The Science of Groundwater

Introduction

Groundwater supplies drinking water to approximately two-thirds of Vermonters. It is estimated that 320,000 Vermonters get their water from approximately 100,200 private wells (not including dug wells or springs). [1] Groundwater is clearly an important resource for Vermonters. To help to understand the science of groundwater protection, VNRC has created this document outlining the fundamentals of this vital resource.

Groundwater or Surface Water?

Groundwater is surface water. It happens to be underground. It is not uncommon for people to talk about groundwater and surface water as separate types of water. Indeed, our current regulatory system segregates the two when in reality they are fundamentally connected. However, they are inextricably linked. Groundwater contributes to surface water, and surface water contributes to groundwater and the two are inseparable.

Groundwater is water that is underground. Water cycles from atmospheric (clouds, rain etc) to surficial (surface water) to subsurface (groundwater) as a part of the hydrologic cycle. Water molecules spend time in each stage.

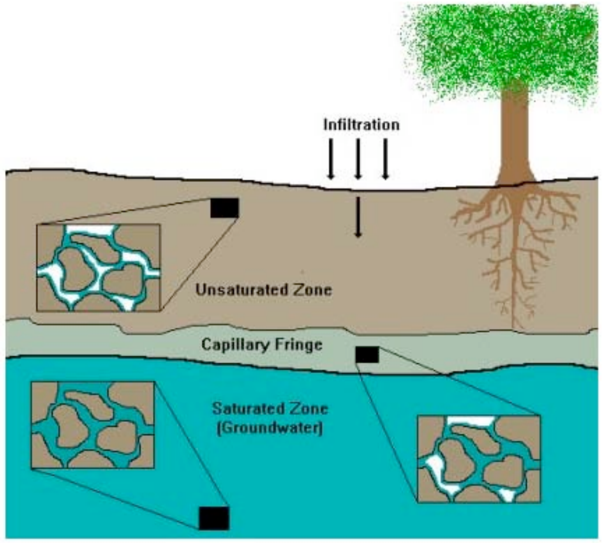
Generally speaking, water spends about a week and a half in the atmosphere, two weeks in stream channels, about ten years in lakes and ponds, a thousand years in glaciers, four thousand years in the ocean, and anywhere from two weeks to ten thousand years in groundwater. Therefore, once water enters the groundwater system, it remains in this location for a very long time. Because of this, pollutants that enter groundwater stay there much longer than they do in, say, streams or rivers.

Groundwater Fundamentals

Groundwater exists in various forms under our feet. There is water between the soil particles, water within fractures in bedrock, water that is held tightly and is unavailable (residual water), and water that saturates soil. There are no underground rivers; all water underground is held in spaces in either rock or soil. These different zones of water have different names.

The first zone immediately under our feet is known as the unsaturated or vadose zone. Here, air fills the spaces between soil, sand and gravel and rocks. In this zone, the spaces in between the soil particles, gravel and rock are not saturated with water, but instead, with air.

[1] State of Vermont 2006 Water Quality Assessment, Clean Water Act Section 305(B) Report.



Moving deeper, towards the Earth's core, and just above the water table, we reach water that has been "wicked" up into soil. This zone is known as the capillary zone, named for the action that "wicks" this water upward. This area is the transitional layer between the unsaturated and saturated zones.[2]

Next we reach the water table, or saturated zone. This is the area of which the upper layer (adjacent to the capillary fringe) is open to atmospheric pressure and below which is saturated with water (groundwater). In the lower levels of the water table, we reach the saturated zone. This is the layer of material that is saturated with water and is referred to as the zone of saturation.

Aquifers

Another fundamental of groundwater is the concept of an aquifer. Aquifers are where most groundwater is found. They are comprised of porous rock or layers of sand and gravel that are saturated with water. There are two general types of aquifers: confined and unconfined.

Confined aquifers are found underneath clay, dense rock or other material layer that is very dense. Because this water is confined, it is under a great deal of pressure. When this water is tapped into, say for a well, the water is released with force, forming what we know as an artesian well. [3]

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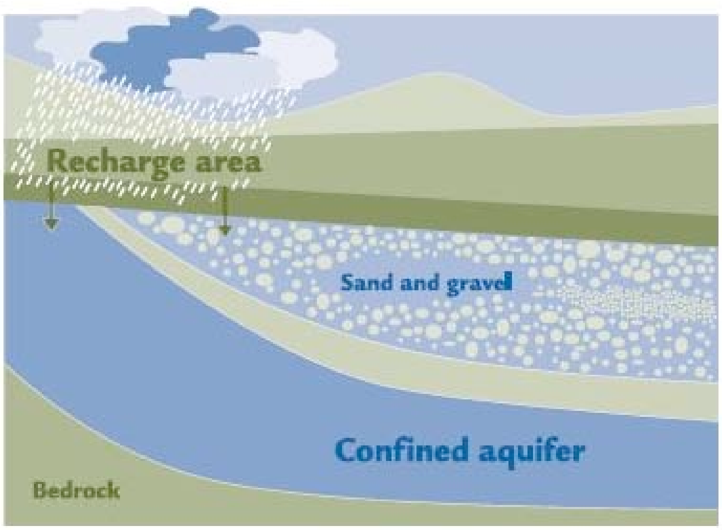
[2] http://oceanworld.tamu.edu/resources/oceanography-book/groundwater.html

