Monitoring Groundwater Conditions

An Online Continuing Education Course for Engineers

Course Number: EN-2028

Credit: 2 Hours / 2 PDH / 2 CPD

Monitoring Groundwater Conditions

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This course addresses the many applications and techniques for sampling and analyzing groundwater. It encompasses the reasons for monitoring groundwater, its constituents, well design, sampling systems and instrumentation used for analysis of the water samples.

Why Monitor Groundwater?

Concerns ranging from the level of groundwater to contaminants that might be present or introduced into groundwater are reasons for monitoring its condition. Contaminated groundwater can affect the conditions of potable wells, rivers and streams and can directly affect the health of humans and wildlife. The level of groundwater can tell geotechnical engineers a lot about the migration of water, underground hydrostatic activity, and the effects of rainfall. Analysis of the water can tell us if fertilizers, a leaking underground storage tank (UST), or other foreign chemical source is introducing contaminants into the groundwater.

So how does an engineer go about determining if this sort of thing is happening? In most cases, groundwater monitoring wells are installed at strategic locations and the water in them is monitored either continuously or periodically for variations in water level and/or concentrations of contaminants. The quantity, locations, depth of the wells, and water sampling methods must all be considered and are largely determined by the purpose for monitoring. Monitoring of groundwater conditions may be necessary in order to comply with certain regulatory requirements, for research purposes, or simply in response to a desire to know if a certain condition or activity is creating a potential groundwater issue that could affect neighboring homes or wildlife.

Regulatory Requirements

Monitoring wells may be required in order to comply with Federal, state, or local regulatory requirements that pertain to underground or above ground storage tanks that contain hydrocarbon products (liquid fuels such as gasoline, fuel oil, jet fuel, kerosene, etc..) or chemicals that could enter the groundwater below if leaks or spills were to occur. Above ground tanks for hazardous chemicals and fuels are now required to have some form of secondary containment, such as a dike wall, a non-permeable berm, or a double- walled tank with an interstitial space that acts as a second, impermeable barrier between the stored substance and the surrounding soil and groundwater.

Such regulatory requirements went into effect in the 1980s for new and existing storage tank installations and remain in effect for all new installations. Most regulatory statutes also require that the interstitial space between barriers or tank walls be continuously monitored for leaks; and in some cases also require monitoring wells to be installed near the tanks as a secondary means of detecting that the secondary containment has been breached and that a leak and groundwater contamination has occurred. Leak detection systems have been specifically designed for that purpose.

Prior to any type of fuel or chemical tank, or tank farm design or installation, the applicable regulatory requirements must be fully reviewed and understood. Failure to comply with the regulations can result in substantial fines and risk an environmental hazard.

Geological Conditions - Aquifers and Aquitards

According to the U.S. Geological Survey (USGS) an estimated one million cubic miles of the world's ground water is stored within one-half mile of the land surface. The total amount of ground water in storage is more than 30 times greater than the nearly 30,000 cubic-miles of fresh-water lakes and more than the 300 cubic miles of water in all of the world's streams at any given time.

The geological makeup of subsoil conditions contributes to the ground's ability to retain water. The makeup of the subsoil may be rock, sand, clay, or a combination of those things. Voids within and between rocks and soil can fill up with water when located below the water table.

