Teaching Groundwater Hydrology in a Wetland Ecology Class

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I taught Wetland Ecology 25 times: 15 as an Adjunct Associate Professor at the University of Michigan and UM-Dearborn while I worked at the USGS-Great Lakes Science Center in Ann Arbor and 10 as the Empire Innovation Professor of Wetland Science at SUNY--The College at Brockport in my native western New York State. During the first year in giving the wetland hydrology lectures in Michigan, founded on water budgets, I realized that non-hydrology students had great difficulty understanding groundwater. They can see surface water and precipitation and likely learned about evapotranspiration in a plant ecology course. However, groundwater is an unseen mystery, and typical text material is too complicated to unravel that mystery. Fortunately, about that time, my friend, the late Tom Winter, handed me the new USGS Circular 1139 – Ground Water and Surface Water: a Single Resource (Winter et al. 1998), and I quickly realized that I had a solution.

I have long-contended that wetland science students should take a hydrology course (Wilcox 2008) and made it a requirement for undergrads when I created the Wetland Ecology concentration at Brockport. My wetlands grad students must take the Hydrology course offered by the Earth Sciences Department. However, some in the Wetland Ecology class need special attention on hydrology, especially groundwater hydrology. So, as a follow-up on describing how I teach redox as a Chinese buffet (Wilcox 2019), I will now describe my approach to teaching wetland groundwater hydrology to the uninitiated using Circular 1139 figures accompanied by material from other sources. By no means is this meant to capture the breadth of groundwater science, but it provides the general understanding needed by a Wetland Ecology student. To show how I present the lecture, I will progress through individual figure- and written text-Powerpoint slides (each identified by •) (*with accompanying text of my spoken explanations in italics*).

- See Figure 1. *From your understanding of a water budget, you can see that in addition to surface water and precipitation, input to a wetland may include water from beneath the surface. Flow from the wetland may also include groundwater (as well as surface water and evapotranspiration).*

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- See Figure 2. *As precipitation reaches the surface, some of it enters the ground. There is enough water to saturate the soil and support a water table at a given elevation. This groundwater may flow to a surface water body, as shown here.*
- *It is time to learn some terms*.

  -**Water Table**: water level in an unconfined aquifer below which the pores are generally saturated

  -**Aquifer**: underground porous "water-bearing" strata that can store and transmit amounts of water large enough to be considered usable by humans or ecosystems, consisting of rocks and unconsolidated deposits that are saturated from above or from structures sloping toward it

FIGURE 1. https://water.usgs.gov/nwsum/WSP2425/images/fig18.gif

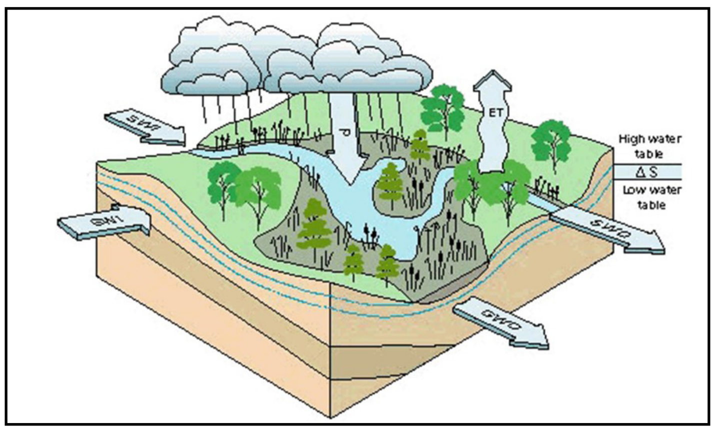
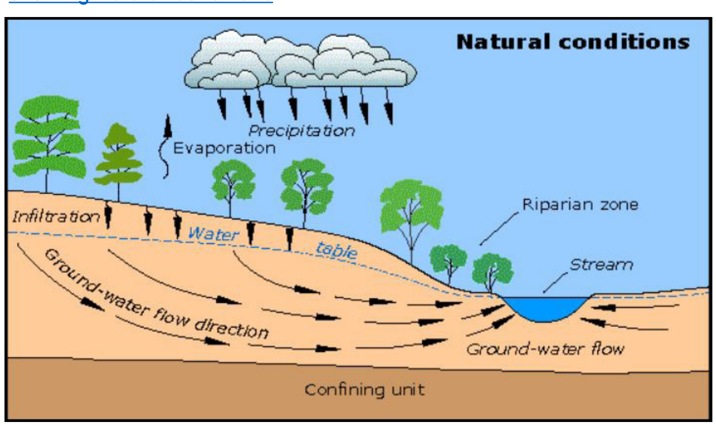


FIGURE 2. https://www.usgs.gov/media/images/groundwater-flow-showing-natural-conditions



-**Unconfined Aquifer**: an aquifer in which the upper boundary is the water table

-**Confined Aquifer**: an aquifer whose upper and perhaps lower boundary is defined by a layer of natural material that does not transmit water

- -**Confining Layer**: geologic material through which only insignificant amounts of water can move; located below unconfined aquifers or above and below confined aquifers
Note that Figure 2 shows a confining layer beneath the surficial or unconfined aquifer.

-**Permeable Layer**: a layer of porous material through which water freely passes as it moves through the ground

-**Impermeable Layer**: a layer of material (e.g., clay) through which water essentially does not pass

FIGURE 3. Redrawn by Peter Veneman from Richardson et al. (2001).

