Water Well Reports and Hydrogeology

Filling in those blanks doesn't just satisfy some agency's requirements. Good well reports also provide hydrogeologists from the public and private sector with valuable information regarding local ground water systems. By Dennis Nelson

HYDROGEOLOGISTS ARE OFTEN CALLED UPON TO evaluate an aspect of a ground water system—for example, the direction of ground water flow, the potential impact of a given land use on ground water, the potential impact of a well on another well or nearby stream, or the "capture zone" for a given well. In order to conduct such an evaluation, the hydrogeologist must have actual or reasonable estimates of the physical and hydraulic properties of the geologic material through which ground water is moving.

In some cases, data may be available in the form of geologic maps, aquifer tests, monitoring wells, or written reports. In many cases, however, the only information available is in the form of well reports (well logs), filed by well constructors at the time of drilling.

The importance of water well reports in hydrogeological investigations cannot be overstated. The information collected by well constructors during and after the drilling of a well is often the only information available to the hydrogeologist. In many cases, it is our only "window" into the aquifer. The purpose of this article is to describe the type of ground water information needed to conduct typical hydrogeological assessments, and how the data collected by well constructors is used to obtain this information.

Hydrogeologic Data

For hydrogeologists to make reliable assessments about the current and future status of ground water, they need to know where ground water occurs in the subsurface, what the properties are of the various geologic units below the surface, and how fast and in what direction ground water is moving.

Obtaining the data necessary for these studies can be time consuming and expensive. Well reports, however, can provide information that can be used to determine if further data is needed, and if so, what data and from where. In this article, important hydrogeologic parameters that are used will be discussed first, followed by several general examples of how they are used. Finally, how a typical well report can be used to acquire this data will be described.

Depth to the Aquifer

It is necessary to identify which geologic unit is the aquifer, i.e., the porous and permeable rock or sediment that contains ground water, and the depth at which it occurs. It is often also important to know the type of geologic materials that occur from the surface down to the top of the aquifer.

Nature of the Aquifer

The nature of the aquifer can be described as either unconfined or confined. An unconfined aquifer has the water table as its upper surface; there are no significant low-permeability layers between the water table and the surface; and the aquifer is recharged locally, in the immediate vicinity of the well. The top of the aquifer, the water table, can rise or fall depending on water use and amount of recharge to the aquifer.

A confined aquifer has a low-permeability geologic formation (a confining layer) as its upper boundary; the ground water in the aquifer is under pressure; the aquifer is separated from the surface by the confining layer and generally is recharged at some distance from the well, e.g., in nearby or distant areas of higher topography.

Hydraulic Head (h)

The hydraulic head is a measure of the energy that the water at a certain depth possesses because of its elevation and the pressure exerted through the weight of the water above it. Hydraulic head has units of feet, and generally corresponds to the elevation of water in the well. Hydraulic head is the driving force for ground water movement either in a horizontal or vertical direction. Ground water moves from where the head is higher to where the head is lower.

If we have enough hydraulic head data for an aquifer over a given area, we can contour the head elevation just like the ground elevation is contoured on a topographic map. Ground water will move from high head areas to low head areas and will generally flow in a direction that crosses the contours at a 90° angle (see Figure 1).

The change in hydraulic head (h1 − h2) over the distance from point 1 to point 2 (D1,2) is the gradient (I), calculated as

$$I = (h1 - h2)/D1,2$$

In Figure 1, assuming points 1 and 2 represent individual wells, the gradient would be the difference in head between well 1 (~102 feet) and well 2 (~68 feet) divided by the horizontal (map) distance between the two wells.

Thickness of the Aquifer (b) and Water-Bearing Zones

To evaluate the amount of ground water moving through the aquifer or its ability to supply ground water to wells, it is necessary to know the thickness of the aquifer. It is also important to be able to identify whether the aquifer is uniform throughout its thickness or consists of one or more discrete water-bearing zones.

Aquifer Porosity (n)

The volume of open space relative to the total volume of the aquifer (porosity) and the degree to which these pore spaces are interconnected (effective porosity) controls the volume of water in the aquifer and the amount of water that can be reasonably withdrawn from the aquifer.

