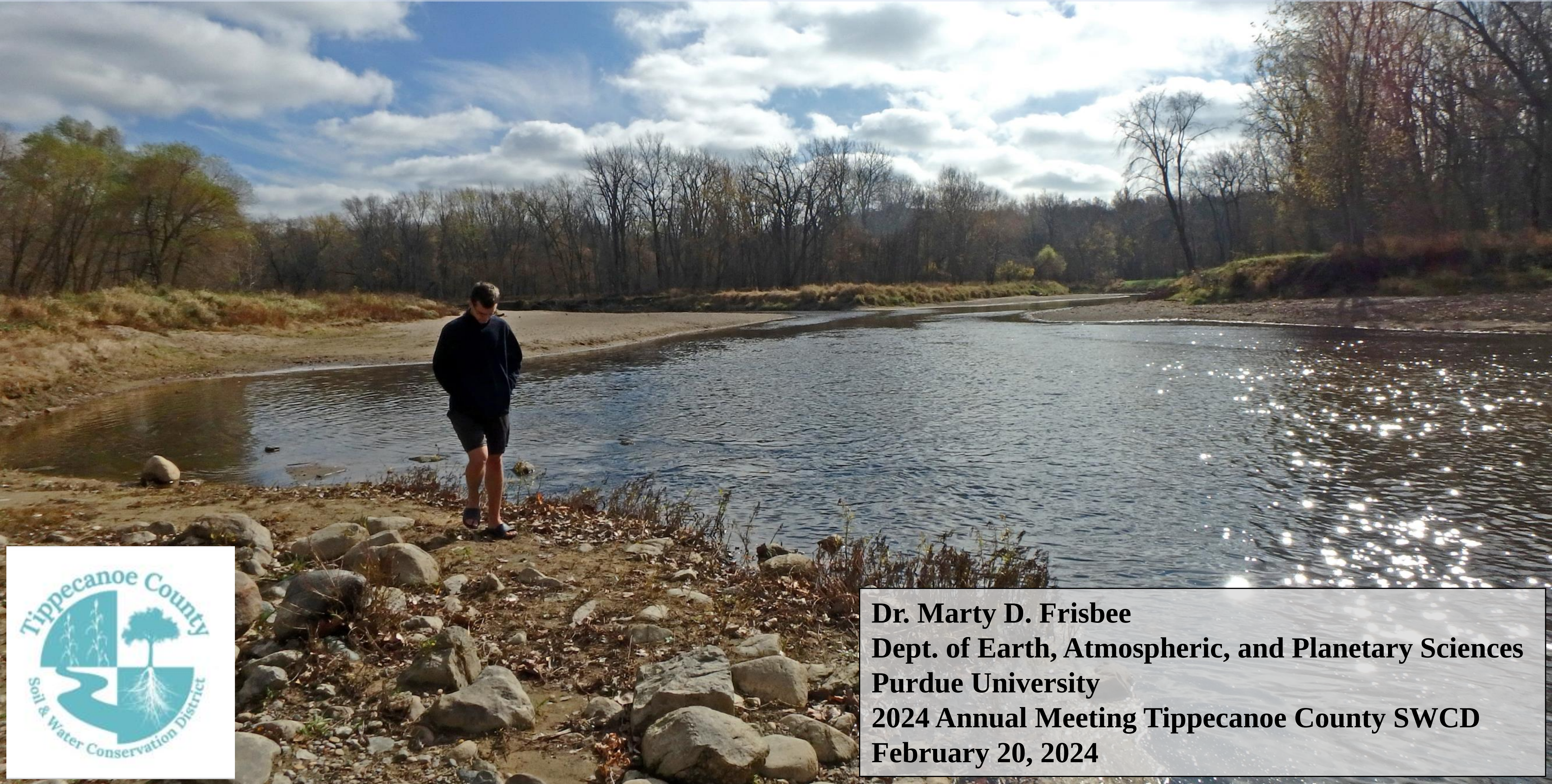
# How can groundwater withdrawals impact the agricultural and ecological communities in Tippecanoe County?



Tippecanoe County Soil & Water Conservation District

**Dr. Marty D. Frisbee**
**Dept. of Earth, Atmospheric, and Planetary Sciences**
**Purdue University**
**2024 Annual Meeting Tippecanoe County SWCD**
**February 20, 2024**

**Brief Personal Introduction:**

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**Associate Professor of Hydrogeology**
**Dept of Earth, Atmospheric, and Planetary Sciences (EAPS)**
**Purdue University**
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**I'm a hydrogeologist. A hydrogeologist is someone who studies groundwater flow in soil and rocks. I study the interactions between groundwater and surface water. In particular, I investigate how climate change and land-use change affect groundwater flow processes, and how these, in turn, affect surface water systems and their aquatic ecosystems. I'm interested in quantifying response times of aquifers to these perturbations and how the systems change following perturbations. I use field measurements, geochemistry, isotopes, and models in my research.**

# What controls groundwater flow? What makes groundwater flow in the subsurface?

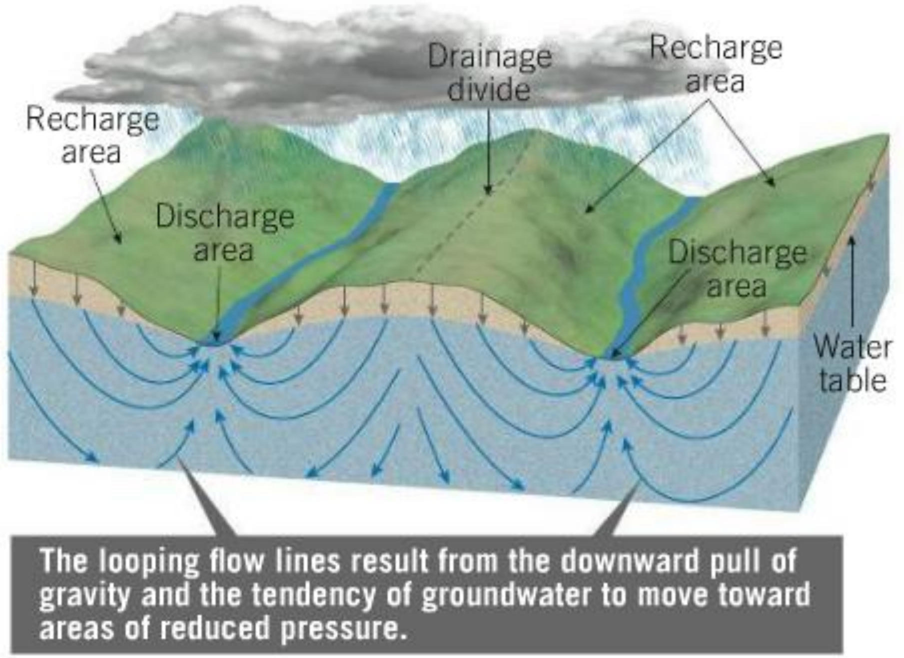
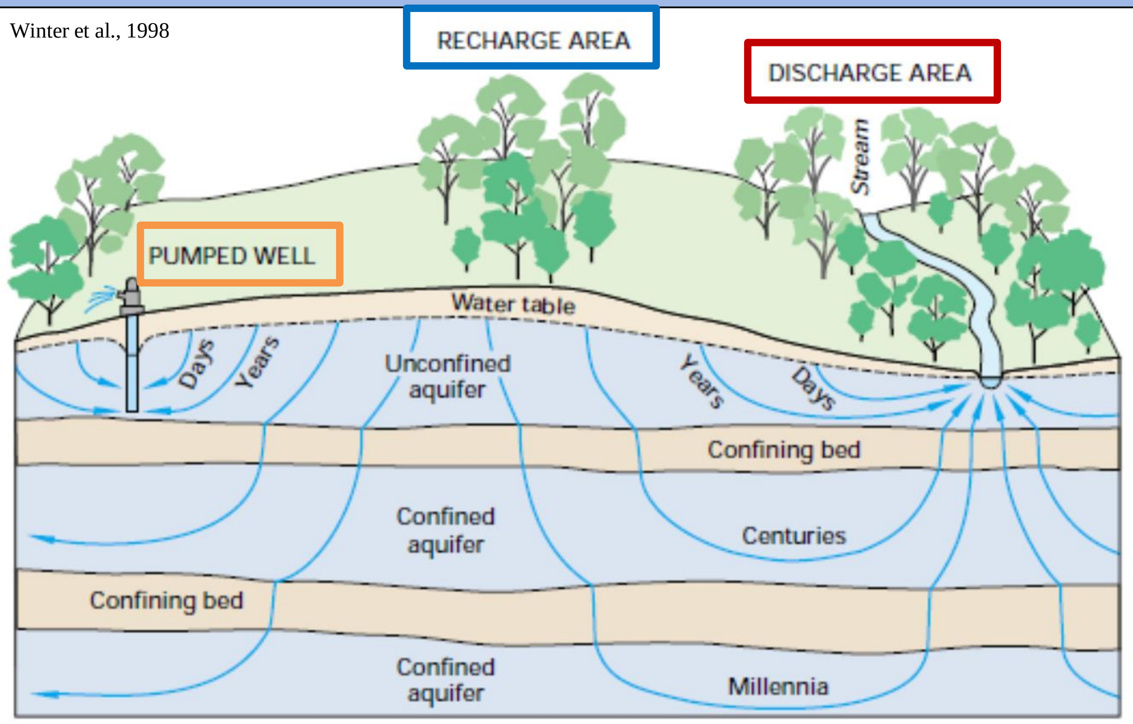



**Figure 3.35 Groundwater movement** Arrows show paths of groundwater movement through uniformly permeable material.

Lutgens and Tarbuck, 2017



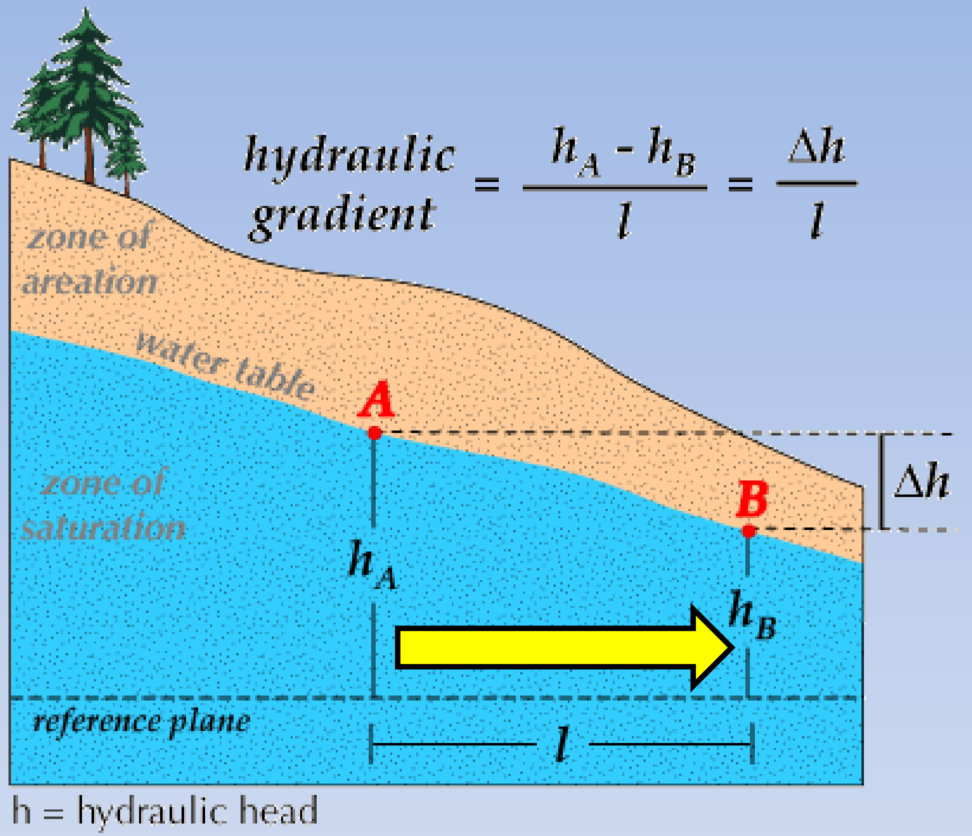

Winter et al., 1998

**Groundwater is recharged at topographic highs (where the topography is high – see blue box in image above).**

**Groundwater is discharged at topographic lows (where topography is lowest – see red box). Or, groundwater can be captured by a well (see orange box) as we'll discuss later.**