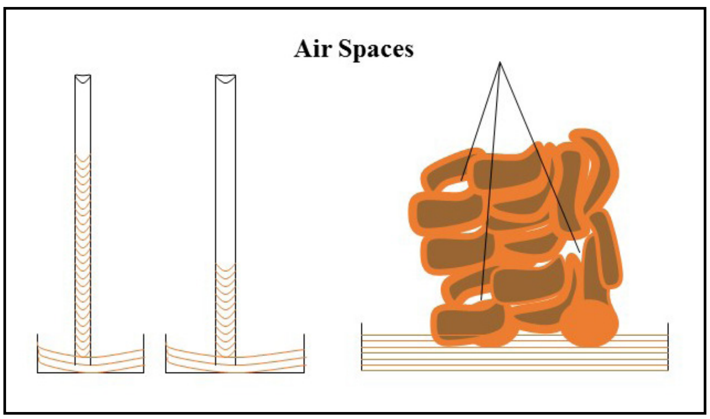
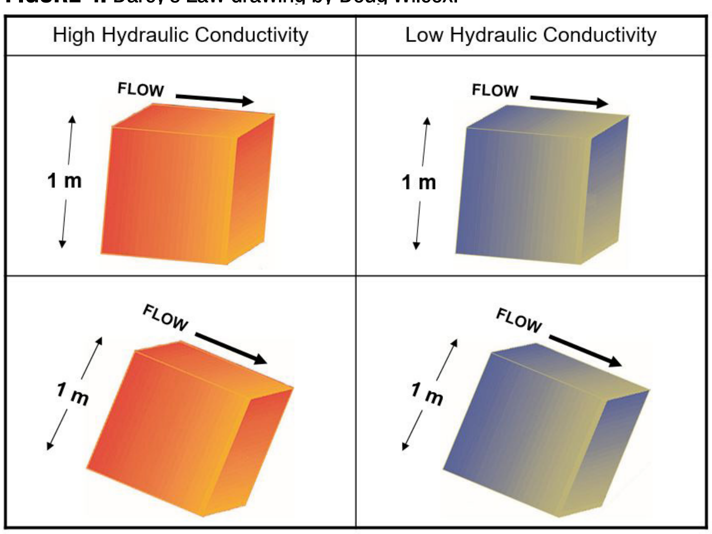


FIGURE 4. Darcy's Law drawing by Doug Wilcox.



DARCY'S LAW

$$Q = K \cdot A_x \cdot i$$

Q = flow rate of ground water (m^3/sec)
K = hydraulic conductivity (m/sec)
A_x = cross-sectional area (m^2)
i = hydraulic gradient (m/m)

-**Aquitard**: underground geological formation that is only slightly permeable and yields inappreciable amounts of water when compared to an aquifer

-**Hydraulic Conductivity**: ease with which water can flow through porous media

- -**Vadose Zone** (unsaturated zone): pore spaces between grains are filled with both water and air (above the water table)

-**Phreatic Zone** (saturated zone): pore spaces are filled with water; the "water table" describes the surface of the phreatic zone

-**Groundwater Recharge**: inflow of water to the groundwater system

-**Groundwater Discharge**: outflow of water from the groundwater system
Refer to Figure 2.

- See Figure 3.

-**Capillarity**: the ability of soil pores to retain water; effect is strongest in smallest pores and negligible in large pores

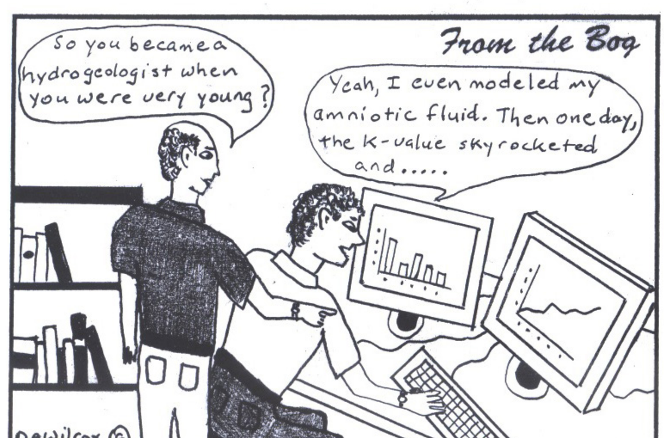
-**Capillary Fringe**: a zone just above the water table that is saturated or near saturation; in sands, it is virtually 0 and may be as high as 30-45 cm in clayey materials

- See Figure 4. *Darcy's Law can be shown in different ways; we shall use this form. Darcy's Law is used to explain the flow of groundwater and is the foundation for much of the science of groundwater hydrology*

It is a measure of Q -- the rate of flow of water as volume/time (e.g., cubic meters per second) and is composed of:

-the hydraulic conductivity K or ability of water to flow through the soil (m/sec), which differs greatly by soil

FIGURE 5. From the Bog drawing by Doug Wilcox.



Darcy's Law of Childbirth

type (very high for gravel, fairly high for sand, very low for clay). This is a characteristic of both the water viscosity and the soil, it is not the measure of flow (Q).

-A is the size of the plane or area across which flow is measured (m^2)

-i is the hydraulic gradient (similar concept to slope) across which the flow is measured (m/m)

-note that the units on the right side of the equation equal those on the left

To help illustrate Darcy's Law, I created this diagram. Each block represents a cubic meter of water that will pass left-to-right across the 1 m^2 plane at the right side. High hydraulic conductivity is represented by the lighter orange shading, and low hydraulic conductivity is represented by the darker blue shading. The hydraulic gradient is represented by different slopes of the blocks between the top and bottom rows.

