Grounding Water: An Exploration of the Unseen World Beneath Our Feet

Kerry Schwartz, Director, Arizona Project WET

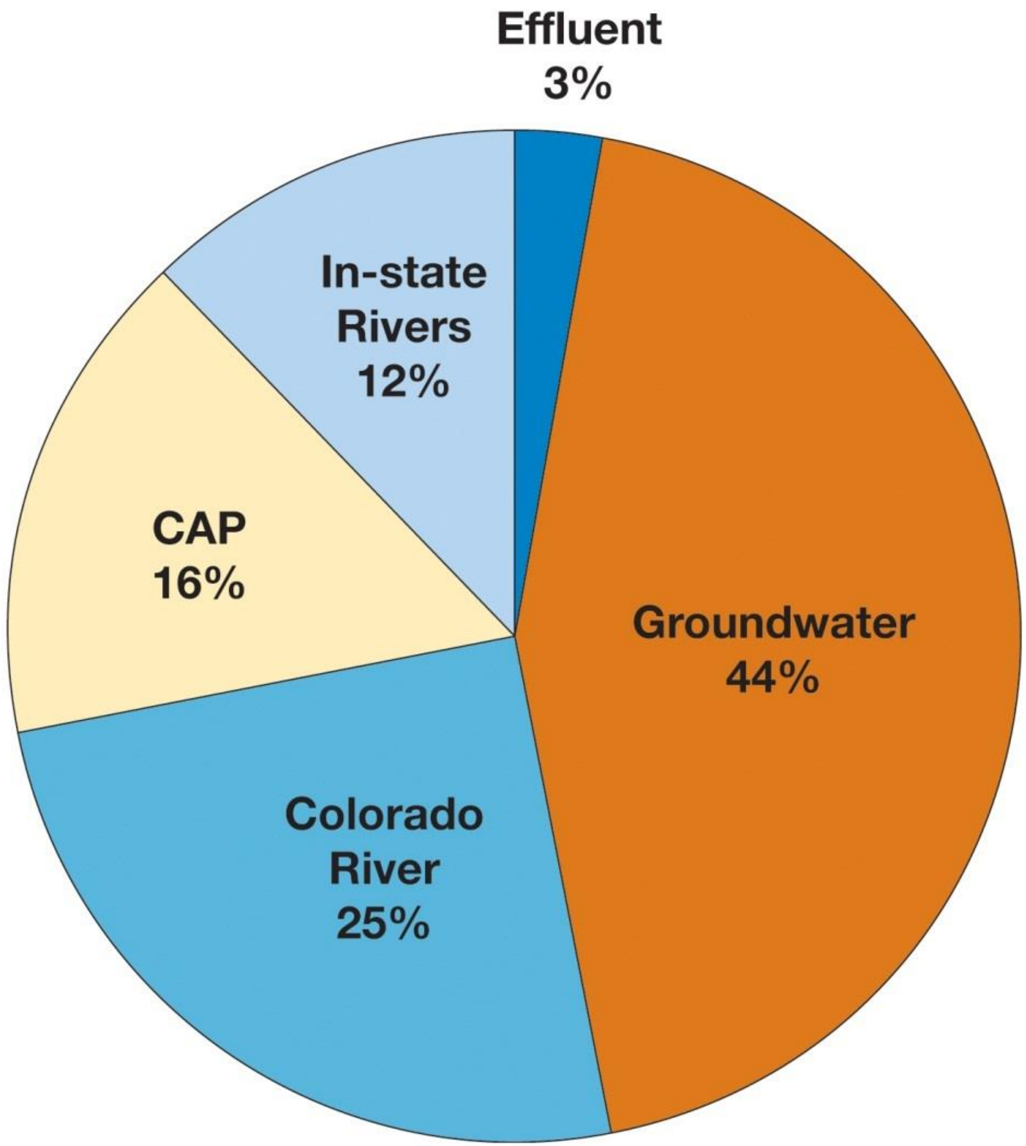
Protect Your Groundwater Day: Tuesday, September 9, 2014

What I Hope to Convey

- Groundwater is important.
- The sources of peoples’ misconceptions about groundwater need to be addressed in our instructional tools.
- The use of models can greatly assist in building conceptual understanding.
- People need to understand the groundwater system in order to protect it.

Worldwide

- Groundwater is the most abundant source of fresh water on earth, (97% of non-frozen fresh water).
- Approximately 44 % of the world's population regularly depends on GW. (NGWA, 2014)
- Globally GW provides 25% to 40% of the world's drinking water. (http://www.un-igrac.org/dynamics/modules/SFIL0100/view.php?fil_Id=126)
- Over the past century, groundwater withdrawal has grown to exceed natural renewable groundwater storage (or safe yield) in many areas of the globe. (Narasimhan, 2010)



Water Supply

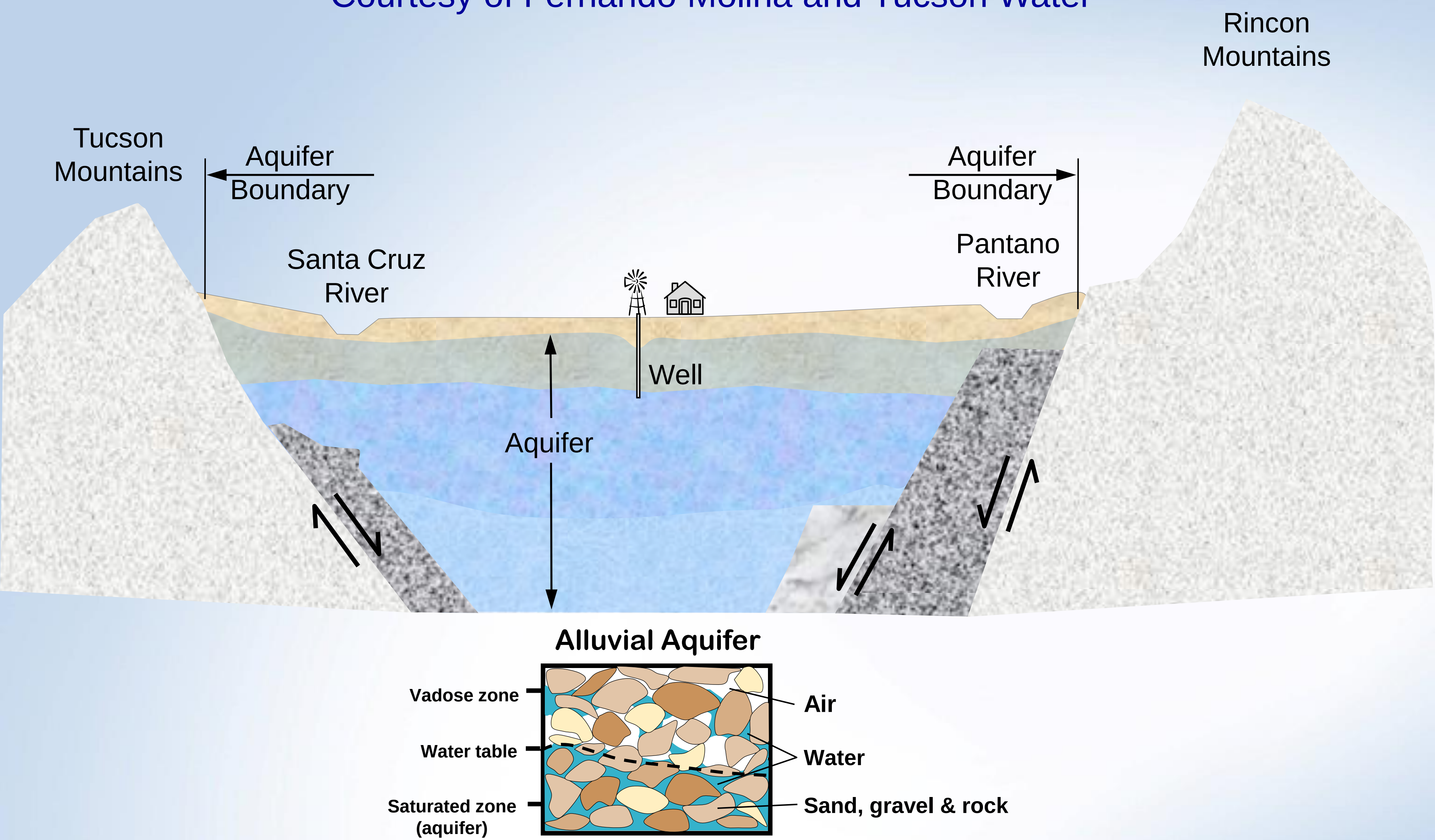
Groundwater Use in the Arid West

Figure 14. *Percentage of population of each State in the contiguous Western United States dependent on ground water for domestic water needs. From U.S. Geological Survey (1998).*

Water Availability for the Western United States—Key Scientific Challenges
By Mark T. Anderson and Lloyd H. Woosley, Jr., USGS Circular 1261, 2005

Aquifer Cross-Section

Courtesy of Fernando Molina and Tucson Water



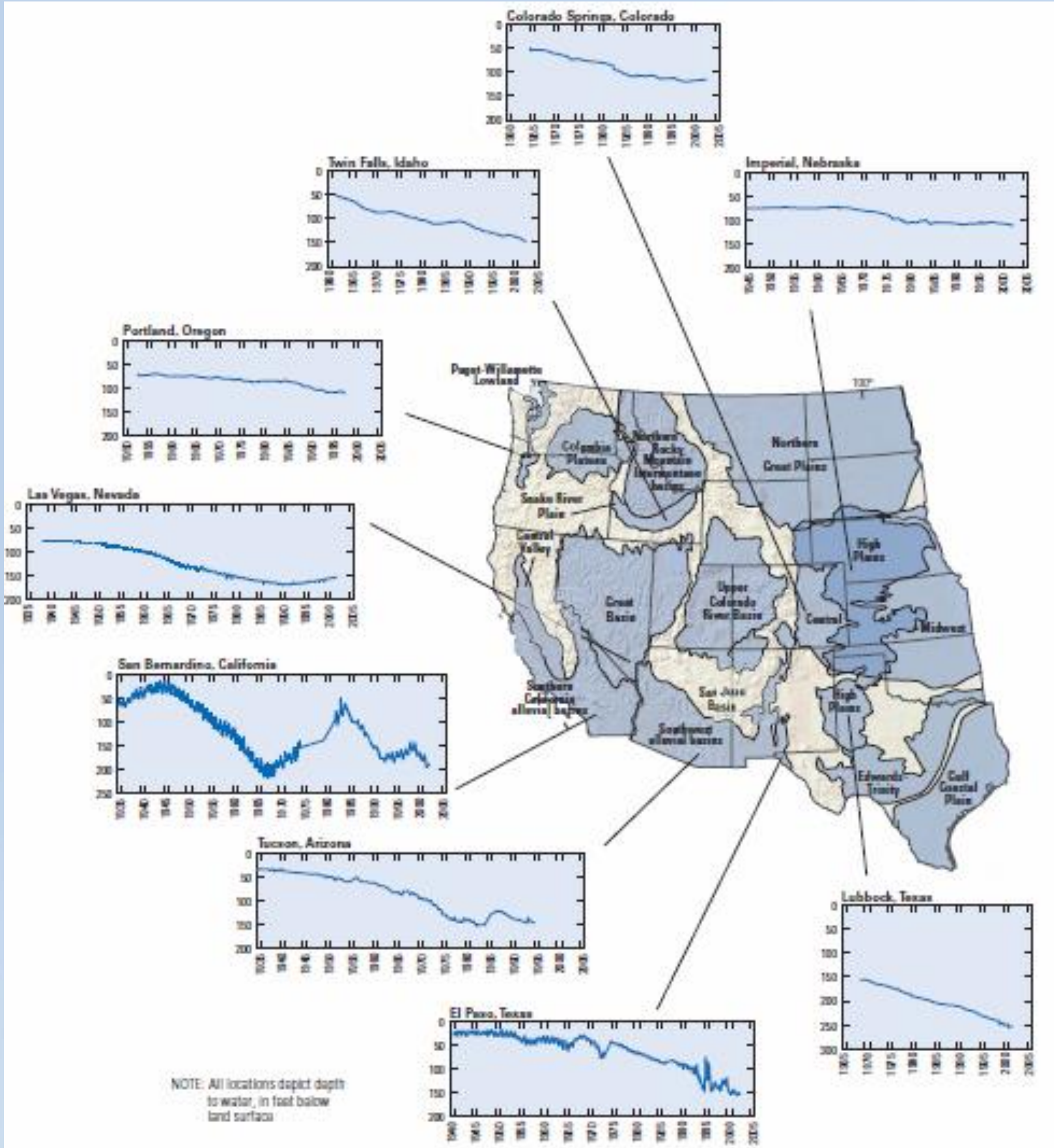
Basin Full of Groundwater

Amount of groundwater in storage :

- At 500’ below the 1966 water table ~ 30.5 million acre-feet
- At 1,000’ below the water table ~ 52 million acre-feet

Geohydrology and Water Resources of the Tucson Basin, Arizona, 1973 By E. S. DAVIDSON
WATER RESOURCES OF THE TUCSON BASIN, GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1939-E

Tucson Basin is ~10,000 feet deep in the middle of the Basin!



Major aquifers in the contiguous Western United States and select hydrographs showing changes in depth to water below land surface.

Water Availability for the Western United States—Key Scientific Challenges
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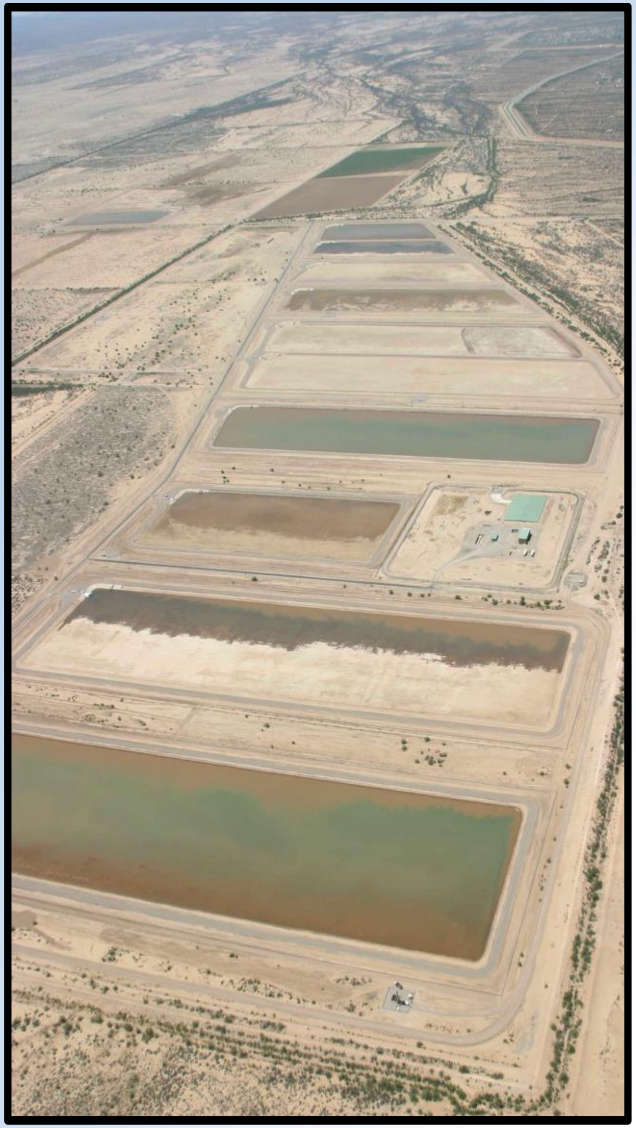
In Arizona: The Groundwater Management Act (GMA) of 1980

Established required groundwater management in Active Management Areas.

Tucson Active Management Area (TAMA) has a goal of Safe Yield Goal: To achieve and thereafter maintain a long-term balance between the annual amount of groundwater withdrawn and the annual amount of natural and artificial recharge in the active management area.

- Required the adoption of Assured Water Supply Rules, which require growth to depend on *renewable supplies*.
- Conservation programs for each water using sector and management plans are developed by the Arizona Department of Water Resources every 10 years.

Recharging Colorado River Water



- CAP water recharged through surface spreading basins (543 acres)

-Wells, Reservoirs, Booster Stations, and Transmission Lines

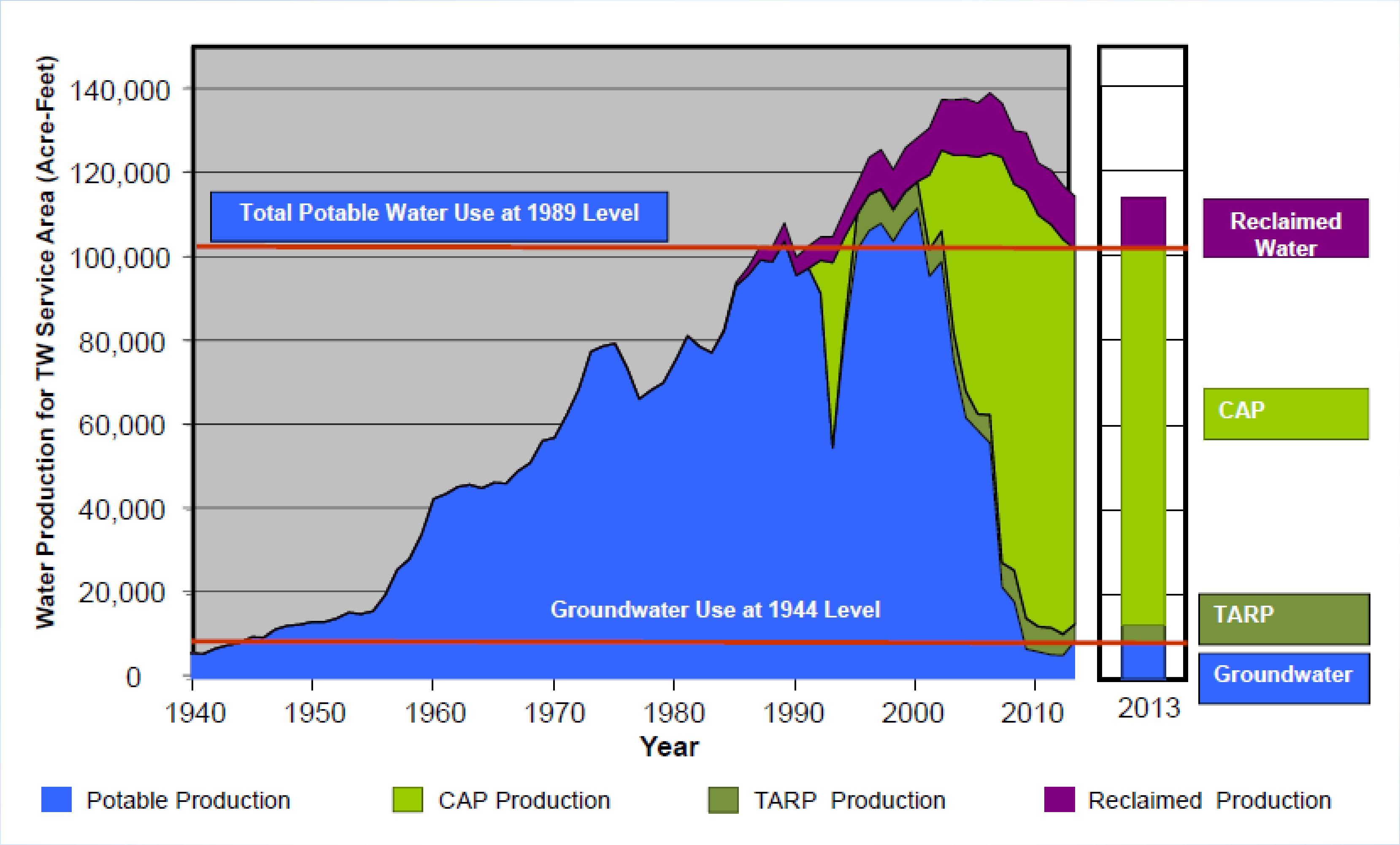
1 Million Acre Feet (AF) Recharged April 2013

“Banking” 44,000 AF per year

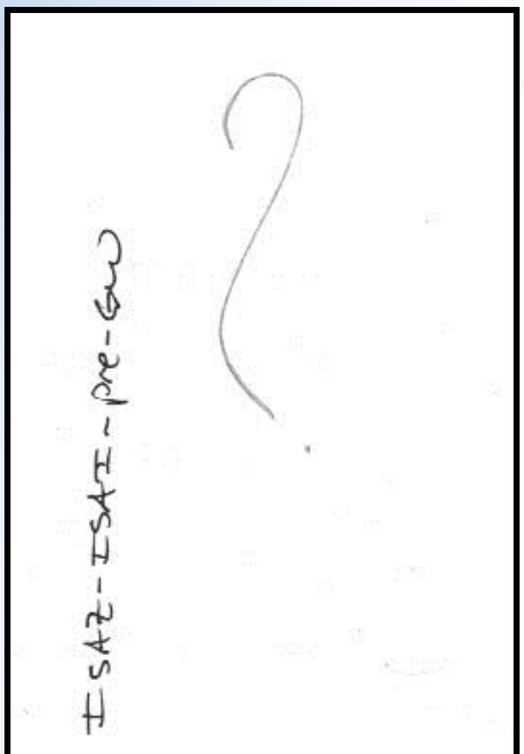
Courtesy of Fernando Molina and Tucson Water

Transition to Renewable Supplies

Courtesy of Fernando Molina and Tucson Water



How do you teach about a complex system that you can’t even see?