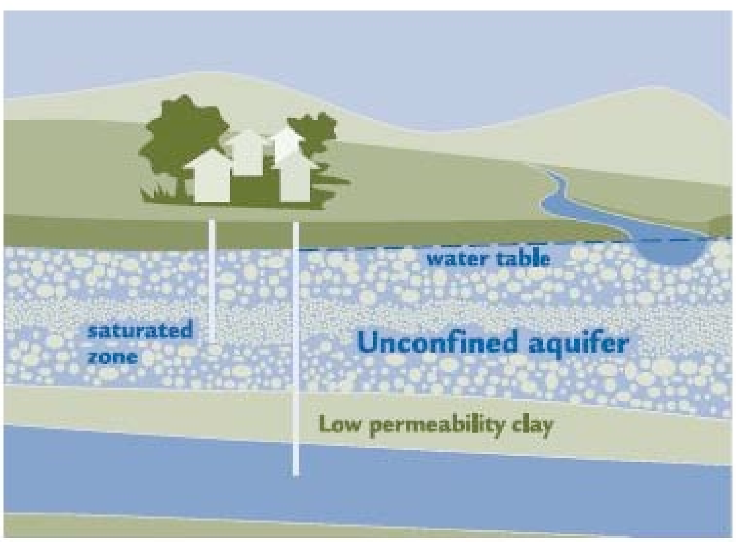
[3] http://www.tol.bc.ca/index.php?option=com_content&task=view&id=1063&Itemid=900



Confined Aquifers:

In a confined aquifer, groundwater is sandwiched by impervious layers of material (such as fine silt or clay) called **aquitards**. The surface aquitard prevents the passage of contaminants into the aquifer. As such, confined aquifers are often good sources of drinking water. However, confined aquifers are not completely protected and may still be vulnerable to contamination at their recharge area, which may be located kilometres away and exposed.

Unconfined aquifers are more common and are overlain by a more permeable layer, such as sand and gravel. These aquifers are usually fed by rainwater percolating through the soil. If you could look inside this type of aquifer, you would see a layer of material that is saturated with water. These types of aquifers are more common than confined aquifers and the water in them may have arrived more recently by percolating through the soil above the water table. [4]



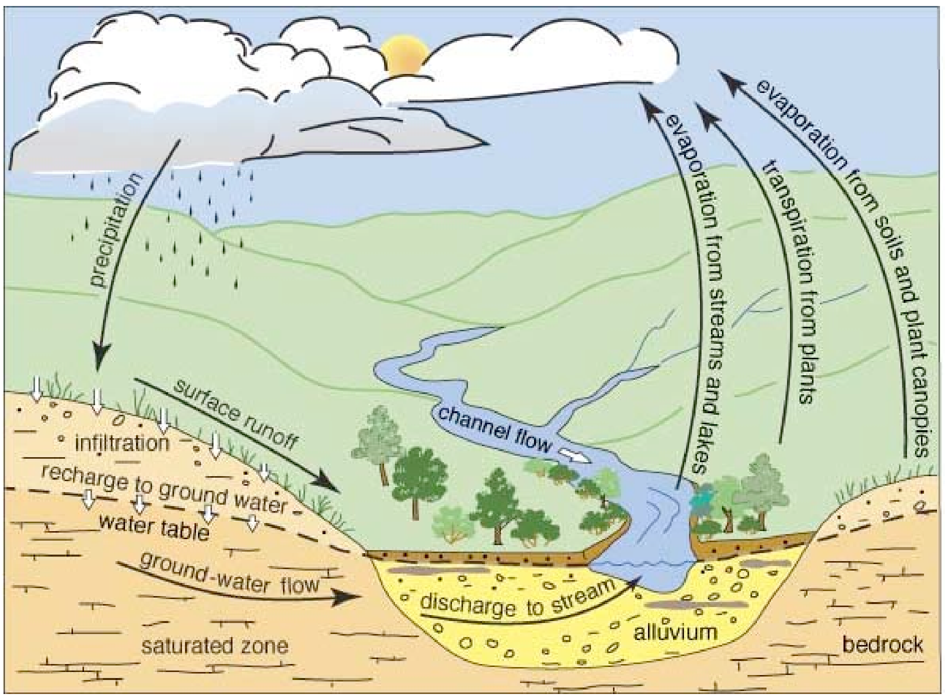
Unconfined Aquifers:

Unconfined aquifers do not have an impermeable layer overying and protecting the aquifer. Instead, the overburden consists of highly permeable material, such as sand or gravel. Because surface water and contaminants can pass readily through the overburden to the water table, an unconfined aquifer is more susceptible to contamination.