From top to bottom, rate of flow Q will be greater when the hydraulic gradient i is greater because there is a greater potential to make water flow downhill. From left to right, Q will be greater for the orange block because water can flow more easily if the hydraulic conductivity or value of K is high.

- See Figure 5. *Increasing the value of K may also explain initiation of childbirth.*
- See Figure 6. *To understand groundwater hydrology, you must be able to think in three dimensions. I will try to add the third dimension to what you may already know in two dimensions.*

Did you ever delineate a watershed, given elevations of the land surface or contour lines on a topo map? Look at block A. If the numbers represent land-surface elevations on a hillside, you could construct a topo map like in block B with contour lines decreasing in value toward the bottom of the hill. If you were a drop of water falling in the upper right corner, you would not wander downhill in a random manner, you would go straight downhill as fast as you could – perpendicular to the contour lines, as in block C.

Well, the numbers are not land-surface elevations; they are the elevations of the water table or of water in water-table wells (the circles seen from above). The same principles apply – flow goes perpendicular to the contour lines). These elevations are typically below the land surface but they don't have to be. If they are higher than land surface then the aquifer is called artesian, meaning that water has the potential to flow above the land surface.

FIGURE 6. Figure A-2 from Circular 1139.

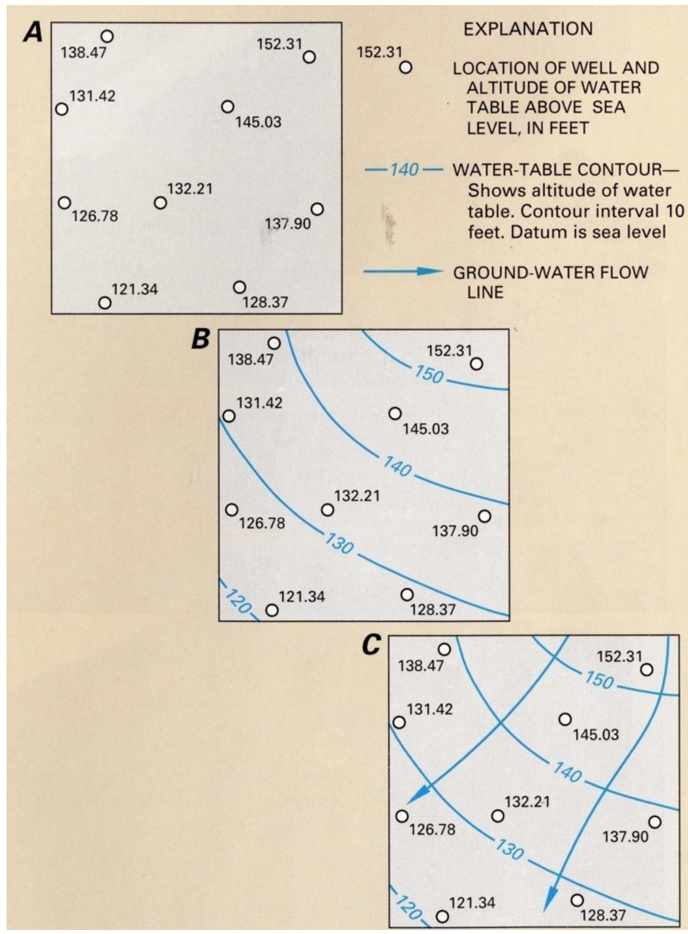


FIGURE 7. Figure A-3 from Circular 1139.

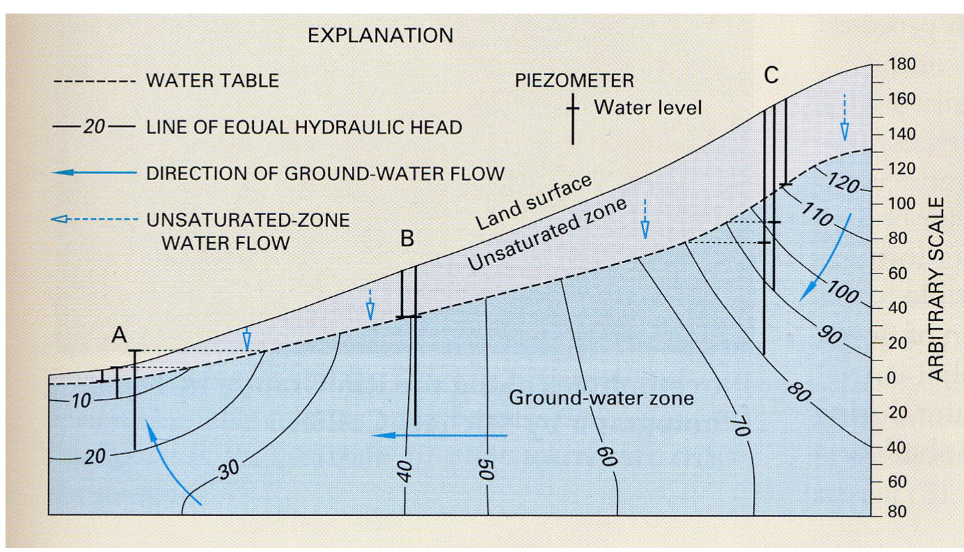


FIGURE 8. Photo by Doug Wilcox.

