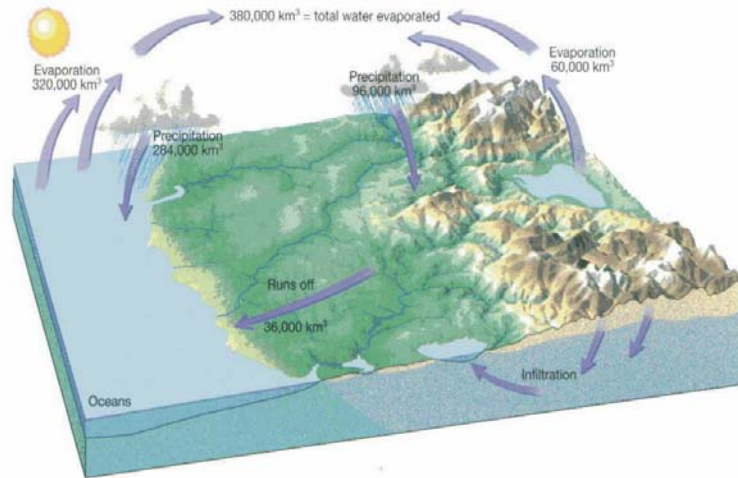


## RUNNING WATER AND GROUNDWATER

### I. Introduction

In this exercise we will investigate various features associated with streams and groundwater. Our drinking water ultimately comes from either streams or groundwater, and contamination of these sources is a significant environmental hazard. Therefore, a basic understanding of hydrologic processes is useful in helping us identify the source of drinking water contamination.

The movement of water at the earth's surface is represented by the hydrologic cycle (Figure 1). Water is evaporated from the ocean and land, transported via the atmosphere, and then returned to the ocean and land as precipitation (rain, snow, sleet, etc.). Precipitation that falls on the land either remains at the surface and becomes surface runoff or infiltrates the surface and becomes part of the groundwater system. This is a closed system, water is neither lost or gained, but the water is redistributed. Hence, changing climatic conditions due to changes in the atmospheric circulation can redistribute water on the earth's surface so that locally one can have periods of drought or excessive precipitation.



**Figure 1.** The hydrologic cycle. From Tarbuck et al. (2003).

The availability of potable water (note that sea water has a high salt content and, therefore, sea water is not potable) is a major factor in human habitation. You may know that the only reason large numbers of people can live in Southern California is because of the diversion of water from the Colorado river and other rivers to southern California. You may also know that in the arid west, where the availability of water is crucial to the raising of live stock and agriculture, water rights were a major and contentious issue. Here in the northeast, because of a history of industrial development, the purity of water is a major concern. Determining the source of contaminants in river and groundwater is an exercise in Forensic Geology.

### II. Streams and rivers

Water moves downhill until it reaches a *base level* below which it cannot flow. The area that serves as the catchment for the overland flow moving to the stream is referred to as the *drainage basin*. The drainage basin for any particular stream can be defined by determining the topographic high points around the stream. There are two fundamentally different types of rivers, related to how they interact with the groundwater system:

1. *Effluent rivers* are rivers that get some of their water from the groundwater system. The surface of the stream directly relates to the surface of the groundwater (called the water table), and the stream will rise and fall as the water table rises and falls. You will have noticed that even in late summer, when there

hasn't been any significant rainfall for an extended period of time, there is still water in the Merrimack River. Hence, effluent streams have a base level flow determined by the groundwater system. You also know that at other times of the year, during the spring snow melt and times of high rainfall, there is a great deal of water in the Merrimack. This additional water is due to both increased overland flow and infiltration of water into the groundwater system that raises the groundwater table.

2. *Influent rivers* are rivers that add water to the groundwater system. They are most commonly found in arid climates where the groundwater table is deep below the land's surface. However, even in humid climates such as the northeast, rivers can show influent behavior if an external variable, such as the removal of groundwater for drinking water, leads to a lowering of the local water table (see section on groundwater).

The amount of water flowing in a stream is referred to as *discharge*. A river's discharge is equal to its *cross-sectional area* multiplied by its *velocity*:

$$\text{Discharge} = \text{Velocity} \times \text{Cross-sectional area}$$

Discharge generally increases downstream because water is added by tributaries joining the stream. The above equation suggests that a river should become deeper and wider and flow faster if its discharge is increased. Downstream increases in width and depth are easily noticed but increases in velocity are offset by lower downstream gradients.