**Groundwater commonly discharges to creeks, streams, and rivers (blue arrows in images). This is called baseflow and it supports perennial flow in streams and rivers (perennial means that it flows year-round). Baseflow is vital to aquatic ecosystems in streams and groundwater is vital to crenobiotic (spring-obligate) species (by definition, you can't have springs without groundwater).**

# Groundwater flow is driven by the hydraulic gradient of the system.




**Groundwater flow (discharge) is described by Darcy's Law:**

$$Q = -KA\frac{dh}{dL}$$

**This equation is similar to Ohm's Law (for the flow of electrical current) and Fourier's Law (for the flow of heat).**

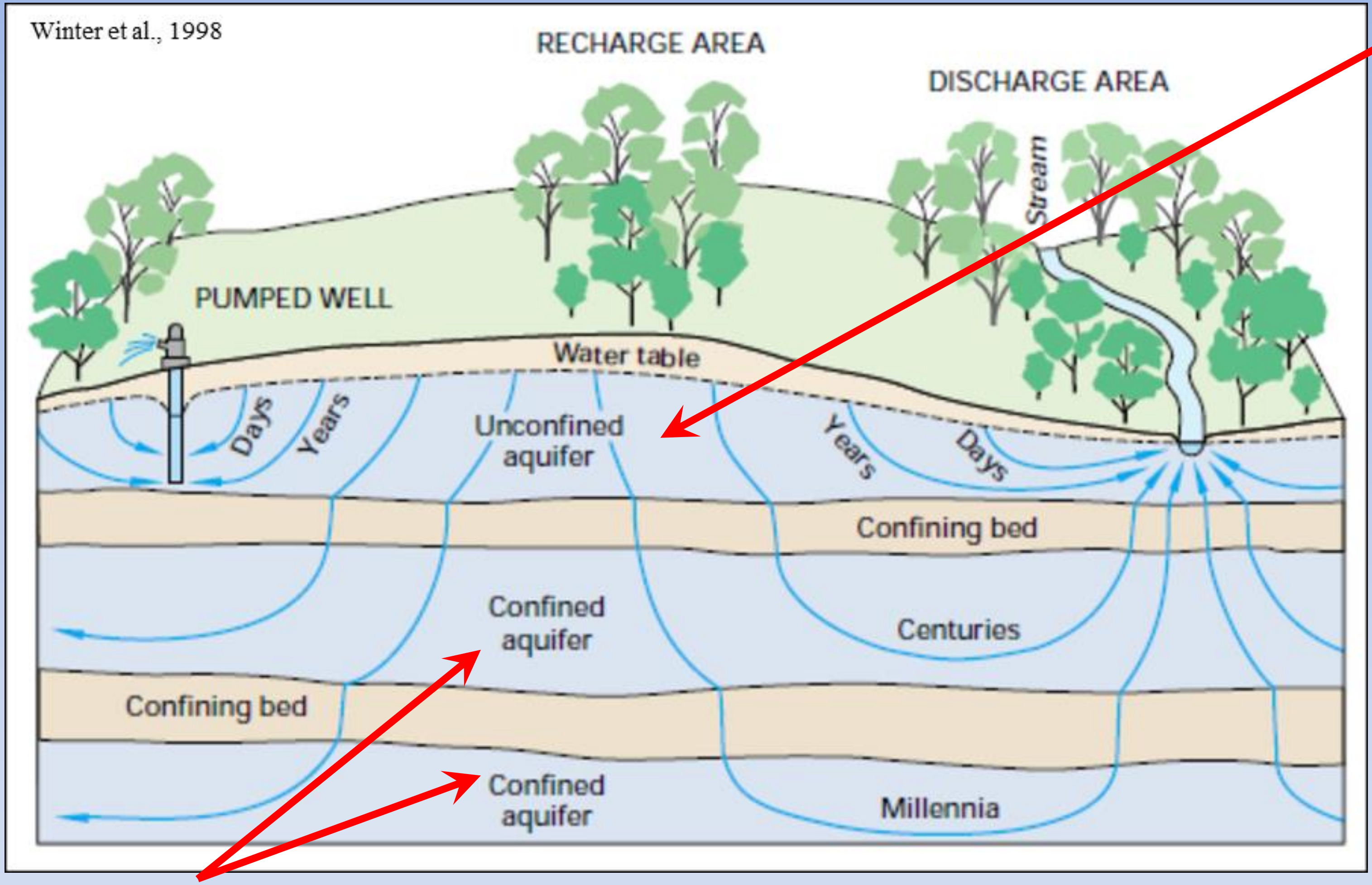
**K = hydraulic conductivity (units of length/time ~ *m/sec*) – It has units of velocity, but it is NOT a velocity!**

**A = cross-sectional area through which groundwater flows (units of length$^2$ ~ m$^2$)**

**dh/dL = hydraulic gradient = [change in hydraulic head]/[change in length] (units of length/length ~ dimensionless) = ($h_A$ – $h_B$)/L in the image on the left.**

**Q = volume of groundwater flow per time (units of length$^3$/time ~ *m$^3$/s*)**

# There are many different types of aquifers.




Unconfined Aquifer (*a.k.a*, phreatic aquifer) = an aquifer that is open to the atmosphere and not located beneath confining layer. The water table is the upper boundary of the aquifer.

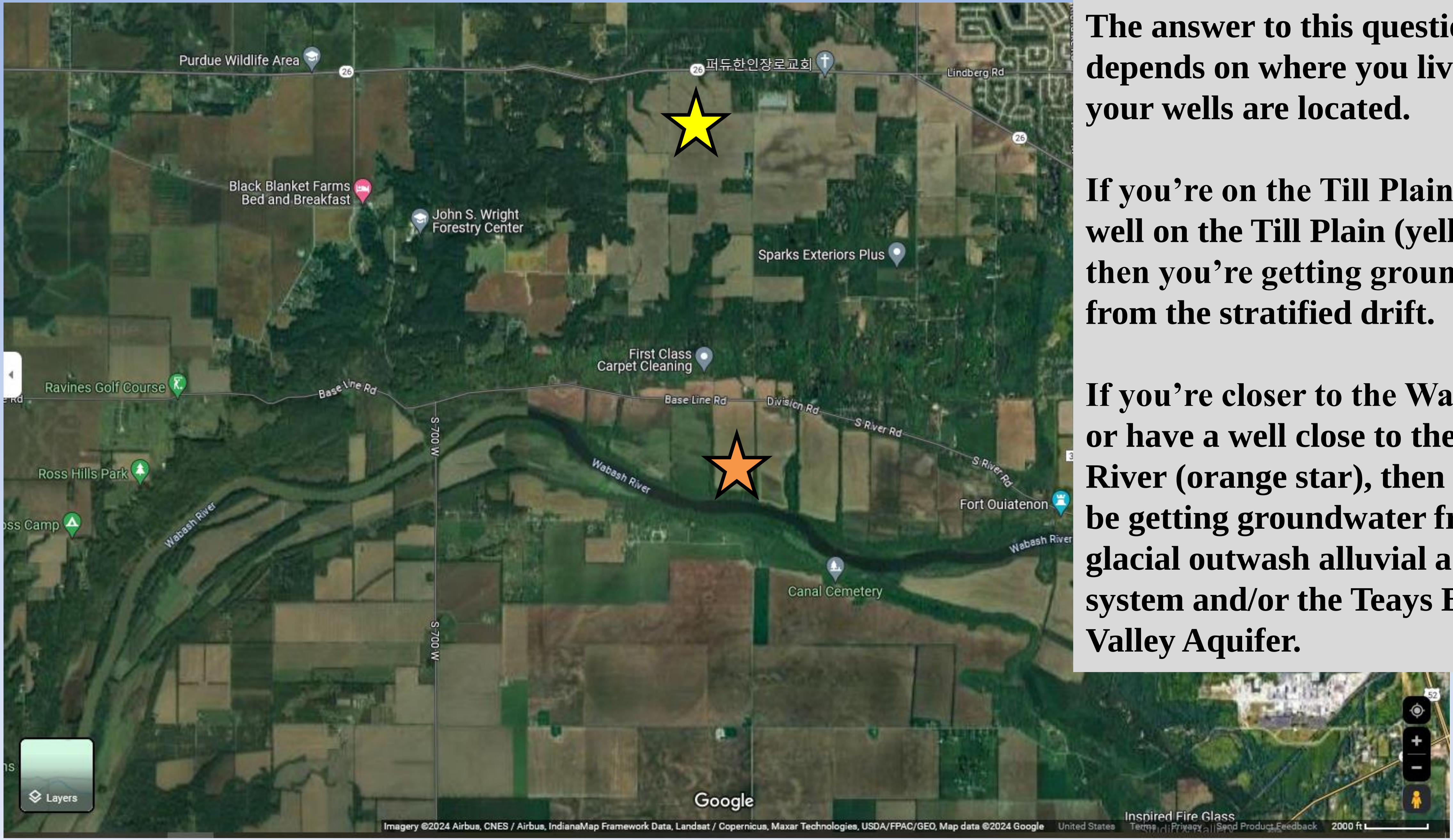
The surface of the unconfined aquifer is called the water table. Unconfined aquifers are not under pressure. The surface of the water table commonly mimics the land-surface topography or is a muted expression of the land-surface topography.

In addition, the water table will rise in response to recharge and fall in response to droughts!

Confined Aquifer = an aquifer that is found beneath a confining layer or between confining layers (confining layers are also called aquitards). The confining units define the upper and lower boundaries of the aquifer.

The surface of the confined aquifer is called the potentiometric surface. Since confined aquifers are under pressure due to lithostatic pressure (opposing effective stress and water pressure itself), the potentiometric surface may rise above the upper confining unit. Artesian conditions occur when water overshoots the top of the well.