- A common pre assessment drawing when we were asking 4th graders to draw that they think the groundwater system looks like

***Table 2.**—Principal types of data and data compilations required for analysis of ground-water systems*

Physical Framework

- Topographic maps showing the stream drainage network, surface-water bodies, landforms, cultural features, and locations of
- structures and activities related to water
- Geologic maps of surficial deposits and bedrock
- Hydrogeologic maps showing extent and boundaries of aquifers and confining units
- Maps of tops and bottoms of aquifers and confining units
- Saturated-thickness maps of unconfined (water-table) and confined aquifers
- Average hydraulic conductivity maps for aquifers and confining units and transmissivity maps for aquifers
- Maps showing variations in storage coefficient for aquifers
- Estimates of age of ground water at selected locations in aquifers

Hydrologic Budgets and Stresses

- Precipitation data
- Evaporation data
- Streamflow data, including measurements of gain and loss of streamflow between gaging stations
- Maps of the stream drainage network showing extent of normally perennial flow, normally dry channels, and normally
- seasonal flow
- Estimates of total ground-water discharge to streams
- Measurements of spring discharge
- Measurements of surface-water diversions and return flows
- Quantities and locations of interbasin diversions
- History and spatial distribution of pumping rates in aquifers
- Amount of ground water consumed for each type of use and spatial distribution of return flows
- Well hydrographs and historical head (water-level) maps for aquifers
- Location of recharge areas (areal recharge from precipitation, losing streams, irrigated areas, recharge basins, and recharge wells), and estimates of recharge

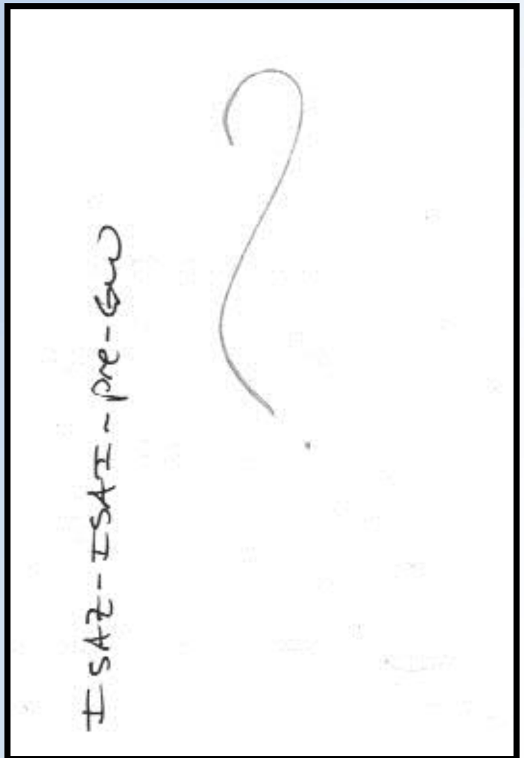
Chemical Framework

- Geochemical characteristics of earth materials and naturally occurring ground water in aquifers and confining units
- Spatial distribution of water quality in aquifers, both areally and with depth
- Temporal changes in water quality, particularly for contaminated or potentially vulnerable unconfined aquifers
- Sources and types of potential contaminants
- Chemical characteristics of artificially introduced waters or waste liquids
- Maps of land cover/land use at different scales, depending on study needs
- Streamflow quality (water-quality sampling in space and time), particularly during periods of low flow

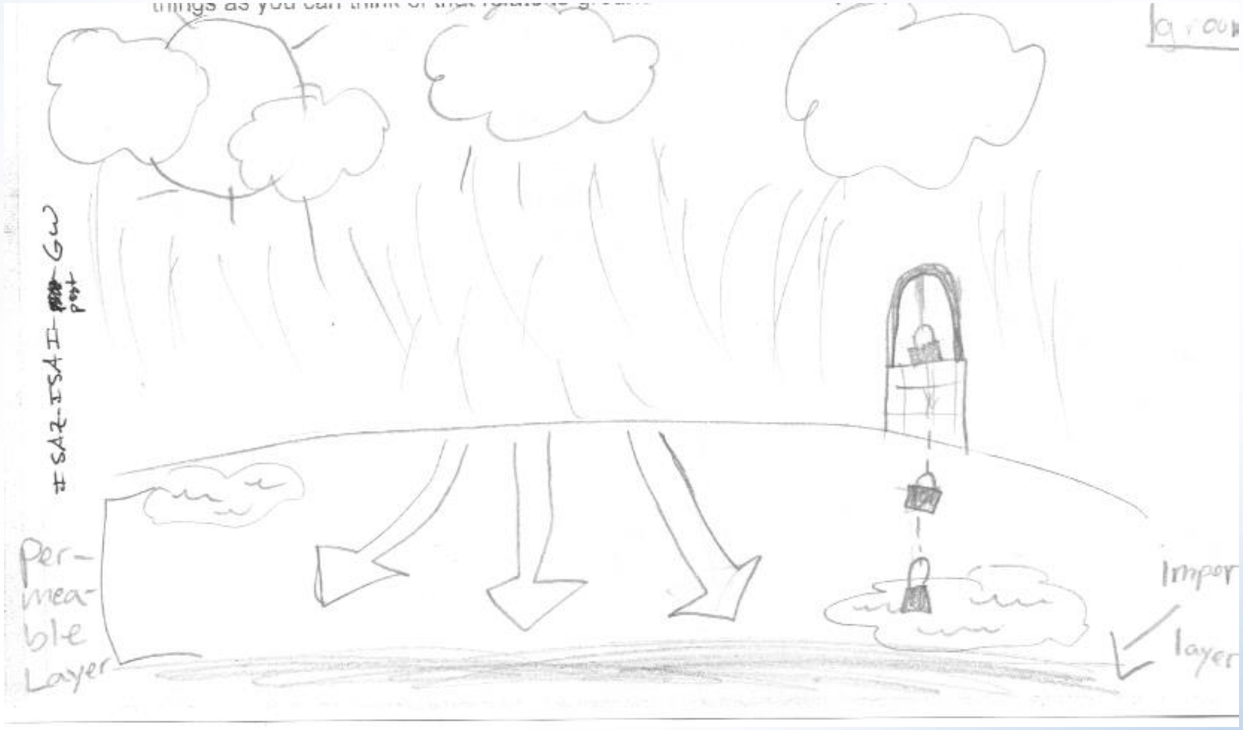
From: *Sustainability of Ground-Water Resources --USGS Circular 1186*

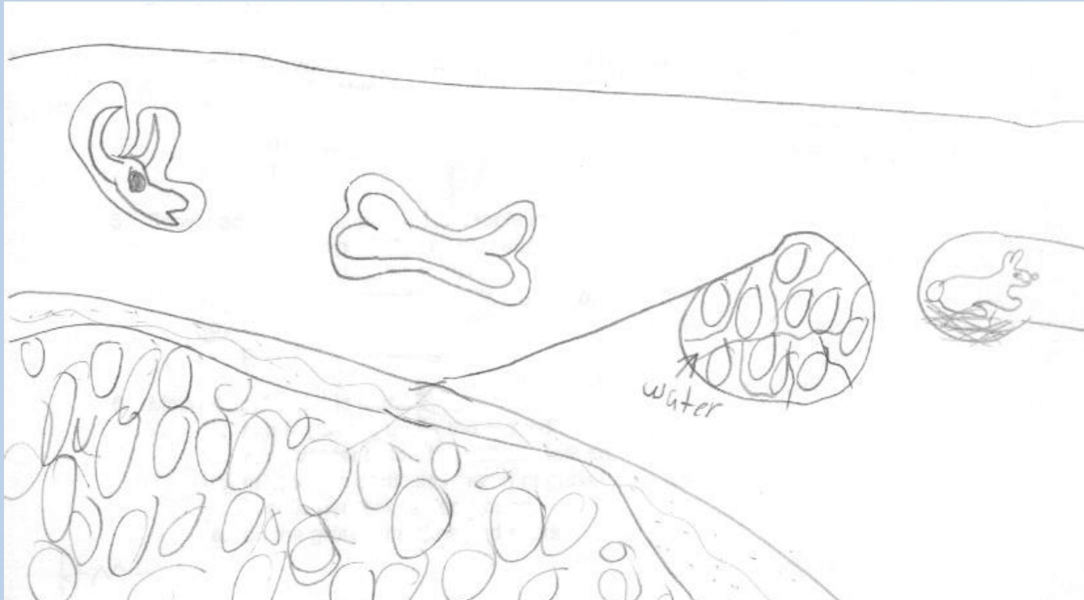
Grounding Water: Building Conceptual Understanding through Multimodal Assessment