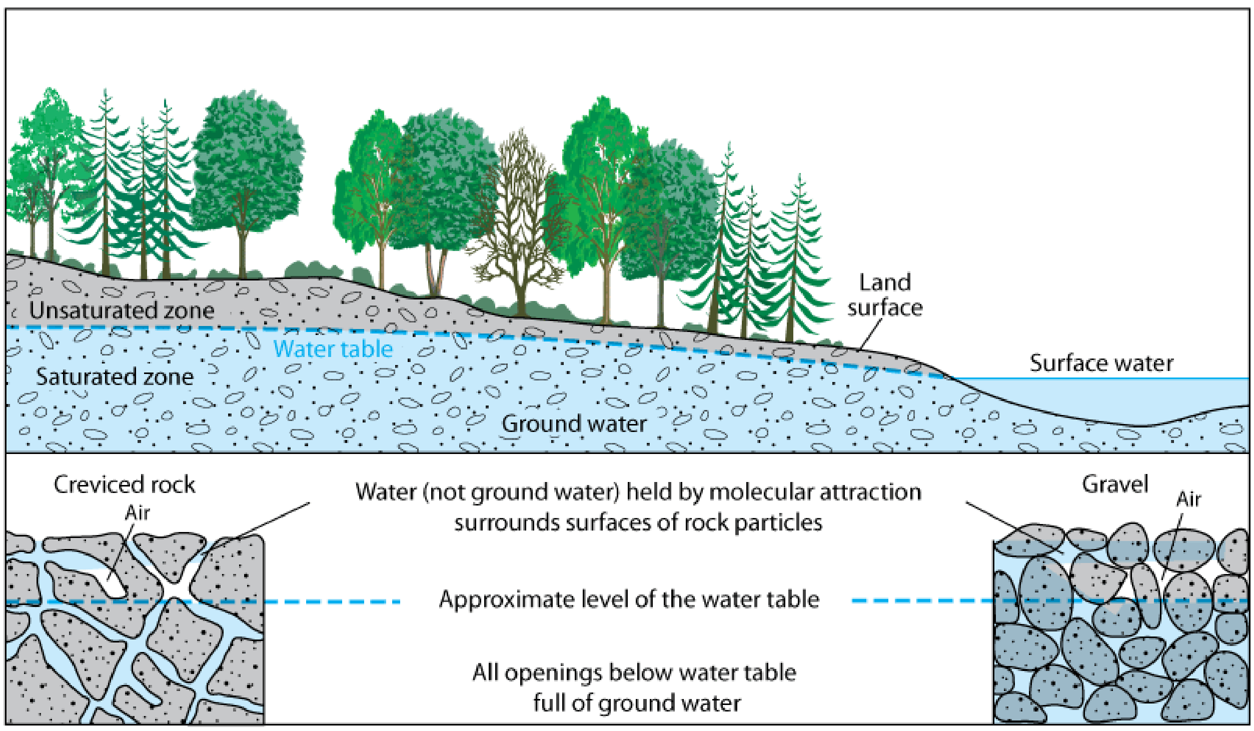

Figure No. 1 – Location and Makeup of Groundwater
Source: U.S. Geological Survey (USGS)

When a water-bearing rock below a water table readily transmits water to wells and to springs, it is referred to as an *aquifer*. An aquifer may consist of a layer of gravel or sand, a layer of sandstone or cavernous limestone, or a large body of fractured rock, such as granite, that contains large openings. The amounts of water that an aquifer will yield to a well can range from a few hundred gallons a day to as much as several million gallons a day. The word "aquifer" is derived from two Latin words: "aqua" or water; and "ferre", which means to bear or to carry. Water leaving an aquifer is referred to as *discharge water*.

Precipitation will eventually add water back into the porous rock that makes up an aquifer. The rate of recharge is not the same for all aquifers because of the variations in porosity of the rock. Pumping water too quickly from a well can draw down the water level in the aquifer and eventually causes a well to yield less and less water and may eventually run it dry. This is generally not a concern for monitoring wells since the volume of water samples necessary for analysis is typically very small – on the order of one liter.

In some cases the porous rock layers are tilted in the earth, with a confining layer of less porous rock, such as clay or shale, located above and below the porous layer. This condition is referred to as a *confined aquifer*.