Water-table Well: a pipe that over a considerable length has openings or is slotted and measures the elevation of the water table at a given location; often used for sampling of groundwater to determine concentrations of various solutes

*To add that third dimension, let's look at a representation of block C from the side (*I then look into the edge of the screen*).*

- See Figure 7. *If we were looking at this from above, as in the last figure, there would be a contour line coming out of the screen at 120 and one at 110, etc. (let's call them meters).* (I hold a pencil coming out of the screen to make the point), *but they are not straight lines, they waver around* (move the pencil). *In fact, they are not even lines; they are planes* (I hold up a sheet of paper coming out of the screen following several of the isopleths and wave it around into classroom space).

So, how does groundwater flow across this diagram? As shown by the solid arrows, it goes perpendicular to those planes, from high numbers to lower numbers.

Let's look at this figure more closely. In the upper right, there is enough recharge from precipitation to

FIGURE 9. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_052914.pdf

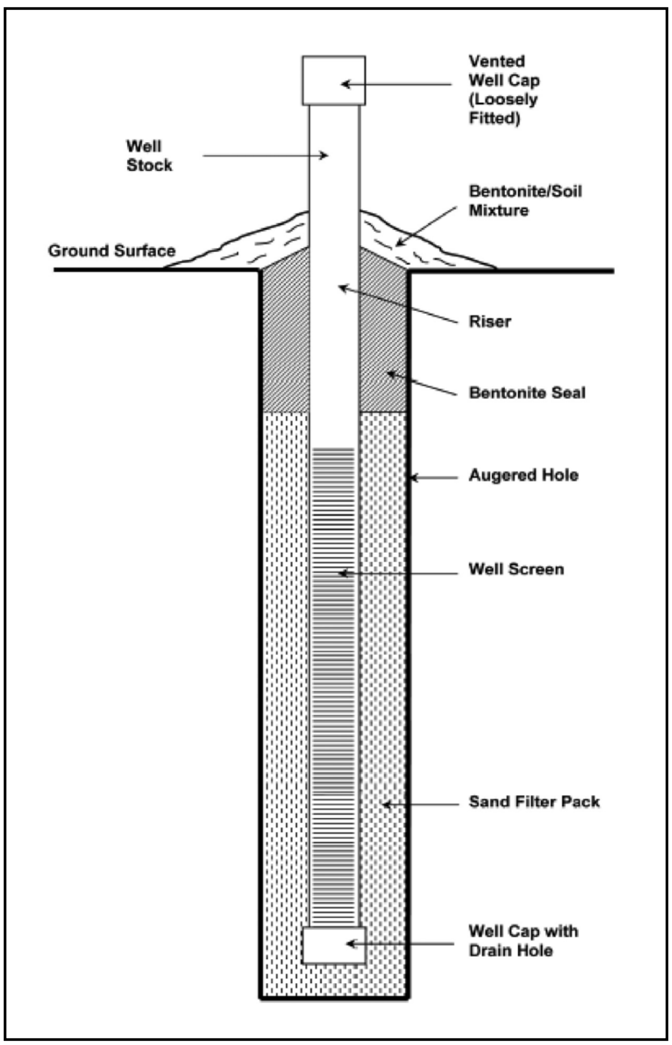


FIGURE 10. Photo by Don Rosenberry.

FIGURE 11. Redrawn by Peter Veneman from Richardson et al. (2001).

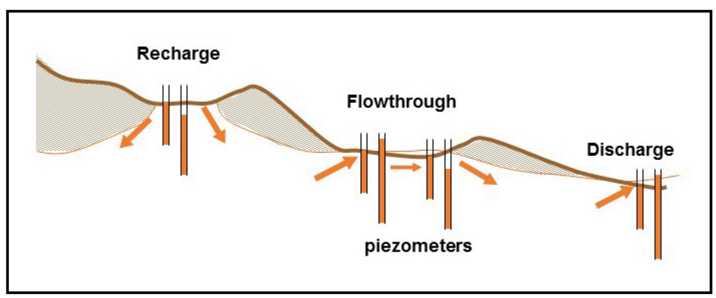
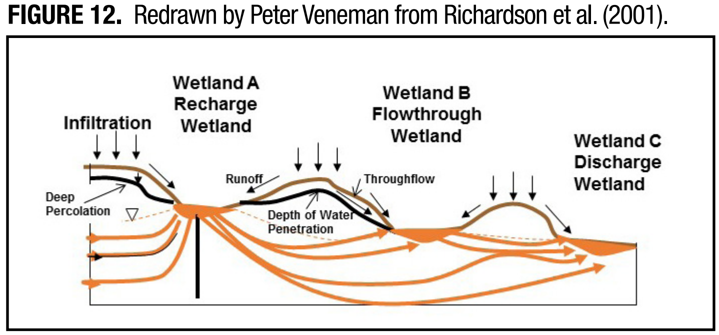


FIGURE 12. Redrawn by Peter Veneman from Richardson et al. (2001).



support a water table at 120m, but it is actually water pressure or hydraulic head supporting the plane coming out of the screen at 120. As groundwater flow progresses downhill, that pressure decreases, and flow (solid arrow) goes from higher pressure to lower pressure perpendicular to the planes represented by the isopleths.