Pre-Test



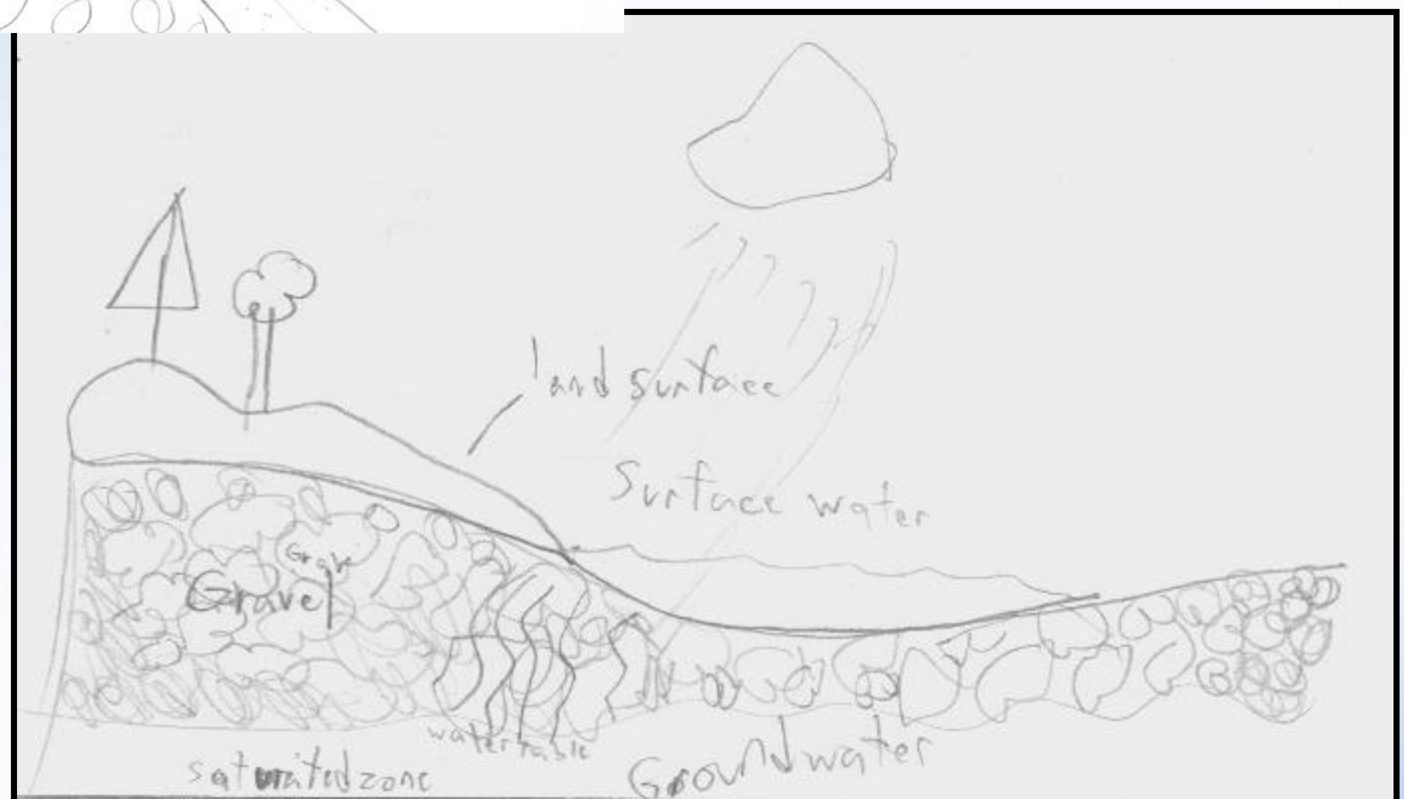
Post-Test





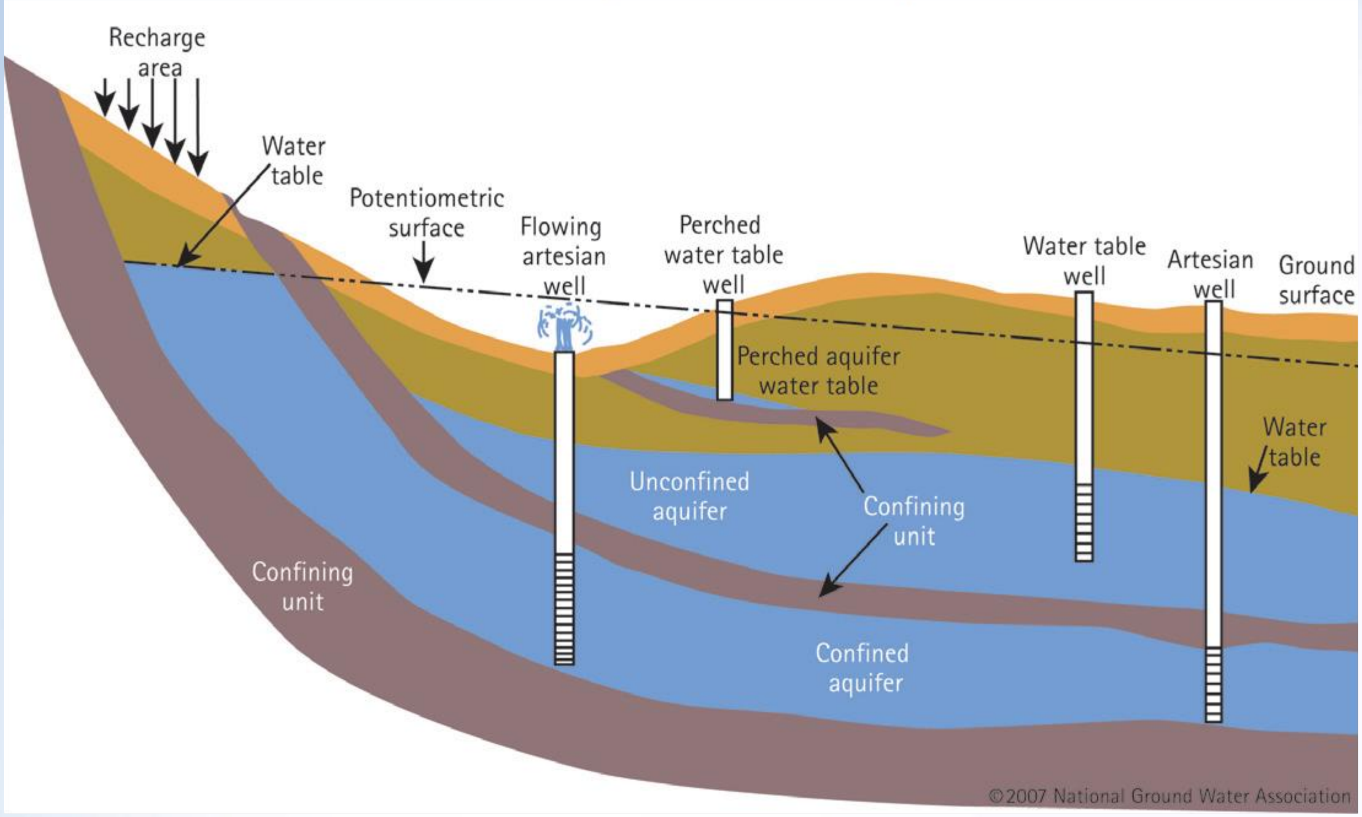
Groundwater

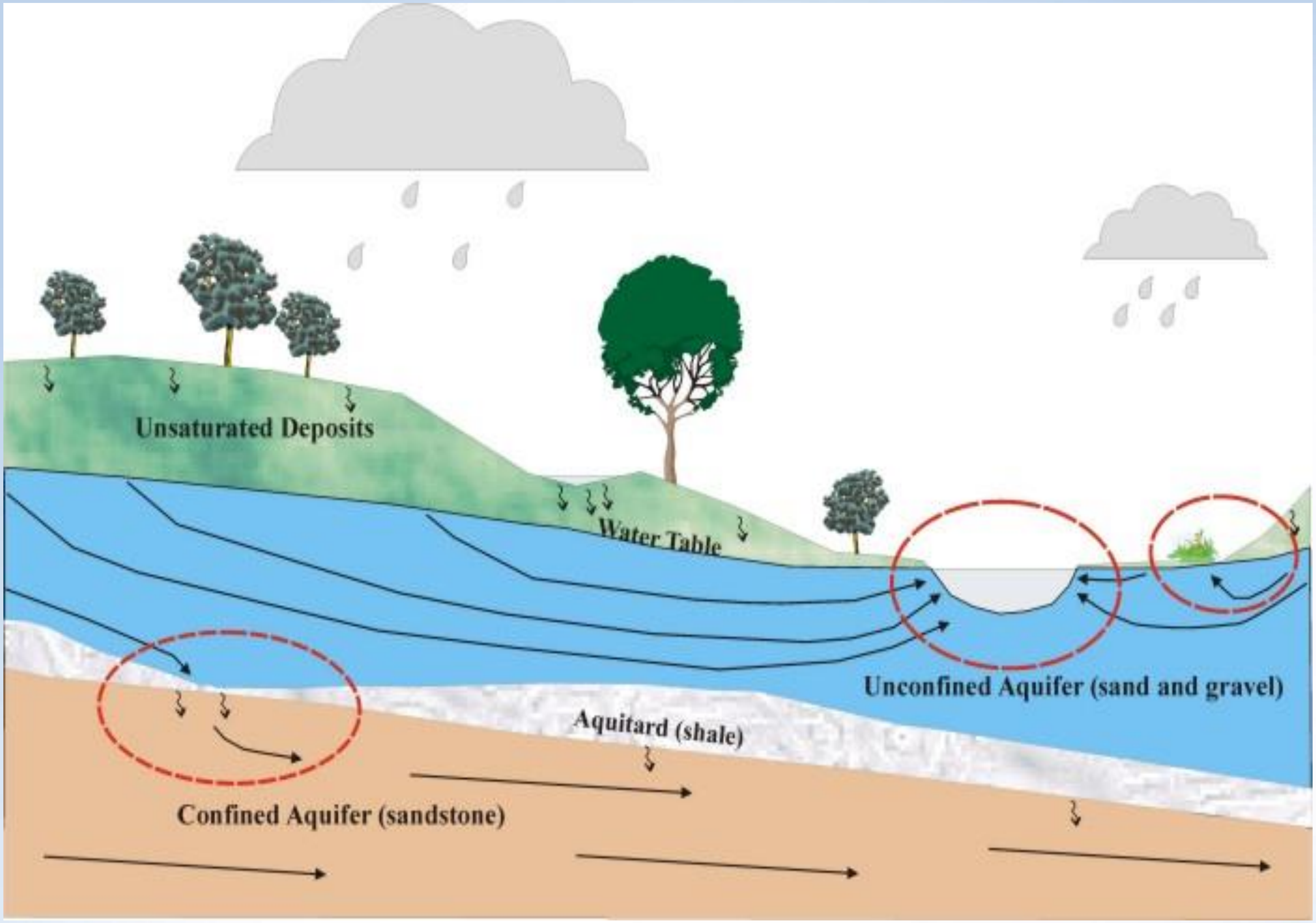
Post-Tests



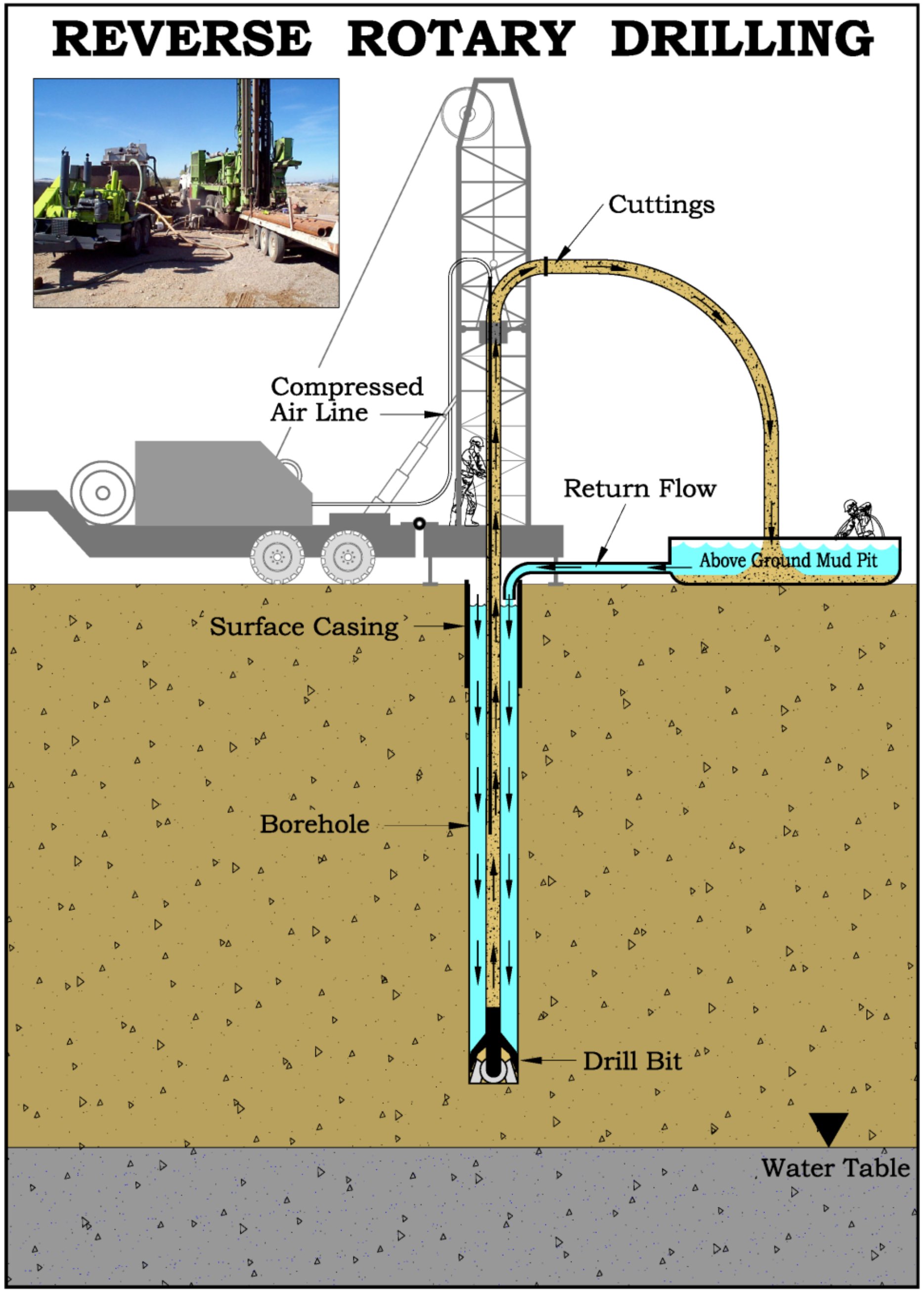
Misconceptions Caused by Instructional Diagrams: Groundwater is blue and looks like a lake underground.

Groundwater Illustrations Can Lead to Misconceptions

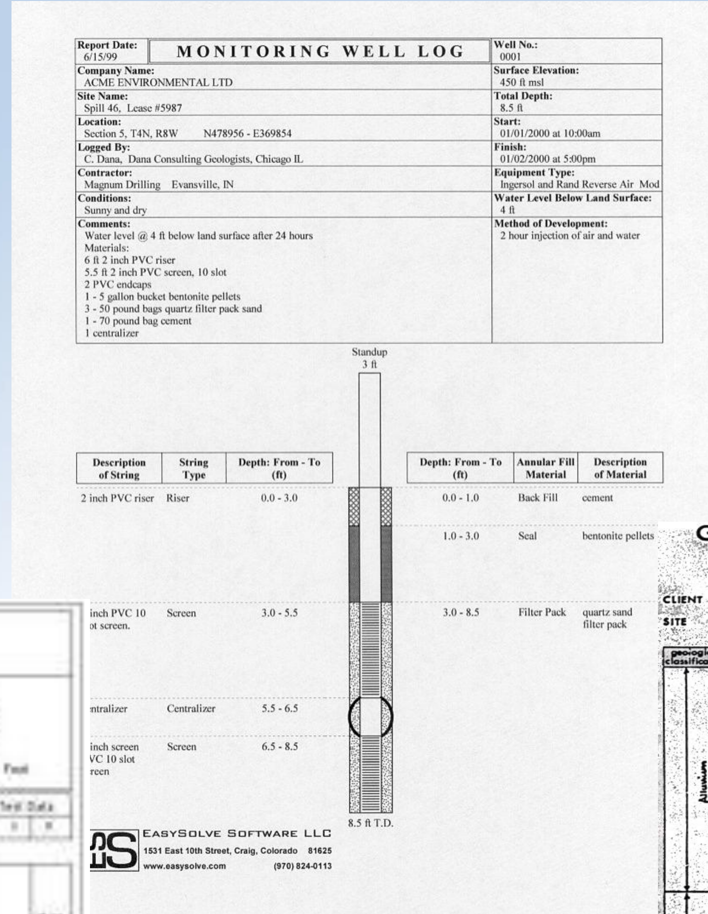


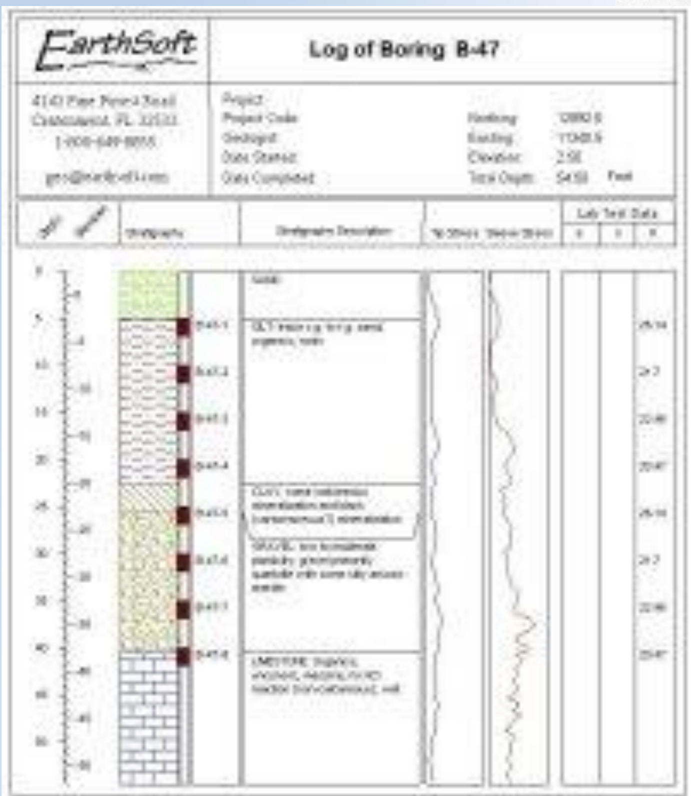


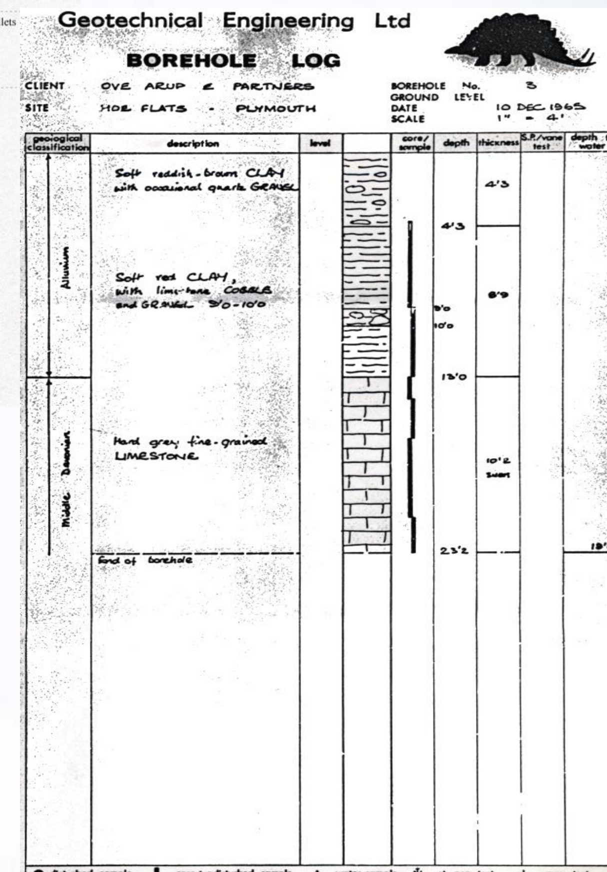
Unsaturated Deposits
Water Table
Unconfined Aquifer (sand and gravel)
Aquitard (shale)
Confined Aquifer (sandstone)


REVERSE ROTARY DRILLING
Cuttings
Compressed
Air Line
Return Flow
Above Ground Mud Pit
Surface Casing
Borehole
Drill Bit
Water Table

Borehole and Well Logs





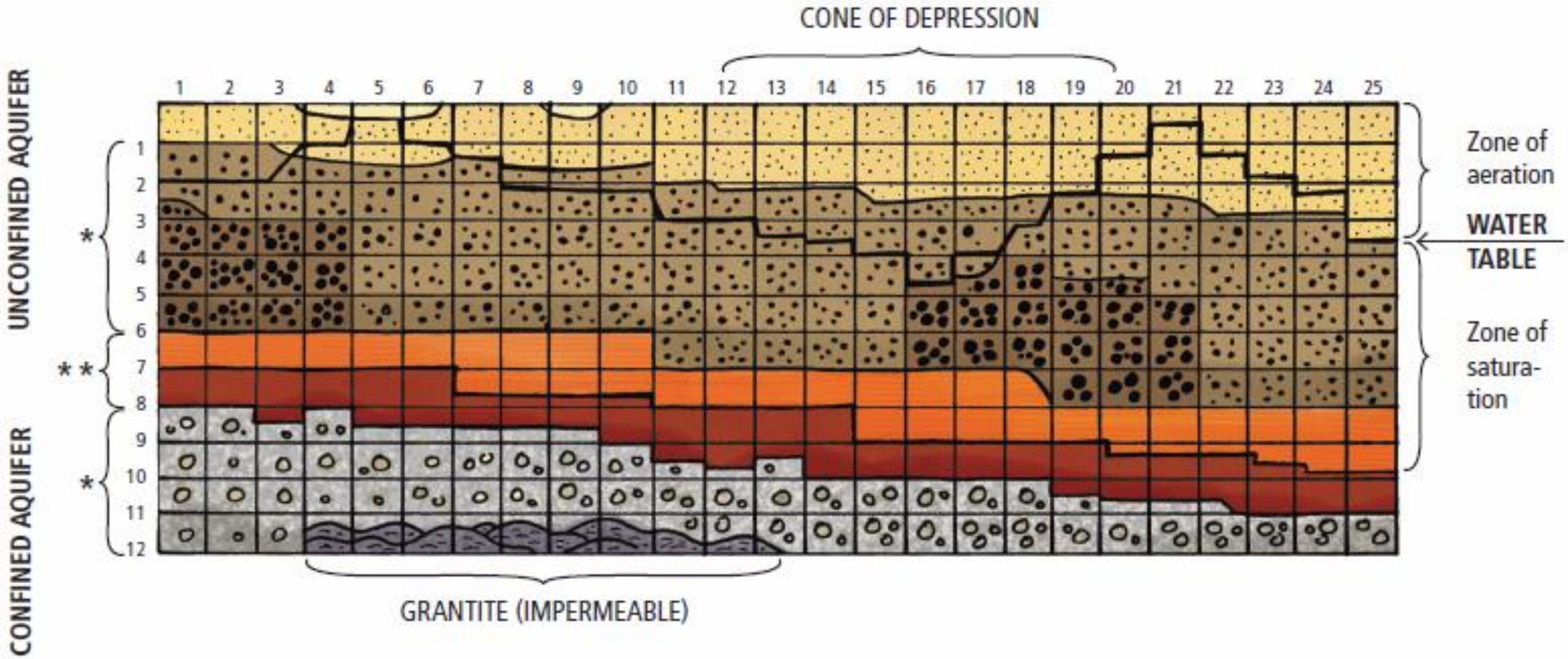


Get the Groundwater Picture

KEY Note: numbers in vertical columns are in inches.

Well Number Land Use Type	Water Table	Fine Sand	Medium Sand	Coarse Sand	Sand-stone	Clay Layer	Gravel Layer	Granite
1 farmland	2	0 - 1	1 - 2 ½	2 ½ - 6	6 - 7	7 - 8	8 - 12	—
2 farmland	2	0 - 1	1 - 3	3 - 6	6 - 7	7 - 8	8 - 12	—
3 farmland	2	0 - 1 ½	1 ½ - 3	3 - 6	6 - 7	7 - 8 ½	8½ - 12	—
4 wetland	1	¼ - 1 ½	1 1½ - 3	3 - 6	6 - 7	7 - 8 ¼	8 ¼ - 11 ½	11 ½ - 12
5 wetland	¼	½ - 1 ½	1 ½ - 6	—	6 - 7 ¼	7 ¼ - 8 ¼	8 ¼ - 11 ½	11 ½ - 12
6 wetland	1	¼ - 1 ¾	1 ¾ - 6	—	6 - 7 ¼	7 ¼ - 8 ½	8 ½ - 11	11 - 12
7 farmland	1 ¾	0 - 1 ¾	1 ¾ - 6	—	6 - 7 ¾	7¾ - 8 ¾	8 ¾ - 11	11 - 12
8 farmland	2 ½	0 - 1 ¾	1 ¾ - 6	—	6 - 7 ¾	7 ¾ - 8 ¾	8 ¾ - 11	11 - 12
9 landfill	2 ½	¾ - 1 ¾	1 ¾ - 6	—	6 - 7 ¾	7 ¾ - 8 ¾	8 ¾ - 11	11 - 12
10 industry	2 ½	0 - 1 ¾	1 ¾ - 6	—	6 - 7 ¾	7 ¾ - 9	9 - 11	11 - 12
11 industry	3	0 - 2	2 - 7	—	7 - 8	8 - 9 ¼	9 ¼ - 11 ½	11 ½ - 12
12 urban area	3	0 - 2 ¼	2 ¼ - 7	—	7 - 8 ¼	8 ¼ - 9 ½	9 ½ - 11 ½	11 ½ - 12
13 urban area	3 ½	0 - 2¼	2¼ - 7	—	7 - 8 ¼	8 ¼ - 9½	9 ½ - 11 ½	11 ½ - 12
14 urban area	3 ¾	0 - 2 ¼	2 ¼ - 7	—	7 - 8 ½	8 ½ - 9 ¾	9 ¾ - 11 ½	11 ½ - 12
15 urban area	4	0 - 2 ¾	2 ¾ - 4½	4 ½ - 7	7 - 9	9 - 9 ¾	9 ¾ - 12	—
16 urban area	5	0 - 2 ¾	2 ¾ - 4 ½	4 ½ - 7	7 - 9	9 - 9 ¾	9 ¾ - 12	—
17 farmland	4	0 - 2 ¾	2 ¾ - 4 ½	4 ½ - 7 ½	7 ½ - 9	9 - 10	10 - 12	—
18 wastewater treatment plant	3	¼ - 2 ½	2 ½ - 4		4 - 7 ½	7 ½ - 9	9 - 10	10 - 12
19 farmland	2½	0 - 2 ¼	2 ¼ - 4 ½	4 ½ - 8	8 - 9	9 - 10 ¼	10 ¼ -12	—
20 river	1 ½	¼ - 2 ½	2½ - 4½	4 ½ - 8	8 - 9 ¼	9 ¼ - 10 ½	10 ½ - 12	—
21 river	½	1 - 2½	2 ½ - 5	5 - 8	8 - 9 ¼	9 ¼ - 10 ½	10 ½ - 12	—
22 river	1 ½	¼ - 3	3 - 8	—	8 - 9 ¼	9 ¼ - 10 ½	10 ½ - 12	—
23 national park	2	0 - 3	3 - 8	—	8 - 9 ½	9½ - 10 ¾	10 ¾ - 12	—
24 national park	3 ¼	0 - 2 ¾	2 ¾ - 8	—	8 - 9 ¾	9 ¾ - 11	11 - 12	—
25 national park	3 ¾	0 - 3	3 - 8	—	8 - 10	10 - 11 ¼	11 ¼ - 12	

Well Log Ground Water (Cross Section)



KEY:

* Permeable layers

** Imperemeable layer (clay)

Note: numbers in vertical columns are in inches


SIDE UP
MARKS-A-LOT

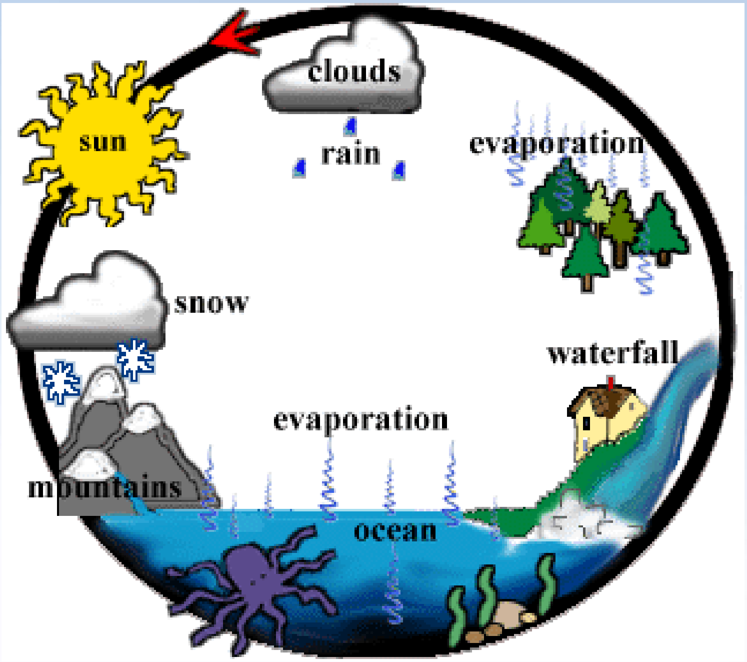
Close-up of Wells

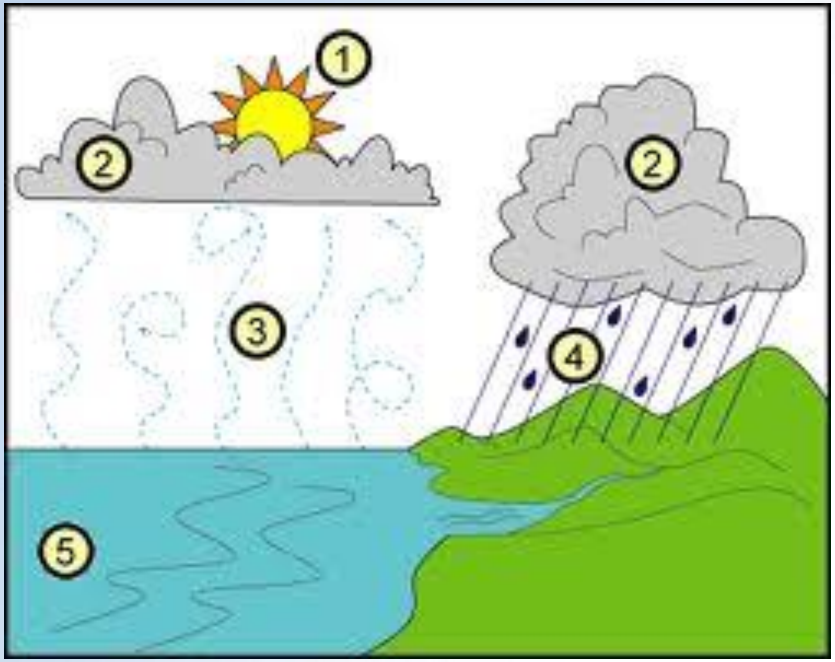
Where is the Groundwater?