# What types of aquifers do we have in Tippecanoe County?

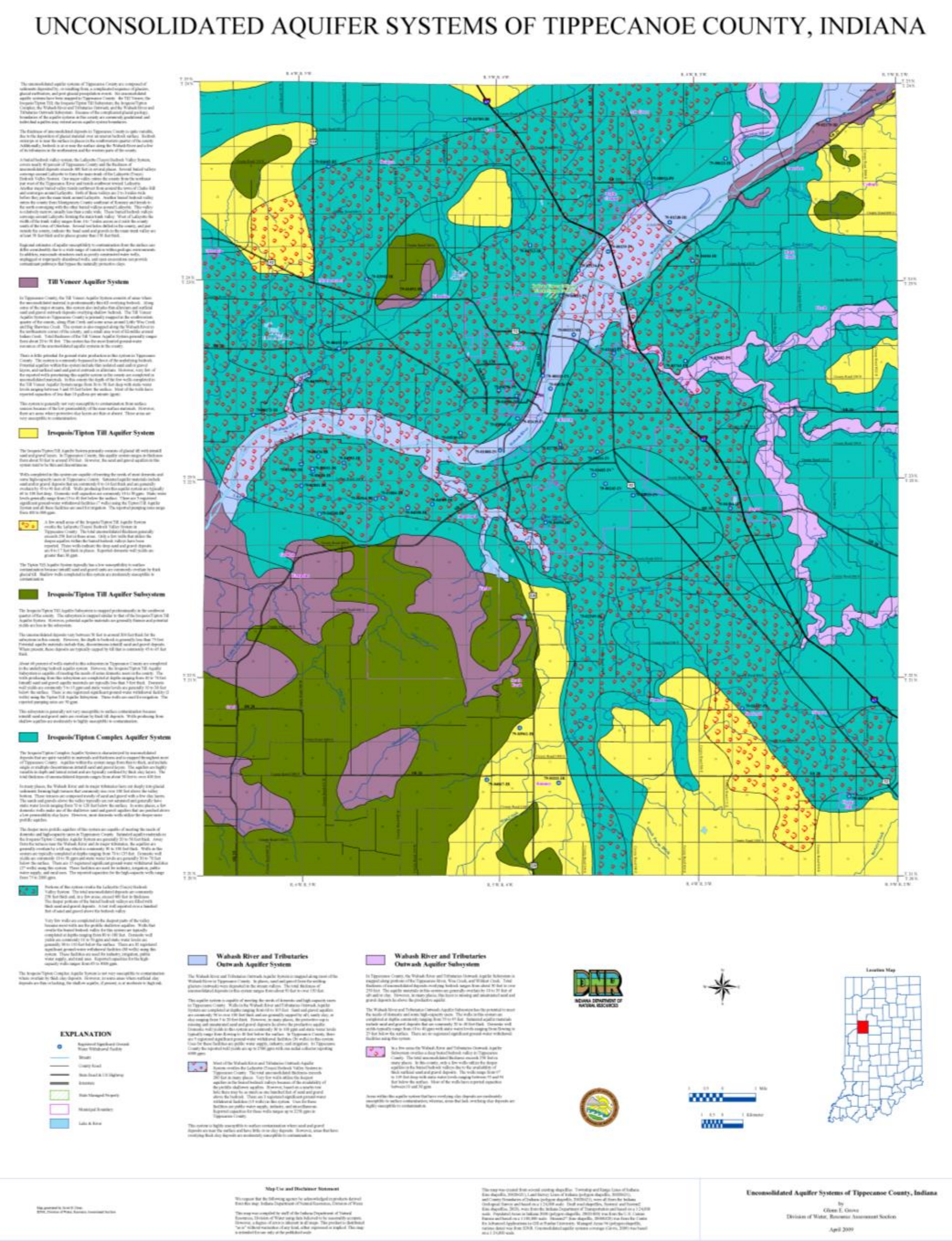


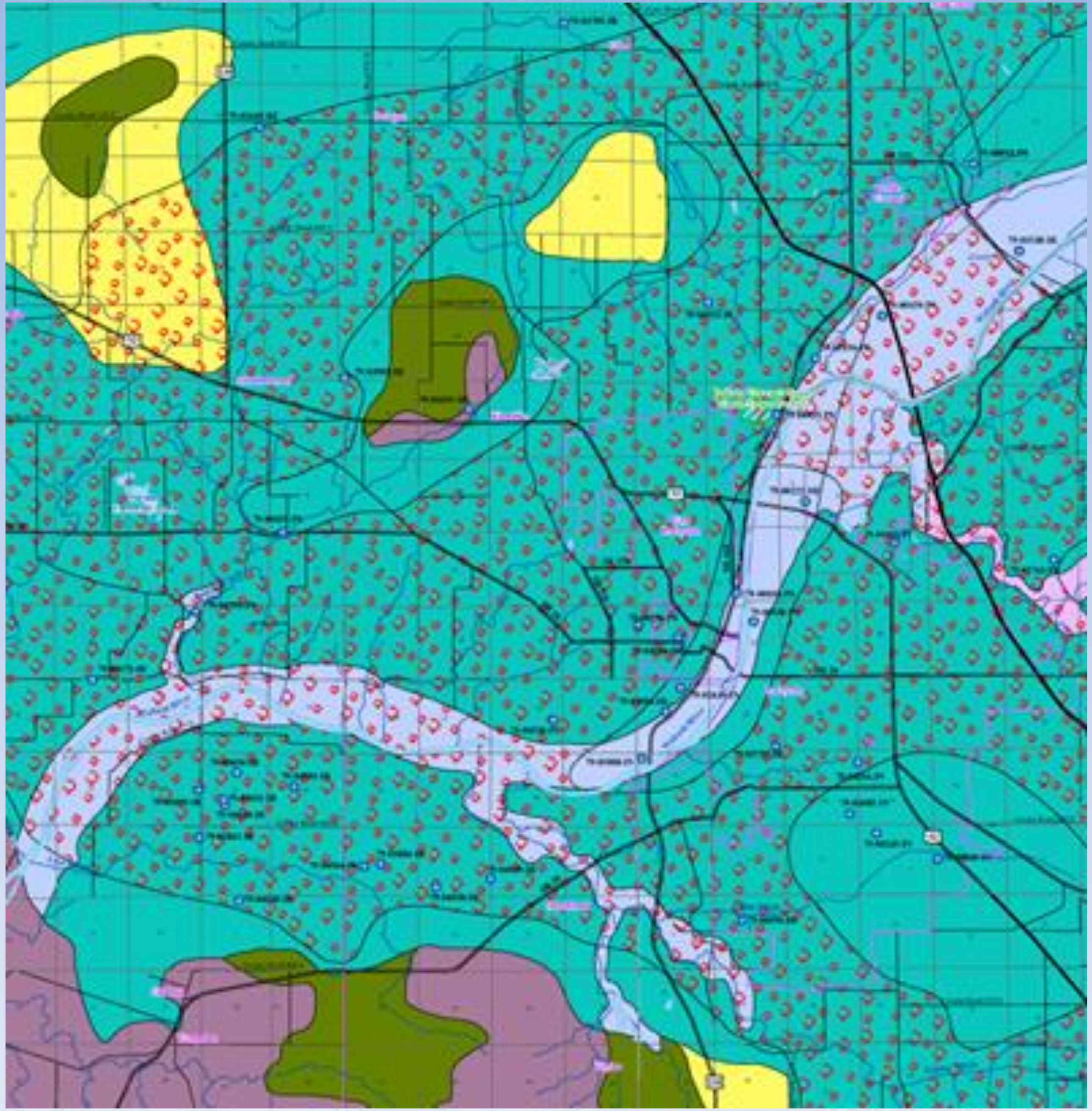

**The answer to this question really depends on where you live or where your wells are located.**

**If you're on the Till Plain or have a well on the Till Plain (yellow star), then you're getting groundwater from the stratified drift.**

**If you're closer to the Wabash River or have a well close to the Wabash River (orange star), then you may be getting groundwater from the glacial outwash alluvial aquifer system and/or the Teays Buried Valley Aquifer.**

# What do the aquifers in the stratified drift look like?



# Let’s look at well record for a local well installed in stratified drift.

**Record of Water Well**

**Indiana Department of Natural Resources**

**Reference Number** 126806

**Driving directions to well** ROSS BIOLOGICAL RESERVE ADJACENT TO THE HILLS- 8 MILES WEST OF PURDUE UNIVERSITY CAMPUS

**Date completed** Jul 11, 1978

| **Owner-Contractor** | **Name** | **Address** | **Telephone** |
|---|---|---|---|
| Owner | PURDUE UNIVERSITY | W. LAFAYETTE, IN | |
| Driller | FINDLAY DRILLING INC | 3025 S 50 E LAFAYETTE, IN | |
| Operator | ROBERT FINDLAY | License: null | |

**Construction Details**

| | | | |
|---|---|---|---|
| Well | **Use:** | **Drilling method:** Rotary | **Pump type:** |
| | **Depth:** 234.0 | **Pump setting depth:** | **Water quality:** |
| Casing | **Length:** 229.0 | **Material:** | **Diameter:** 5.0 |
| Screen | **Length:** 5.0 | **Material:** | **Diameter:** 5.0 **Slot size:** 80 |

**Well Capacity Test**

**Type of test:** | **Test rate:** 100.0 gpm for 1.0 hrs. | **BailTest rate:** gpm for hrs.

**Drawdown:** ft. | **Static water level:** 155.0 ft. | **Bailer Drawdown** ft.

**Grouting Information**

**Material:** | **Depth:** from to

**Installation Method:** | **Number of bags used:**

**Well Abandonment**

**Sealing material:** | **Depth:** from to

**Installation Method:** | **Number of bags used:**

**Administrative**

**County:** TIPPECANOE | **Township:** 23N **Range:** 6W

**Section:** SW of the SE of the NW of Section 26 | **Topo map:** OTTERBEIN

**Grant Number:**

**Field located by:** JH | **on:** Jul 17, 1979

**Courthouse location by:** | **on:**

**Location accepted w/o verification by:** | **on:**

**Subdivision name:** | **Lot number:**

**Ft W of EL:** | **Ft N of SL:** | **Ft E of WL:** 1650.0 | **Ft S of NL:** 2600.0

**Ground elevation:** 671.0 | **Depth to bedrock:** | **Bedrock elevation:** | **Aquifer elevation:** 437.0

**UTM Easting:** 494221.0 | **UTM Northing:** 4473040.0

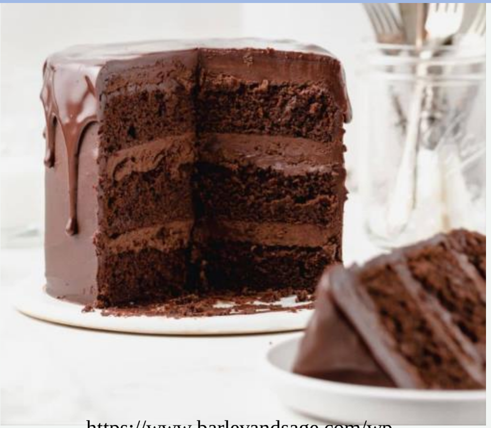
**Well Log**

| Top | Bottom | Formation |
|---|---|---|
| 0.0 | 2.0 | TOP SOIL |
| 2.0 | 15.0 | CLAY |
| 15.0 | 31.0 | GRAVEL |
| 31.0 | 88.0 | CLAY |
| 88.0 | 132.0 | SAND |
| 132.0 | 149.0 | CLAY |
| 149.0 | 226.0 | S&G |
| 226.0 | 234.0 | GRAVEL |