[4] http://www.tol.bc.ca/index.php?option=com_content&task=view&id=1063&Itemid=900

Groundwater and Surface Water Connections

The lower levels of water in streams is groundwater that has traveled from an unconfined aquifer into a stream bed. Groundwater flow maintains the base flow of a stream during drier times of the year like the hot days of August. This cool groundwater entering the stream keeps the temperature of the water low enough so that oxygen-loving organisms can survive through the "dog days" of summer. The factors that dictate this flow are discussed below. Groundwater is the source of water for streams, springs, lakes and wetlands. Because of this connection, it is impossible to talk about surface water without also considering groundwater flow.[5]



The source of groundwater is through precipitation or surface water that percolates downward. This is called recharge. Approximately 5-50% of annual precipitation results in groundwater recharge. The amount varies depending on climate, land use, soil type, geology and many other factors. In some areas, streams literally recharge the aquifer through streambed infiltration, called "losing" streams. Left untouched, groundwater naturally arrives at a balance, discharging and recharging to streams depending on hydrologic conditions such as rain and snowmelt.

[5] http://www.kgs.ku.edu/Publications/PIC/pic23.html&h=291&w=600&sz=20&hl=en&start=18&um=1&tbnid=xOJ14atOH2YEKM:&tbnh=65&tbnw=135&prev=/images%3Fq%3D%2Baquifer%2Btype%26um%3D1%26hl%3Den%26sa%3DG

Groundwater Flow

Now that we've talked about the fundamentals of groundwater, let's look a little deeper into what happens underground.

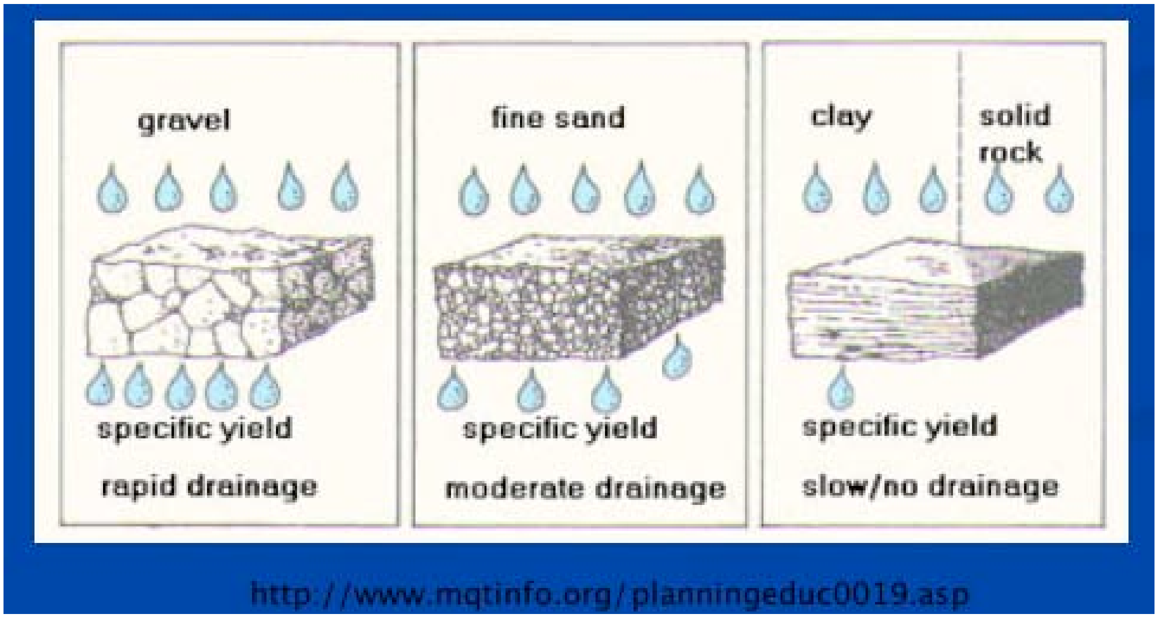
Groundwater flow is impacted by a complex set of interactions of several factors. Some of those factors are hydraulic gradients, hydraulic conductivity, soil porosity and the specific yield of the soil.

Hydraulic gradients determine the nature of the flow. Generally, water moves from a high gradient to a low gradient, just like most everything else in nature. Usually this means water runs from a higher elevation to a lower elevation. Given all of the other factors that influence flow, however, this is just one piece of the puzzle.