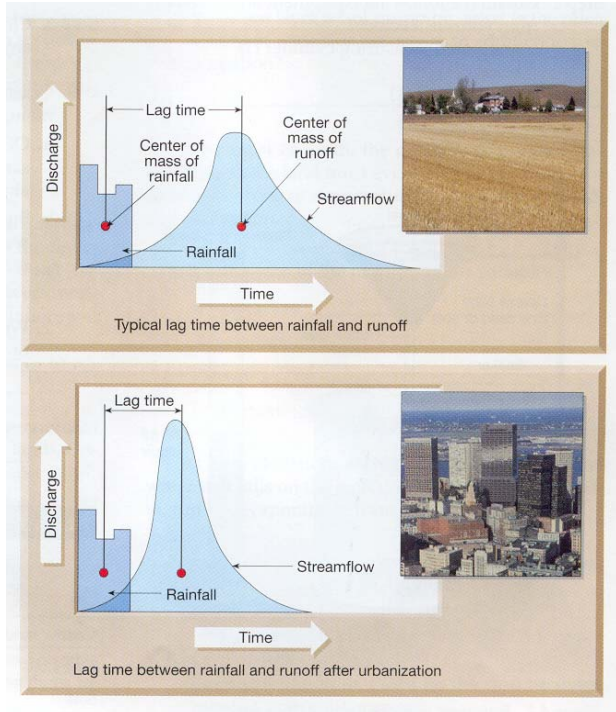
**Exercise 1.** Relationship between discharge, velocity and cross-sectional area.

1. We make observations at two points, *A* and *B*, along a river. *B* is downstream from *A*. At *A* the stream is 30 meters wide, has an average depth of 2 meters and an average velocity of  $2 \text{ m sec}^{-1}$ . Calculate the discharge of the stream. How much water will flow by point *A* in 1 hour.
  
2. At *B* the stream discharge is the same but the width is now 20 meters. The average depth is still 2 meters. Calculate the average velocity.

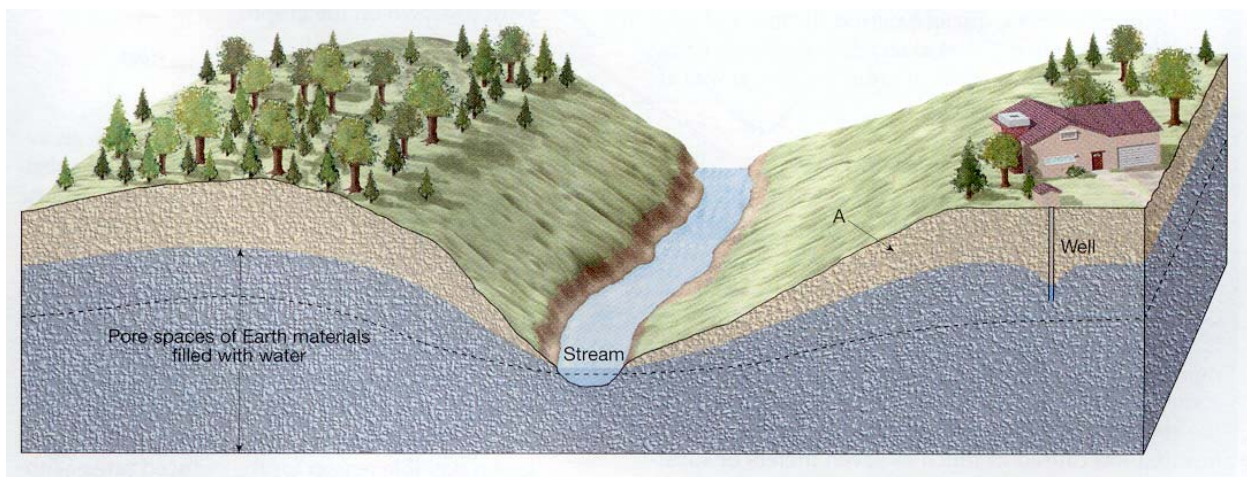
Urbanization also has a significant impact on discharge (Figure 2). Before an area is developed, the natural ground cover (trees, shrubs, grasses, etc.) retards the overland flow of water to a stream. In addition, some of the precipitation will infiltrate the ground and move into the groundwater system. When the natural conditions are disturbed and, in particular, are replaced by impervious surfaces (surface that don't allow infiltration) such as asphalt and concrete, there is both a notable increase in the total amount of overland flow (because of the lack of infiltration) and the rapidity of the overland flow. The result is a notable increase in stream discharge, a much higher peak discharge, and a much shorter time between the precipitation event and the peak discharge. These changes can, and have, led to an increase in urban flooding. Also note that in an urbanized areas various kinds of pollutants, particularly those related to transportation, are readily available. For example consider cars that have oil leaks and are parked for a period of time at a shopping center. During a precipitation event this oil is washed off the parking lot and into the local streams.