**Comments** MC437; PROFESSOR VERIFIED

# What do the aquifers in the stratified drift look like?

**Well Log**



https://www.barleyandsage.com/wp-content/uploads/2022/01/triple-chocolate-layer-cake-1200x1200-1.jpg

| Top | Bottom | Formation |
|---|---|---|
| 0.0 | 2.0 | TOP SOIL |
| 2.0 | 15.0 | CLAY |
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| 132.0 | 149.0 | CLAY |
| 149.0 | 226.0 | S&G |
| 226.0 | 234.0 | GRAVEL |

**Comments** MC437; PROFESSOR VERIFIED

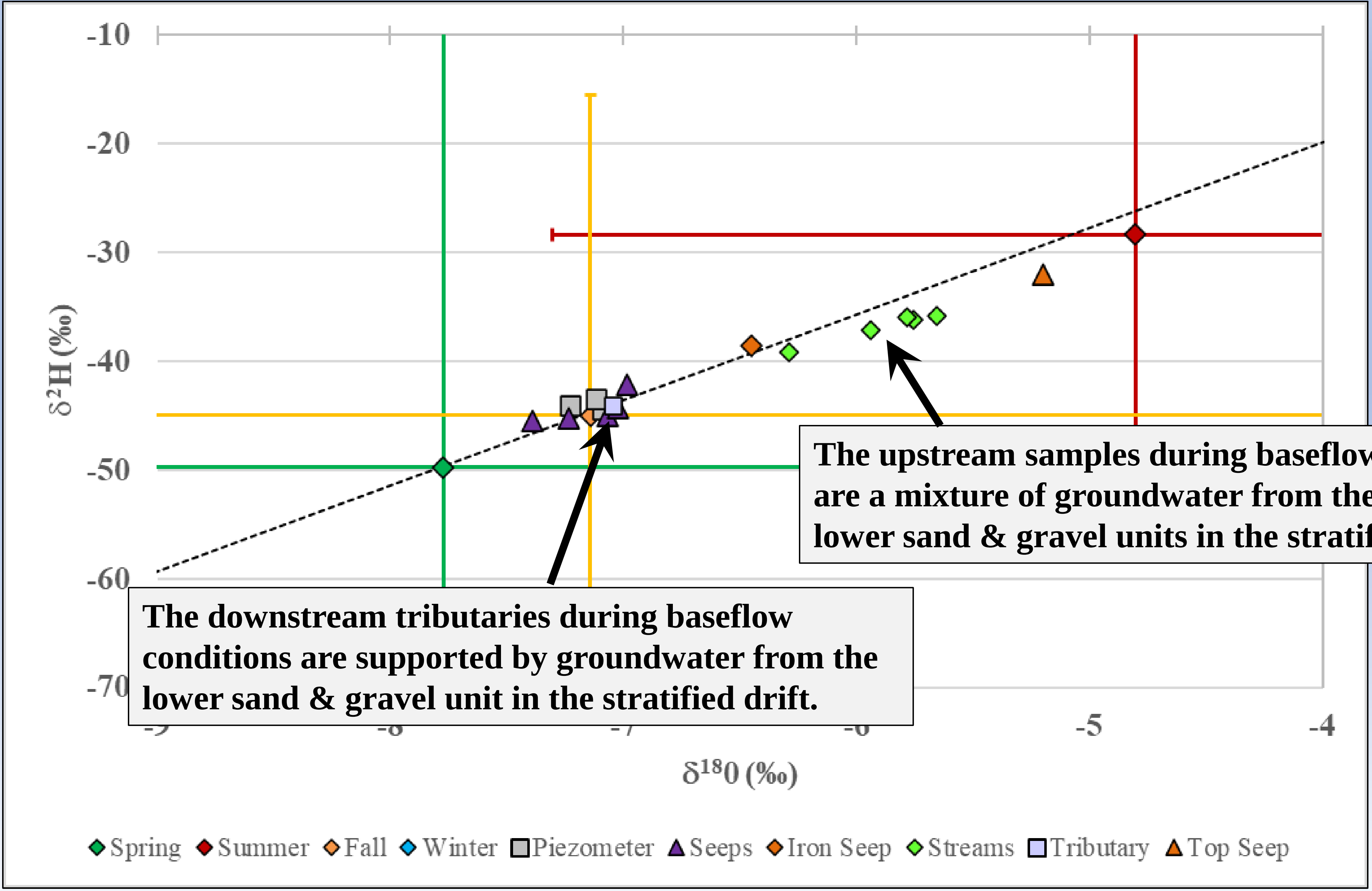
**Well logs in the well record show the geology of the subsurface. Here we see a stratified geologic column that is pretty common on the Till Plain (units are shown as feet below land surface). Stratified simply means that there are several distinct layers sand and gravel that are separated by thick clay layers.**

**It's like a layer cake. The sand & gravel (S&G) layers are usually confined to semi-confined and they are water-bearing. Some older wells (40s, 50, 60s) were installed in the 2nd sand and gravel layer, but most recent wells are installed in the 3rd or lower unit. The 3rd sand and gravel layer is usually a good aquifer and sufficient for domestic and high-capacity wells. However, these layers may not be spatially continuous everywhere.**

**We still do not have a complete understanding on how and where these aquifers are recharged.**

**However, we know a little more about <u>when</u> they are recharged.**

# Stable isotopes of water ($^{2}H$ and $^{18}O$) are useful for identifying source waters and mixing relationships in the stratified drift aquifers.




**The upstream samples during baseflow conditions are a mixture of groundwater from the upper and lower sand & gravel units in the stratified drift.**

**The downstream tributaries during baseflow conditions are supported by groundwater from the lower sand & gravel unit in the stratified drift.**

Stable isotopic composition of samples relative to the non-weighted Local Meteoric Water Line [LMWL, dashed line; Welp-Smith et al., 2020] given by: $\delta 2H = 7.97 \times \delta 18O + 11.7$; $r2 = 0.99$, based on data collected from 2015 to 2019.

# Now, let's look at a well record for a local well installed near the Wabash River floodplain.

| Well Log | Top | Bottom | Formation |
|---|---|---|---|
| | 0.0 | 3.0 | SANDUY LOAM |
| | 3.0 | 17.0 | GREY CLAY |
| | 17.0 | 20.0 | COARSE SAND & GRAVEL |
| | 20.0 | 25.0 | COARSE SAND W/ MED-COARSE GRAV |
| | 25.0 | 35.0 | COARSE GRAVEL |
| | 35.0 | 50.0 | MED-COARSE GRAVEL |
| | 50.0 | 55.0 | COARSE-MED SAND, SOME GRAVEL |
| | 55.0 | 70.0 | VERY FINE SAND (SILTY) |
| Comments | MC 440; FIELD LOCATED FROM LOCATION MAP (IN MASTER FILE PACKET); 82-A TEST | | |

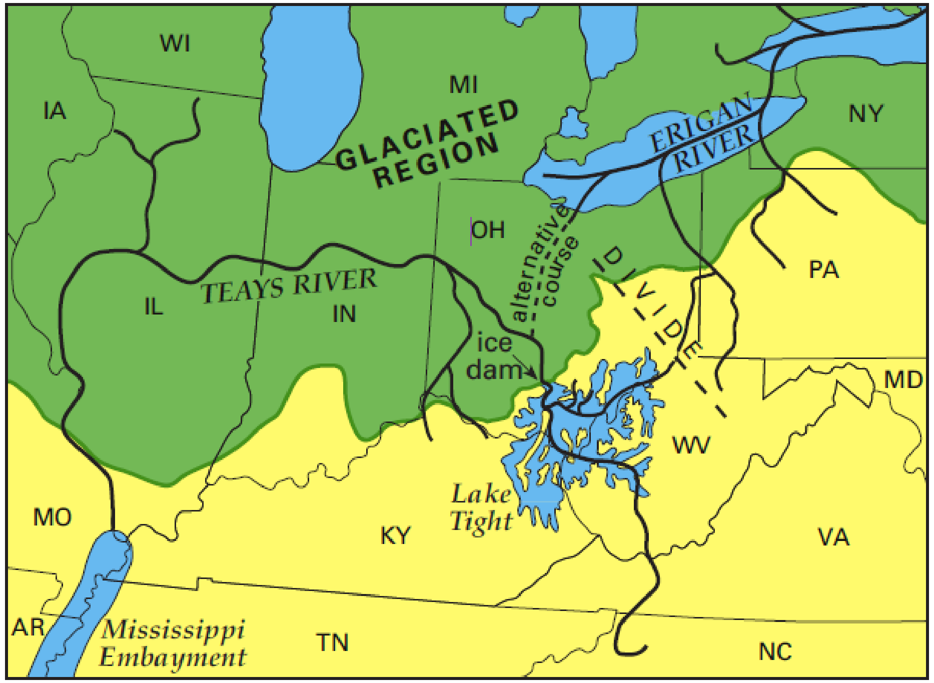
**Here we see a relatively thick sequence of medium sand and gravel and coarse sand and gravel. In some well logs we see interbedded layers of clay. Clay is not present here except at the surface.**

**The Wabash River and Tributaries Outwash Aquifer System are largely unconfined. This aquifer system overlies the Teays Buried Valley Aquifer in much of Tippecanoe County. Data on both aquifers suggest that they are capable of producing up to 2250 gpm and some wells have reported higher yields.**

**We still do not have a complete understanding on how and where these aquifers are recharged either. They are alluvial aquifers and this means that they are in near constant communication with the river. Water from the river enters the aquifer and groundwater discharges from the river to the aquifer. The exchange rates are not known.**

**We do not know if the lower sand and gravel units in the Till Plain adjacent to the river valley discharge groundwater to the alluvial aquifer system. And if they do, we do not know the magnitude of the exchange.**