On the left side of the figure, the flow line is going up. Why would that happen? There may be a confining layer that does not let flow continue going right-to-left. The hydraulic head decreases as elevation increases, and flow is upward. We will return to this in a few minutes..

There are also some other notations on this figure. We will get back to them, but first, we need to learn some more terms.

- See Figure 8. ***Water-Table Well***. *Note that the width of the slots should be smaller than the smallest diameter soil grains so that water, but not sediment, can flow through them.*
- See Figure 9. *Here is an illustration of how water-table wells may be installed.*
- See Figure 10. ***Piezometer***. *Note that a true piezometer is open only at the bottom of the pipe, but to speed up well response, a short distance is slotted, often 10 to 20 cm.*
- -Piezometers need to be installed at different depths to assess the **vertical direction of flow** (nested piezometers).

  -If the water in the deep piezometer is at a lower depth than in the shallow piezometer, the groundwater flow is downward, indicating recharge conditions (Figure 7, notation C).

  -If the water in the deep piezometer is at a higher level than in the shallow piezometer (Figure 7, notation A), the groundwater flow is upward, indicating discharge conditions.

  -If the water level in all piezometers, no matter how deep, are the same, then there is no potential for vertical flow and the flow is simply horizontal (Figure 7, notation B).
- See Figure 11. *As seen on the left in this figure, the shallow piezometer has higher water levels than the deep piezometer, so flow is downward (recharge). On the right, the deep piezometer has the higher water levels, so flow is upward (discharge). In the middle, discharge occurs on one side and recharge occurs on the other, and the wetland is flowthrough.*
- See Figure 12. *These flow systems can be very complicated, with recharge from Wetland A on the left being discharged to Wetland B in the middle but also flowing deeper and discharging at Wetland C. Wetland B serves as a flowthrough wetland.*
- See Figure 13. *Deep regional flow systems can also discharge to wetlands.*
- See Figure 7 again. *The vertical bars under notation C are piezometers open to water input only at the bottom. The open bottom of the longest bar (deepest piezometer) on the left has a hydraulic head or piezometric pressure of 80m, meaning that the column of water inside that pipe will rise to an elevation of 80m in the piezometer. That piezometric pressure is equivalent to a water table at 80m, as shown on the scale to the right. The middle bar is a piezometer exposed to a hydraulic head of 90m; the water level of 90m shows that there is piezometric pressure supporting a water table at an elevation of 90. Similarly, the bar on the right shows piezometric pressure supporting*

FIGURE 13. Figure 24 from Circular 1139.

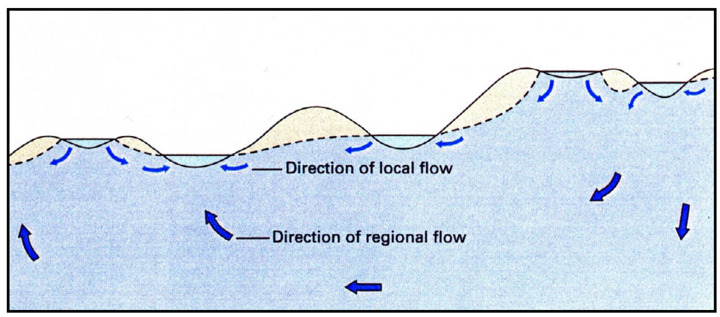


FIGURE 14. https://www.usgs.gov/media/images/artesian-wells-can-bring-water-land-surface-naturally