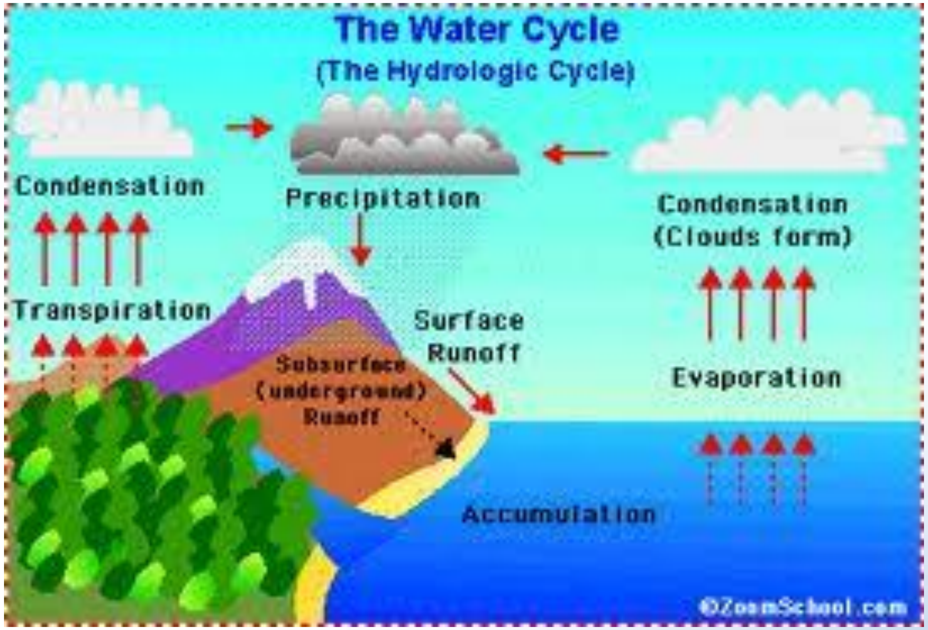
Misconceptions Caused by Instructional Diagrams:

Is Groundwater part of the Water Cycle?

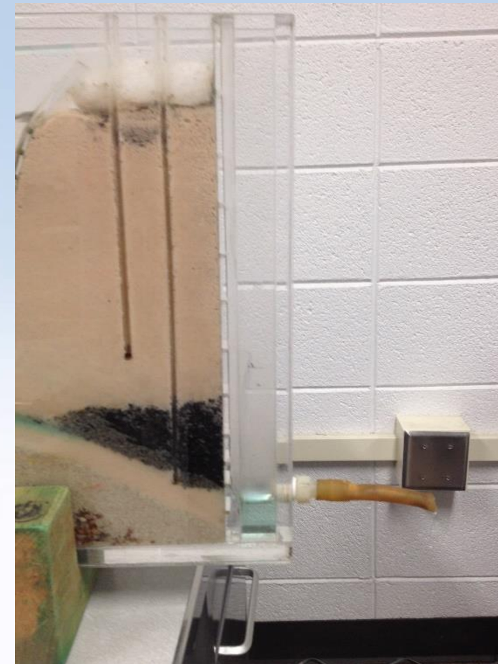
Traditional Water Cycle Models Don't Go Underground





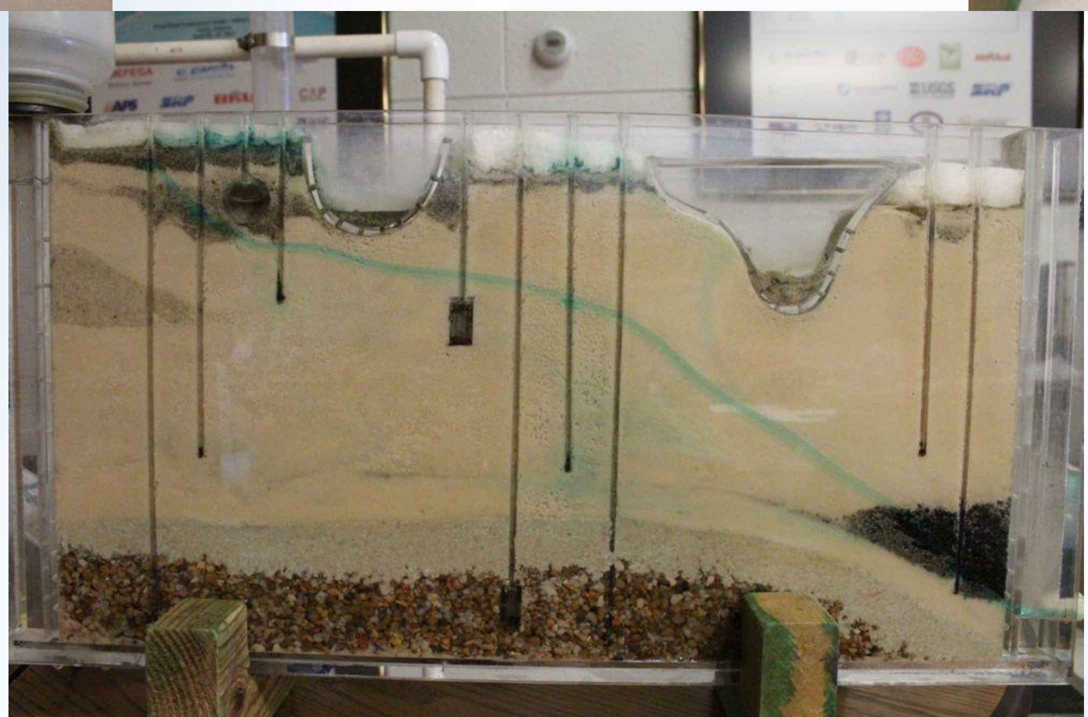


A System

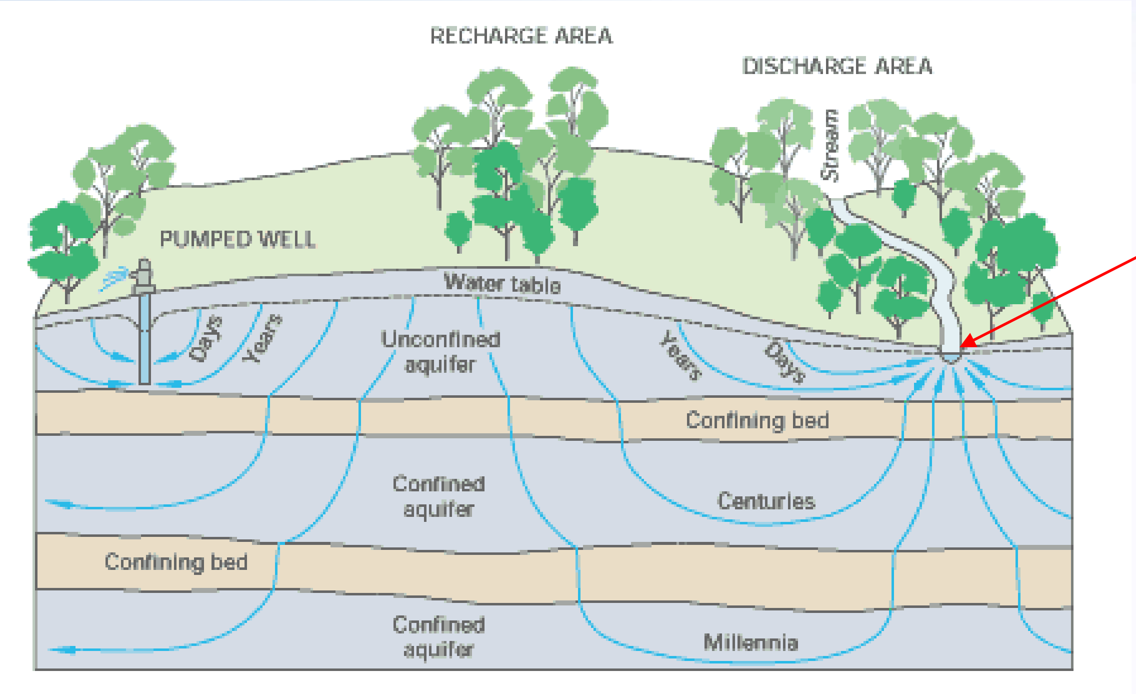


Recharge Area

Discharge Area



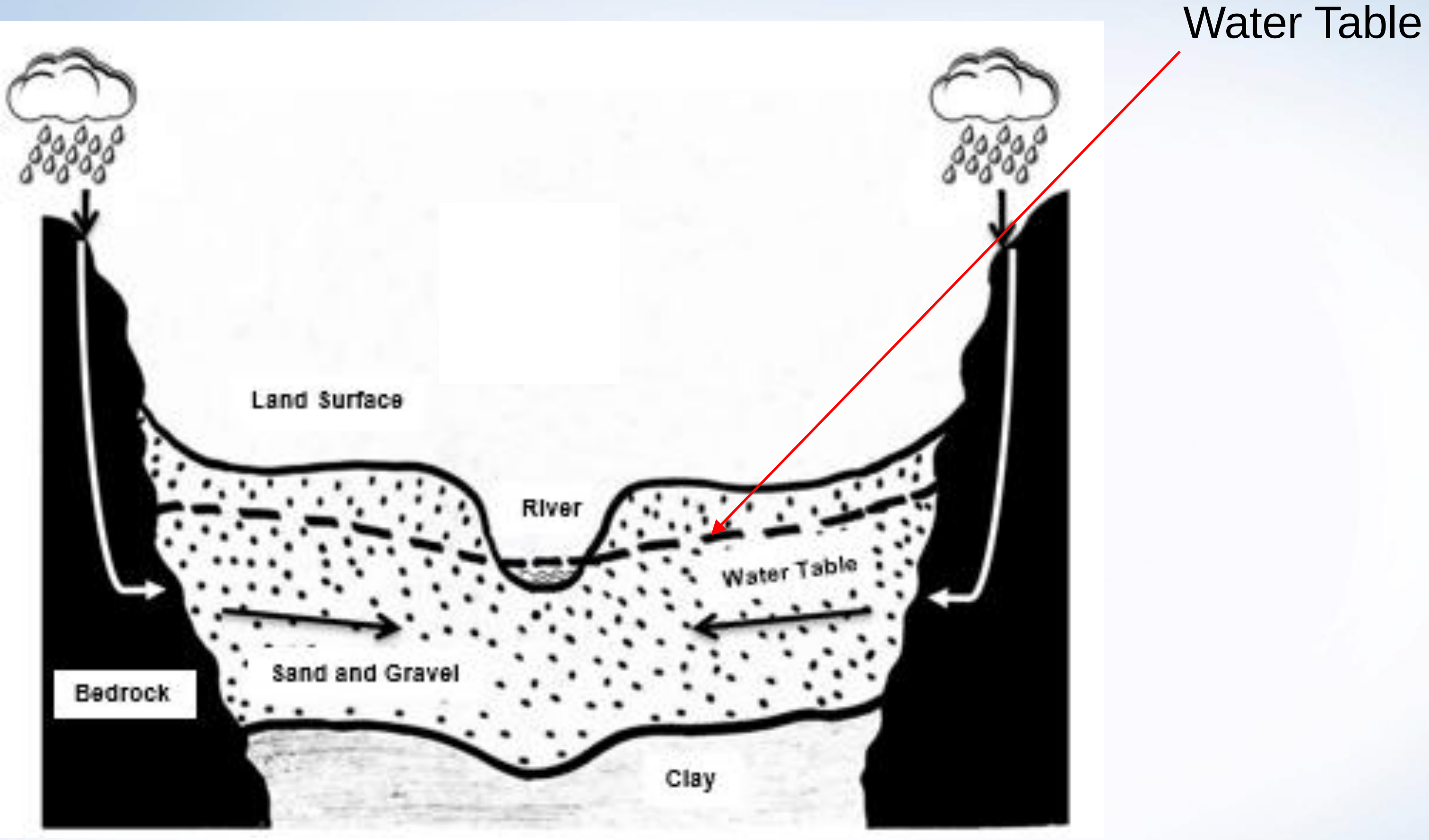
Recharge and Discharge



Where the water table crosses the land surface, there is surface water.

From: *Ground Water and Surface Water A Single Resource--USGS Circular 1139*

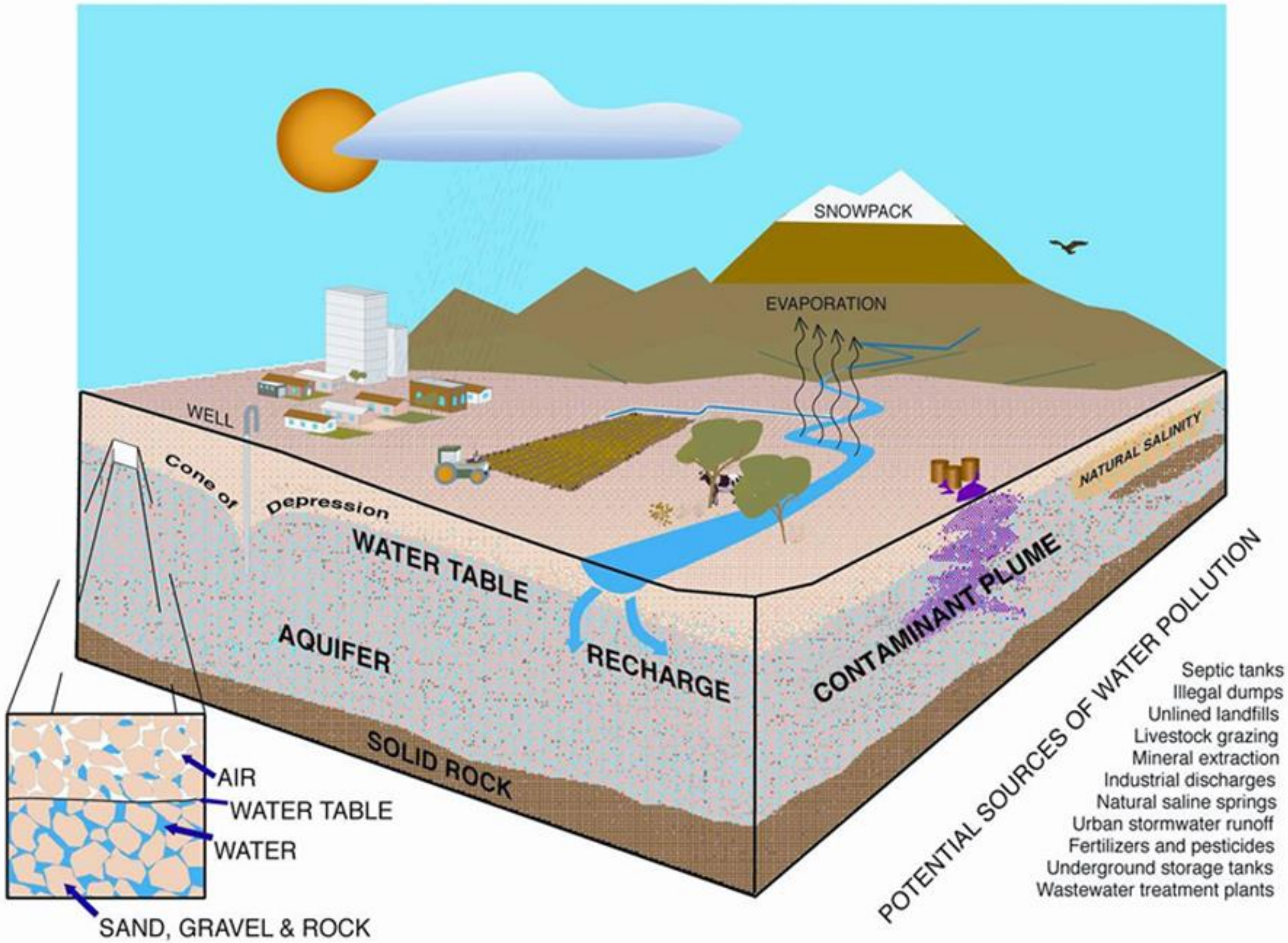
Where is the Water Table?