Every soil has a specific hydraulic conductivity. This conductivity determines the ease with which water can move through soil. This function is related to a number of factors, including the properties of the fluid being transmitted (groundwater) such as viscosity, intrinsic permeability of the soil and the soil porosity. Hydraulic conductivity is also scale dependent, so that measurements taken in one place cannot be directly extrapolated to the aquifer scale. Because of the very complex nature of hydraulic conductivity, it cannot be directly measured but is determined from fieldwork, laboratory data or via computer models.

Soil porosity also impacts how water flows. Soils like sand and gravel, which have large pore spaces, move water faster than soils with small porosity, such as clays. This is why sand and gravel aquifers are often tapped into and why clay layers often form an impermeable layer in the soil.

Another factor influencing groundwater flow is the specific yield of a soil. This factor, also known as the drainable porosity, indicates the volume of water that a given aquifer will yield when all the water is allowed to drain out of it under the forces of gravity. Different soils have different abilities to pass water through them. Water never completely drains from soil; there are always particles that are so tightly bound to the soil that no amount of pumping can pull them away.



Groundwater Availability

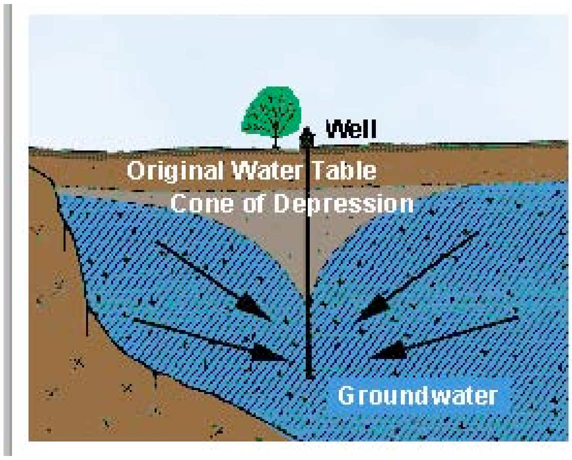
Just like groundwater flow, there are many complicated factors that influence groundwater availability. Among these factors are:

- Precipitation (what falls from the sky)
- Infiltration (what moves through the ground)
- Groundwater discharge (what moves out of the water table)
- Groundwater recharge (what moves into the water table)
- Shallow and deep groundwater flow (how water moves through the ground)
- Groundwater pumping (how much groundwater is removed by humans)
- Evaporation and transpiration (evaporation of water from the internal process of plants)(how much water goes back into the air)

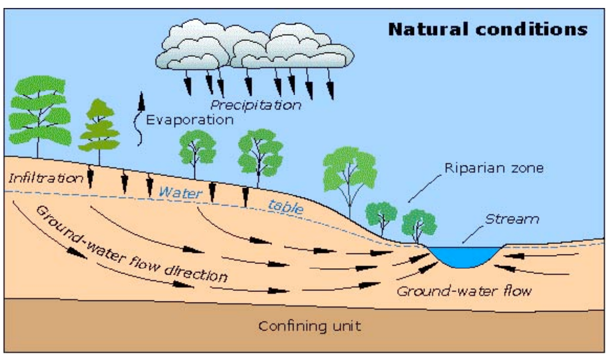
Effects of Pumping

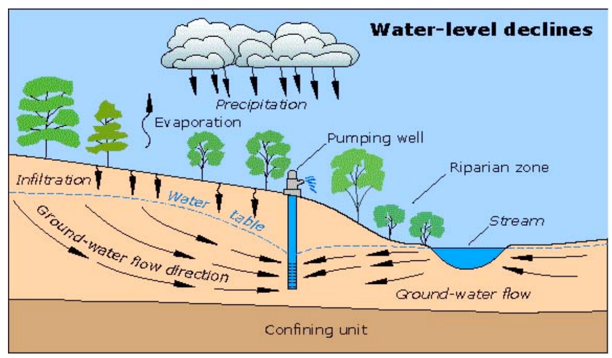
When water is pumped from an aquifer faster than additional water can reach the well, the water table is depressed around the well. This results in what is called a cone of depression.[6]

[6] http://www.rcrc.nm.org/glossary/gl-cone-of-depression.html



These cones of depression can be very large (up to half a mile in some cases). If the cone of depression reaches another well, that well may run dry. If it reaches nearby streams, it could cause the streams to dry up. [7]





Summary

Groundwater is a precious and finite resource and its travels through the hydrological cycle and through our lives is crucial. Many factors contribute to how much water is available and how it flows through the earth and these factors are important to help us to understand how our actions can impact groundwater.

For more information on work in Vermont to protect our water resources, please visit VNRC's website at www.vnrc.org.

[7] http://www.amiadini.com/newsletters/environmental-enlightenment-061.html