
Recovery Test	• Aquifer transmissivity. • Qualitative assessment of well losses (related to well efficiency).	Several hours to several days.	• A foot-valve must be fitted to the base of the main riser pipe. • Pump cannot be removed during the test.

7.13 Presentation of Pumping Test Data

The guidelines below recommend the minimum criteria (where applicable) for how pumping test data should be compiled, presented, and summarized to document that the hydraulic properties of the zone(s) of interest have been adequately determined.

- Preliminary evaluation of hydrogeologic conditions, including all data used to plan and design the test.
- Summary of the design and implementation of the pumping tests including, but not limited to:
    - Hydrogeologic zone into which the pumping well is completed (i.e. areal extent, thickness, lateral and vertical extent).

- Pumping well construction (justification should be provided if the well screen is partially penetrating).
- Duration of pumping.
- Rate of pumping and method for determination.
- Location of all observation wells.
- Hydrogeologic zone(s) to be monitored (including depths, thickness, and spatial relationship to the pumped zone).
- Observation and pumping well construction.
- Method of water level measurements (for each well).
- Methods for gathering data used to correct drawdown and establishment of existing trends in water levels.
- Procedures for the discharge and disposal (if necessary) of pumped water.
- Date and time pumping began and ended.

- Raw data, including water level measurements, time of measurement in minutes after pumping started or ended, drawdown, pumping rates, etc. should be included in tabular form. All data should be expressed in consistent units. Water levels in nearby surface water bodies should also be provided, if taken. If the data set is large, it may be provided on a compact disc (CD).

- Data plots (e.g., time versus [vs.] drawdown, distance vs. drawdown, discharge vs. time, etc.)

- Calculations: equations used for calculating hydraulic properties, etc.

- In the event that any hydraulic boundaries are encountered by the cone of depression during the test, the documentation should contain 1) a reference to the data plot on which the boundary's impact can be observed, 2) identification of the type of boundary, and 3) a discussion addressing the boundary's effect on the hydraulics at the site. For pumping wells, an evaluation of casing storage effects should be included.

- Comments, noting any external events (e.g., change in weather patterns, passage of train or heavy machinery). In the event that drawdown data need adjustment due to external effects or reduction in saturated thickness, separate data plots depicting both adjusted and unadjusted drawdown versus time and versus distance should be presented for the appropriate wells. Any plots, graphs, or equations used to determine the magnitude of drawdown adjustment should also be presented.

- Data analysis methods and/or programs, including assumptions, limitations and their applicability to the site.

- Interpretation of the data using both results of the test and other available hydrogeologic information.

8.0 CALCULATIONS

8.1 Data Corrections

Water level data, graphs, and interpretations must be corrected or evaluated as appropriate for the following:

- Decreases in saturated thickness (unconfined aquifers)
- Aquitard compression (Noordbergum effect: temporary water level increases in monitored zones above the pumping zone)
- Barometric pressure changes
- Partially penetrating production and observation wells
- Well (or borehole) efficiency
- Effects of ambient water level trends
- Delayed aquifer yield or storage release
- Recharge and/or impermeable boundaries
- Tidal, river level or surface loading changes
- Recharge events (rainfall, snow melt) during the week preceding the test, during the test, or during the recovery period
- Influence from nearby pumping wells
- Any other unaccounted-for hydrogeologic conditions

The combined references listed at the end of this document cover all of the above.

8.2 Analysis Methods

Many methods (e.g., Theis, Cooper-Jacob, etc.) and computer software programs exist for interpreting multiple well pumping test data. The hydraulic properties computed by a particular method can only be considered correct if the assumptions included in the conceptual model on which the method is based are valid for the particular system being tested. Because the computed values depend on the choice of conceptual model used to analyze the data, the selection of an appropriate model is the single most important step in analysis.

It is beyond the scope of this document to detail or discuss the various methods. ASTM Method D4043-96 (2010) and Ohio EPA (2006) provide useful information for proper selection of appropriate methods. Additional information on aquifer analysis methods and/or programs can be found in Batu (1998), Dawson and Istok (1991), and Kruseman and de Ridder (2000).

Data collected during a pumping test are subject to a variety of circumstances that may be recognized in the field or may not be apparent until data analysis has begun. In either case, all information (including field observations) must be examined during data correlation and analysis.

9.0 QUALITY ASSURANCE/QUALITY CONTROL

All gauges, transducers, flow meters, and other equipment used in conducting pumping tests will be calibrated before use at the site. Copies of the documentation of instrumentation calibration must be obtained and filed with the test data records. The calibration records will consist of laboratory measurements and, if necessary, any on-site zero adjustment and/or calibration will be performed. Where possible, all flow and measurement meters will be checked on-site using a container of measured volume and stopwatch; the accuracy of the meters must be verified before testing proceeds. Records must be maintained, documenting the level of competency for the Contractor’s personnel who will conduct the testing.

10.0 DATA VALIDATION

Data verification (completeness checks) must be conducted to ensure that all data inputs are present for ensuring the availability of sufficient information. This may include but is not limited to Site ID, Well ID, distance from pumped well, start and end dates and times, depth to water measurements, type of equipment used (measurement methods), pumping rates, etc. These data are essential to providing an accurate and complete final deliverable. The contractor's Task Leader (TL) is responsible for completing the UFP-QAPP verification checklist for each project.

11.0 HEALTH AND SAFETY

Based on Occupational Safety and Health Administration (OSHA) requirements, a site-specific health and safety plan (HASP) must be prepared for response operations under the Hazardous Waste Operations and Emergency Response (HAZWOPER) standard, 29 CFR 1910.120. Field personnel working for EPA's Environmental Response Team (ERT) should consult the Emergency Responder Health and Safety Manual currently located at https://response.epa.gov/_HealthSafetyManual/manual-index.htm for the development of the HASP, required personal protective equipment (PPE) and respiratory protection.

12.0 REFERENCES

American Society for Testing and Materials (ASTM), 2010. Method D4043-96 (2010): Standard Guide for the Selection of Aquifer-Test Methods in Determining the Hydraulic Properties by Well Techniques.

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Bureau of Reclamation. 1985. Ground Water Manual. U.S. Department of the Interior.

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13.0 APPENDIX

A – Pumping Recovery Test Datasheet

APPENDIX A
Pumping/Recovery Test Datasheet
SOP: ERT-PROC-2045-20
January 2020

FIGURE 1. Example Pumping/Recovery Test Datasheet

SITE ID: ________________________ DISTANCE FROM PUMPED WELL (FT): __________

WELL ID: _______________________ LOGGER: ___________________

PUMP SPECIFICATIONS: ____
PUMP MANUFACTURER & MODEL #: ____
DISCHARGE LINE SPECIFICATIONS (type and diameter): ___________________________________

TEST START

DATE: ____________
TIME: ____________
STATIC WATER LEVEL (FT): _____

TEST END

DATE: ______________
TIME: ______________
STATIC WATER LEVEL (FT): _____

AVERAGE PUMPING RATE (GAL/MIN _____________________
MEASUREMENT METHODS ______________________________
COMMENTS ____
____

ELAPSED TIME (MIN)	PUMP TEST DEPTH TO WATER (FT)	PUMPING RATE (GAL/MIN)	RECOVERY TEST ELAPSED TIME (MIN)	DEPTH TO WATER (FT)	COMMENTS