PROTECTING YOUR GROUNDWATER SOURCE

Michael Black, P.E.
DWR Consultants, Inc.

Illustrations by
Chris Metzgar

In most cases, land and structures are worthless without a good water supply. Water, more than any other utility, defines the value and use of your property. Therefore, it is wise to carefully consider the source and reliability of your existing or future groundwater source against the long-term use and value of your property.

There are, of course, numerous legal and administrative requirements associated with groundwater. However, this article focuses on the hydrogeology, well design, and testing to assure a good source of water.

> An article titled "Water Wars: Whose water is it and why do I need a permit to use it?" is available on the NESC Web site at *www.nesc.wvu.edu*. The fall 2003 *On Tap*, also available on this site, had several articles about groundwater.

A hydrogeology assessment involves examining the geology controlling the available groundwater. Hydrogeology evaluates geologic formations relative to their ability to store and transmit groundwater. An aquifer is a soil or rock formation that provides groundwater to the pumping well. Basic principles for groundwater include:

- Three basic types of aquifers (storage and flow) are generally considered (see Figure 1). The operator must understand the differences between these types of aquifers and how they impact the source assessment and protection. The testing, analysis, geochemistry, delivered water chemistry, and recharge vary significantly between types of aquifers.
- Corrosion is a very important and often overlooked element in the design of groundwater systems, and geochemistry plays an important role in corrosion.
- Determining the storage and flow characteristics of the aquifer requires well-planned and executed pump tests.