### III. Groundwater systems

Precipitation that is absorbed into the ground migrates downward through soil and bedrock until it reaches a depth below which all void spaces are saturated (Figure 3). This level marks the upper surface of the local *water table*. The zone in which the void spaces are filled with fluid is called the *zone of saturation* and the zone in which the void spaces are not completely filled with water is referred to as the *zone of aeration*. The position of the water table is variable and its depth changes with surface topographic irregularities; being slightly elevated under hills and somewhat depressed under valleys. Water within the saturated zone is not



**Figure 2.** The effect of urbanization on stream flow. Top, natural conditions. Bottom, after urbanization. From Tarbuck et al. (2003)



**Figure 3.** Zones of aeration and saturation and the location of the water table. Note cone of depression developed around the well. From Tarbuck et al. (2003).

stagnant, but slowly migrates through soil and bedrock by following local gradients in the water table surface. When this slowly moving groundwater reaches an intersection of the water table with the land surface it forms a spring or is added to a lake or stream.

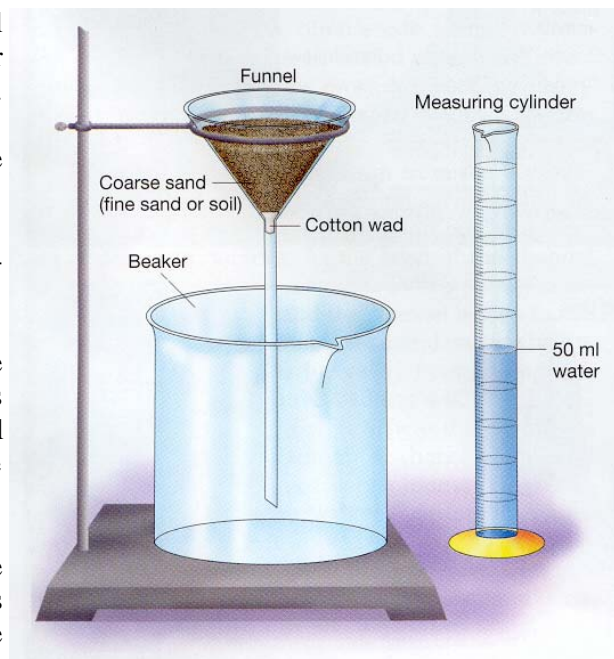
When water is pumped from a well, groundwater flows towards the well. This is not an instantaneous process and generally water is extracted from the well faster than it can be replenished by groundwater flow. The result is a *cone of depression* (a local depression developed in the water table around the well, Figure 3). The rate at which water moves towards the well is determined by the slope of the water table and the ease with which the water can move through the subsurface material (the hydrologic conductivity). This relationship is known as Darcy's Law and we will use this relationship in the Civil Action case.

It is important to understand the difference between porosity and permeability. *Porosity* is the total void space in a material. For example, sand has a porosity of around 30%. If you look at a pile of sand you will see that there are gaps between the sand grains. All the sand grains must touch, but they are not completely interlocked. Mud has an even higher porosity of around 50%. *Permeability* is the ease with which a fluid can move through a material (this is directly related to hydrologic conductivity). This movement depends on the interconnectedness of the void spaces. For example, in sand the void spaces are connected and sand is permeable. On the other hand, despite the large porosity of mud, the void spaces are not interconnected and mud has a low permeability. The permeability (hydrologic conductivity) is an important factor in determining the rate of groundwater flow.

### Exercise 2. Determination of permeability

We can do a relatively simple experiment that will enable us to estimate the permeability of a particular material. The experimental setup is shown in Figure 4.

- Step 1.** Place a small wad of cotton in the neck of the funnel.
- Step 2.** Fill the funnel above the cotton about two-thirds full with coarse sand.
- Step 3.** With the bottom of the funnel placed in the beaker, measure the length of time that it takes for 50 ml of water to drain through the funnel filled with coarse sand. Record the time in the data table, Table 1.
- Step 4.** Using the measuring cylinder, measure the amount (in milliliters) of water that has drained into the beaker and record the measurement in the data table.
- Step 5.** Empty and clean the measuring cylinder, funnel, and beaker.



**Figure 4.** Equipment setup for permeability experiment. From Tarbuck et al. (2003).

**Step 6.** Repeat the experiment two additional times, using fine sand and then soil. Record the results of each experiment in the appropriate place in the data table. (*Note:* In each case, fill the funnel with the material to the same level that was used for the coarse sand and use the same size wad of cotton.

**Table 1.** Data table for permeability experiment

	Length of time to drain 50 ml of water through funnel	Milliliters of water drained into beaker
Coarse sand		
Fine sand		
Soil		

1. Of the three materials you tested, which one had the greatest permeability? Which one had the least permeability?
  
  
  
  
  
  
  
  
  
  
2. Suggest a reason why different amounts of water were recovered in the beaker for each material that was tested.
  
  
  
  
  
  
  
  
  
  
3. Write a brief statement summarizing the results of your permeability experiment.