Groundwater

Objectives:

1. To understand how water is stored underground and how it moves
2. To understand how wells function and what static water levels are
3. To understand the status of the aquifer in Tucson

Background:

What is groundwater?

The simplest definition is that groundwater is water contained in the saturated soil and rock materials below the surface of the earth. People sometimes believe that groundwater is water made by mysterious processes deep within the earth. Actually, groundwater is not new water; it is "recycled" water that is related to all the other water on earth by a process called the hydrologic cycle.

The source of groundwater is precipitation. When rain falls on the surface, some of it runs off the land into lakes and streams (runoff), and some soaks into the ground (infiltration). The water soaking into the ground first goes through an unsaturated zone. In the unsaturated zone, or vadose zone, some of the spaces between the soil particles are filled with water, and some are filled with air. Some of the water in the unsaturated zone will be lost to the atmosphere by evapotranspiration.

Soils in the unsaturated zone, are able to hold water in small pores against the force of gravity because of surface tension or cohesion, which is the attraction that water molecules have for one another, and because of attractive forces between the soil particles and the water molecules, known as adhesion. Water in larger pores is subject to the force of gravity and is the source of water that moves downward to become groundwater.

Below the unsaturated zone, the water reaches a zone in the sand and gravel where all the cracks and spaces in the soil or rock are filled with water. This is called the saturated zone. Water in the saturated zone is groundwater. The top of the saturated zone is called the water table.

Groundwater moves slowly down gradient between the grains of soil or in cracks in rock until it reaches a point where it can discharge at the surface, such as a lake, stream, or wetland, or until it is withdrawn from a well. It then becomes surface water again. The groundwater that we use today may have traveled through the hydrologic cycle hundreds or thousands of times since the earth was formed.

How is water stored underground?

Groundwater is stored underground in the pore spaces of saturated soil and rock materials. An underground unit of soil or rock which can yield a significant quantity of groundwater to

wells is called an aquifer. Groundwater flows through interconnected pore spaces in aquifers. Groundwater may flow at different rates in different types of aquifers. Aquifers are not always uniform either horizontally or vertically, because of differences in composition or properties of the material making up the aquifer.

Aquifers may be separated by layers which do not transmit much water. These layers are called confining layers (aquitards). If a confining layer exists above an aquifer which is fully saturated, this aquifer is then a confined or artesian aquifer. Confined aquifers contain water that is under substantial pressure. Aquifers without a confining layer above them are called unconfined aquifers or water table aquifers and contain water that is under atmospheric pressure.

The groundwater model you will be looking at in this activity has two aquifers: an unconfined aquifer of white sand with a small area of gravel included, and a confined artesian aquifer of gravel along the bottom. The aquifers are separated by a confining layer containing clay.

Wells

The most common method for withdrawing groundwater is to penetrate the aquifer with a vertical well and then pump water up to the surface. Deep wells, those more than 30 m (100 ft) deep, are most commonly used for public water supplies. They can penetrate extensive aquifers with more dependable yields of water and better water quality than shallower wells can. Deep wells are typically 100-300 mm (4-6 in.) in diameter. They are drilled using percussion or rotary drilling techniques. Deep wells are permanently lined with a metal pipe called a casing. (Plastic [PVC] casings are used in some instances). The space between the ground and the casing is filled with cement grout. The casing and the grout serve to seal off poor water quality coming from the surface and upper soil layers, protecting the well from contamination. A sanitary seal is installed at the top of the casing to further protect the water quality. In unconsolidated aquifers, a slotted well screen is usually attached to the bottom of the casing to strain silt and sand out of the well water. These basic features of deep well construction are illustrated in Figure 1.