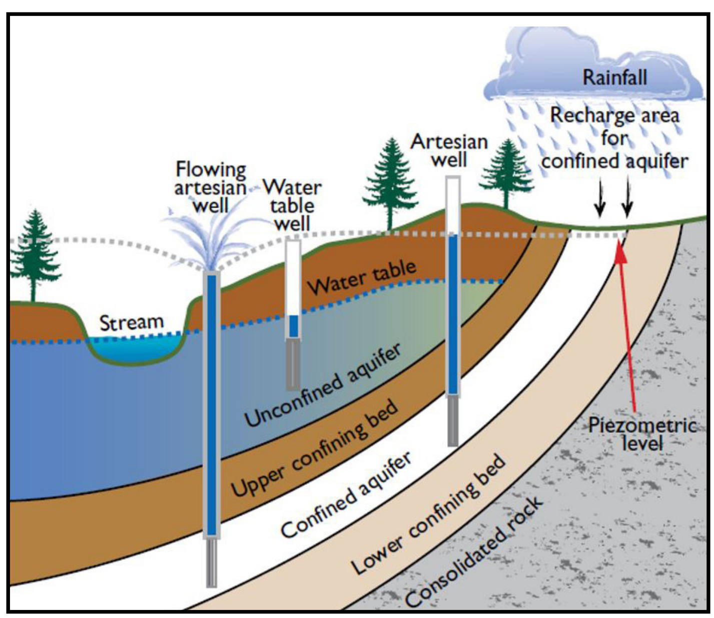
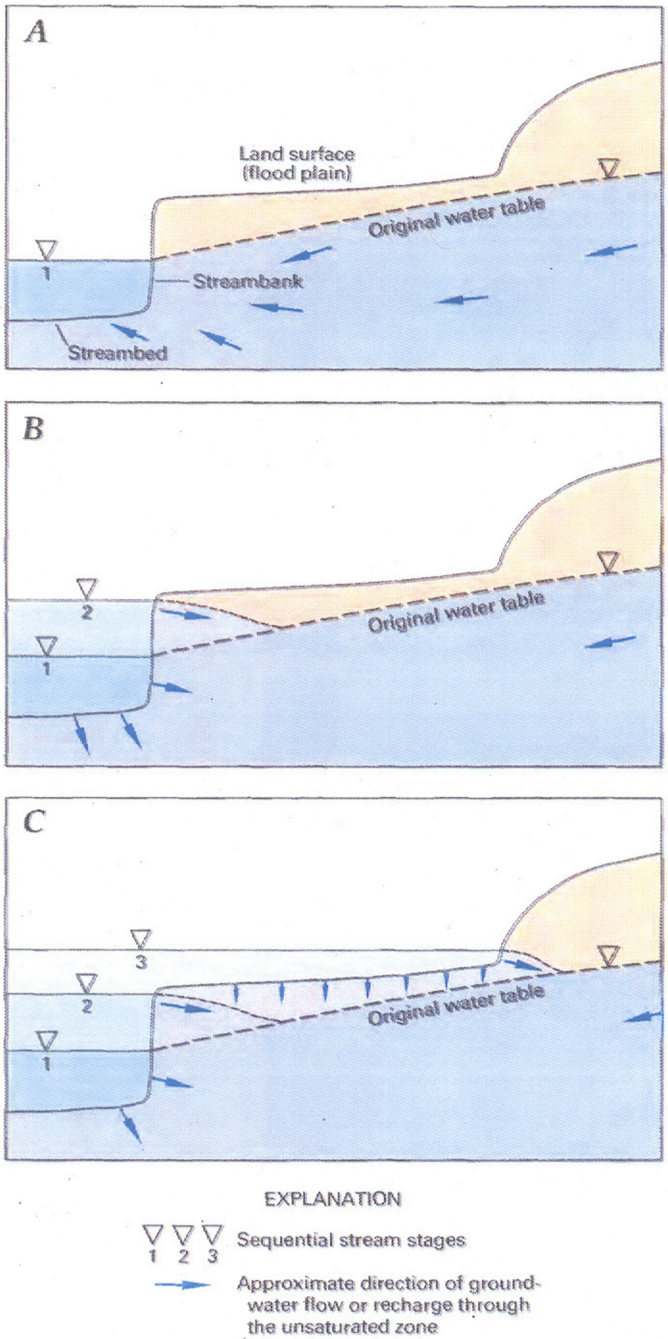


FIGURE 15. Figure 12 from Circular 1139.

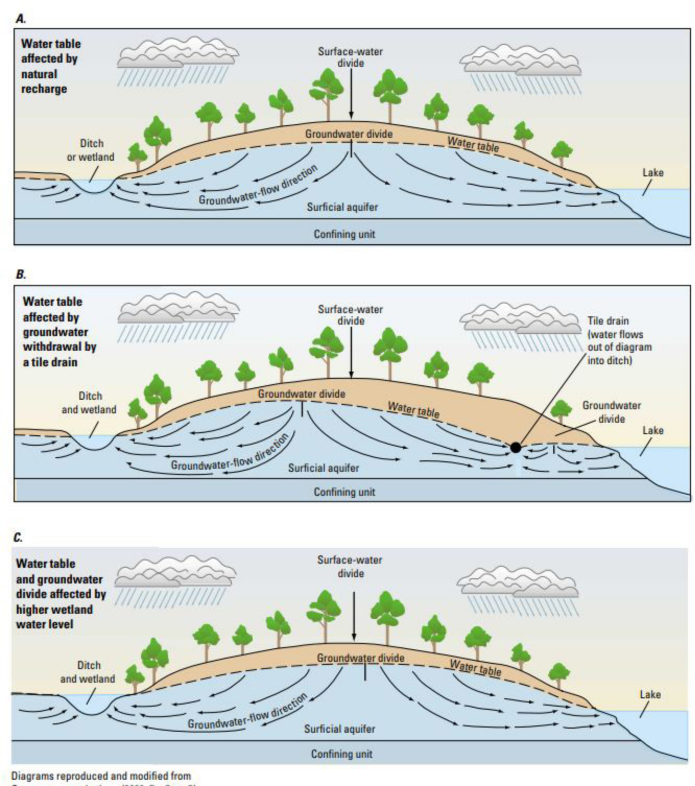


a water table at 110m. As noted in the previous slide, since water in the deep piezometer is at a lower depth than in the shallow piezometer, groundwater flow is downward.

The right-most bar (piezometer) under notation A on the left side of the figure shows the deep piezometer exposed to a hydraulic head of 20m and the shallower piezometer next to it with a head of 10m. Again, since water in the deep piezometer is at a higher level than in the shallow piezometer, groundwater flow is upward. Note that water in the deep piezometer may flow out above the land surface.