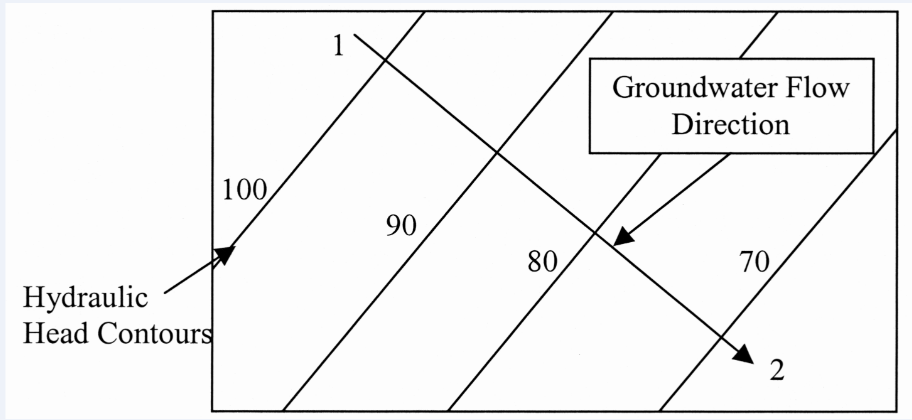

Figure 1.

For a given gradient, the effective porosity strongly influences the velocity in which the ground water is moving.

Permeability of the Aquifer (K)

The permeability, or hydraulic conductivity, of the aquifer is a measure of how fast ground water can move through the aquifer. Hydraulic conductivity has units of distance/time, e.g., feet/day, although it does not represent an actual speed.

Examples of the Use of Hydrogeological Parameters

Is the Aquifer Unconfined or Confined?

As indicated previously, whether an aquifer is confined or unconfined has important implications for its vulnerability to pollution. The most direct method of determining this characteristic is to compare the hydraulic head to the elevation of the top of the aquifer.

Unconfined aquifers have the water table as their upper boundary. The water table is at atmospheric pressure and therefore when the aquifer is drilled into, the water level in the well remains at the same elevation as the water table. Confined aquifers contain water that is under pressure. When the aquifer is drilled into, the water level in the well will rise to a higher elevation than that of the top of the aquifer (remember that water seeks its own level).

Volume Rate of Ground Water Moving Through an Aquifer

If we wanted to know how much ground water was traveling through an aquifer, we can apply Darcy's law, which states that the rate (Q) is equal to the hydraulic conductivity (K), times the cross-sectional area of the aquifer (A), times the hydraulic gradient (I):

$$Q\ (ft^3/day) = K\ (ft/day) \times A\ (ft^2) \times I\ (ft/ft),$$

where $I = (h1 - h2)/d$ in Figure 2.

Consider a gravel quarry that intersects an aquifer through a thickness of 50 feet and a width of 500 feet. If the aquifer had a hydraulic conductivity of 50 feet/day with a gradient of a 1-foot drop for every 1000 feet of horizontal distance (I = 0.001), what volume of ground water would have to be pumped out of the quarry each day in order to keep it dry?

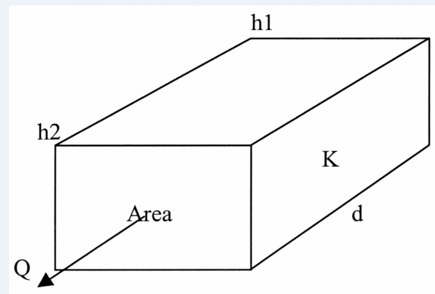

Figure 2.

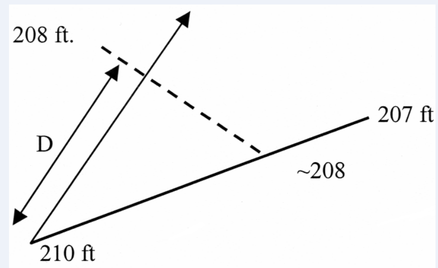

Figure 3.

$$Q\ (ft^3/day) = 50\ ft/day \times (50\ feet \times 500\ feet) \times 0.001\ (ft/ft)$$

$$Q\ (ft^3/day) = 1250\ ft^3/day$$ or approximately 9300 gallons per day

It is common to combine the hydraulic conductivity and aquifer thickness to yield a number referred to as the transmissivity (T = Kb), a parameter that is more directly related to the volume of ground water flow. Using the transmissivity term, Darcy's law becomes

$$Q\ (ft^3/day) = T\ (ft^2/day) \times w\ (ft) \times I\ (ft/ft)$$

In What Direction Is Ground Water Flowing?

The direction of ground water flow is from higher to lower hydraulic head. Consequently, if we have wells that produce from the same aquifer, we can estimate the direction of ground water flow. The hydraulic head can be measured by lowering a probe through the observation port of a number of wells, all within the same relative time period, i.e., within a few days of each other.

A minimum of three wells is required to estimate the direction of flow. We can also determine the gradient from these wells. The method is referred to as a three-point solution and is illustrated in Figure 3.

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Three wells from the same aquifer have hydraulic heads (elevation of the water table) of 207, 208, and 210 feet as shown in Figure 3. What is the direction ground water is flowing and what is the gradient?