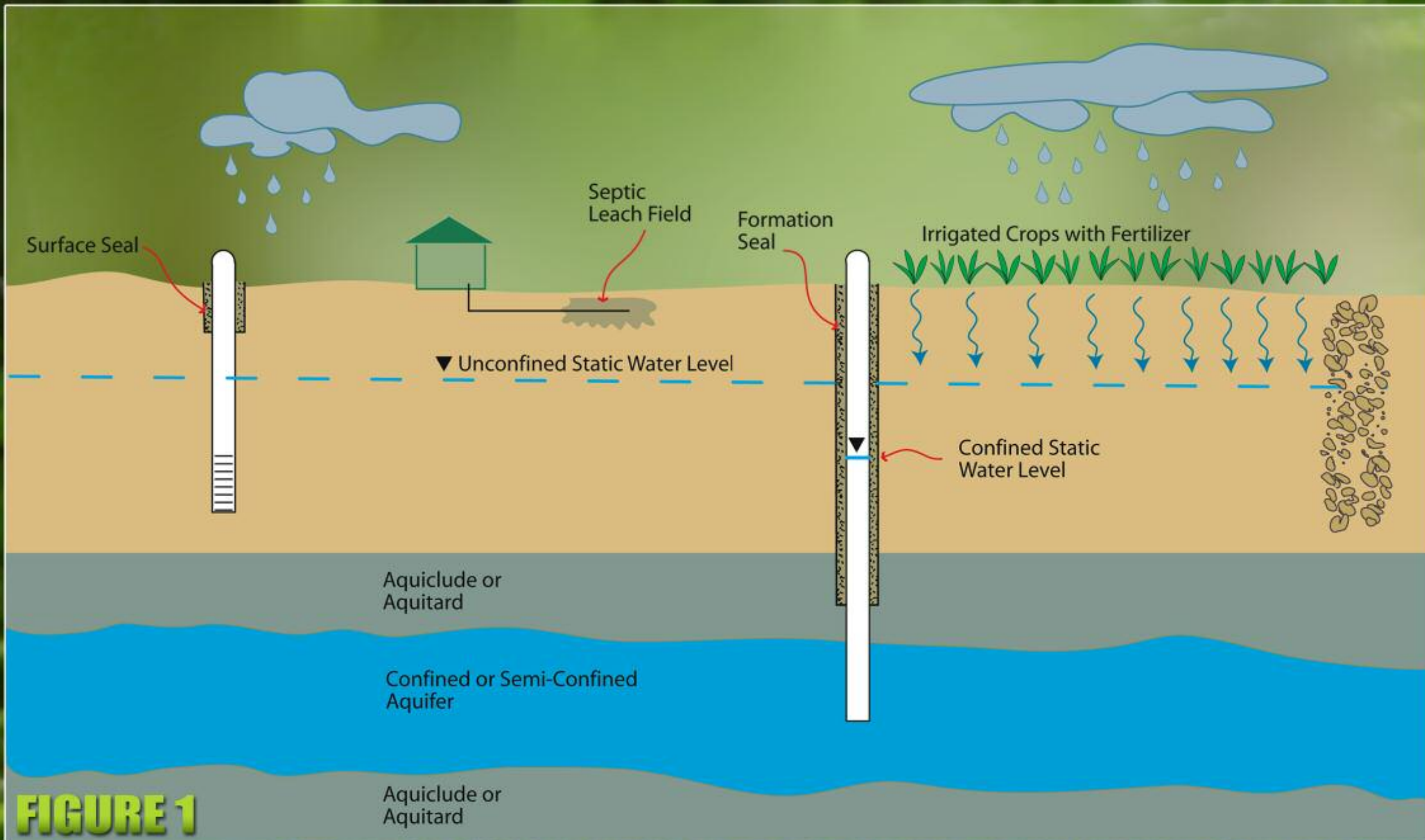

FIGURE 1

Not All Aquifers Are Alike

The terms “aquitard” and “aquiclude” are used to describe aquifers. An aquitard (sandy silt soil) stores and leaks enough groundwater to the pumped aquifer to provide significant groundwater to the pumping well. An aquiclude (clay or massive rock) essentially seals an aquifer and provides no appreciable groundwater to the pumping well. There are three different types of aquifers: unconfined, semi-confined, and confined.

Unconfined Aquifers

If an unconfined aquifer exists, it will always be above both semi-confined and confined aquifers. (See Figure 1.) Imagine a lake filled with gravel to 10 feet *above* the water surface. An unconfined aquifer would be created. The top of the groundwater table is at atmospheric pressure exactly as it existed for the former lake. A groundwater well, placed in the deepest part of the former lake, enjoys access to more groundwater than a well placed near the shallow banks of the former lake.

A pumping well drilled into our hypothetical unconfined aquifer lowers the groundwater level in the well, and the groundwater runs through the gravel into the well due to the depressed groundwater level at the well. Simply put, groundwater always runs downhill and settles in a low spot. Over time the “cone of depression” around the well grows in diameter until equilibrium is reached with recharge into the aquifer balanced against the pumping rate out of the well. Compared to leaky or confined aquifers (discussed below), unconfined aquifers enjoy a higher rate of groundwater storage per unit volume.

Recharge to the unconfined aquifer remains similar to the former lake. The stream feeding the former lake should provide the same flow to our newly created unconfined aquifer. Rain, irrigation, and other infiltration to the aquifer provide recharge as well. Assuming the well is placed at the deepest point of the former lake and the pumping rate exceeds recharge, the groundwater from the former lake will be removed over time and the aquifer will be destroyed except for the available recharge.

Semi-Confined (Leaky) Aquifers

A semi-confined aquifer (see Figure 1) receives some groundwater contribution from an aquitard. The aquitard may be above, below, or both above and below the aquifer. The semi-confined aquifer designation is somewhat relative. For example, a clean, coarse sand in an aquifer may be bounded by a sandy silt. If the sandy silt flows enough groundwater, vertically, to the coarse sand aquifer to affect the flow properties of the aquifer, then it is semi-confined. Furthermore, the silty sand may also provide a vertical connection with an unconfined aquifer above. A pump test, along with a review of the geology, helps to determine if an aquifer is semi-confined, unconfined, or confined.

Confined Aquifers

Confined aquifers (see Figure 1) differ considerably in the mechanics of groundwater delivery to the well. Recharge to these aquifers is very slow compared to unconfined aquifers. In many cases, using groundwater from confined aquifers is “groundwater mining,” because the recharge is so slow.