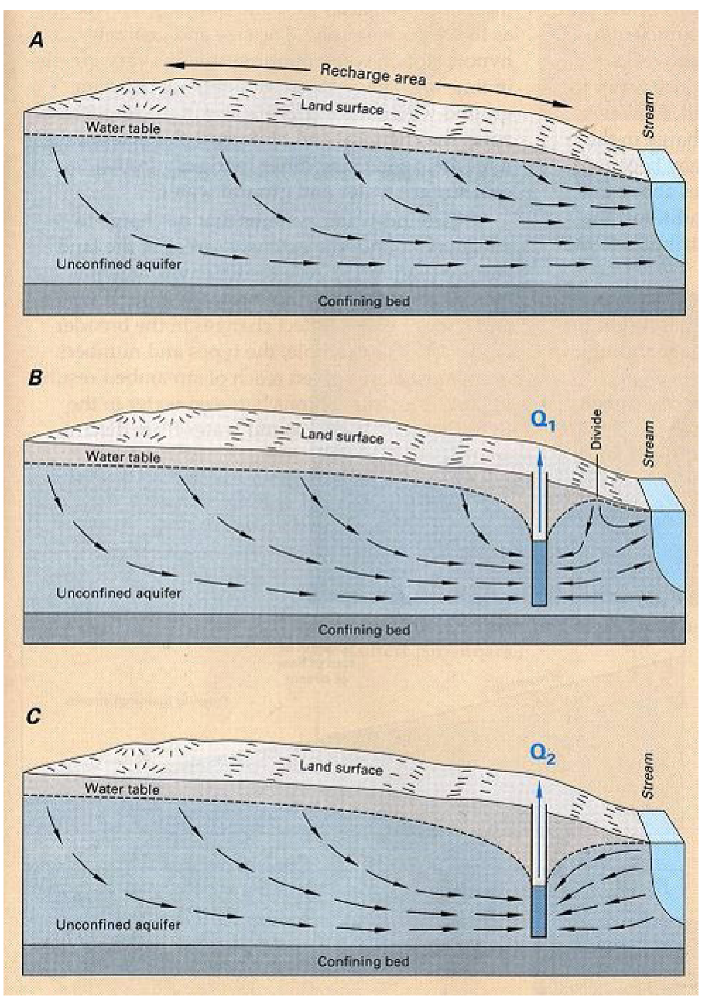
- See Figure 14. *So, now we have a new term:* ***Artesian Aquifer****. If a confined aquifer is tapped by a well, the water in the well may rise above land surface (discharge conditions) if supported by sufficient piezometric pressure.*
- See Figure 15. *The water table can also be influenced by surface water levels. In diagram A, groundwater flow is into the stream (or wetland). In B, stream water levels rise above the original water table (a common occurrence during a flood), and the stream begins recharging groundwater, In C, it becomes even more extreme (perhaps during an extreme flood).*
- See Figure 16. *Water flows and groundwater divides can also be influenced by outside changes in hydrology. In diagram A, the surface water and groundwater divides are both at the crest of the hill, with flows going nearly the same in both directions. In diagram B, a tile drain on the right side is drawing water away, lowering the water table and creating a major shift of the apex of the water-table mound to the left of the land-surface divide. In diagram C, higher water levels in the wetland on the left shift the groundwater divide to the right of the land-surface divide.*

FIGURE 16. https://pubs.usgs.gov/sir/2013/5003/pdf/SIR2013-5003.pdf



- See Figure 17. *In addition to tile drains, the water table can be reduced by pumping from wells. In diagram B in this figure, pumping from the well creates a groundwater divide by intercepting some of the water that otherwise would have flown to the stream. The V shape around the well is really a three-dimensional cone – called a cone of depression. When pumping of the well is increased in diagram C, the divide disappears, and the well pulls water from the stream.*
- See Figure 18. *So, how does groundwater influence development of wetlands on the landscape? In diagram A, complex flow fields drive water to near the surface. In diagram B, a break in slope of the land surface exposes the water table and brings groundwater to the land surface. In diagram C, a depression in the landscape receives groundwater discharge, and in diagram D, the depression receives enough surface runoff and precipitation to create a recharge wetland that allows the adjacent and underlying groundwater system to rise to the elevation of the wetland surface stage.*

FIGURE 17. Figure C-1 from Circular 1139.



- See Figure 19. *Temporary changes in the water table can also occur. At the top, water collecting in the depression can infiltrate at a greater rate and result in focused recharge that causes a mound in the water table. On the bottom, evapotranspiration can draw water away and create a cone of depression.*

FIGURE 18. Figure 17 from Circular 1139.