Smaller hands-on models for students

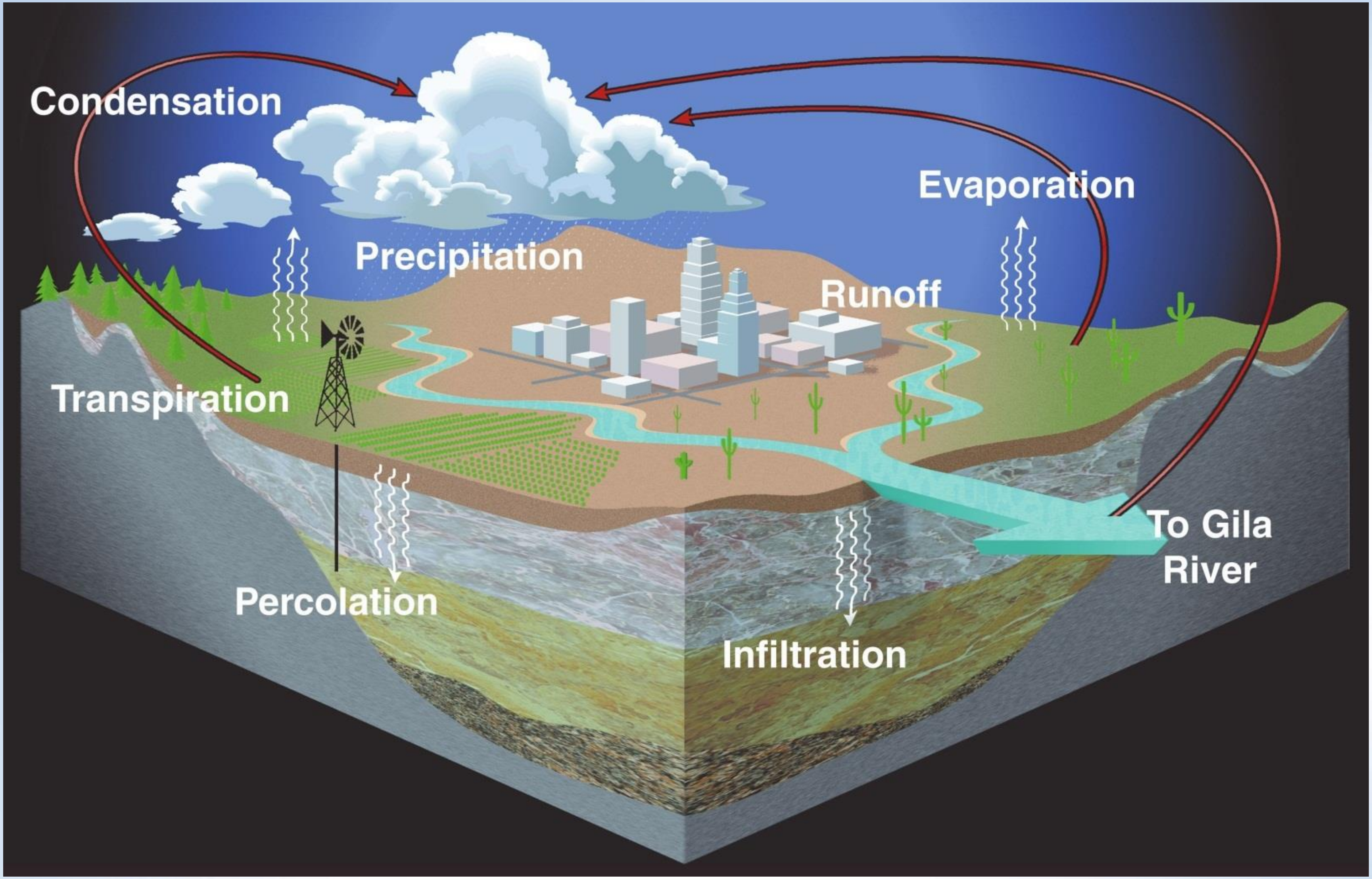
What happens when we pump water out of the groundwater system?

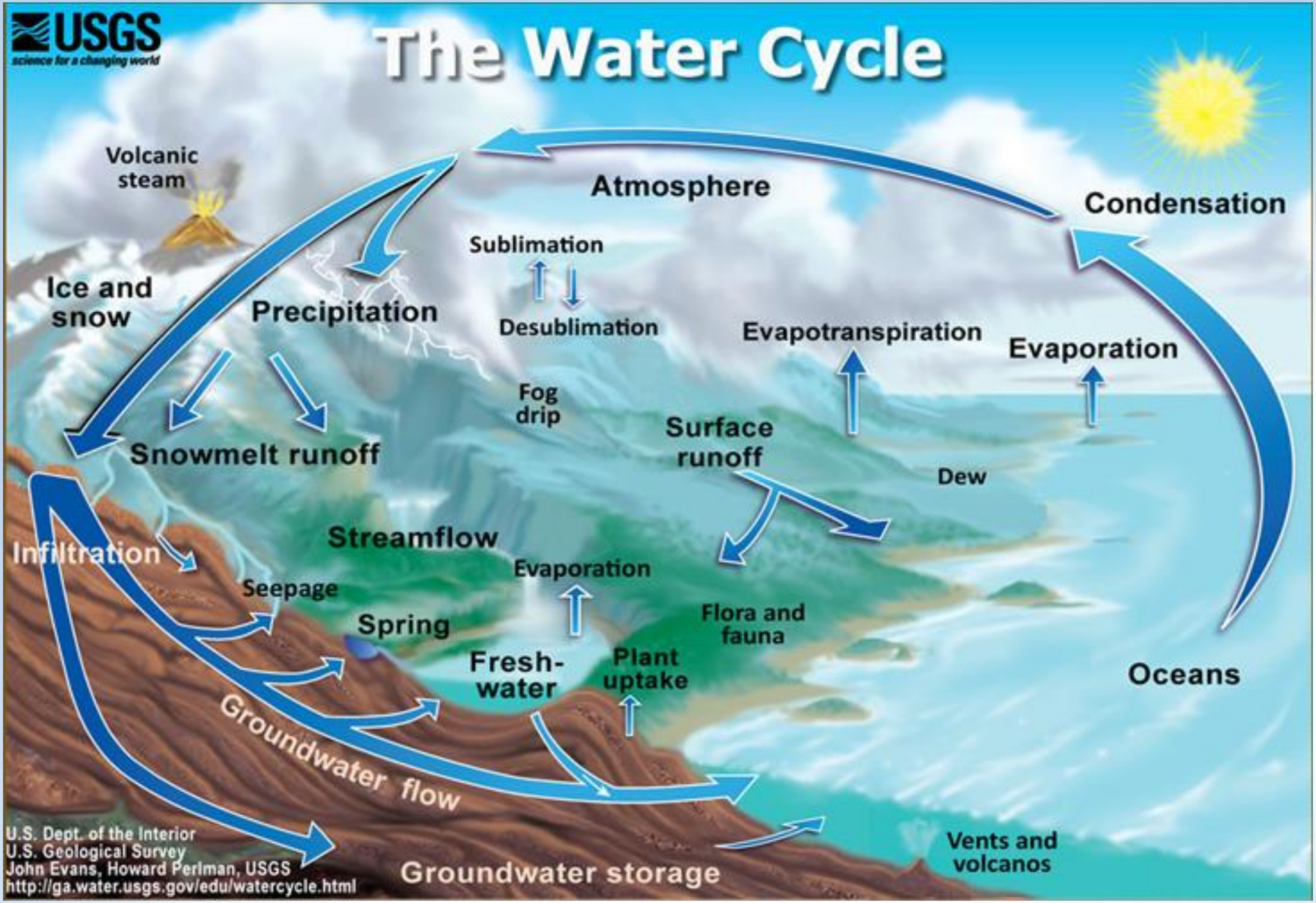
The Groundwater System has to be part of the Hydrologic Cycle!



Source: The University of Arizona Water Resources Research Center, Water Map Poster (Version 2).

The Water Cycle



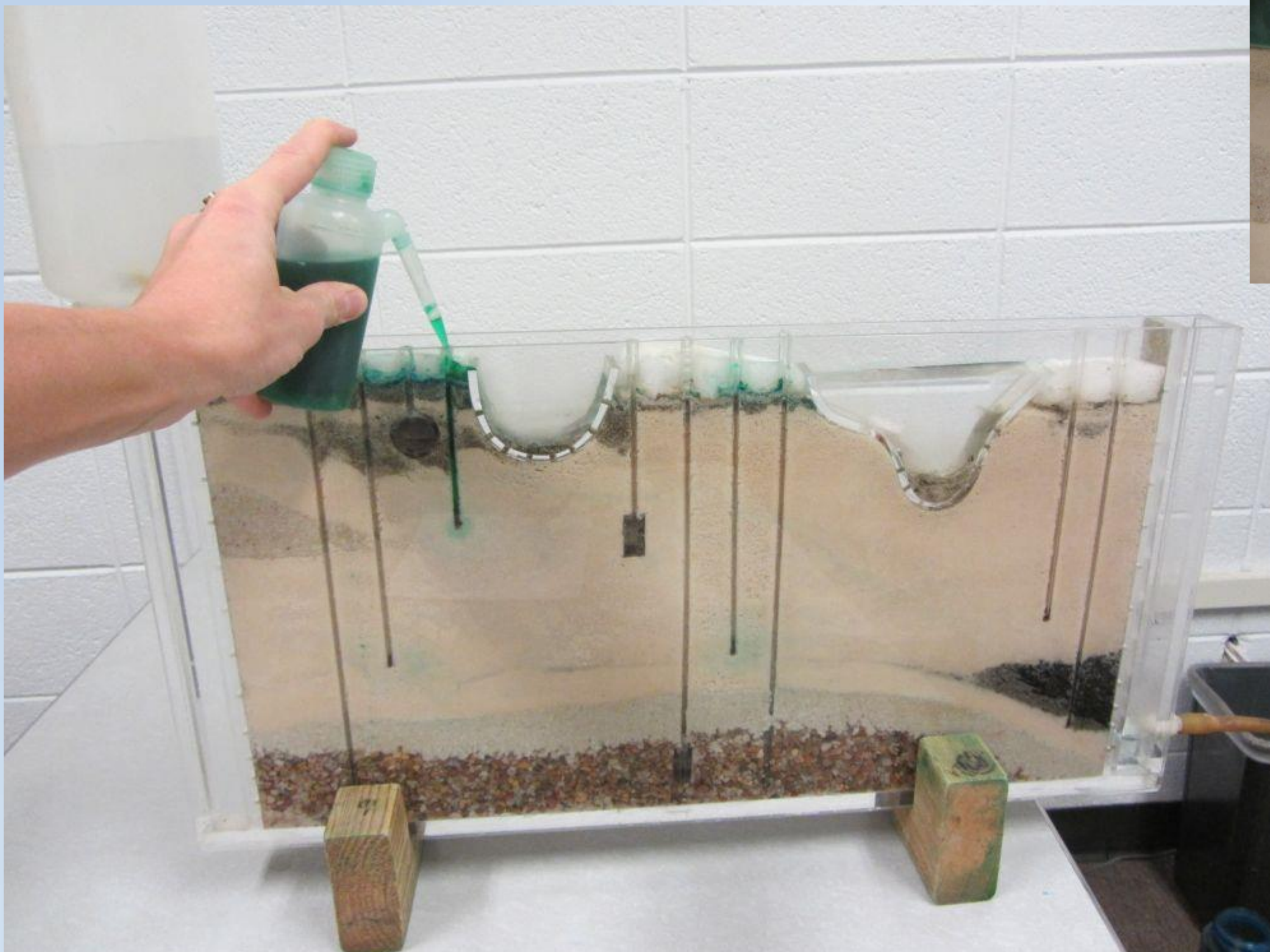

USGS
science for a changing world
The Water Cycle
Volcanic steam
Atmosphere
Condensation
Sublimation
Desublimation
Ice and snow
Precipitation
Evapotranspiration
Evaporation
Fog drip
Surface runoff
Snowmelt runoff
Dew
Streamflow
Infiltration
Evaporation
Seepage
Spring
Flora and fauna
Fresh-water
Plant uptake
Oceans
Groundwater flow
Vents and volcanos
Groundwater storage
U.S. Dept. of the Interior
U.S. Geological Survey
John Evans, Howard Perlman, USGS
http://ga.water.usgs.gov/edu/watercycle.html

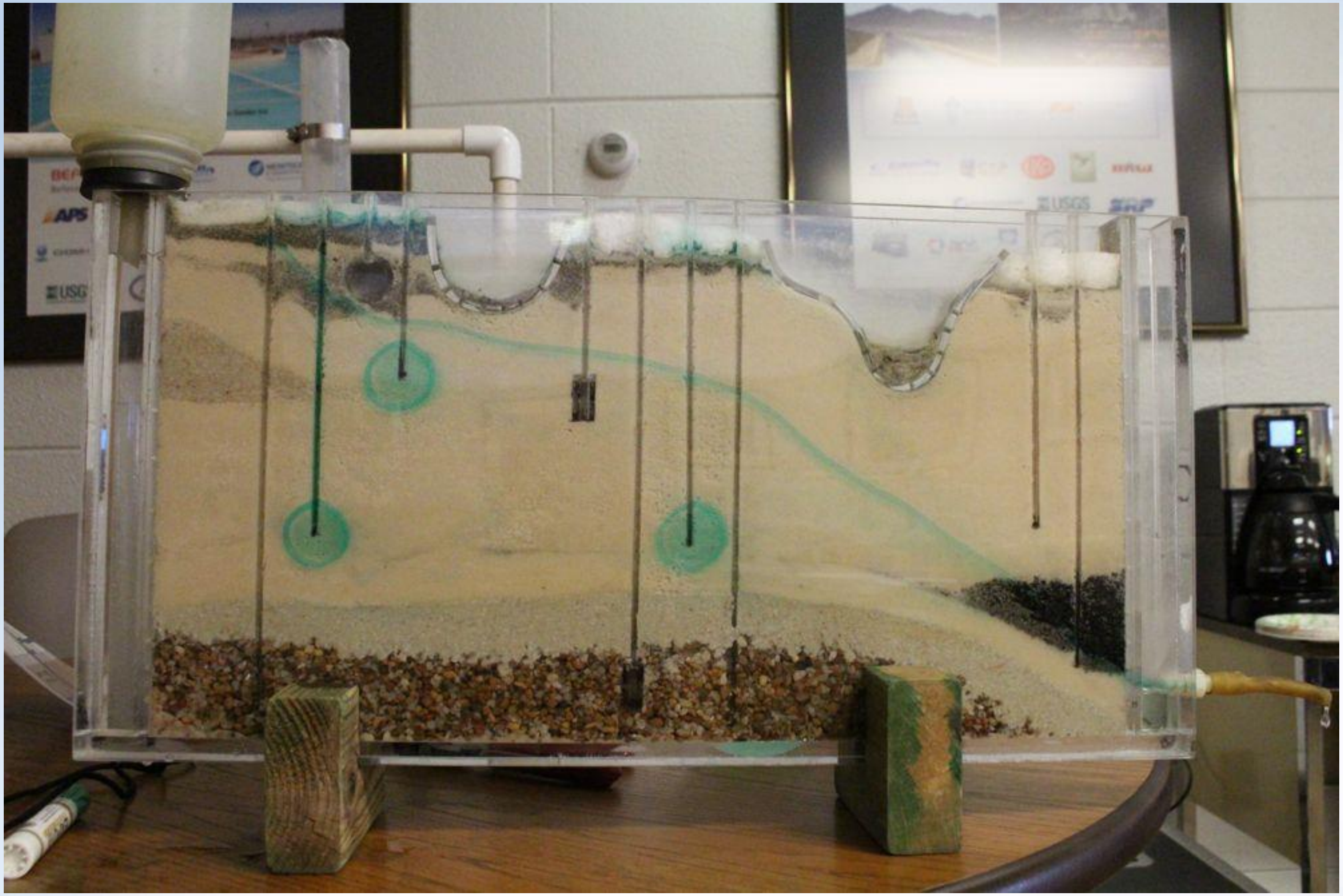
Misconceptions Caused by our Analogies:

Groundwater is like a big underground river.

Water Moves Through Earth Materials

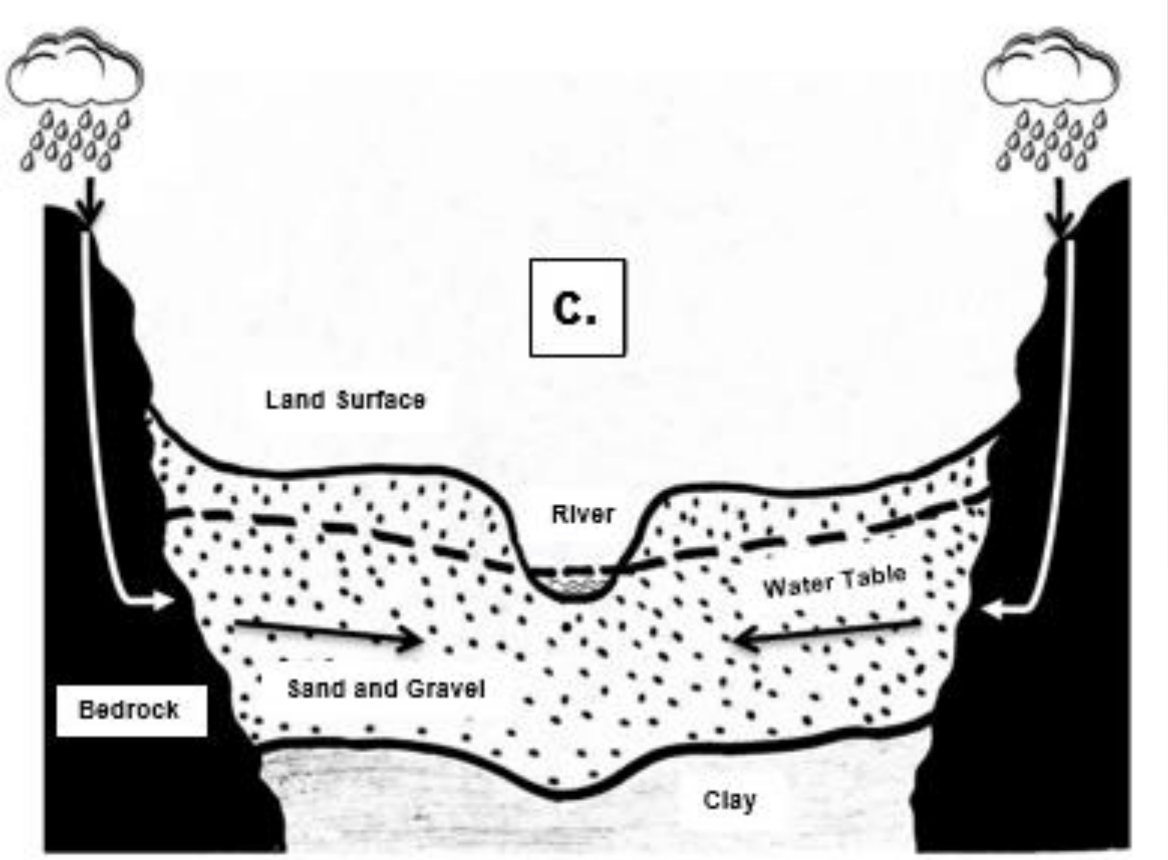

Water Receivers





APS
USGS
SRP

Annual Conference
USGS
aps

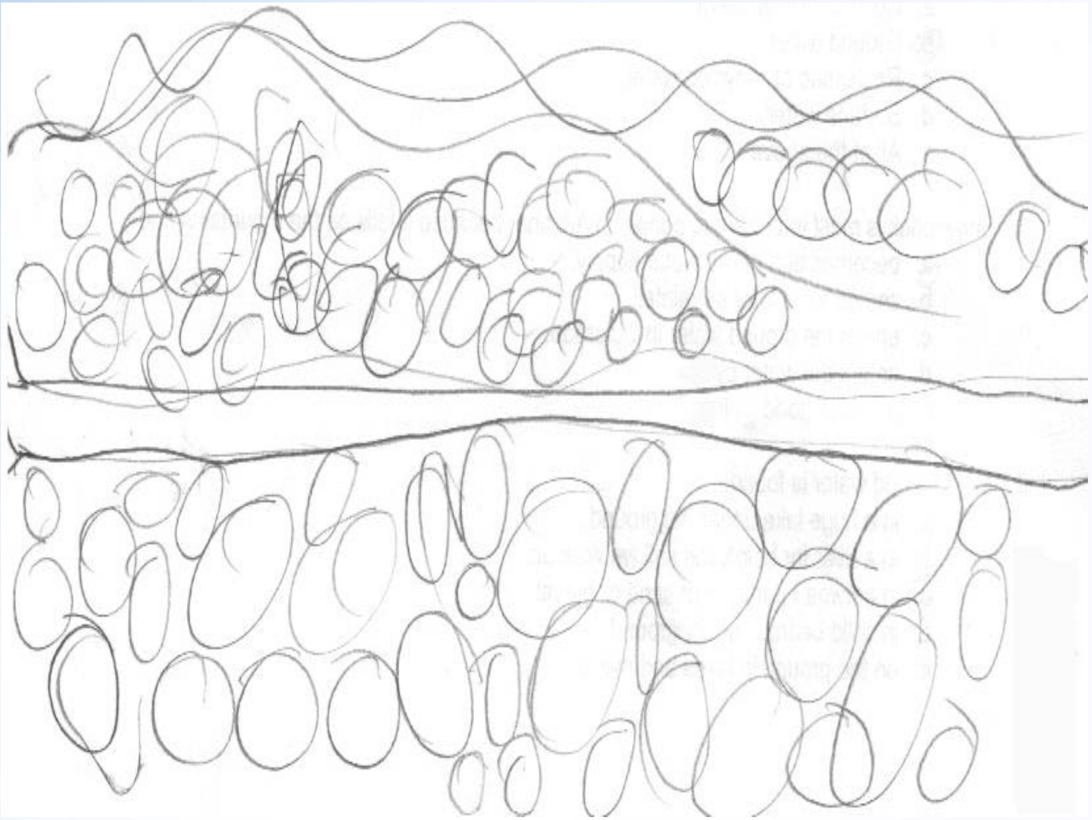
Groundwater is between the grains of sand and gravel … not in a lake or river.