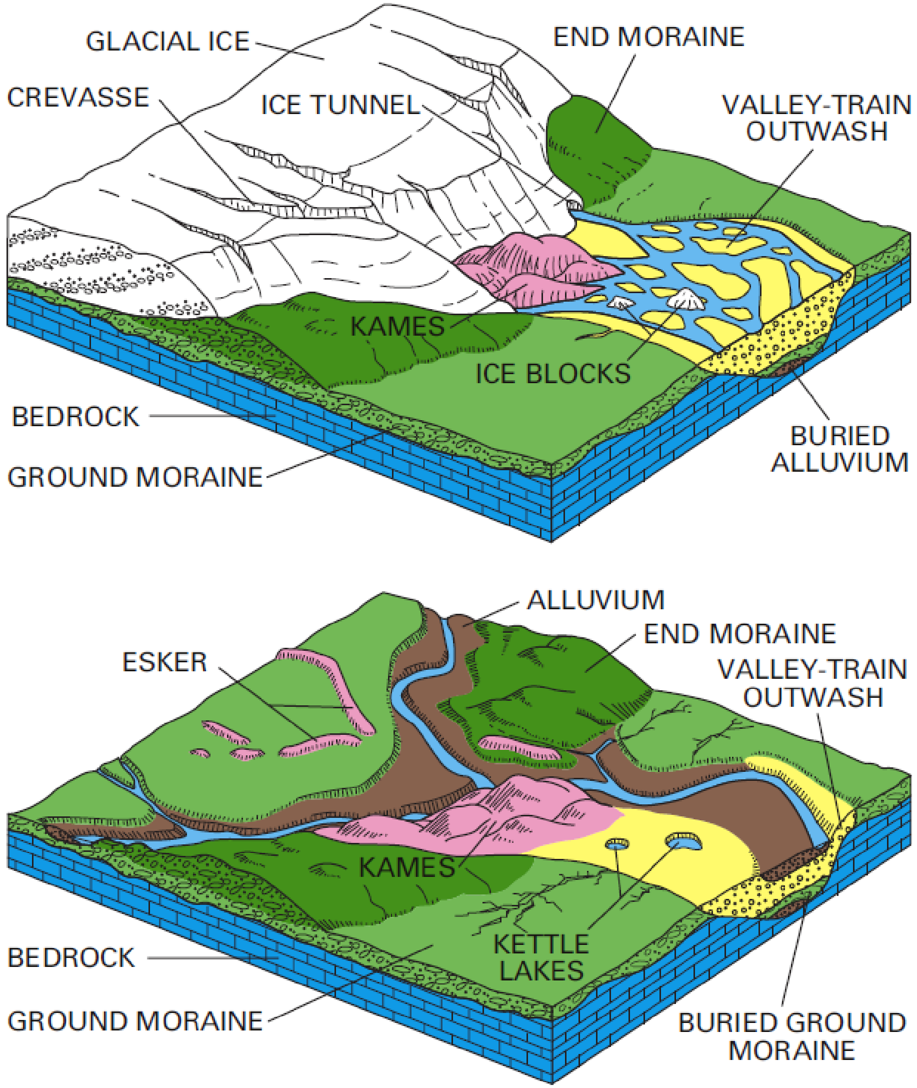
# What is the Teays Aquifer? What is the Wabash River Outwash Alluvial Aquifer?




*Preglacial Teays River in north-central U.S.*

Hansen, 1997

**Above: The Teays River was an ancient river that originated near Blowing Rock, NC. It flowed across western VA, WV, and OH. It entered IN near the headwaters of the Wabash River, flowed across northern IN and IL to its confluence with the early Mississippi River.**

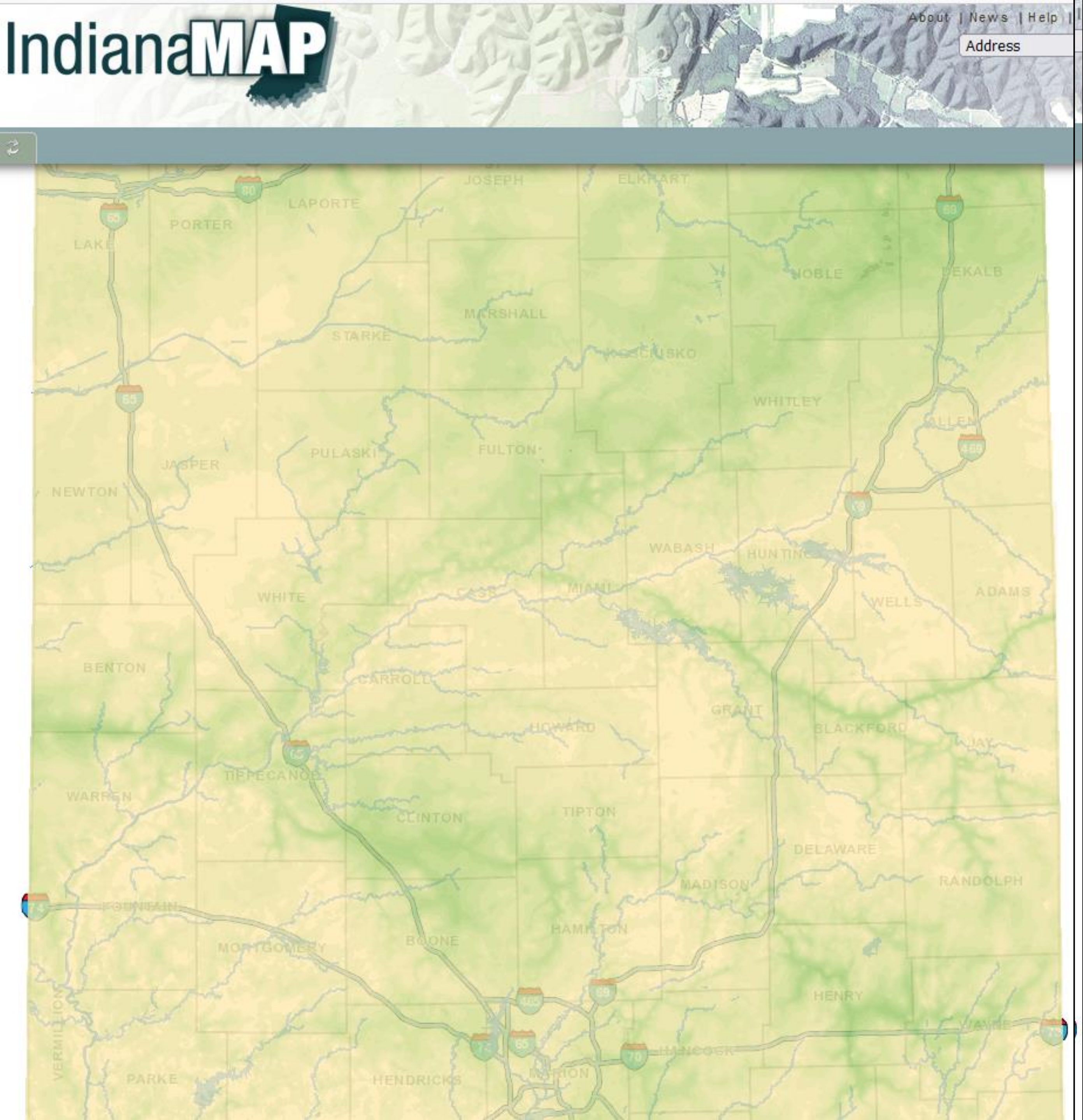



*Landscape during maximum advance and after retreat of ice.*

Hansen, 1997

**The Teays River valley was buried during an early glacial advance around 1.3 Ma (1.3 million years ago). The river valley was filled with sand and gravel and this sediment hosts the Teays Bedrock Valley Aquifer.**

**Young (more recent) glacial advances and retreats deposited glacial sediment on top of the Teays Bedrock Valley Aquifer. These include the Wabash River Outwash Alluvial Aquifer System.**

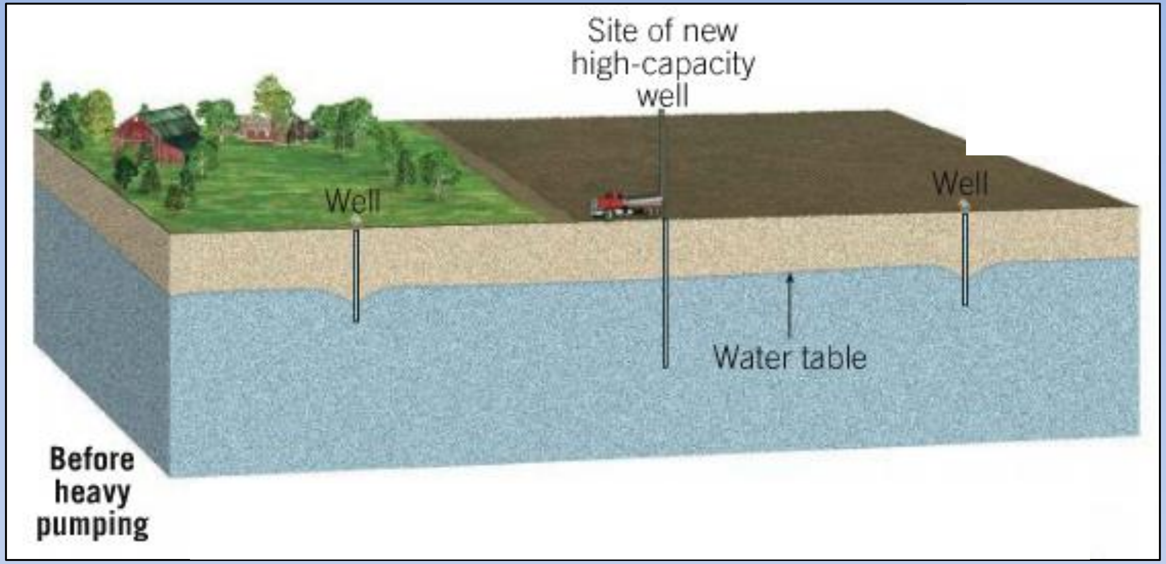



**This image is taken from the old version of IndianaMap. The basemap shows the modern drainages and lakes in blue.**

**The image on top shows the unconsolidated thickness. The dark green feature looks like a river network. It traces the old Teays River valley and tributaries to the Teays.**

**Note how the Teays River flowed west of West Lafayette and into IL, whereas the modern Wabash River flows to the southwest and then due south.**

# What happens when we pump groundwater from a well?

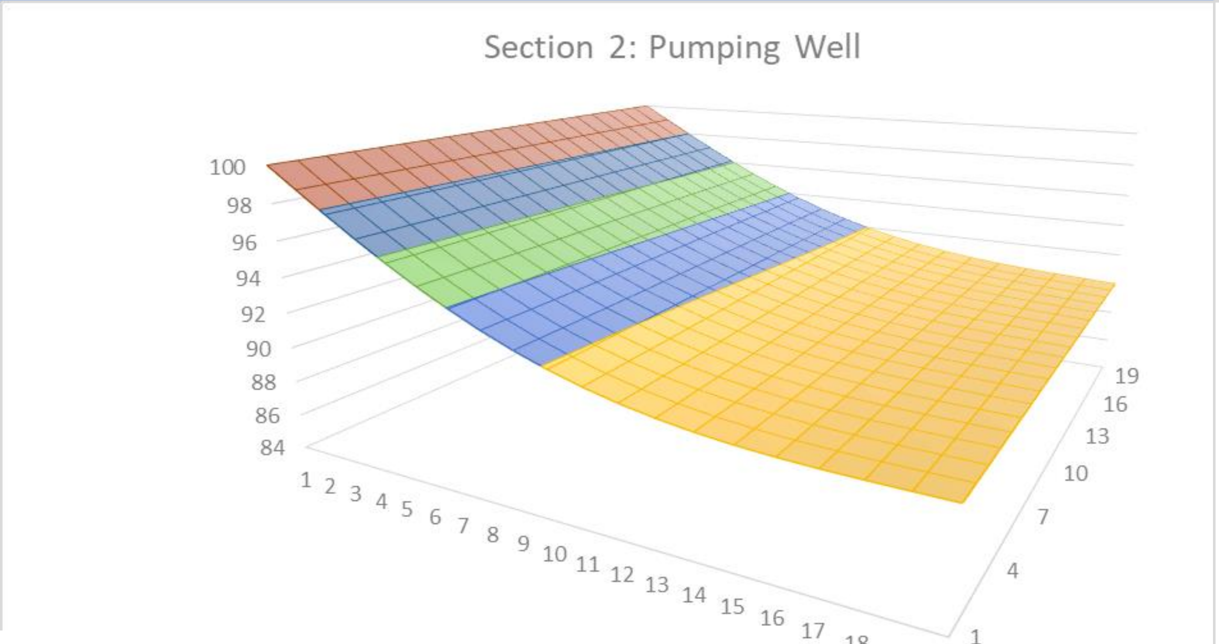



In very simple terms, a __well__ is a hole that it is bored into the ground to pump groundwater from an aquifer.