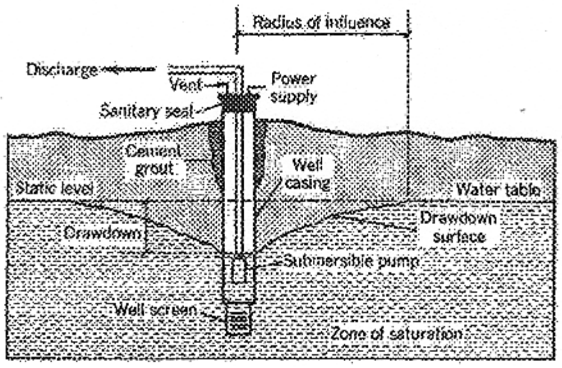


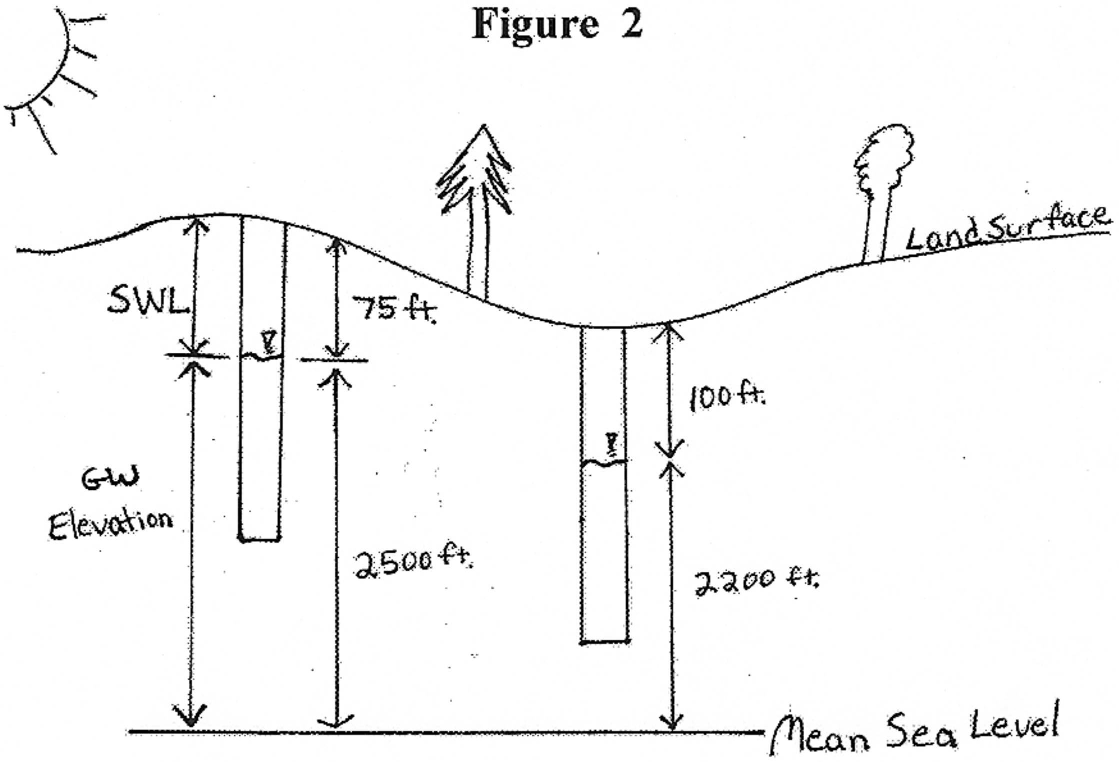
Figure 1

Schematic diagram of a water table well showing the drawdown that occurs during water withdrawal by pumping.

The distance from the ground, down to the water level in a well (water table) before the well is pumped is called the static water level (SWL). The distance from mean sea level up to the water level is the groundwater elevation, as seen in Figure 2. When the well is pumped, the water level in the well drops below the static level, as seen in Figure 1. The elevation difference between the static level and the pumping level is called the drawdown. A drawdown surface of the water table, or cone of depression, is formed around the well during pumping.