Groundwater is moving because gravity works underground too.

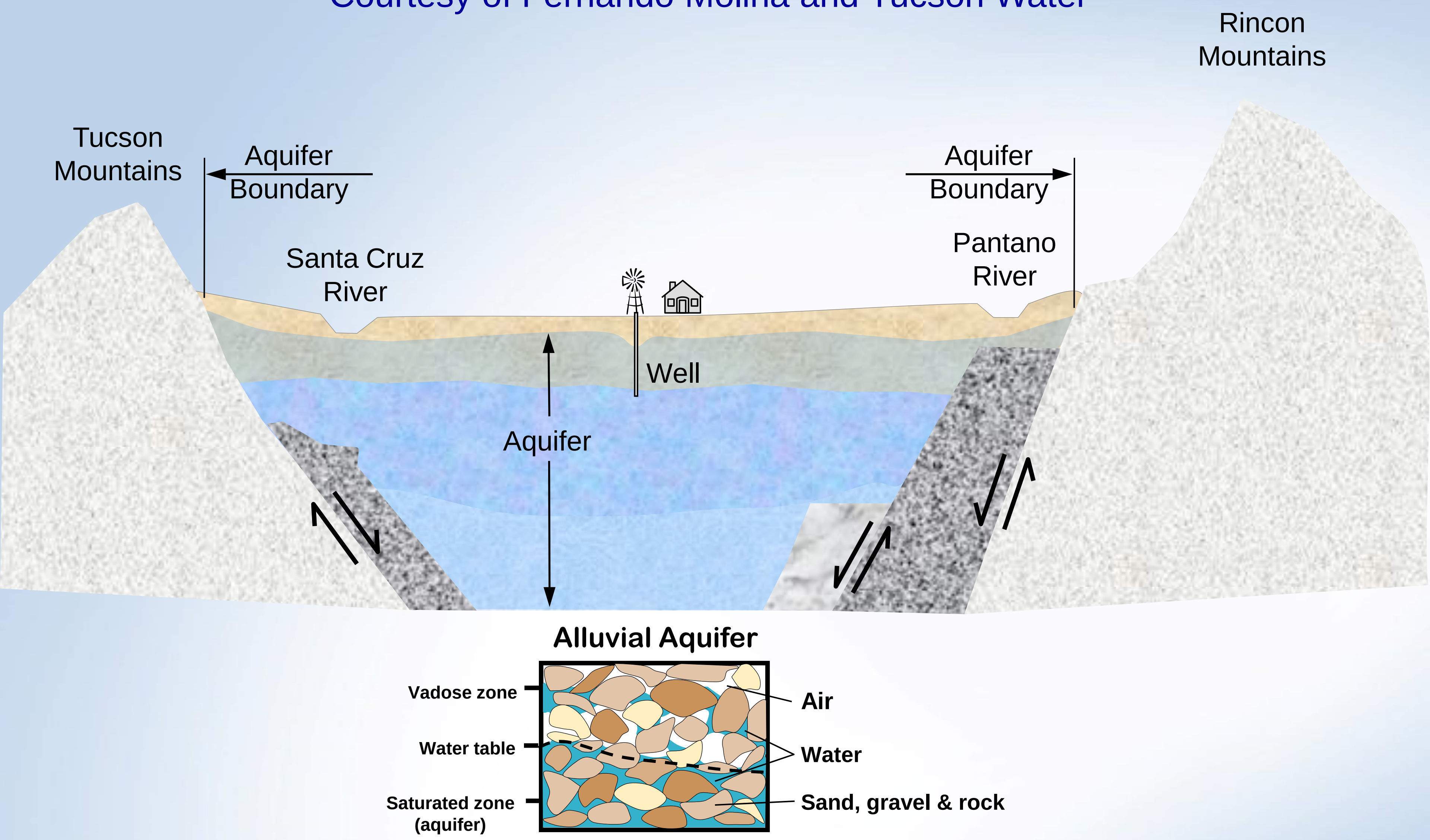
Groundwater is connected to surface water and part of the hydrologic cycle.

Persistency in Holding on to Beliefs



Aquifer Cross-Section

Courtesy of Fernando Molina and Tucson Water



Land subsidence in the Eloy area, central Arizona.

Photograph provided by the U.S. Geological Survey.

Water Availability for the Western United States—Key Scientific Challenges
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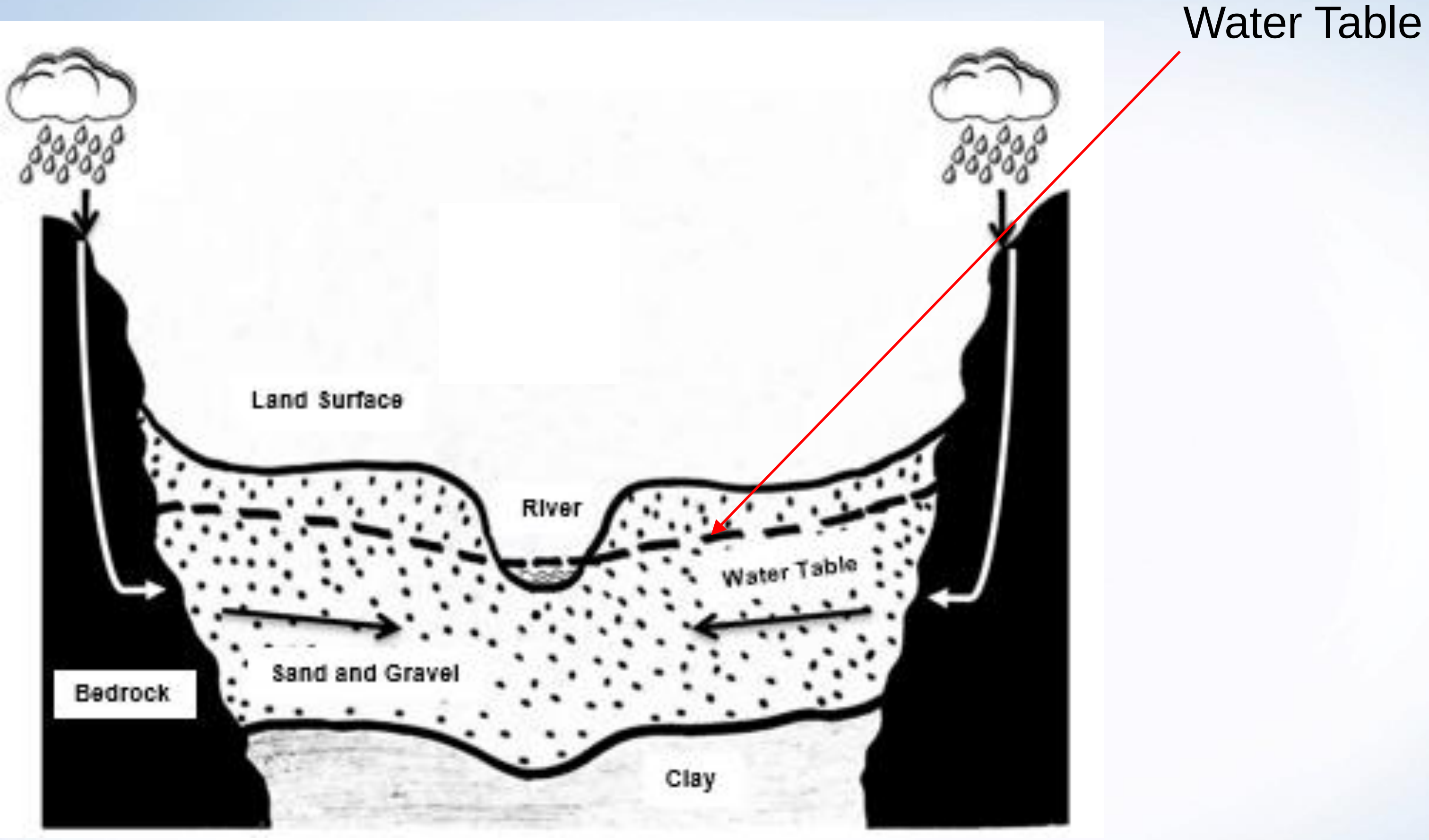
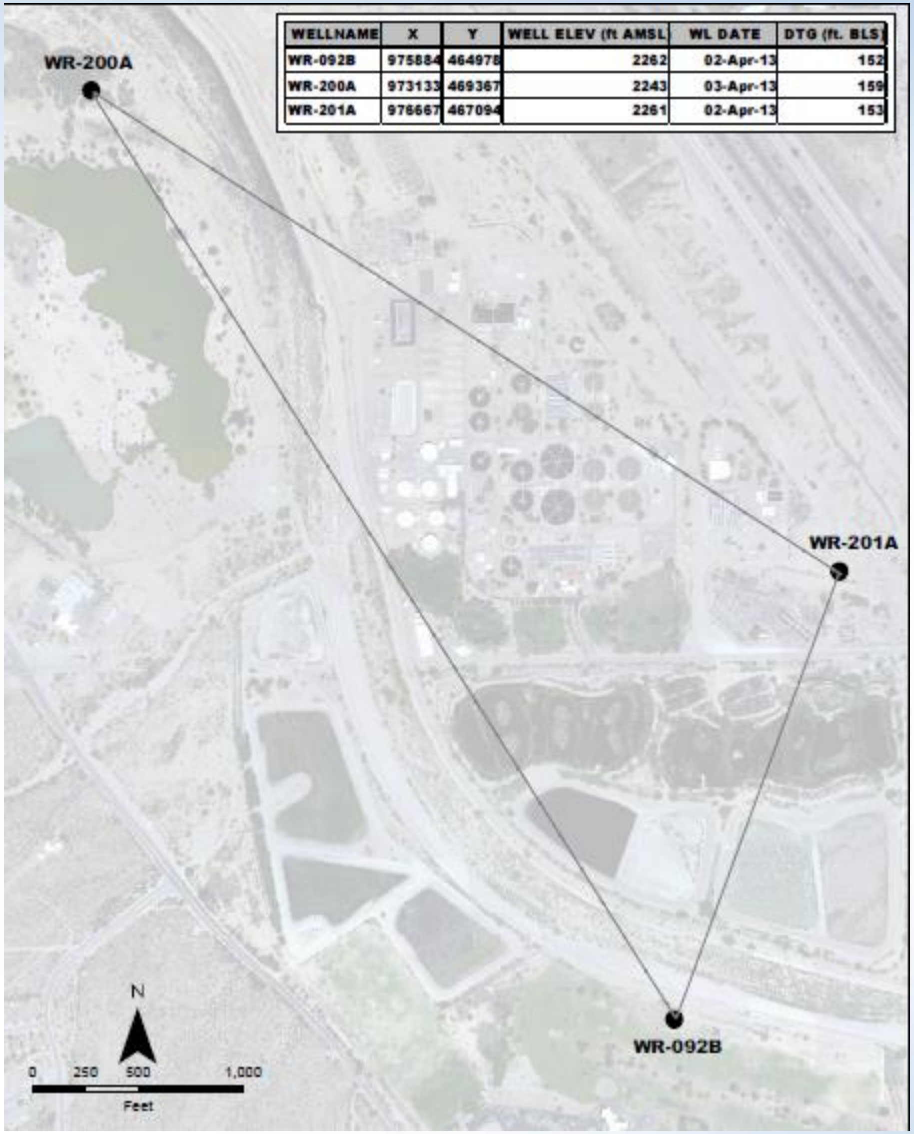
Where is the Water Table?

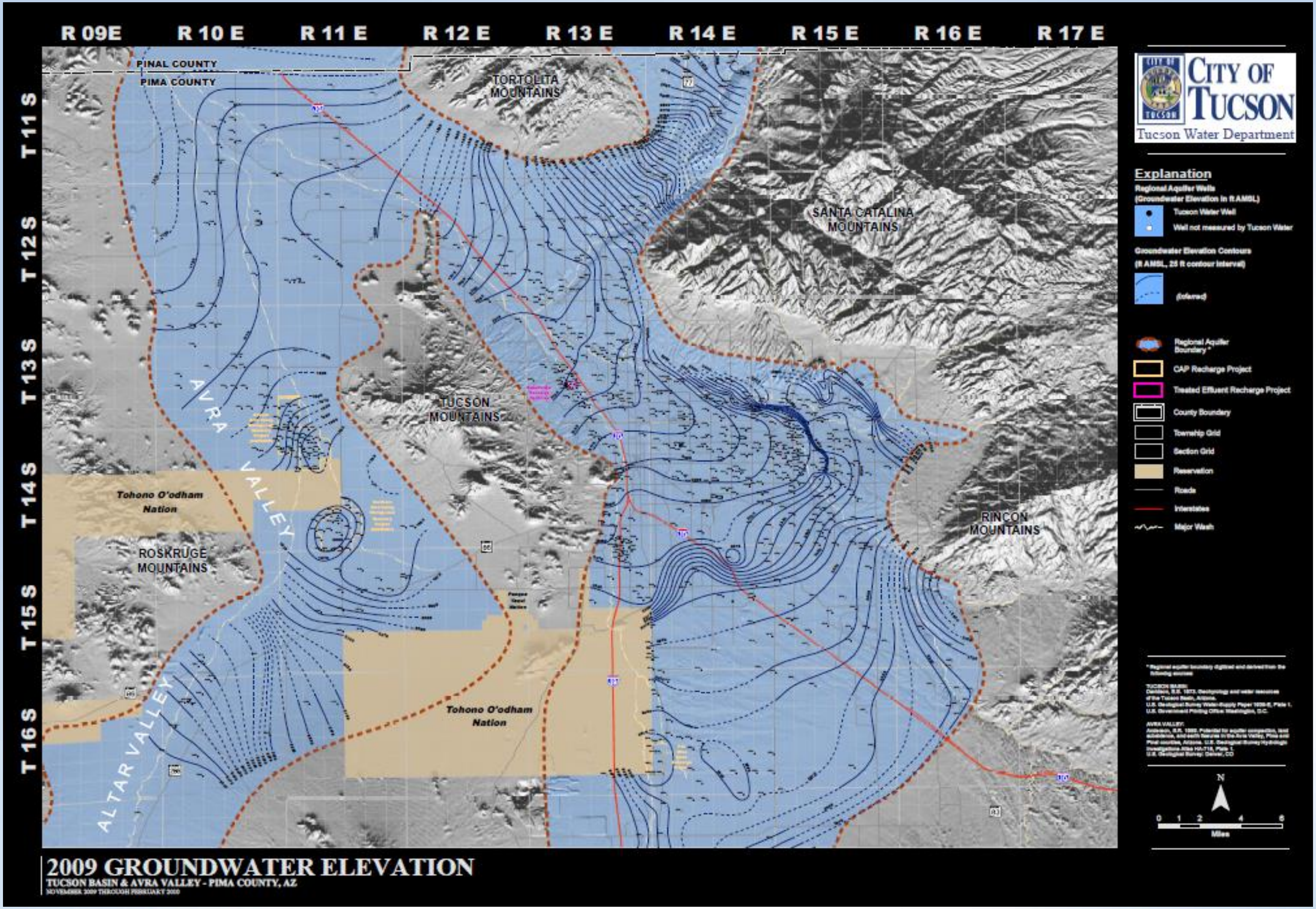


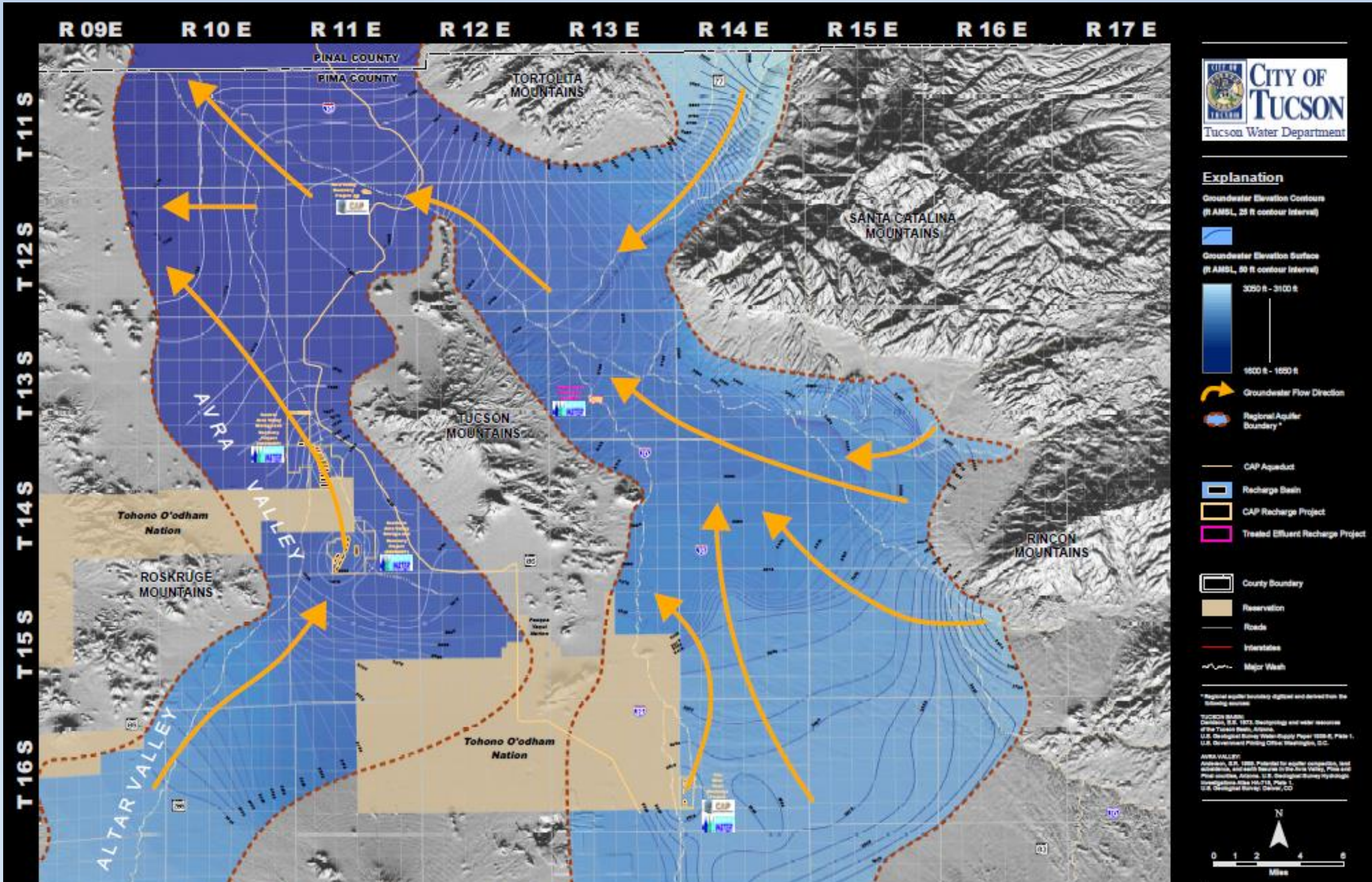
Groundwater Gradient

STEM Academies teach about the water table elevation and flow direction



WELLNAME	X	Y	WELL ELEV (ft AMSL)	WL DATE	DTG (ft. BLS)
WR-092B	975884	464978	2262	02-Apr-13	152
WR-200A	973133	469367	2243	03-Apr-13	159
WR-201A	976667	467094	2261	02-Apr-13	153