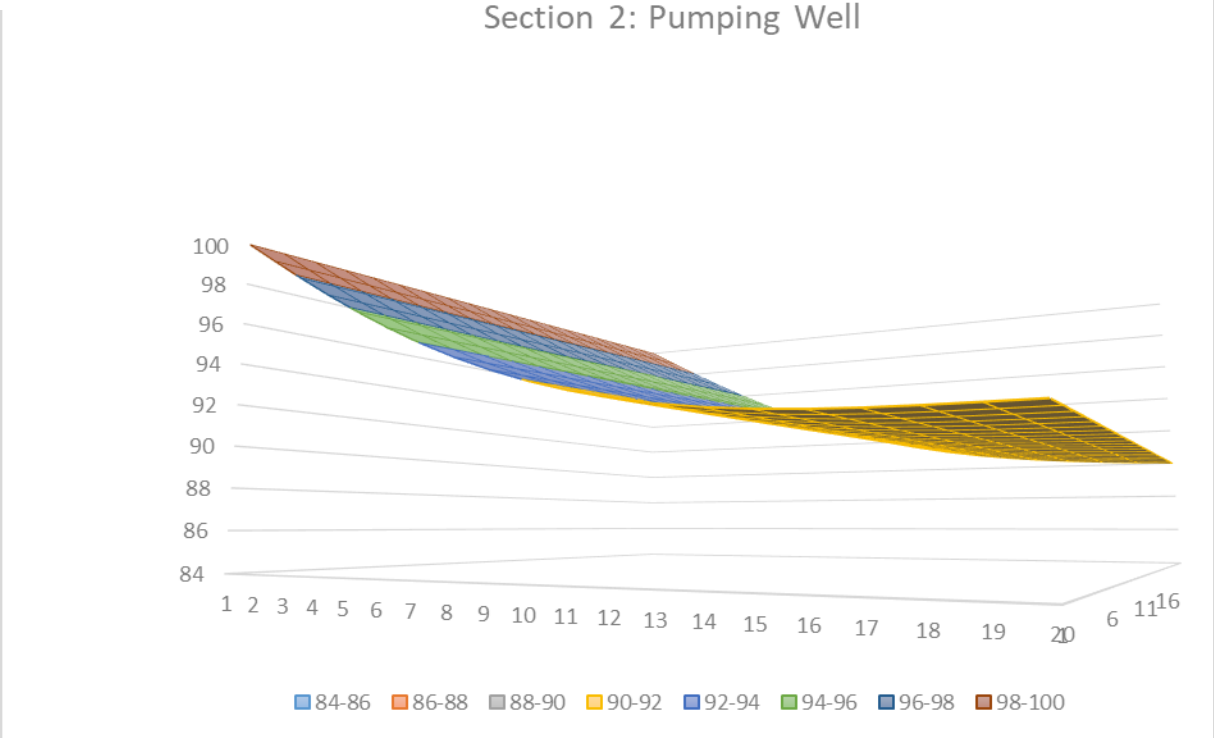
Prior to groundwater pumping, the water table is usually relatively flat or gently sloping.

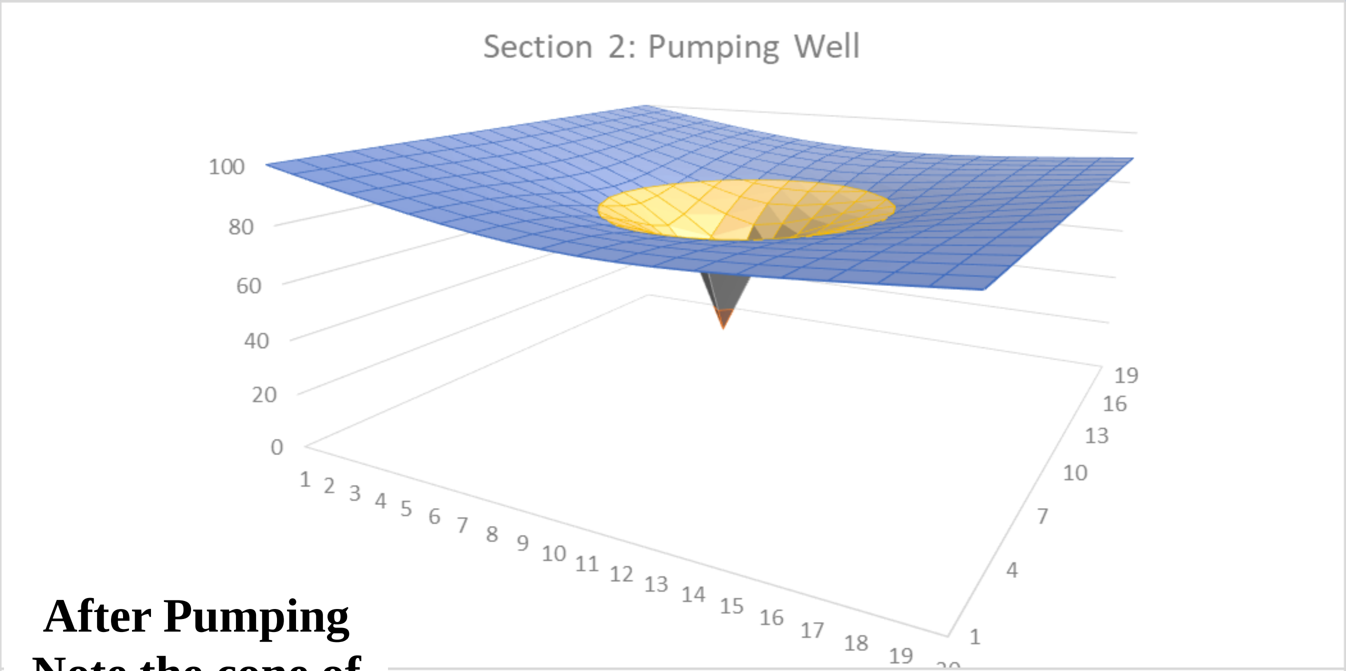
In this image, you can see that the 2 wells are slightly affecting the water table. This is called __drawdown__!

A conical shaped depression forms in the water table in response to pumping. This is called a __cone of depression__!