We begin by drawing a line from the lowest (207 feet) to highest (210 feet) value of head. We note that somewhere along that line, the elevation of 208 feet, the intermediate value, must fall. If we assume that the water table has a constant slope, an elevation of 208 feet will occur one-third of the way from 207 to 210 ([208-207]/[210-207]). Once we have determined where the 208 feet elevation occurs along the line, we can draw a line from that point to the well with the 208 feet hydraulic head. This line represents the 208 feet contour on the water table. As mentioned before, ground water tends to flow directly across, i.e., perpendicular to, the contours from higher head to lower head. The arrow, then, represents the direction of flow.

The gradient can be calculated by measuring D, the distance along the perpendicular from the well, with the 210-foot head to the 208-foot contour using the equation

$$I = (h2 - h1)/D = (210 - 208)/D$$

Note that the three-point solution works best on wells that are relatively close to one another.

How Fast Is Ground Water Moving?

The speed of ground water movement in the downgradient direction can be calculated using a modified version of Darcy's law:

$$V \text{ (ft/day)} = KI$$

This equation assumes that ground water is moving across the entire area of the aquifer, but in the real world, ground water does not flow that way. Ground water is moving only through the pore spaces (actual openings in that area). As a result, we have to include the porosity (n) in this equation:

$$V = KI/n$$

Using the gravel quarry example given before (K = 50 ft/day; I = 0.001; n = 0.25), the velocity of ground water through the aquifer can be determined as follows:

$$V = (50 \text{ ft/day} \times 0.001)/0.25 = 0.2 \text{ foot/day}$$

What Is the Drawdown Associated with Pumping of a Well?

Often we would like to know how the pumping of one well might affect the water level in another. There is a relation between the pumping rate of the well, the transmissivity of the aquifer, the distance between wells, the storage coefficient of the aquifer, and the duration of the pumping event.

The storage coefficient of an aquifer is related to how much water is released from the aquifer as the hydraulic head of the ground water drops. The storage coefficient is slightly less than porosity for an unconfined aquifer (from 0.10 to 0.25) and is significantly less than porosity in a confined aquifer (from 0.01 to 0.000001 or less). For unconfined aquifers, using the porosity is a reasonable approximation in most cases.

No simple expression is available to determine drawdown as a function of distance for a given set of conditions; however, there are a number of computer programs that can perform this calculation with input of the previously mentioned parameters.

Using the Well Report

Although most of the proposed questions can best be addressed through more detailed hydrogeologic investigations, we can often make reasonable estimates from available well reports if they have been carefully filled out (see The Well Guy, "Lithology," May 2002, *Water Well Journal*). Well report forms vary from state to state, but most contain data that is relevant to a hydrogeologic investigation. Using typical entries from a well report form, let's examine where we can obtain the data we need.

Well Location

For most hydrogeologic studies, the precise location of the well is very important. In many cases, wells are located only to the nearest section or perhaps quarter-quarter section. In the latter case, we still only know the location to the nearest 40 acres. Over the last few years, well constructors have been using tax lot information to locate wells. This is an improvement, but depending on lot size, there still may be significant uncertainty.

We hope that more and more well constructors will take advantage of low-cost global positioning system (GPS) technology and begin reporting well location as latitude and longitude. There are 24 satellites positioned above the earth's surface and at any given time; off-the-shelf GPS units are capable of linking to three or more of these and determining locations within 100 feet or less. Such high-precision locations greatly enhance our ability to use the well report data to determine direction of ground water flow, ground water gradients, variation of aquifer properties throughout an area, and so on.

Well Tests

Most well reports require the well constructor to perform some level of pump test to evaluate the capacity of the well. If the well constructor has carefully monitored the rate of water production (Q) and drawdown (s) associated with that production over the period of the test (t), the hydrogeologist can often derive useful information regarding the permeability or hydraulic conductivity (K) of the aquifer.

The specific capacity (SC) of the aquifer at the well site is defined as the ratio of the discharge of the well to the total drawdown:

$$SC = Q \text{ (gpm)}/s \text{ (ft)}$$

The transmissivity of the aquifer can be estimated from the specific capacity through the following relationship:

$$T \text{ (ft}^2\text{/day)} = AC \times SC \text{ (gpm/ft)}$$

where AC is a number varying in value depending on the aquifer characteristics.

If the hydrogeologist can determine the aquifer thickness from elsewhere in the well report, the hydraulic conductivity can be derived from this transmissivity value.

It must be stressed that the specific capacity data can in no way replace the time-drawdown information acquired from a well-designed constant rate aquifer test. However, it does provide an approximation, and if enough specific capacity data can be found for an area, reasonable estimates can be made. For information on conducting aquifer tests, see *www.ohd.hr.state.or.us/dwp/docs/gwater.htm* and click on "How to prepare for an aquifer test."