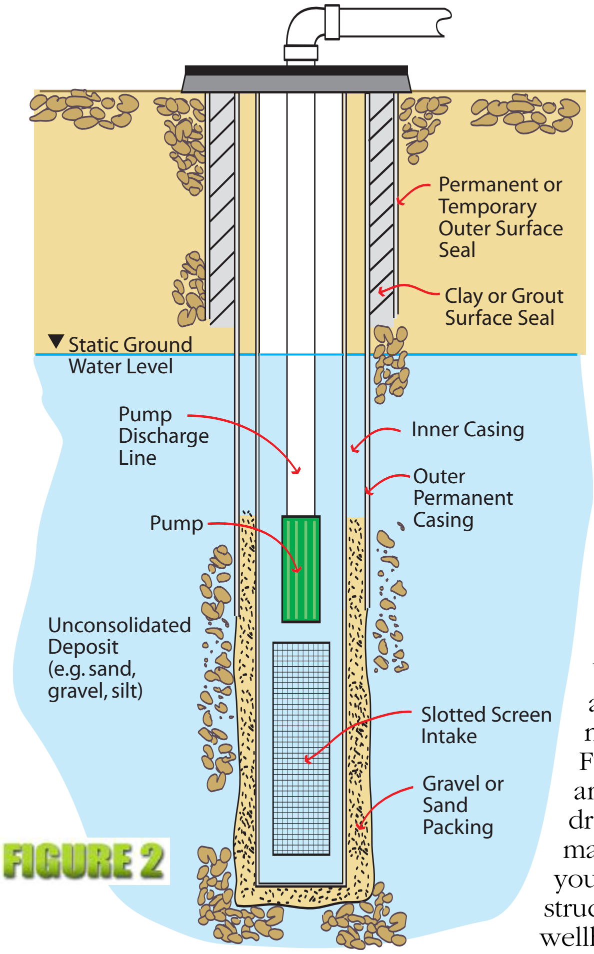

FIGURE 2

Confined aquifers are bounded above and below by aquicludes. The groundwater and aquifer matrix are under pressure from the weight of the overburden (soil and rock) above. Once the well bore encounters the confined aquifer, the groundwater expands and squeezes out from the soil or rock matrix consistent with the overburden pressure in the aquifer. Most often, the static groundwater level rises well above the top of the aquifer.

Well Design and Construction

Constructing groundwater supply wells presents an often-costly process with an inherent level of risk. An improperly constructed well or an improperly abandoned well can serve as an easy way for pollution to enter your water source. The American Water Works Association provides a document that can be used as a specification for your well so that it meets national standards (see the references for more information).

Your well should offer the maximum flow reliability with installed features to protect against future pollution from the surface or other polluted aquifers above or below your groundwater source. Problems with well construction include: (1) improper formation seals, (2) failure to completely penetrate aquifers, (3) the occasional lack of well screens, and (4) lack of access to test the well. Many wells are constructed with the minimal features based on the lowest cost, an approach that is often "pennywise and pound foolish." Furthermore, if nearby wells are improperly constructed and draw from your aquifer, they may pollute your aquifer even if your well is properly constructed. This is an issue for your wellhead protection program.

Formation seals provide two advantages. First, they keep the groundwater from your aquifer from leaking out into other aquifers. Second, they keep groundwater from other potentially polluted aquifers from leaking into your aquifer. The grout formation seal (shown in Figure 2) keeps contaminants from the unconfined aquifer and upper confined aquifer from reaching the pumping aquifer. The seal keeps the water in the pumping aquifer from leaking around the side of the casing into the aquifers above. Figure 2 also shows that the well completely penetrates the aquifer, providing the maximum flow potential into the well. As the static water level decreases, a pumping well, founded at the bottom of the aquifer, can receive water until the aquifer is exhausted.

Figure 3 shows a well screen in an unconfined, unconsolidated aquifer. Unconsolidated simply means that the soil or rock will run into the well over time. This not only causes considerable pump damage, but also reduces flow into the well. The cure for this problem is to install a well screen. A competent consulting engineer or the manufacture's engineer should design the well screen.

Figure 4 shows a plan view of a completed well with services. Note the air line and one-inch diameter pipe access. These features are crucial for well testing. The one-inch diameter pipe allows for the temporary installation of a pressure transducer and "depth-sounder" or "e-tape" to determine the water level during pump testing.

Well Testing

According to Freeze and Cherry, "A pumping test provides *in situ* values, and these values are, in effect, averaged over a large and representative aquifer volume." In other words, when you drill the well, only a tiny fraction of the groundwater source is evaluated. A pumping test provides an interrogation of a large area surrounding your well. The duration of the pump test depends on the geology and type of aquifer. Kruseman advises that a semi-confined aquifer, confined aquifer, and unconfined aquifer may often be tested in 16, 24, or 24 to 36 hours. However, most tests can be terminated after 24 hours.

After a geologic review, a pump test provides the best information for determining the quality and quantity of your groundwater source. In addition, it provides crucial information on how to best protect your groundwater source (wellhead protection). Pump tests for small flow systems are most often limited to one pumping well. Therefore, it is crucial that the single well is constructed and equipped to meet long-term demand and testing requirements. As the pump test provides the quantitative data for competently assessing wellhead protection areas, it is important that the pump tests provide accurate data. This work is best left to experienced professionals who have the practical and academic background to design and conduct these tests.

The basis for accurate data collection and interpretation is contingent upon three factors. First, a competent and comprehensive hydrogeology review must be performed. This includes an accurate well log. Second, full penetration of aquifers provides the most reliable long-term groundwater supply and removes assumptions from the pump test analysis. Partial penetration of aquifers should be avoided. If partial penetration of aquifers is unavoidable, nearby well logs should be available to assess the total aquifer thickness. Third, access for groundwater-level measuring instruments must be provided.