As the distance from the well increases, the slope of the drawndown curve flattens out, eventually merging with the undisturbed static water level. The horizontal distance from the well to the area where the water table has not been appreciably affected by the pumping is called the radius of influence of the well. This is also demonstrated in Figure 1.

Figure 2



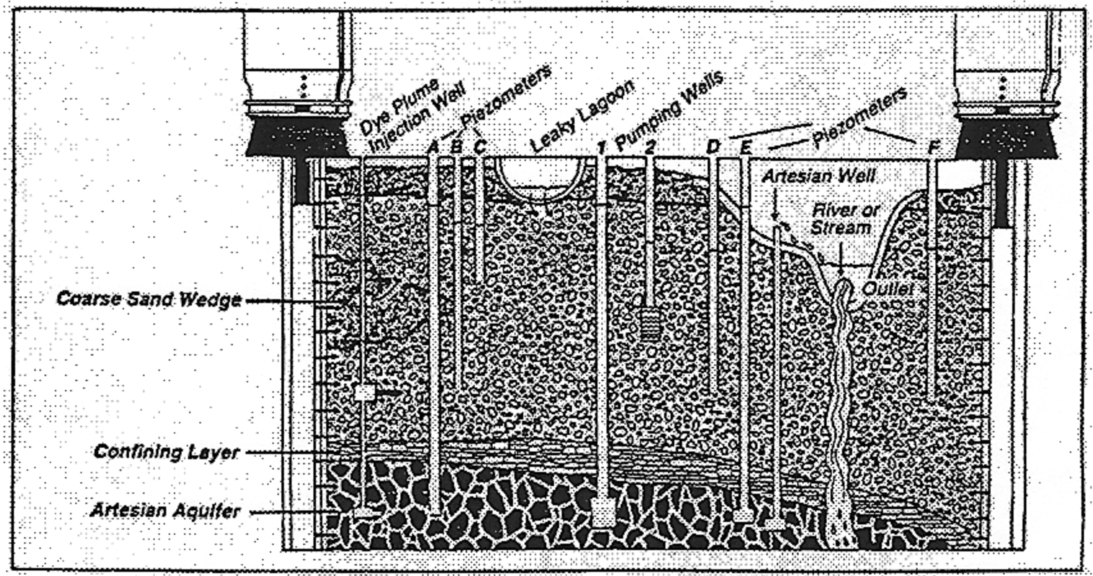
When a well is drilled to penetrate any aquifer, water will enter the well casing. In an unconfined aquifer, the water level will stabilize in the well at the top of the saturated zone, which is called the water table. In a confined aquifer, water in the well will rise above the top of the aquifer because confined aquifers contain water under pressure. The level to which the water rises is called the potentiometric surface. The potentiometric surface of the confined aquifer is analogous to the water table of the unconfined aquifer. If the potentiometric surface is above the surface of the ground, a flowing well or spring may result.

Where does groundwater come from, and where is it going?

Once water percolates down to the water table to become groundwater, it starts to move slowly down gradient toward an area where it can discharge at the surface of the ground. Those areas where water enters the groundwater system are called recharge areas, and those areas where groundwater reappears at the surface of the ground are called discharge areas.

Groundwater recharge areas are usually located in upland areas. However, where topographic differences are small, most of the land area can be considered part of the recharge area. Groundwater discharge areas are normally topographically low areas such as lakes, rivers, and wetlands. The amount of groundwater recharge that occurs is related to the size and degree of connectivity of the pores in the soil, the topography, and the timing and intensity of the precipitation.

Groundwater Model



Darcy's Law on the flow of water through porous material

In the 1850s, a French engineer, Henry Darcy, studied aspects of the movement of water through porous materials such as those found in groundwater aquifers. His results have become widely used in groundwater study and are known as Darcy's Law. Darcy found that the amount of water that flowed through porous materials in a cylinder was directly related to the cross-sectional area of the cylinder and the differences in height at the two ends of the cylinder. He also found that the flow was directly proportional to the hydraulic conductivity (K) of the material.