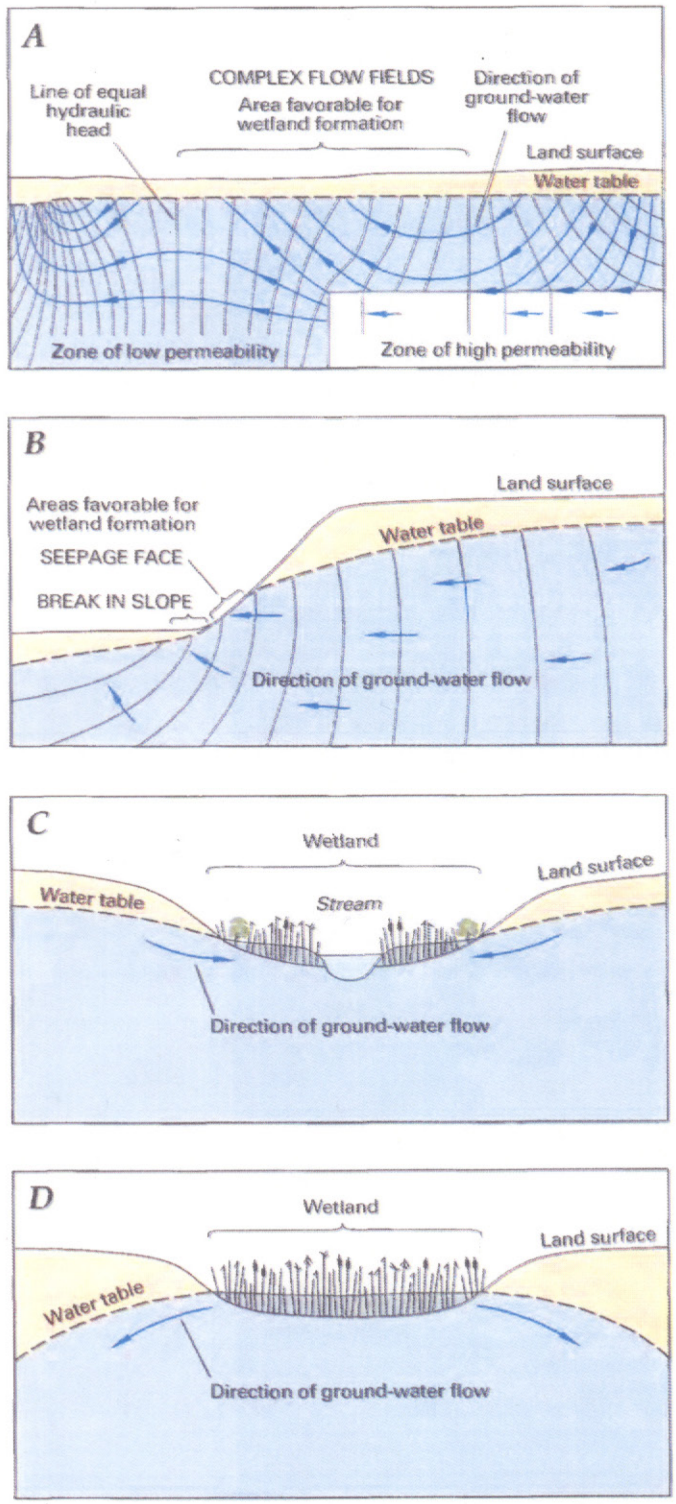


FIGURE 19. Figures 6 and 7 from Circular 1139.

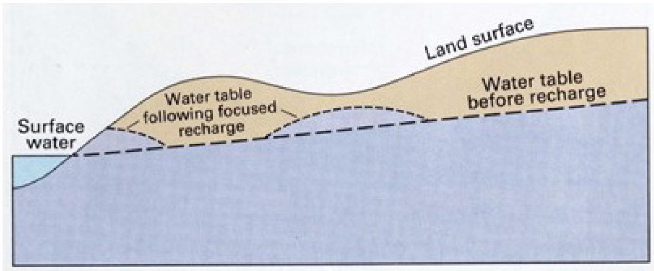


Figure 6. *Ground-water recharge commonly is focused initially where the unsaturated zone is relatively thin at the edges of surface-water bodies and beneath depressions in the land surface.*

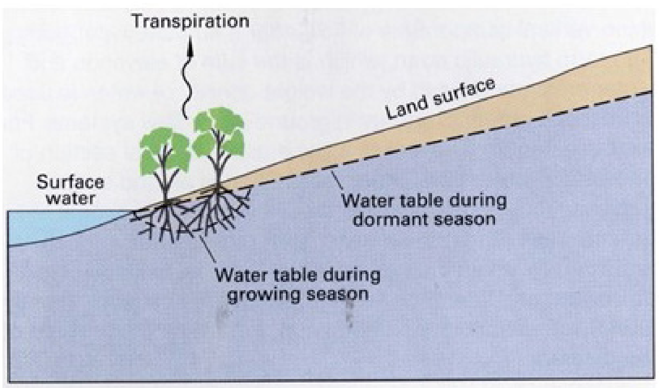
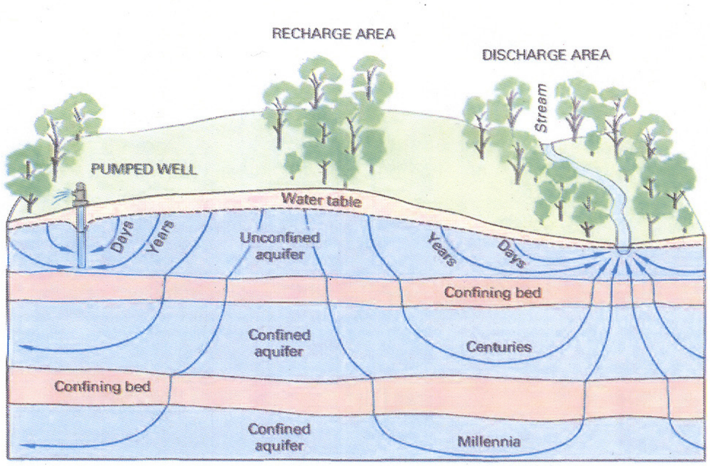


Figure 7. *Where the depth to the water table is small adjacent to surface-water bodies, transpiration directly from ground water can cause cones of depression similar to those caused by pumping wells. This sometimes draws water directly from the surface water into the subsurface.*

FIGURE 20. Figure 3 from Circular 1139.



- See Figure 20. *Finally, how quickly does groundwater move through the ground? In an unconfined aquifer, water recharged near a stream (or wetland) may discharge in days or years, depending on soil type and relative hydraulic conductivity. Water that slowly works its way into a confined aquifer may take centuries to discharge. Water in an even deeper confined aquifer may take millennia before it can discharge.*

For additional information on wetland hydrology, see Chapter 2 – Wetland Formation and Hydrology in *Wetland Indicators* (2nd edition; Tiner 2017). ■

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