Designing a Pump Test

The person or firm conducting the pump test should have the following information:

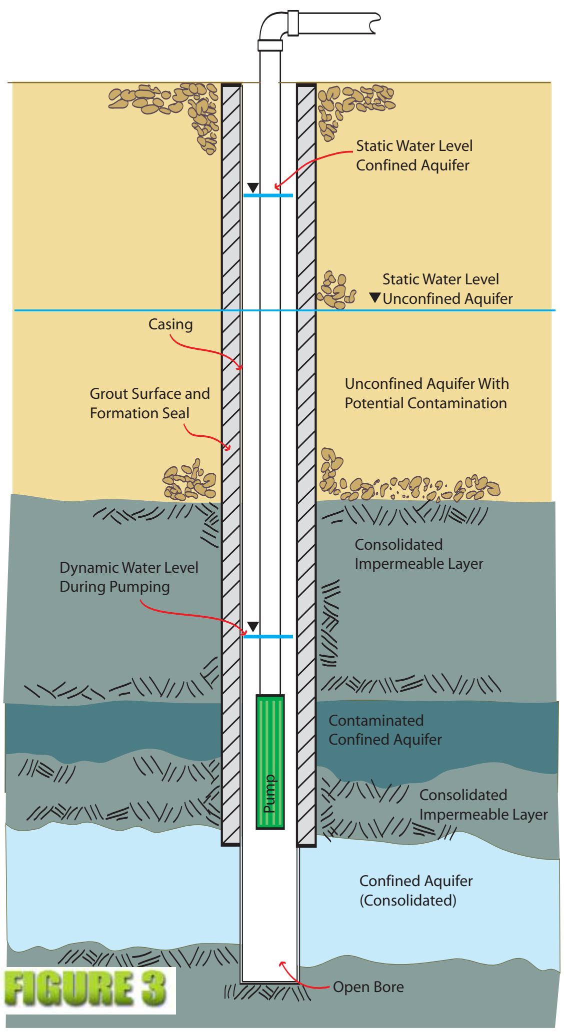

FIGURE 3

- description of use (e.g., industrial, residential, processing);
- groundwater right;
- regulatory identification for water system;
- location address and description of the 1/8 section with township and range.
- required average and maximum flow;
- an assessment of groundwater chemical analysis requirements. Alkalinity is required to determine corrosion properties of the groundwater and should be included in the suite of tests. Furthermore, a tritium analysis will help determine the classification of the aquifer, and wellhead protection requirements;
- well log; and
- pump curve(s).

Required Wellhead Features for a Pump Test

Much time and effort (along with the added consultant's fees) can be avoided if the well is ready to test. The following features, at a minimum, are required to efficiently conduct a pump test:

- A location to discharge the groundwater from the pump test that will not damage the client's property or adjoining properties. The pumped groundwater should be discharged in a way that prevents its return to the aquifer.
- A one-inch diameter pipe (open at bottom) along the discharge line (see Figure 4) for groundwater head level measuring equipment (i.e., pressure transducers and e-tapes). Pressure transducers provide the most accurate method to conduct pump tests. An e-tape provides alternative confirmation and a backup to the pressure transducers.
- A way to measure the discharge rate. This can either be an installed flow meter, or an acoustic meter installed on the outside of the pipe. The meter should be accurate to within five percent of the flow at the prescribed testing flows. Further, the gauge needs to be in a low turbulence area.
- A way to throttle the well discharge (usually a valve in the outlet pipe down stream from the flow measuring device). Generally, butterfly valves do not provide the level of control necessary to accurately manage flow. Most often, metal globe or gate valves are best.
- A way to measure system pressure. This is normally a pressure gauge, used to measure the total dynamic head (TDH) for comparing pump and well efficiency.
- Two each 1/4 to 1/2 inch, valved ports, installed downstream of the pressure gauge and flow gauge to allow sampling for geochemical, groundwater quality, and sand content.

