Some Domestic Well Yield Testing Methods

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Background: There are several methods for testing domestic water wells to determine the potential yield. Three of the more common methods in the Appalachian Region are the specific capacity, well recovery and the peak demand tests. Specific capacity and well recovery are science-based tests. Whereas, the peak demand test is more subjective. The peak demand test is frequently employed by lending institutions to determine if the entire water delivery system yields the minimal amount of water to sustain an occupied dwelling. While there is likely no consensus as to which method is the best for determining yield, ground-water scientists generally prefer specific capacity and/or well recovery methods.

The importance of determining well yield with respect to surface and underground mining operations is fairly self explanatory. If mining activities adversely impact the yield of a domestic-use well, then the mine operator is accountable to rectify the situation. There needs to be an objective means by which to determine if the yield of a well has been adversely affected. There also needs to be a method by which the yield of the replacement well can be compared to the pre-mining well yield rate to determine if the replacement supply is equivalent (30 CFR § 701.5). Conventional pumping and slug tests cannot be used, because they are designed to estimate the properties of the aquifer itself (i.e. transmissivity, hydraulic conductivity, etc.), not the well yield.

Specific Capacity Test: The specific capacity of a well is given in normalized units of gallons per minute per foot of drawdown (gpm/ft). In other words, the average yield rate of the well is divided by the change in water level for the time period of pumping.

A variable-speed pump works best for this type of test. However, in many cases the existing well pump has to be used. Existing pumps are usually directly wired to a pressure-activated on-off switch, so the pump may cycle on and off during the test. In cases where the existing pump is used, it is best to discharge water from an access point (valve) as close to the holding tank as practicable and use the spigot to regulate the flow rate. If at all possible, bypass the holding tank and/or the pressure switch altogether. If the pressure on-off switch cannot be avoided, it is recommended that the test be run longer than the 1 to 2 hours recommended below (3 to 4 hours is suggested). This will allow a better averaging of the pumping rate over a longer time period.

For wells used in single family dwellings, specific capacity tests are generally performed for a minimum of 1 to 2 hours, but tests tend to run much longer (e.g. 24 hours or more) for larger wells used for several homes or small municipalities. The well is pumped at a constant rate throughout the test. In the common low-yielding wells of the Appalachian Plateau (less than 5 gallons per minute (gpm)) it is suggested to pump at two to three gpm. If you have some previous knowledge of the well’s yield potential, you should adjust your pumping rate up or down accordingly. The pumping rate must be checked and recorded repeatedly throughout the test (a bucket and stopwatch works best) to insure a consistent rate as possible is maintained. Average pumping rate will need to be determined from those data. Be sure to discharge the water far enough away from the wellhead to preclude recycling (artificial recharge) of the water back to the well during the test.

It is extremely important that the water level drawdown in the well stabilizes during pumping for the test to be truly accurate. The water level is measured initially and at frequent intervals throughout the test. A pressure transducer with data logger or an electric tape work well to monitor the water level.

Testing and analysis is generally performed as follows:

1. A pump is placed into the well (if one is not already there).
2. The pre-testing water level is measured and recorded after the water level has stabilized from the pump introduction.
3. Record the time and start the pump.
4. Measure the pumping rate and quickly adjust the rate if needed.
5. Continue to measure the pumping rate throughout the test. Remember, when the water level is drawn down, the pumping rate will decrease because the pump has to overcome a greater head. So, the pump speed, if using a variable-speed pump, will have to be increased or the regulating valve, when using the existing well pump, may need to be opened up more to compensate.
6. Start out measuring water levels every minute or less. The water level recording intervals may expand to perhaps every five or more minutes as the test continues, if the water level remains fairly stable.
7. As previously stated, for many single-dwelling domestic wells the test should be run for no less than 1 to 2 hours. It is recommended that the test continue for at least one hour after the water level stabilizes.
8. Two people can conduct these tests, but they go more smoothly with three.

Once the test is completed, the data are analyzed to determine the well yield.