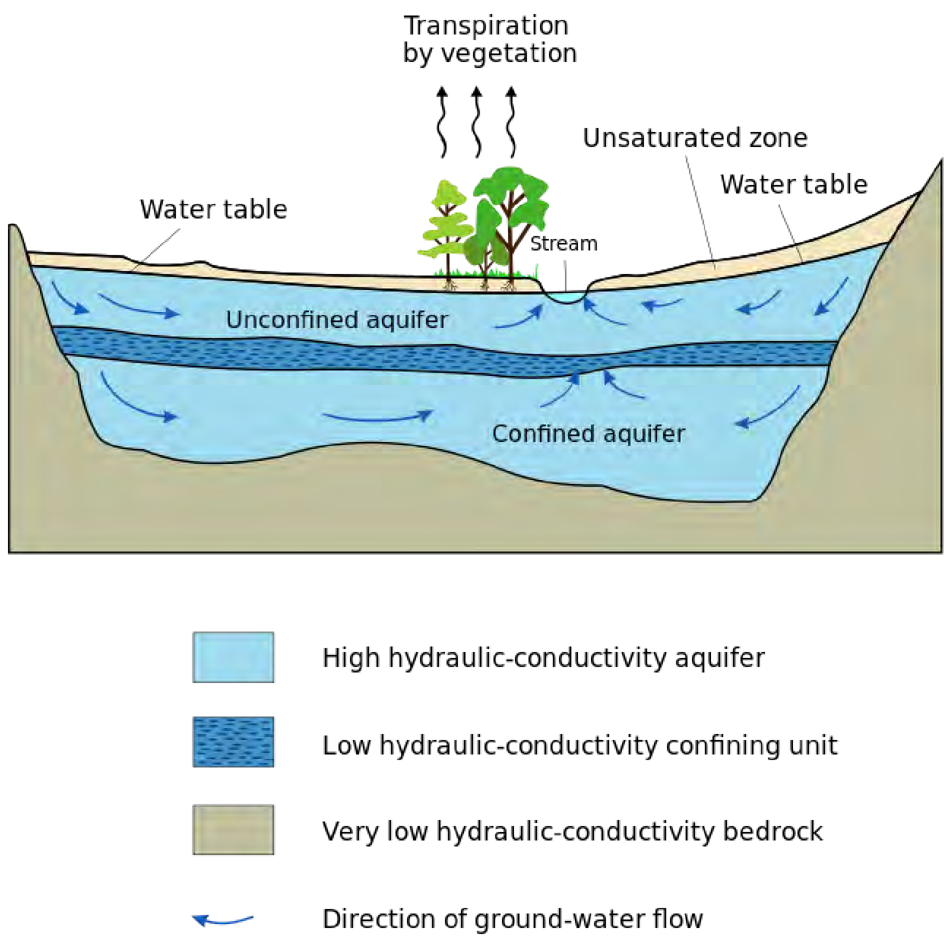

Figure No. 2 – Confined and Unconfined Aquifers
Source: Wikipedia

In such cases, the rock structure surrounding the aquifer confines the pressure of the water in the porous rock. If a well is drilled into the pressurized aquifer, the internal pressure can be sufficient to push the water up and out of the well without the aid of a mechanical pump. This type of well is referred to as an *artesian well*.

An *aquitard* is a subsoil area that tends to restrict the flow of groundwater from one aquifer to another. If an aquitard is completely impermeable, it is also referred to as an *aquiclude* or *aquifuge*. Aquitards are composed of layers of clay or non-porous rock that have a low hydraulic conductivity.

Interactions of Nearby Streams and Groundwater

Streams interact with ground water in all types of landscape conditions. Interaction takes place in three basic ways: streams gain water from inflow of ground water through a streambed; lose water to ground water by *outflow* through a streambed; or both occur, gaining in some reaches while losing in others.

For ground water to discharge into a stream channel, the altitude of the water table in the vicinity of the stream must be higher than the surface of the stream. For surface water to seep into ground water, the altitude of the water table in the vicinity of the stream must be lower than the stream's water surface.

Some streams lose water to the aquifer under normal conditions of stream flow. The direction of seepage through the bed of these streams is attributable to abrupt changes in the slope of the streambed or meanders in the stream channel. The sub-surface zone where stream water flows through short segments of its adjacent bed and banks is referred to as its *hyporheic zone*. The size and geometry of hyporheic zones surrounding streams will vary. Mixing that occurs between ground water and surface water within the hyporheic zone causes the chemical and biological characteristics of the hyporheic zone to significantly differ from adjacent surface water and ground water.