R 09E
R 10 E
R 11 E
R 12 E
R 13 E
R 14 E
R 15 E
R 16 E
R 17 E
T 11 S
T 12 S
T 13 S
T 14 S
T 15 S
T 16 S
PINAL COUNTY
PIMA COUNTY
TORTOLITA MOUNTAINS
SANTA CATALINA MOUNTAINS
TUCSON MOUNTAINS
AVRA VALLEY
Tohono O'odham Nation
ROSKRUGE MOUNTAINS
RINCON MOUNTAINS
ALTAR VALLEY
CITY OF TUCSON
Tucson Water Department
Explanation
Regional Aquifer Wells (Groundwater Elevation in ft AMSL)
Tucson Water Well
Well not measured by Tucson Water
Groundwater Elevation Contours (ft AMSL, 25 ft contour interval)
(inferred)
Regional Aquifer Boundary *
CAP Recharge Project
Treated Effluent Recharge Project
County Boundary
Township Grid
Section Grid
Reservation
Roads
Interstates
Major Wash
N
Miles
2009 GROUNDWATER ELEVATION
TUCSON BASIN & AVRA VALLEY - PIMA COUNTY, AZ

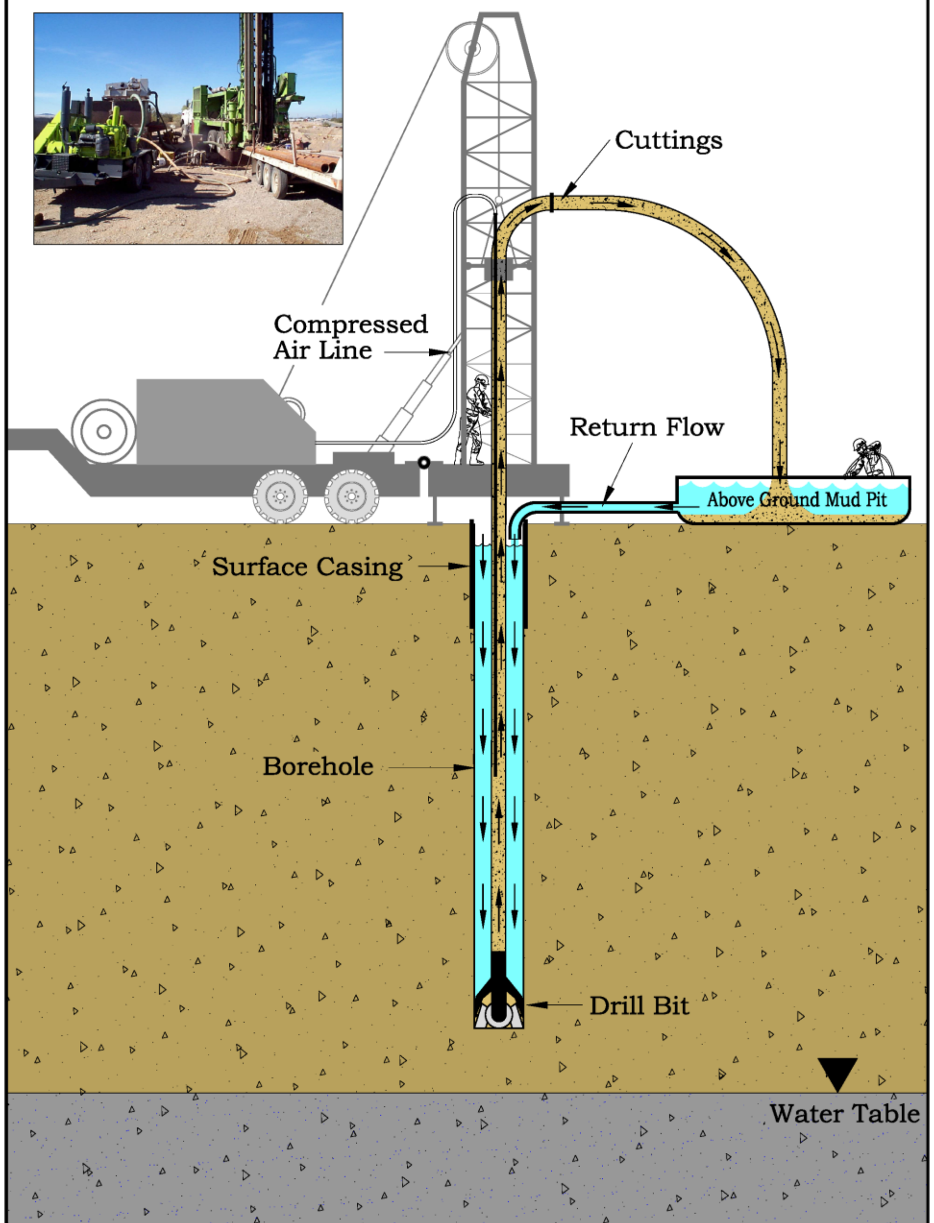


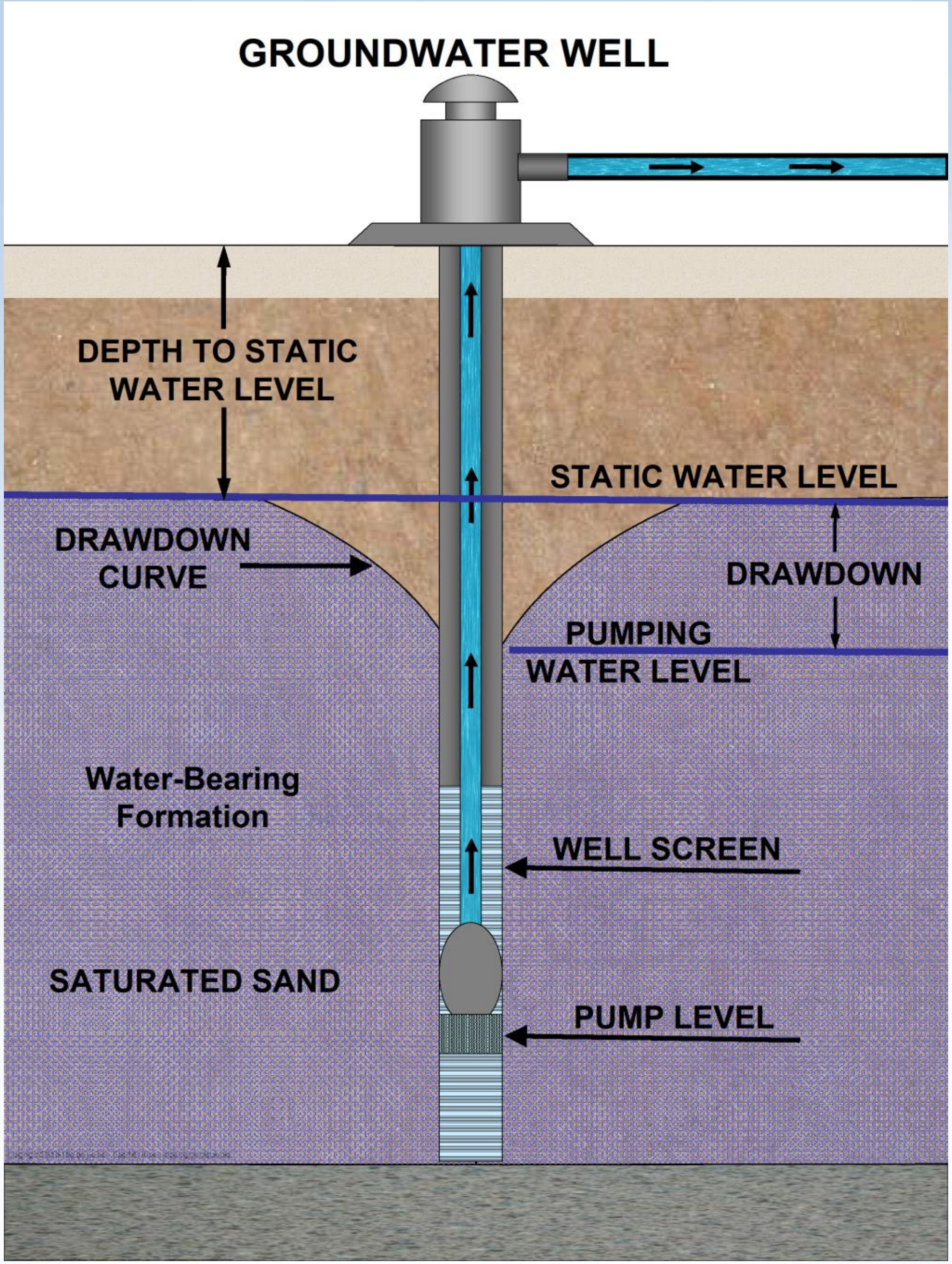
2009 GROUNDWATER GRADIENT AND FLOW DIRECTION

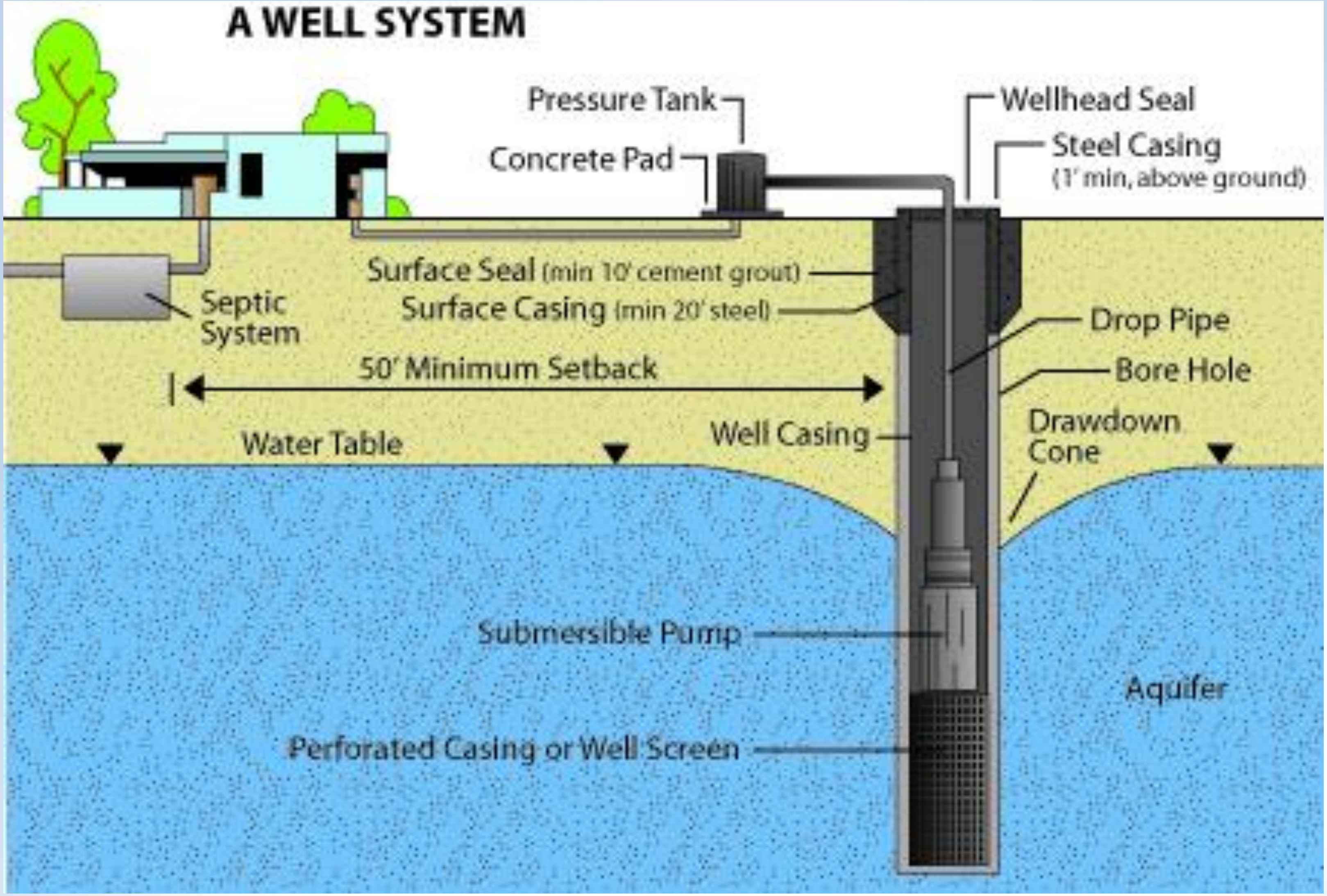
TUCSON BASIN & AVRA VALLEY - PIMA COUNTY, AZ

Groundwater is an important part of our water supply!

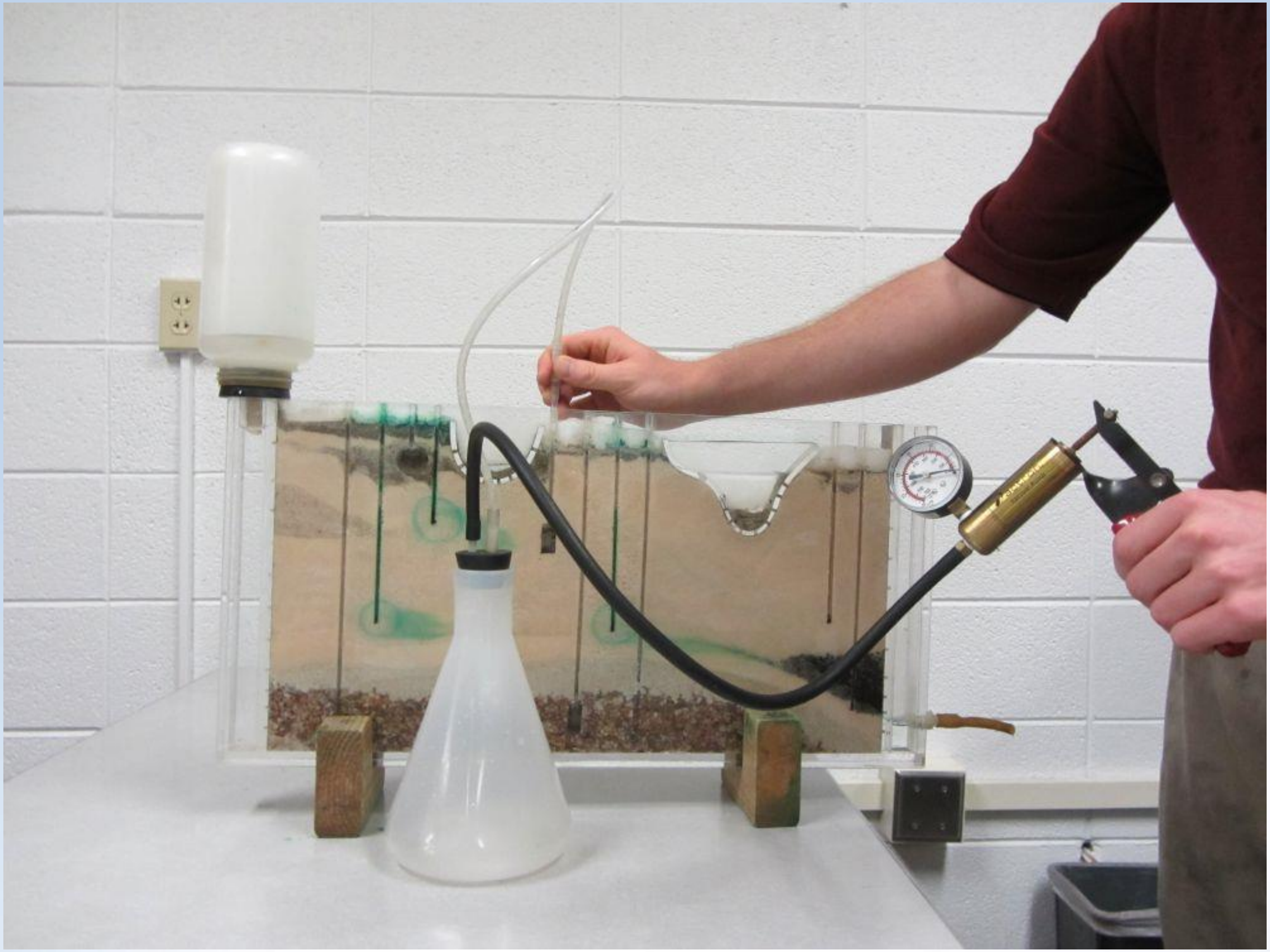
REVERSE ROTARY DRILLING

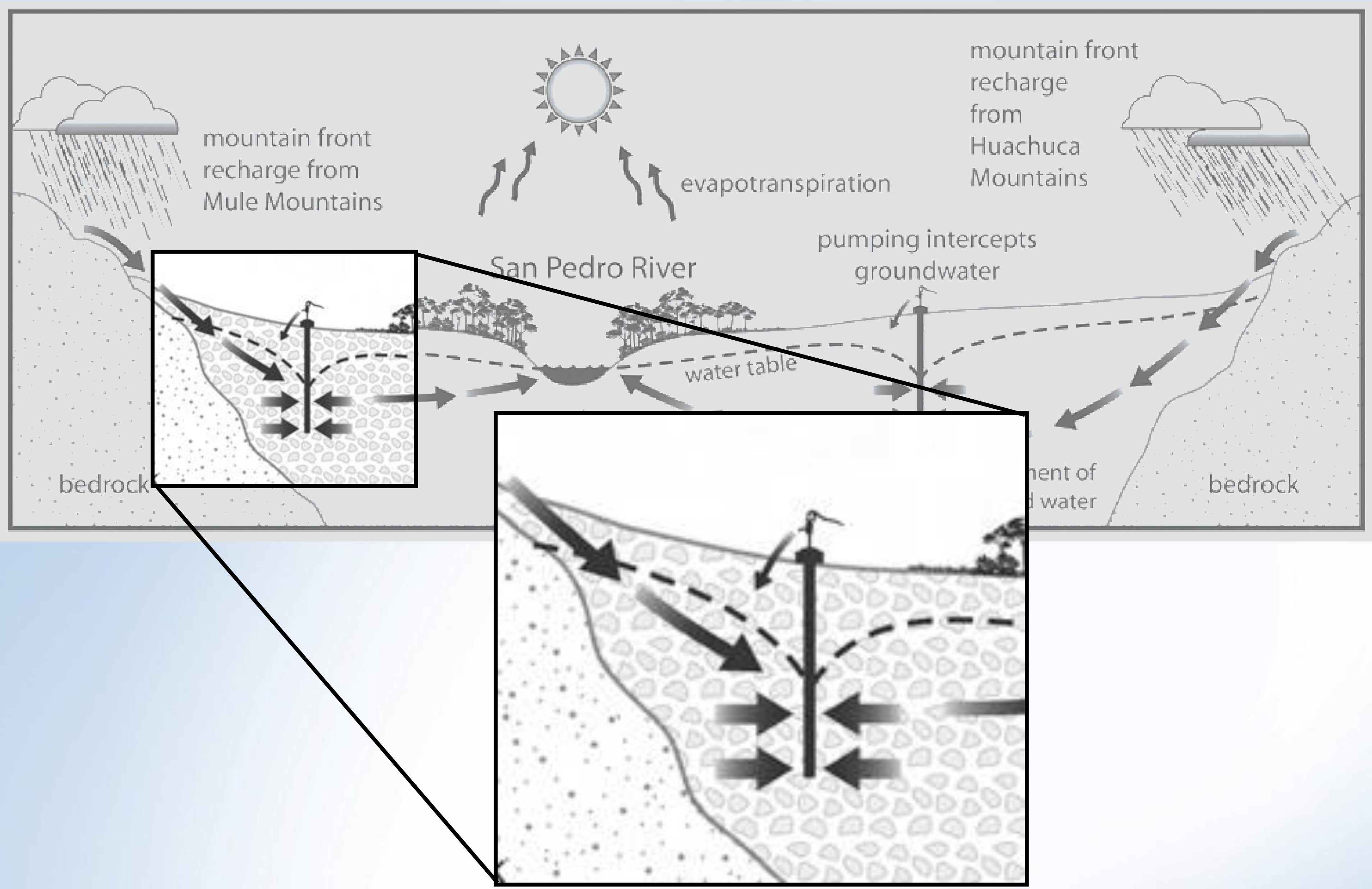



GROUNDWATER WELL
DEPTH TO STATIC WATER LEVEL
STATIC WATER LEVEL
DRAWDOWN CURVE
DRAWDOWN
PUMPING WATER LEVEL
Water-Bearing Formation
WELL SCREEN
SATURATED SAND
PUMP LEVEL