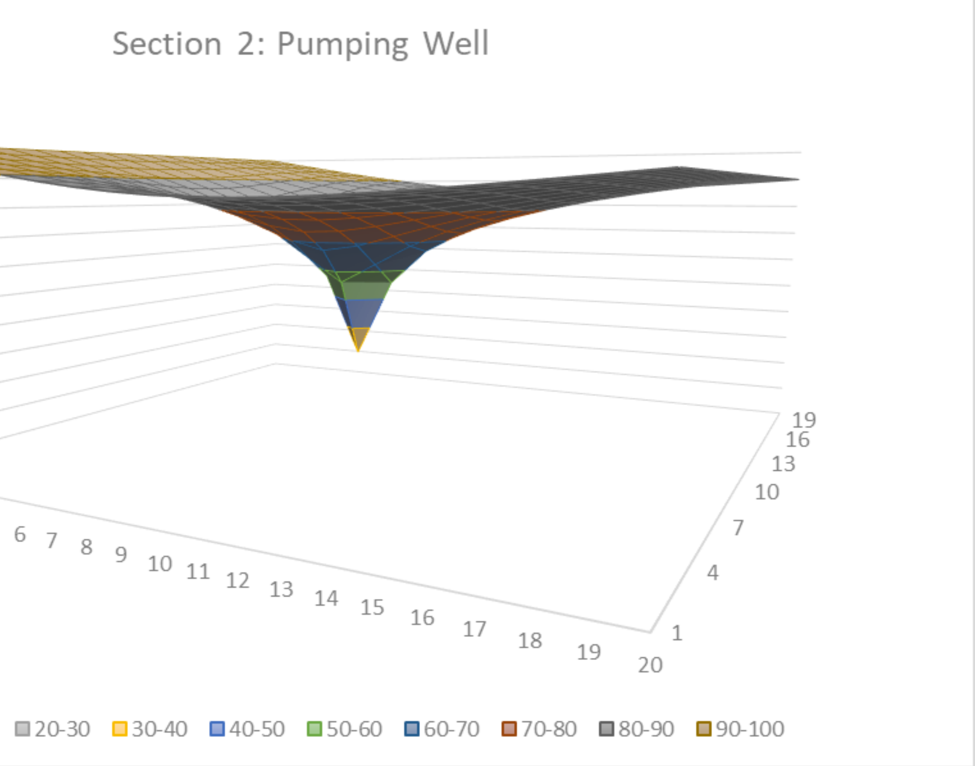



**Before Pumping**




**After Pumping**
**Note the cone of depression**



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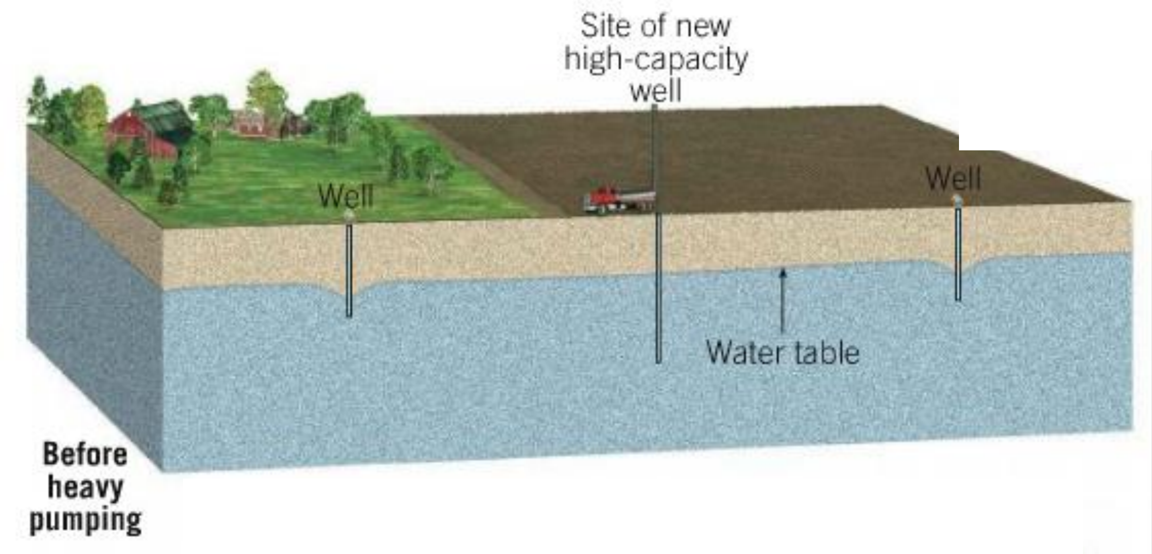
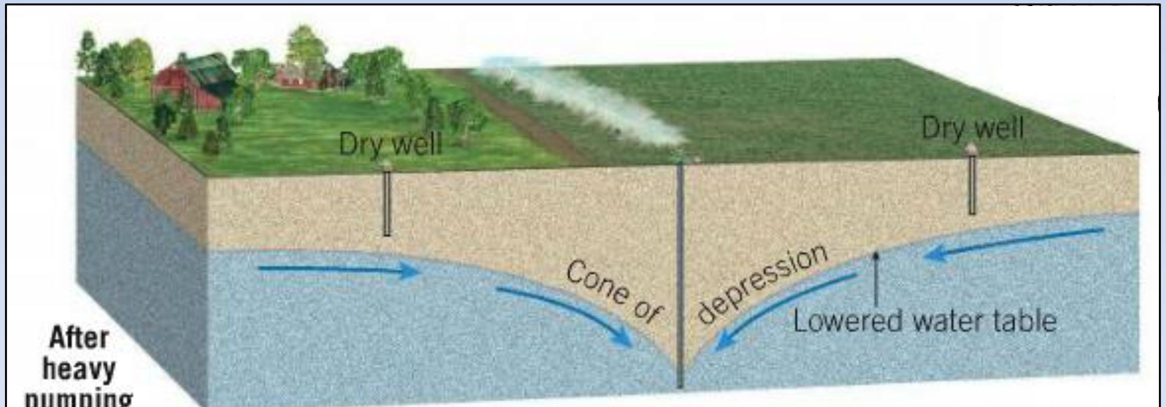



Lutgens and Tarbuck, 2017

**Usually, we are concerned with agricultural impacts to aquifers rather than pumping impacts to agriculture!**

**In very simple terms, a <u>well</u> is a hole that it is bored into the ground to pump groundwater from an aquifer.**

**Prior to groundwater pumping, the water table is usually relatively flat or gently sloping.**

**In this image, you can see that the 2 wells are slightly affecting the water table. This is called <u>drawdown</u>!**

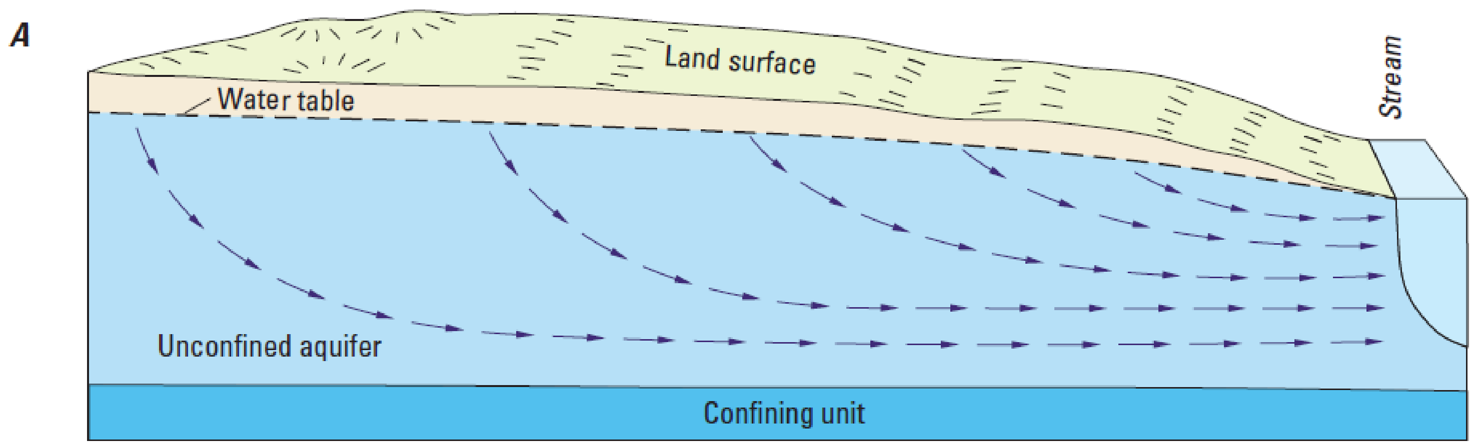
**A conical shaped depression forms in the water table in response to pumping. This is called a <u>cone of depression</u>!**

**Now, suppose that a high-capacity well is installed.**

**Once groundwater pumping begins at the high-capacity well, the cone of depression becomes larger (the water table near the new well starts to decline deeper and more steeply). The 2 pre-existing wells are now dry. This is just one simple scenario. *I'm not suggesting that this will happen.***

# What happens when we pump groundwater from a well located near a river?

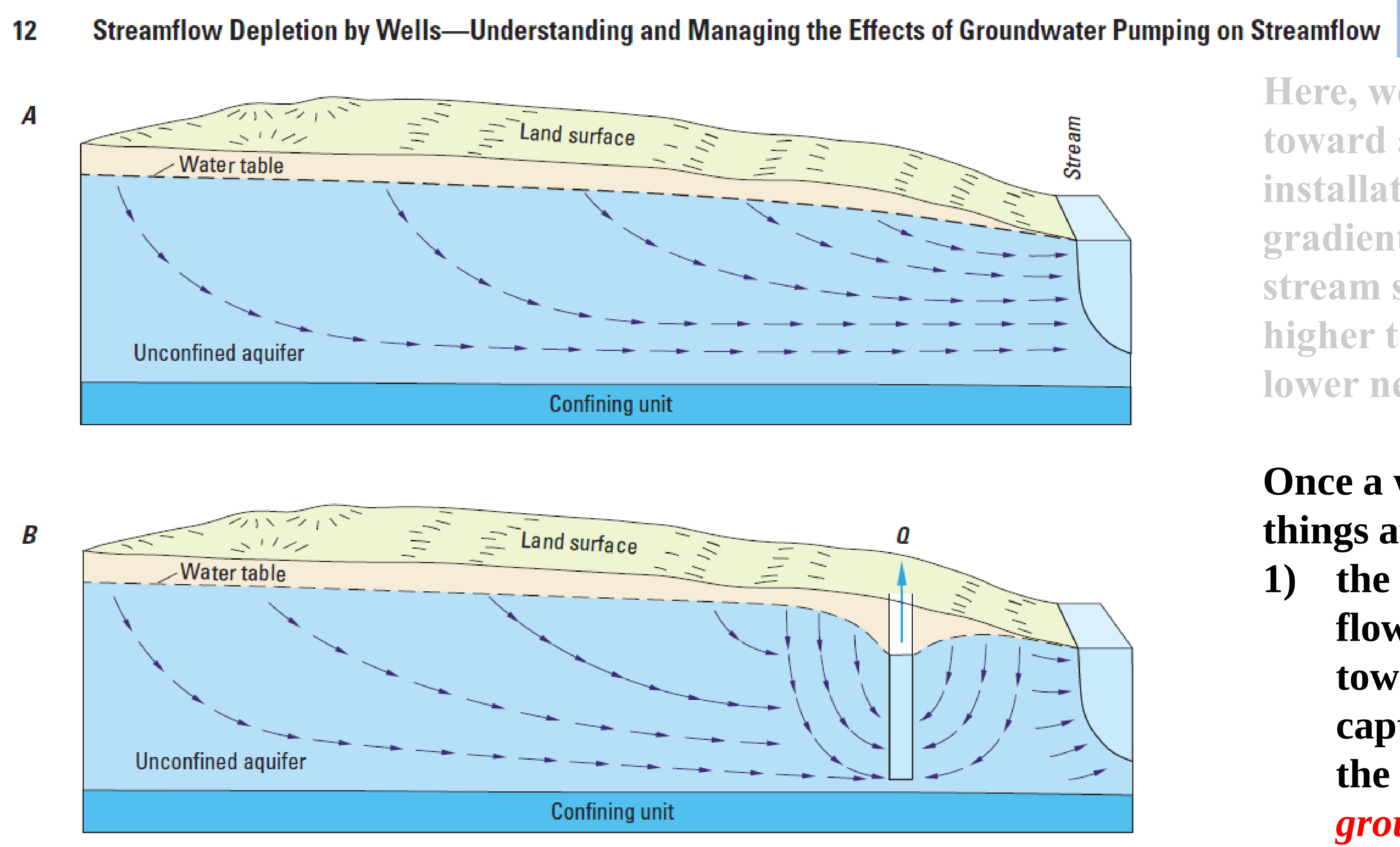
12 Streamflow Depletion by Wells—Understanding and Managing the Effects of Groundwater Pumping on Streamflow




**Here, we see groundwater flowing toward a stream prior to the installation of a well. The hydraulic gradient drives flow toward the stream since the hydraulic head is higher to the left of the image and lower near the stream.**

Barlow and Leake, 2012

# What happens when we pump groundwater from a well located near a river?



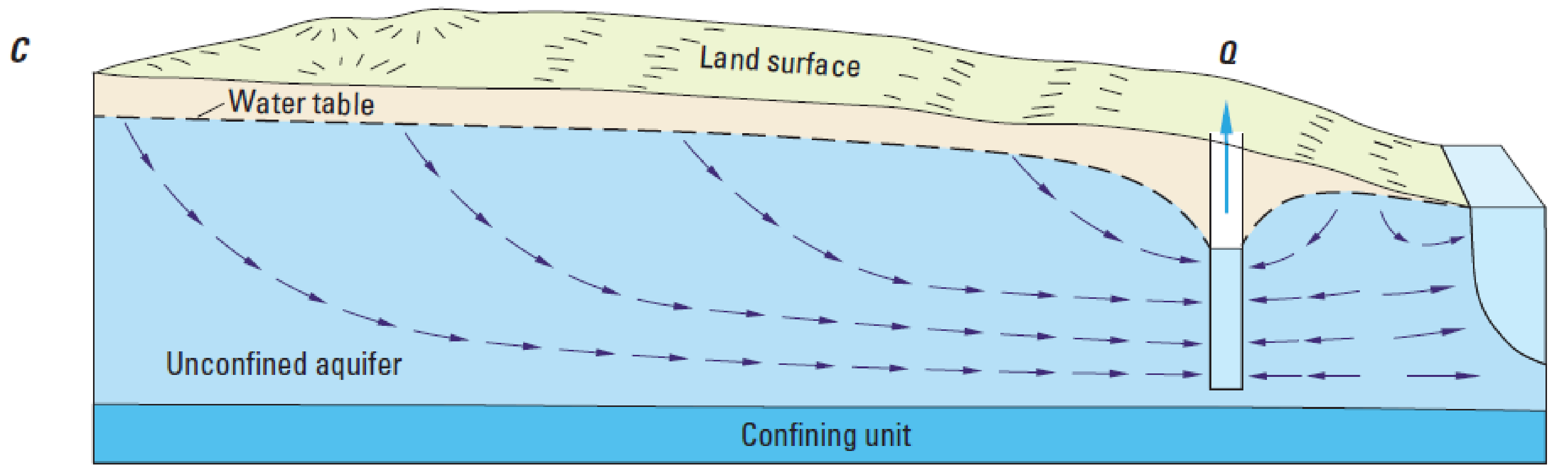

Barlow and Leake, 2012

Here, we see groundwater flowing toward a stream prior to the installation of a well. The hydraulic gradient drives flow toward the stream since the hydraulic head is higher to the left of the image and lower near the stream.