Hydraulic conductivity is a term that relates to both the physical properties of the porous material itself (its permeability), and the physical properties of the fluid that is passing through it. In the case of groundwater, hydraulic conductivity relates both to the earth materials and the water in the aquifer.

Although differences do exist in the amounts of materials dissolved in groundwater and the degree to which groundwater is polluted, these differences are usually not large enough to be important to hydraulic conductivity. There is a significant difference when you compare dissimilar fluids like water and petroleum, however.

Most of the differences in K are explained by the properties of the earth materials themselves. For example, a sand and gravel aquifer might have a K of 50 ft/day. A limestone aquifer might have a K value of 2000 ft/day. Although the porosity of limestone rock itself is very low, the many cracks and crevices in the formation allow water to move through it quite easily. In a sandstone aquifer, the sand itself might be quite similar to the sand in the upper aquifer of the model. However, the pores between the sand grains in sandstone are mostly cemented up with finer materials. This is what causes the sand to hold together as a rock. Since the cement fills up many of the pore spaces, K would be around 0.5 ft/day, two orders of magnitude less than found in loose sand.

Note that even though K has the units of ft/day, it is not a measure of actual groundwater velocity. The actual velocity of groundwater is modified by the hydraulic gradient, or the change in water elevation between recharge and discharge areas.

The equation that Darcy developed is:

$$Q = K I A$$

where:

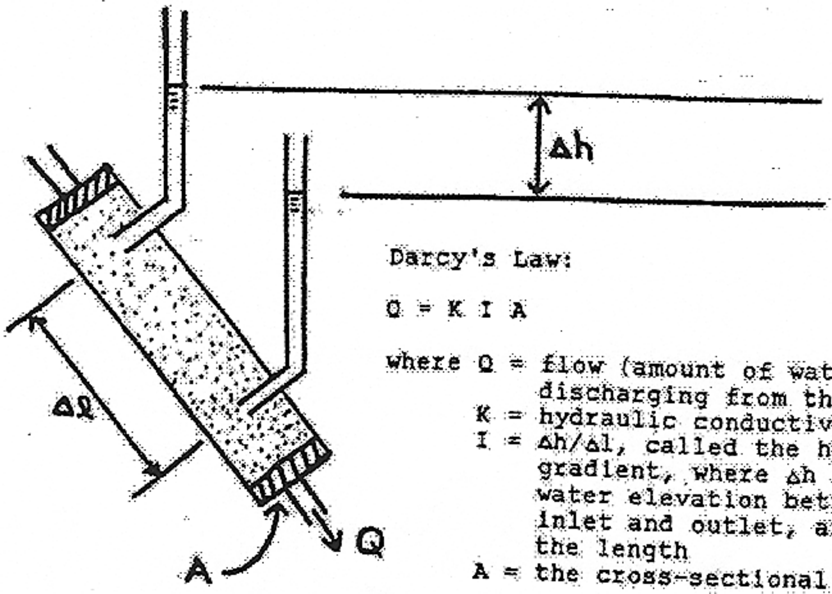
- Q = flow (volume of water/time) discharging from the outlet
- K = hydraulic conductivity in ft/day
- I = $\Delta h / \Delta l$, called the hydraulic gradient, slope of the water table where Δh = the change in water elevation between the inlet and outlet, and Δl = the length between inlet and outlet
- A = the cross-section area

A diagram illustrating Darcy's Law can be found on the following page. A general explanation of Darcy's Law is that the rate of groundwater flow is regulated by the permeability of the aquifer material, the difference in elevation between the recharge and discharge area, and the force of gravity. Darcy's Law has application to real-world groundwater flow studies, but difficulties arise because K can vary within an aquifer, and I, the hydraulic gradient, is not constant, and A, the cross-sectional area, may change between the recharge and discharge area. Calculations are sometimes made using average values for these factors, however.