Many streams are contaminated. Therefore, the need to determine the extent of the chemical reactions that take place in the hyporheic zone is significant, over concern that the contaminated stream water can contaminate shallow groundwater.

Groundwater Constituents

Groundwater typically contains some level of concentration of dissolved minerals. The most common dissolved mineral substances found in groundwater are sodium, calcium, magnesium, potassium, chloride, bicarbonate, and sulfate. In water chemistry, these substances are referred to as *common constituents*. Most are considered harmless or even beneficial. Others, although somewhat rare, are harmful; and a relative few are considered to be highly toxic.

Water that contains high concentrations of calcium and magnesium is said to be *hard*. Water hardness is expressed in terms of the amount of calcium carbonate that it contains. Calcium carbonate comes from limestone or other minerals that form as water is evaporated. Water is considered "soft to slightly hard" when it contains 0 to 60 milligram per liter (mg/L) of these minerals; "moderately hard" between 61 and 120 mg/L; "hard" when it contains between 121 and 180 mg/L; and "very hard" when it contains more than 180 mg/L. Water is generally not considered to be *potable* (suitable for drinking) if the quantity of dissolved minerals in that water exceeds 1,000 mg/L.

Grains Per Gallon	**Milligrams Per Liter (mg/l) or Parts Per Million (ppm)**	**Rating**
less than 1.0	less than 17.1	Soft
1.0 - 3.5	17.1 - 60	Slightly Hard
3.5 - 7.0	60 - 120	Moderately Hard
7.0 - 10.5	120 - 180	Hard
over 10.5	over 180	Very Hard

Table No.1 – Water Hardness

Groundwater constituents may also include introduced pollutants, such as pesticides, metals, and oil; or those found naturally in water that can still be affected by human sources, such as levels of dissolved oxygen, bacteria, and nutrients. The magnitude of the constituents' effects can be influenced by other properties, such as pH and temperature. For example, temperature influences pH and the quantity of dissolved oxygen that water is able to contain.

Groundwater, particularly where the water is determined to be *acidic* (has a measured pH less than 7), often contains excessive amounts of iron. pH is the *hydrogen-ion concentration*. pH level can range from zero to 14, with a pH of 7.0 considered to be "neutral"; a pH level above that is considered to be *caustic*, and a pH level below it is considered to be *acidic*.

Since pH can be directly affected by chemicals that are present in the water, a measured variation in the pH level is considered to be an important indicator of water that is changing chemically. pH is reported in logarithmic units. Therefore, each number represents a 10-fold change in the acidity or caustic condition of the water. For example, water having a measured pH level of 4 would be ten times more acidic than water having a pH level of 5.

Groundwater is generally less likely to contain bacterial pollution than most surface water, because the soil and rocks through which ground water flows tend to screen out most of the bacteria. Bacteria will occasionally find their way into ground water, sometimes in dangerously high concentrations.

Monitoring Well Design

In order to readily obtain samples of subsurface groundwater, a well must be installed. A well used for monitoring groundwater typically does not need to be very large in diameter, and its desired depth is typically a function of the depth of the ... er level and the variability in level or altitude of the water table ... will often tend to vary over time with the am...

The simplest and ... *ll* using a pick and shovel. This type of well ... re the depth of the water table is very shall... nt them from collapsing inward.

Driven wells are co... t earth, such as sand or gravel. A screen is ... out any unwanted sand and other particles. They ... that are located relatively close to the surface.

Modern wells are mo... rly complicated and expensive drilling rig... large trucks, and penetrate the ground ... rock, *percussion bits* that literally crush the ... n the case of rotary drill bits, the bit head may ... as the drill gets further down into the rock mo... head bit may be located at the end of a metal tube. As the dril... begins, the bit starts to drill a hole in the ground by chewing