So what is a hydrogeologist looking for in specific capacity data? Ideally, the SC test will have been accomplished using a pump over a period of at least four hours. Why four hours? Let's consider a 50 gpm test of a 25-foot-thick sand and gravel aquifer. If this test lasts for only an hour, all the water will be derived from within 4.5 feet of the well. This small volume will not be very representative of the aquifer in general. If the test is run over a longer time period, a larger volume of aquifer can be "sampled" and the resulting hydraulic conductivity estimate will be more representative of the aquifer.

Depth to First Water-Bearing Zone

There seems to be two ways that well constructors interpret this parameter. Some report the depth at which water is first encountered in the drill hole while others report the depth where enough water to supply the well is encountered. From the hydrogeologist perspective, the first interpretation is preferred because it tells us where the top of the aquifer is.

It is common to find that an aquifer, i.e., a water-saturated geologic unit, varies in permeability in the vertical sense. For example, consider a 50-foot-thick sand aquifer that occurs at a depth of 30 feet and contains silt in the top 5 feet. The entire 50 feet of aquifer is saturated; however, useful quantities of water can be produced from only the lower 45 feet. First recognizable water would be encountered at 30 feet, while producible water would not be encountered until 35 feet.

From the hydrogeologist's view, the top of the aquifer is at 30 feet. Why is this so important? In order to determine whether the aquifer is confined or is unconfined, we must compare the elevation of the static water level to elevation of the top of the aquifer. In the case just given, the static water level in a well in this aquifer would be at 30 feet. If we had mistakenly thought that the top of the aquifer was at 35 feet, we may have considered it to be confined when actually it is unconfined.

Static Water Level

The driving force for ground water movement is the hydraulic head, and the static water level (SWL) is a measure of that force (head = ground elevation − SWL). If we want to determine the ground water flow direction and the gradient, we may be able to gather that information from well reports. Care must be taken in using SWLs from wells drilled at different times of the year or over a period of years. Careful SWL measurements greatly enhance our understanding of the nature of ground water movement.

Well report forms generally provide space for SWL reporting as a function of depth in a given well. Multiple aquifers exist in most areas and these aquifers may be encountered as one drills deeper into the ground. Identifying where one aquifer ends and another begins is key to identifying the source of ground water to individual wells. Although this often can be determined by careful review of the lithologic log provided by the well constructor, the transition from one aquifer to the next can be indicated by a marked change in the SWL. A change in SWL is a better indicator that a different aquifer has been encountered than the lithologic description.

A progressive change in the static water level with depth can indicate to the hydrogeologist that the area represents a recharge zone (decreasing head with depth) or a discharge zone (increasing head with depth). Identification of recharge and discharge zones may have important implications in ground water protection and identifying the relation between area ground water and local streams.

Water-Bearing Zones

A well report that does not indicate where within the 200 feet of open hole the water is actually coming from does not provide enough information to describe how water moves to the well. In some cases, the screened or perforated portions of cased wells provide a clue, but all too often, the screened interval is either significantly greater or less than the actual thickness of the water-bearing zone(s). Arriving at accurate estimates of aquifer parameters or calculating ground water velocity requires us to know the thickness of the water-bearing zone(s). On well reports, if well constructors can identify the depth(s) where ground water is found and estimate the yield from each zone, the hydrogeologist can increase his or her understanding of the ground water system significantly.

Lithologic Log

The well log portion of the well report describes what the driller encountered in the subsurface. Clear descriptions of the material drilled through, e.g., the relative proportions of silt/clay in the sand units, the locations of weak (fractured) zones in bedrock, whether a clay unit contains lenses or layers of sand, etc., allow the hydrogeologist to better estimate the potential permeability of these zones. This information also allows the hydrogeologist to better estimate the recharge amount, vulnerability from contaminants from the surface, degree of hydraulic connection to surface water, and so on.

Of course, it is not necessary that well constructors be trained geologists. But it is important that their observations, coupled with their experience on a rig, be recorded. Once a hydrogeologist has examined a number of well reports from a given driller, he or she can begin to attach geologic terms to the descriptions provided. Consistency in reporting lithologic character and distribution with depth is very important.

Contributions of Well Constructors to Hydrogeology

This article stresses the importance of data that is recorded on well reports and how that data influences hydrogeologic investigations. Filling in those blanks doesn't just satisfy some agency's requirements, it also provides hydrogeologists from the public and private sector valuable information regarding local ground water systems. Well constructors can provide important contributions to the science by making careful observations and measurements when recording that data on the well report. *WWJ*

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