Note:

This material was taken directly from the Manual for the Use of the Sand-Tank Groundwater Flow Model written by Chris Mechenich, 2nd Ed., Sept. 1990 and from Basic Environmental Technology written by Jerry A. Nathanson, 3rd Ed., 2000.

AN EXPERIMENTAL APPARATUS TO ILLUSTRATE DARCY'S LAW

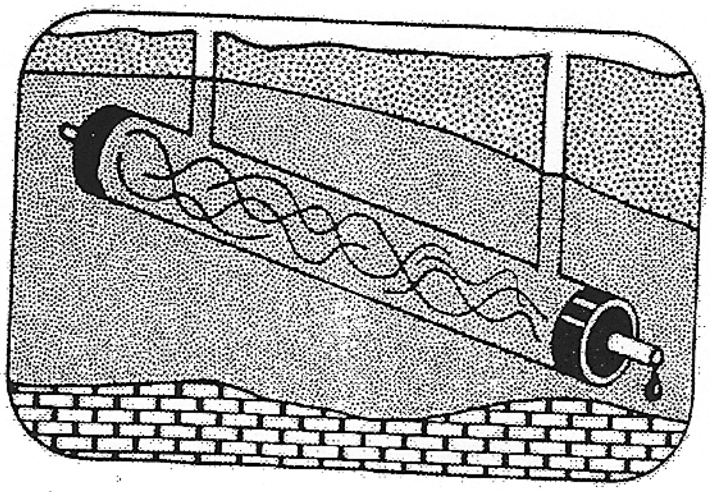


Darcy's Law:

Q = K I A

where Q = flow (amount of water) discharging from the outlet,
K = hydraulic conductivity
I = Δh/Δl, called the hydraulic gradient, where Δh = change in water elevation between the inlet and outlet, and Δl = the length
A = the cross-sectional area

An artist's conception of how Darcy's Law might apply to the real world.



(drawings adapted from <u>Groundwater</u>, Freeze and Cherry, 1979.)

Taken from Manual for the Use of the Sand-Tank Groundwater Flow Model written by Chris Mechenich 2nd Ed., Sept. 1990.

DEFINITIONS

Aquifer a saturated porous medium that will yield a usable quantity of water to a well which is open to the saturated medium.

Water Table an aquifer whose potentiometric surface is the water table.

Artesian an aquifer with a potentiometric surface above the top of the saturated porous medium comprising the aquifer.

Aquitard a saturated porous medium through which water can move, but not in sufficient rates to supply a usable quantity of water to a well.

Aquiclude a saturated porous medium that restricts the flow of water to the point that the material can be considered impermeable (there are probably no true aquicludes).

Porosity (n) a measure of the void space in a porous medium, expressed as the ratio of the volume of the voidspace in a unit volume of material (V_p/V_t), dimensionless.

Specific Yield (S_y) a measure of the amount of water that will drain under gravity from a Water Table Aquifer expressed as the ratio of the volume of water that will drain from a unit volume of the aquifer (V_g/V_t), dimensionless.

Specific Storage (S_s) a measure of the volume of water that will be released from storage in a unit volume of an Artesian Aquifer with a unit reduction of the potentiometric surface, dimensioned 1/L.

Hydraulic Gradient (I) the slope of the potentiometric surface between two points in an aquifer, $(h_2-h_1)/d$, dimensionless.

Hydraulic Conductivity (K) a measure of the ease with which water may move through a unit area of a saturated porous medium, dimensioned L/T.