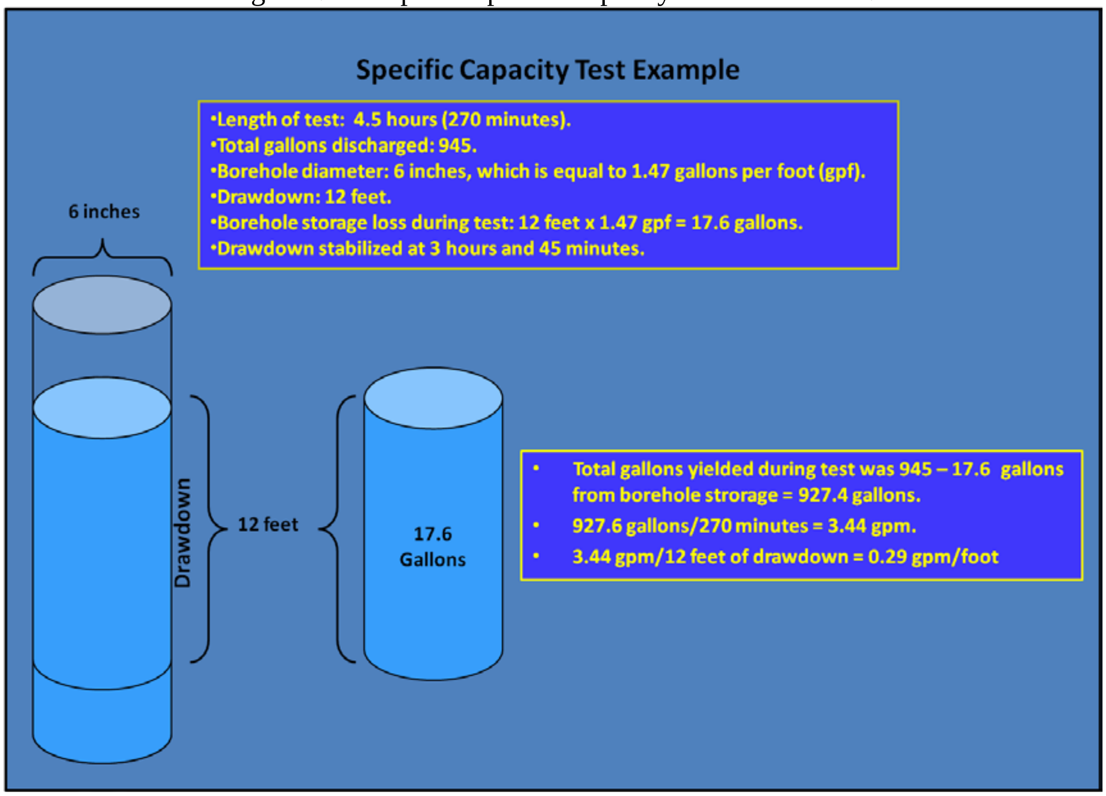
1. The pumping rate is multiplied times the total time pumped to determine the total gallons pumped.
2. The amount of stored water that was removed from the well bore storage (water column) needs to be determined. This value is determined by multiplying the water level change during pumping (say in feet) times the volume of the well bore per linear foot. For example, a 6-inch well has about 1.5 gallons per linear foot of well (Table 1). So, a 10 foot water level change equals 15 gallons. See Figure 1 for an example of this calculation.
3. The amount of water removed from well bore storage (from Step 2) is subtracted from the total gallons pumped (from Step 1). This value will give you the amount of water that the well actually produced during the test.
4. Now divide the resulting number from Step 3 by the total pumping time. To obtain the actual well yield in gallons per minute.
5. Divide the result from Step 4 by the stabilized drawdown measurement to obtain well yield in gallons per minute per foot of drawdown.

Division of the drawdown into the pumping rate normalizes the result and permits comparison from test to test on that well or between wells (e.g., original well and a replacement well). For example, if you pump a well one time at 3 gpm for 2 hours and another time 5 gpm for 90 minutes, <u>theoretically</u> you should end up with a similar specific capacity value for both even though the pumping rates and drawdowns may differ. Otherwise, if you simply pump the well at 3 gpm or 5 gpm and do not measure drawdown, all you know is that the pump, plumbing system and well are capable of 3 gpm or 5 gpm for the time period that you pumped.

As the head difference between the well and the adjacent aquifer becomes larger, the inflow increases in a logarithmic (Darcian) manner. A specific capacity test should be conducted to a point where the drawdown stabilizes. In other words, the ground water inflow rate equals the withdrawal rate by pumping. Therefore, do not pump the well at a rate that exceeds its total yield or it will eventually be dewatered. Be careful not to allow the well to be dewatered during the test because this means the drawdown never came to equilibrium and therefore a true specific capacity estimate cannot be made. However, if you accidentally dewater the well you can still conduct a well recovery test (discussed below).

Ideally, when you determine specific capacity you should compare similar pumping periods and similar rates. It is possible, but not always advisable, to compare the first hour of a 2-hour test to a similar 1-hour test performed at another time. Bear in mind that Risser (2010) observed that different pumping rates or pumping durations as well as a change in the saturated thickness "can have a substantial effect on the comparability of repeated tests."

Figure1. Example of specific capacity test calculations.



In the Appalachian Region most ground-water flow is through fairly shallow fractures (less than 200' from the surface) and the deeper you go the less transmissive the fractures are and less fractures exist. So testing a well in the dry season when the water table is naturally low will likely show a lower well yield than during the wet season when the water levels are elevated. This is because during the dry season test the well accesses mainly less transmissive deeper fractures and there is in general less accessible stored ground water. The wet season test will also utilize the more common shallow transmissive fractures and there is more stored ground water available. So, if you only have one background test, it is best if you retest the well under similar climatic and hydrologic conditions. Compare apples to apples!