Pump Test Results

The pump test, coupled with the hydrogelogic review, provides the following:

- Prior to running a pump test, the pump should be shut off and the water levels monitored over at least a 24-hour and up to a three-day period. This provides rhythmic fluctuations to the water table based on changes in atmospheric pressure and pumping from nearby wells. Without this data, the analysis for all pump tests may be compromised.
- The viability of the aquifer source to meet current and future demands. This is accomplished by a step-test, constant rate test, and recovery test. The step test determines how efficiently the well is constructed and

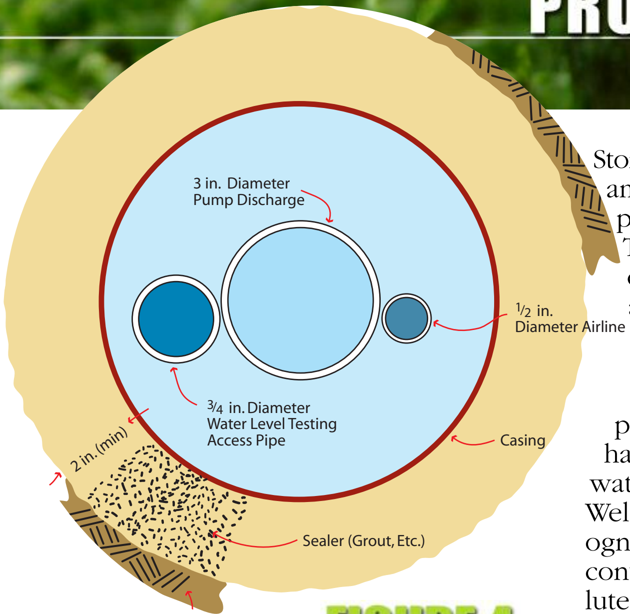

FIGURE 4

equipped for withdrawing water from the aquifer. The constant-rate test determines the properties of the aquifer. The recovery test provides a second method to calculate transmissivity as a check on the transmissivity calculated from the constant rate test.

- A definition of the type of aquifer (i.e., unconfined, semi-confined, confined) with the associated hydraulic properties to determine the wellhead production area.
- The well efficiency with recommendations for improvement.
- A discussion of the groundwater chemistry against regulatory standards and the corrosion potential.
- A discussion of the well bore effects on the test duration.
- Justification for the type of aquifer selected from analysis. If the aquifer is determined to be semi-confined, the rate of leakage should be provided as well.
- An estimate of maximum production for the well if the pump test did not stress the aquifer to its maximum.
- Presentation of the common aquifer properties. Hydrologic conductivity is the ease with which groundwater flows through the soil or rock. Storativity or specific yield is the amount of groundwater available per unit volume of aquifer. Transmissivity is the hydraulic conductivity multiplied by the aquifer thickness.

Wellhead Protection

An appropriate wellhead protection program requires hard work and diligence by the water district personnel. Wellhead protection involves recognizing and managing existing contaminant threats that may pollute groundwater. State or federal regulations require establishing a sanitary control area (SCA) and a wellhead protection area (WHPA). Important technical and management issues not addressed in these prescriptive regulations include the following:

- Determination of a three-dimensional model including the surface and soil/rock stratigraphy, at depth, that may reasonably impact the well.
- Type of aquifer (i.e., unconfined, leaky, confined).
- Direction of groundwater flow.
- Influence of nearby wells that may provide transient changes to the direction of groundwater flow.
- Determination of contaminant sources within the surface area delineated by the SCA and WHPA. Contaminant sources using underground injection or buried beneath the land surface require particular attention. The stratigraphy (e.g., free draining gravel compared to clayey silt) significantly impacts the rate and concentration of potential contaminant migration to the water source.
- Potential "short circuits" to the groundwater source, such as improperly constructed and abandoned wells.

A detailed discussion of wellhead protection is beyond the scope of this article, but wellhead protection requirements vary considerably between the types of aquifers. Whereas an unconfined aquifer is more subject to surface pollution, its influence area is much smaller than a confined aquifer. A confined groundwater source may have a larger WHPA, but surface pollution sources are not as important as penetrations (other wells) within the WHPA.

A professional can be of considerable help in formulating your wellhead protection program, but the long-term responsibility requires regular re-assessments of the plan. The more thought and effort you put in at the outset, the fewer problems you'll encounter in the future. Remember that protection of your groundwater source is protection of your property.

References

American Water Works Association. 1998. "AWWA Standards Committee on Wells." In *AWWA Standard for Water Wells in ANSI/AWWA A100-97*. Denver: ANSI/AWWA.

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

Hemond, H., and E. Fechner-Levy. 2000. *Chemical Fate and Transport in the Environment*. San Diego: Academic Press.

Kruseman, G., and N. de Ridder. 1990. *Analysis and Evaluation of Pumping Test Data*, 2nd edition. Wageningen, The Netherlands: International Institute for Land Reclamation and Improvement.

Michael Black, P.E., is a geoenvironmental engineer with DWR Consultants based in Pasco, Washington. Over the course of his 30-plus year engineering career, Black has worked on numerous projects requiring pumping, clean-up, and sealing of groundwater.