**Once a well is installed, we see two things at early time:**

1) **the well captures groundwater flowing in its original direction toward the stream and it begins capturing groundwater between the well and stream (*all the groundwater pumped from the well comes from storage*),**
2) **the hydraulic gradient is slowly changing near the well.**

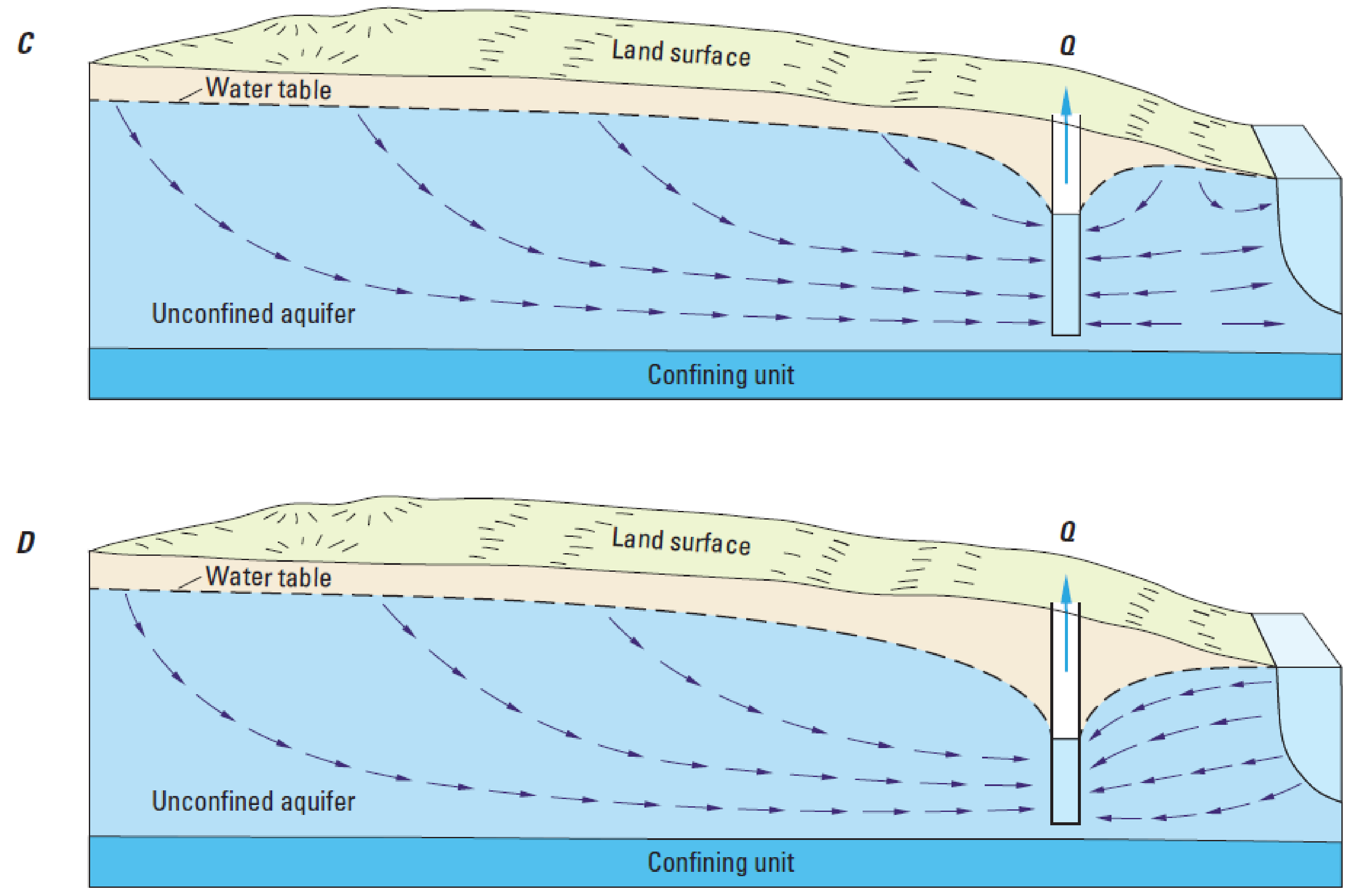
# What happens when we pump groundwater from a well located near a river?




Barlow and Leake, 2012

**At some later time, we see that the water level is decreasing near the well and the cone of depression is enlarging. The well is now capturing groundwater that would otherwise flow to the stream.**

# What happens when we pump groundwater from a well located near a river?




Barlow and Leake, 2012

At some later time, we see that the water level is decreasing near the well and the cone of depression is enlarging. The well is now capturing groundwater that would otherwise flow to the stream.

**At some late time, the well becomes the low potential. Thus, the well captures groundwater flowing toward the stream from the left and it begins to induce recharge through the streambed and begins to capture streamflow.**

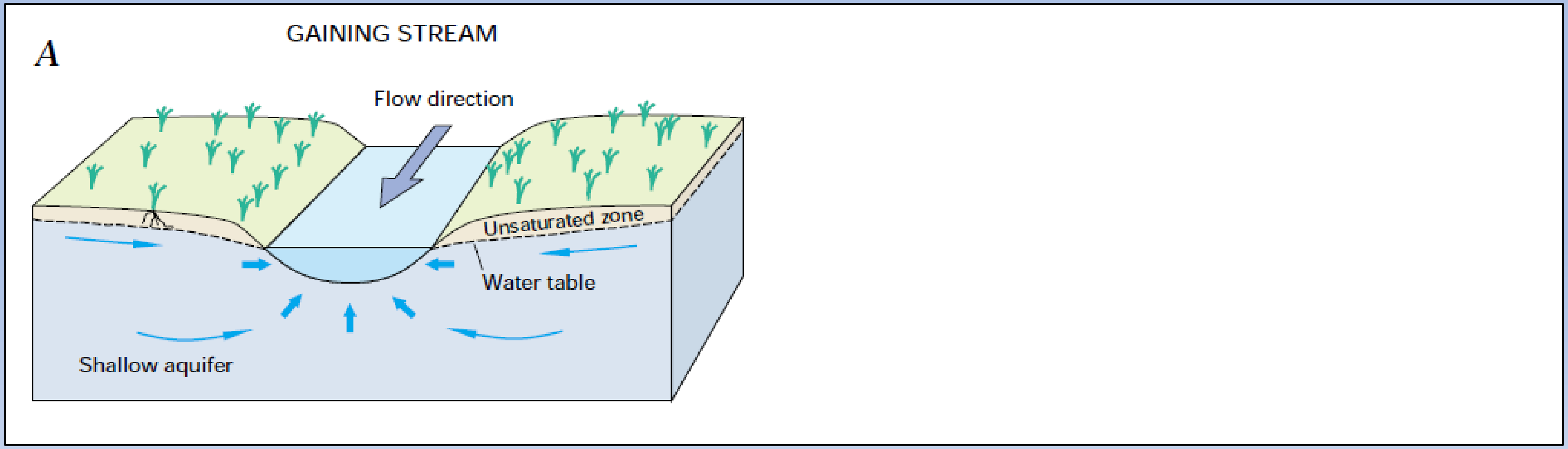
**The water pumped from the well is now a mixture of groundwater and induced recharge from the stream.**

**This is called streamflow depletion and it represents the combined effects of captured groundwater discharge and induced recharge.**

# What are "groundwater/surface-water interactions"?

**Groundwater/surface-water interactions are simply exchanges of water between groundwater systems (aquifers) and surface water systems (creeks, streams, rivers, ponds, lakes, wetlands)**

a. Almost all surface-water bodies are in *hydrological communication* with groundwater – *hydrological communication* means that they exchange water
b. When groundwater discharges to a surface-water body, it transports:
   i. Water (obvious, but we need to connect the "correct" aquifers in models)
   ii. Solutes (from geochemical and microbiological processes), nutrients, and isotopes
   iii. Age-mass (residence times of water)
   iv. Heat
   v. Microbes (microbiological communities)
c. Streams **GAIN** water from groundwater discharge
   i. Groundwater flows "down the gradient" – resulting in discharge to the stream




Winter et al., 1998

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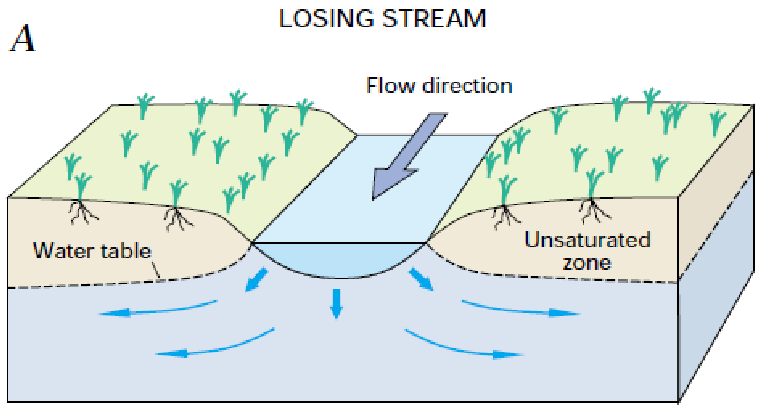
   iv. Heat
   v. Microbes (microbiological communities)
c. Streams GAIN water from groundwater discharge
   i. Groundwater flows "down the gradient" – resulting in discharge to the stream
d. **Streams can LOSE water to groundwater and support groundwater recharge**
   i. **Hydraulic gradient is reversed – induce recharge through streambed**




Winter et al., 1998

# Streamflow depletion can impact longitudinal connectivity, seasonality, thermal refugia, and geochemical characteristics.

Pool and dry river bed along the Ipswich River, Reading, Massachusetts, September 2005.

Barlow and Leake, 2012

https://bloximages.chicago2.vip.townnews.com/myheraldreview.com/content/tncms/assets/v3/editorial/5/a5/5a527726-b961-11e9-91fb-cf587c18da2e/5d4b503fc2060.image.jpg?resize=1043%2C500

**For more information, please see:**

https://www.usgs.gov/publications/basic-ground-water-hydrology

https://pubs.er.usgs.gov/publication/cir1139

https://pubs.usgs.gov/circ/1376/

https://www.in.gov/dnr/water/ground-water-wells/assessment-maps-and-publications/aquifer-systems-mapping-148000/tippecanoe-county/