Darcy's Law the velocity of groundwater flow is a function of the Hydraulic Conductivity and the Hydraulic Gradient ($v=KI$).
Commonly expressed as a volumetric flow equation in the following forms:

$$Q = -KIA$$

$$Q = -KA\,dh/dl$$

Influent and Effluent streams

Streams that are located above the local water table are called **influent** or "losing" streams, as they contribute to the underground water supply (➢ Figure 10.8a). Beneath influent streams there may be a mound of water above the local ground-water table known as a *recharge mound*. A stream that intersects the water table and which is fed by both surface water and ground water is known as an **effluent** or "gaining" stream (➢ Figure 10.8b). A stream may be both a gaining stream and a losing stream, depending upon the time of year and variations in the elevation of the water table.

Where water tables are high, they may intersect the ground surface and produce a spring. Springs also are subject to water-table fluctuations. They may "turn on and off" depending upon rainfall and the season of the year. ➢ Figure 10.9 illustrates the hydrology of three kinds of springs.

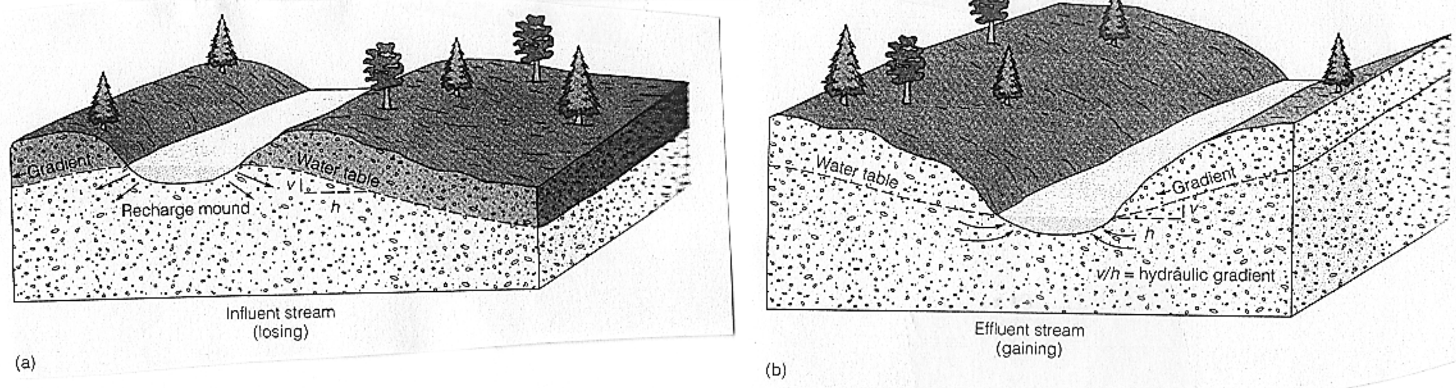
Pressurized Underground Water

Pressurized ground-water systems cause water to rise above aquifer levels and sometimes even to flow to the ground surface. Pressurized systems occur where water-

Wells that penetrate confined aquifers are called *artesian wells,* after the province of Artois, France, where they were first described. Artesian systems are distinguished by a water-pressure gradient called a **potentiometric surface** (see Figure 10.10b). This "surface" is the pressure level to which water will rise in a well at a given point along the aquifer. Wells that penetrate pressurized aquifers—artesian wells—differ from static water-table wells in that static water-table wells depend upon pumping or topographic differences to create a gradient that causes the water to flow. Since the greatest expense in ground-water production is the cost of the energy necessary to lift water to the surface, artesian systems are much desired and exploited. Not all artesian wells flow to the ground surface, because as water is extracted, the potentiometric surface lowers; water may rise only part way up the well bore. Nevertheless, a natural rise of water any distance up the well reduces the cost of extracting ground water.

A common misconception about artesian-well water is that it is purer than other kinds of underground water. Actually, the word *artesian* refers only to the kind of aquifer; it has nothing to do with water quality. Do not be misled by beverage advertisements for "artesian" products.

➢ FIGURE 10.8 (*a*) An influent (losing) stream contributes water to the water table. (*b*) An effluent stream gains water from the water table.



Pipkin, B. (1994). Geology and the Environment.