Well Recovery Test: Monitoring of the water level recovery after pumping also can be used to estimate the well yield. While the yield from a recovery test may be compared to the yield during pumping, it is best to use the recovery test yield rates to compare to the rates from previous recovery tests. It should be noted that the recovery yield rate tends to decrease logarithmically as the water level rises because the decreasing difference in head between the well and the adjacent aquifer. However, in fractured rock aquifers as seen in the Appalachian region, there usually is an early period during the recovery where the water-level recovery is a straight line because most of the inflow is from discrete exposed fractures discharging freely above the water level. The well yield may be estimated from this straight-line portion of the graph.

A recovery test is fairly simple to conduct. A well is pumped down a substantial distance from the initial static water level and then water level recovery is monitored and timed. Often if a well is drawn down significantly during a specific capacity test, a well recovery test can be conducted immediately afterward, once the pump is shut off. The procedure for this test is generally as follows:

1. Pump the well down fairly rapidly.
2. Shut the pump off and record the time.
3. Immediately measure the water level.
4. Continue to measure the water level at frequent intervals recording the time for each measurement. At first, the water levels should be measured at intervals as often as can be physically done. Water levels should be recorded at no less than one minute intervals initially. Later, if the rate of recovery slows, the interval between readings can be lengthened to five minutes or perhaps longer depending on conditions. Use your best professional judgment.
5. It is recommended that the recovery test be continued until the well has recovered at least 90% of the original water level.
6. Determine the volume in gallons per foot of well bore based on the well diameter (Table 1). Multiply the gallons per foot of well bore times the footage of water level rebound during the recovery. Then divide the result by the time of this recovery to a yield estimated rate of gallons per minute.

Caveat: Be careful that the pump that you are using has a functioning foot-valve. Otherwise the water in the piping from the pump may back drain into the well. This would cause the false (too high) recovery rate. If there is no foot valve on the pump, you need to calculate the well recovery rate using data starting after the piping has completely back drained.

It is also generally wise to not continue the test for an extended period in order to allow the water level to recover all the way back to the initial setting. It may take a very long time to return to the pretesting level and this will likely make the well yield rate appear much lower than it actually is.

Peak Demand Test: Lending institutions generally require well-yield testing to illustrate that the water supply yields a sufficient amount of water to the dwelling prior to approving a loan. Peak demand testing is predicated on the premise that if the well and delivery system provide enough water during peak use periods, they will also yield sufficient water the remainder of the time. Peak demand testing determines not only the yield of the well but also includes storage within the borehole and holding tank as well as the pump and plumbing system in the output.

Peak demand tests generally require alternating pumping and resting of a domestic water system at a defined rate for regular intervals over a prescribed time period. The pumping rate is generally based in the anticipated peak water use of the dwelling which is calculated from the number of occupants. However, a pumping rate of 3 to 5 gpm is common.

One common peak demand test method is to operate the system at 5 gpm for 15 minutes, allow it to rest for 15 minutes and then pump it again. This sequence is continued for 4 hours or until the system fails, whichever comes first. Failure will either prevent the loan approval or require development of an adequately producing water supply. It is recommended that the well not be used for at least 24 hours prior to the test.

Some peak demand requirements are based on the home size and characteristics. These requirements suggest that daily demand for a single family residence is 200 gallons per bedroom or 100 gallons per person. The peak load is estimated at 50 percent of the total daily demand with the peak yield rate of 3 gpm per bathroom. For example, a four bedroom home would have an estimated daily demand of 800 gallons with 400 being needed for the anticipated peak load. If the home has three bathrooms, the peak demand rate would be 9 gpm for a period of approximately 45 minutes (400 gallons/9 gpm = 45 minutes).

While peak demand tests may be adequate for the needs of the loaning institution and the residents, it has less of a scientific basis than the other two testing methods discussed. With the peak demand test, the minimum yield a well can produce is determined, but not the actual yield. So, one cannot accurately compare yield tests performed on a well at different times (pre- and post-mining) or between wells (e.g., original versus replacement well).

Table 1. Well Volumes.

Volume of Casing			
Inside Diameter in Inches	Volume in Gallons per Linear Foot	Inside Diameter in Inches	Volume in Gallons per Linear Foot
1.00	0.04	6.50	1.73
1.25	0.08	7.00	2.00
1.50	0.10	7.50	2.30
2.00	0.17	8.00	2.60
2.50	0.29	8.50	2.95
3.00	0.38	9.00	3.31
3.50	0.50	9.50	3.69
4.00	0.66	10.00	4.09
4.50	0.83	10.50	4.50
5.00	1.02	11.00	4.94
5.50	1.24	11.50	5.40
6.00	1.50	12.00	5.81

If additional information is required, contact any of the hydrologists at the Appalachian Regional Office or you can consult any of the following references:

Driscoll, F. G., 1986, Groundwater and Wells, Second Edition, Johnson Filtration System Inc., St. Paul, Minnesota, 1089 p.

MidWest Plan Service, 2009, Private Water Systems Handbook, Fifth Edition, Iowa State University, Ames, IA, 138 p.

Risser, D. W., 2010, Factors Affecting Specific-Capacity Tests and their Application – A Study of Six Low-Yielding Wells in Fractured-Bedrock Aquifers in Pennsylvania, U.S. Geological Survey, Scientific Investigations Report 2010-5212, 44 p.