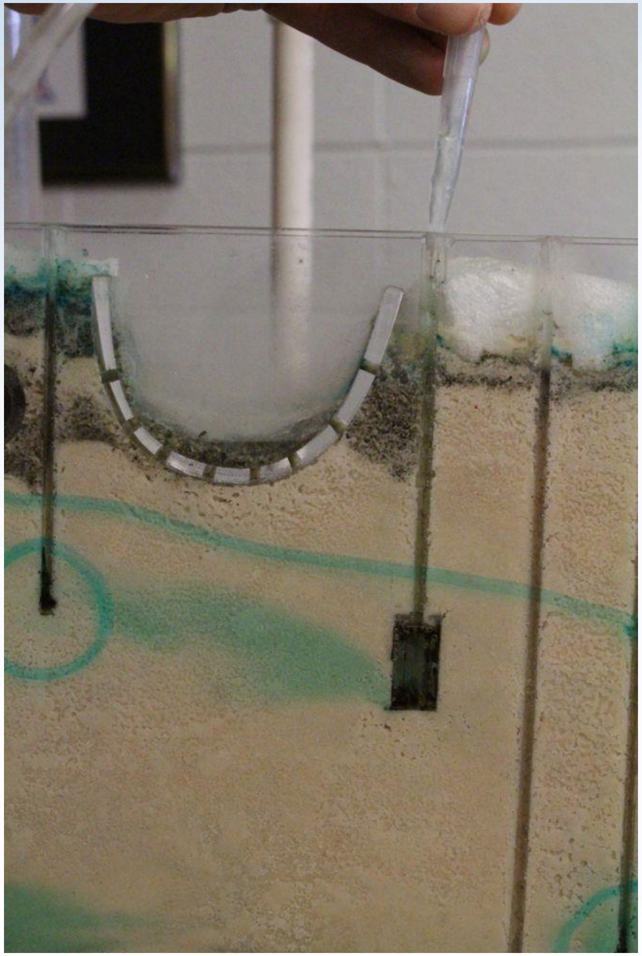



A WELL SYSTEM
Pressure Tank
Concrete Pad
Wellhead Seal
Steel Casing
(1' min, above ground)
Surface Seal (min 10' cement grout)
Surface Casing (min 20' steel)
Septic System
Drop Pipe
Bore Hole
50' Minimum Setback
Water Table
Well Casing
Drawdown Cone
Submersible Pump
Aquifer
Perforated Casing or Well Screen





From: *Howe, E. & Schwartz, K. (2007). Arizona Conserve Water Educators' Guide (1st ed.). Bozeman: Project WET International Foundation.*



ACT

Acknowledge the issue

- There are hazardous substances in common use in households
- Most household water use occurs in a few areas around the home

Consider how it applies to you

- What specific hazardous substances are in and around your home?"
- Where do you and your family use the most water?

Take Action

Water conservation:

- Modify your water use (more water saving tips)
- Install a water saving devices

Hazardous household substances:

- Store them properly in a secure place
- Use according to the manufacturer's recommendations
- Dispose of them safely

IF YOU OWN A WELL

Acknowledge the issue

- Wellheads should be a safe distance from potential contamination
- Septic system malfunctions can pollute groundwater
- Poorly constructed or maintained wells can facilitate contamination
- Improperly abandoned wells can lead to groundwater contamination

Consider how it applies to you

- Is your wellhead a safe distance from possible contamination?
- Is your well/septic system due for an inspection?
- Are there any abandoned wells on your property?

Take Action

- Move possible contamination sources a safe distance from the wellhead
- Get current on your septic system inspection and cleaning
- Get an annual water well system inspection
- Properly decommission any abandoned wells

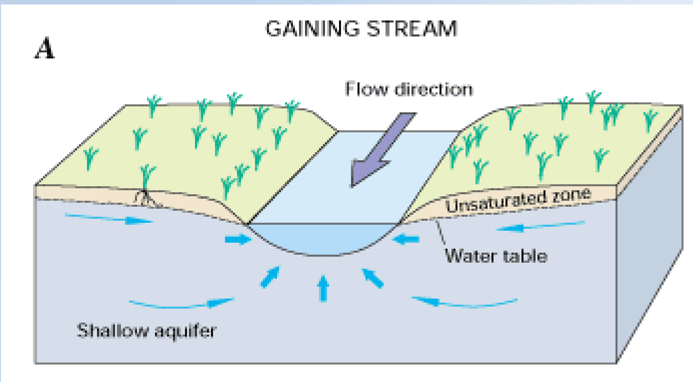
The Groundwater System is part of the Hydrologic Cycle!

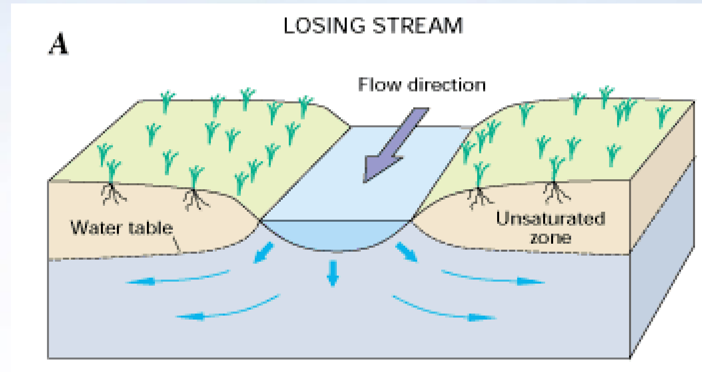
Water Moves Through Earth Materials

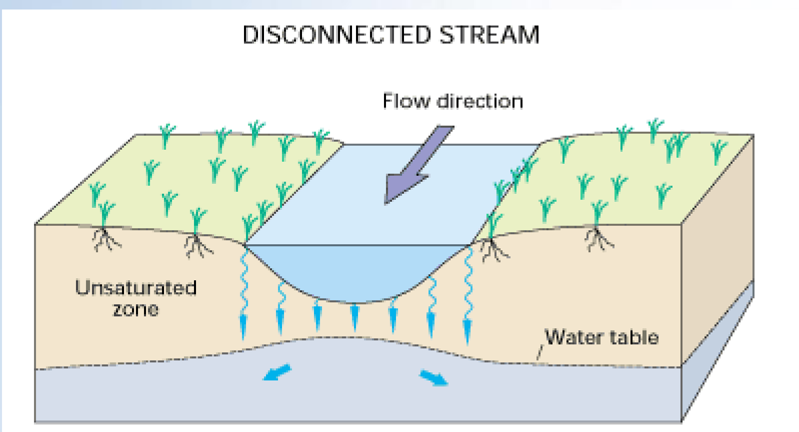
Groundwater is hidden from sight, therefore hard to visualize.

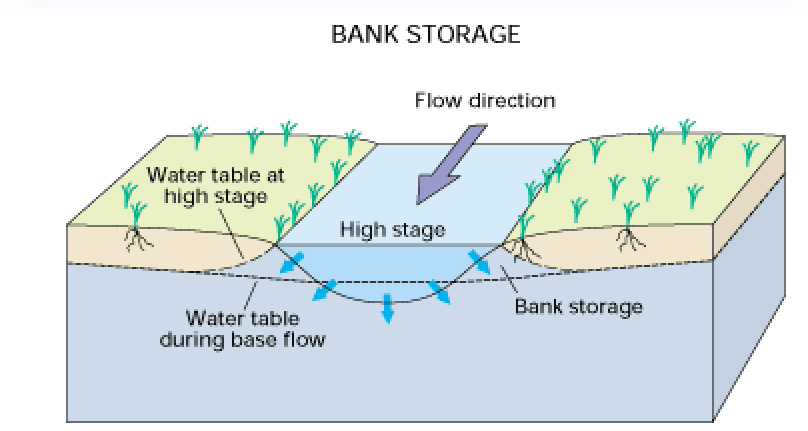
Groundwater and Surface Water Are Connected

Groundwater is an important part of our water supply!



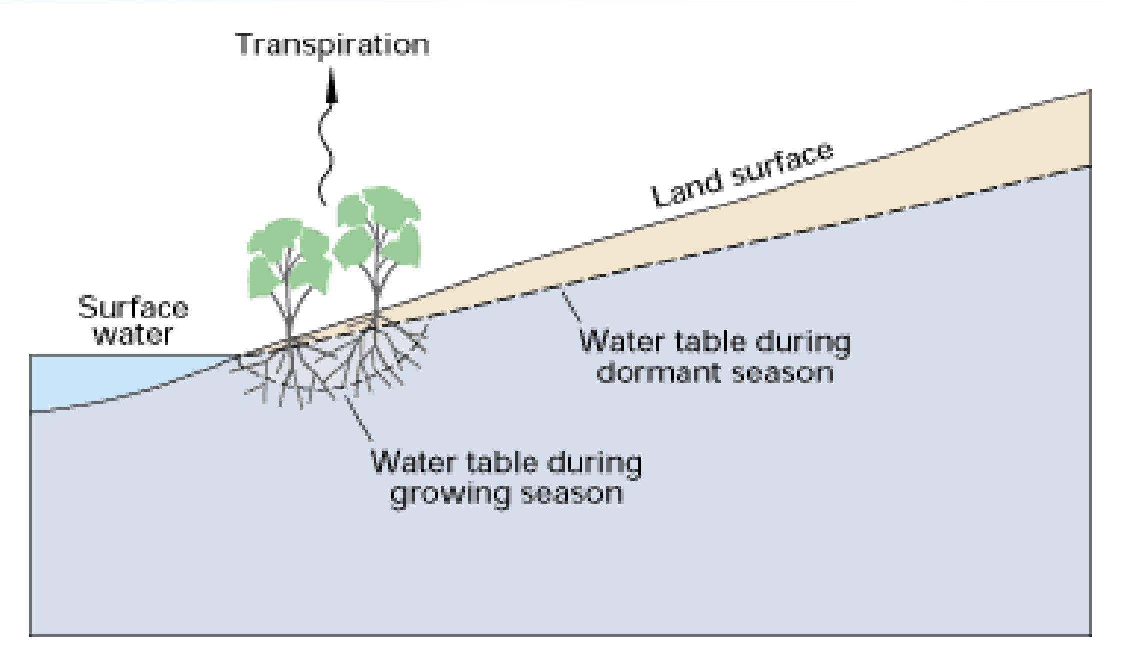






From: Ground Water and Surface Water A Single Resource--USGS Circular 1139

Riparian Areas



From: Ground Water and Surface Water A Single Resource--USGS Circular 1139

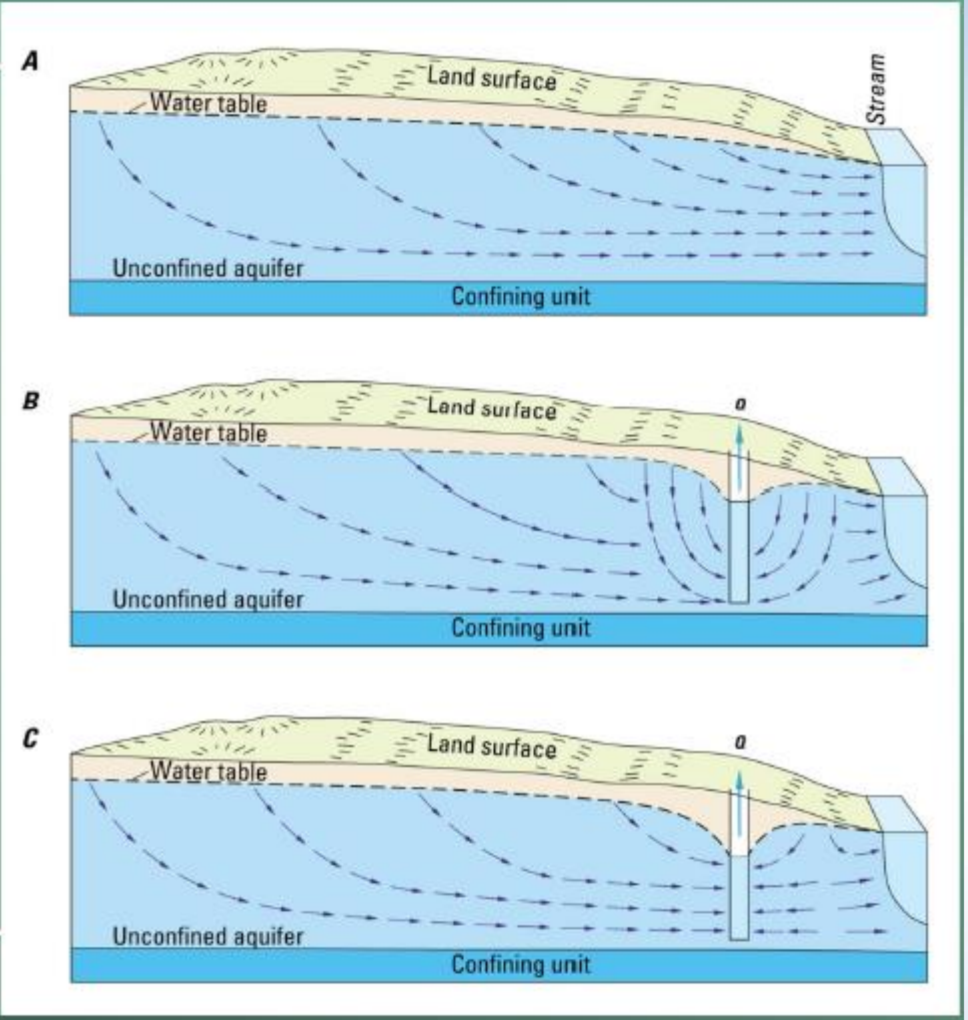
Groundwater/ Surface Water 101

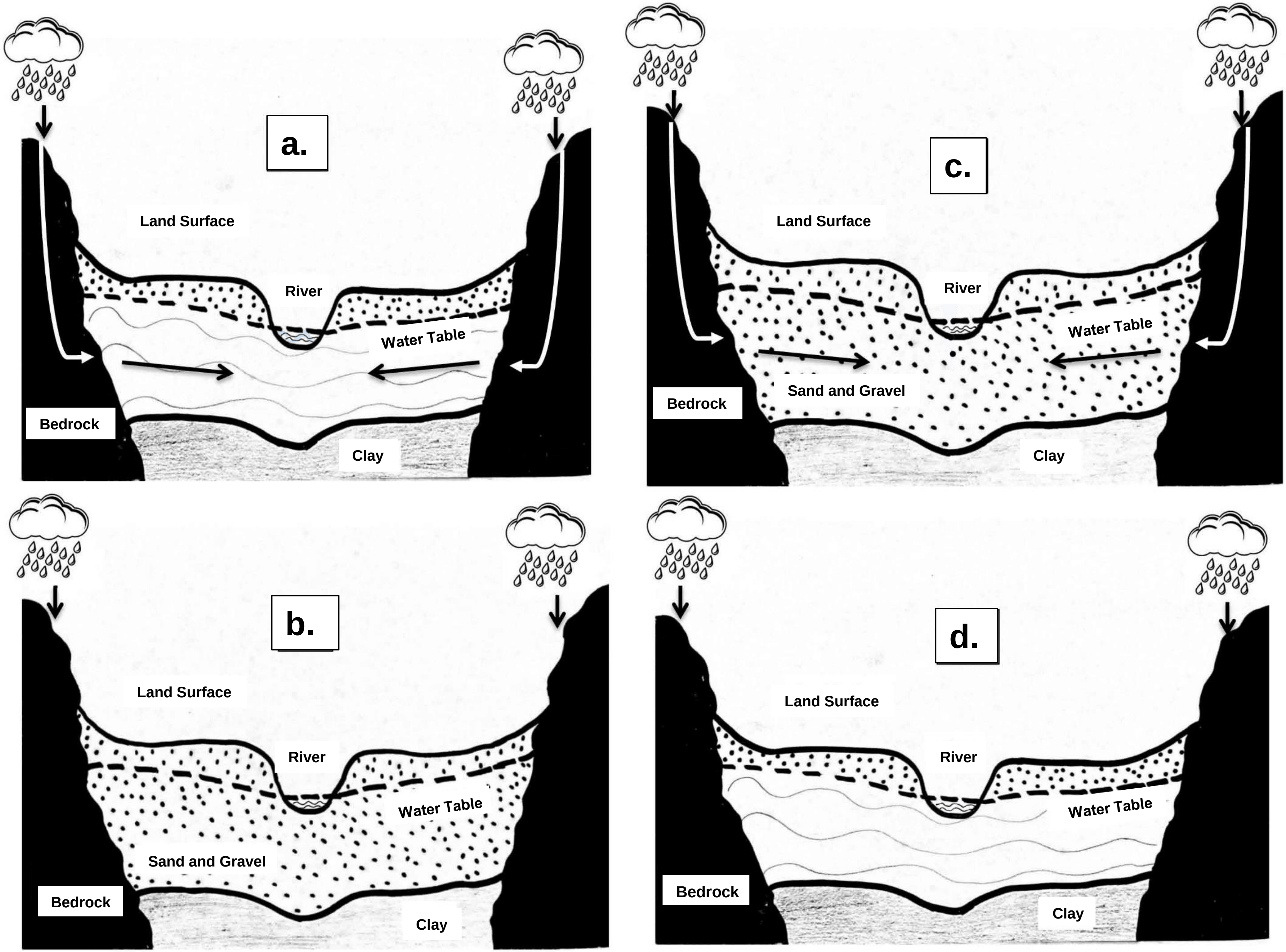
A. Initial Steady State

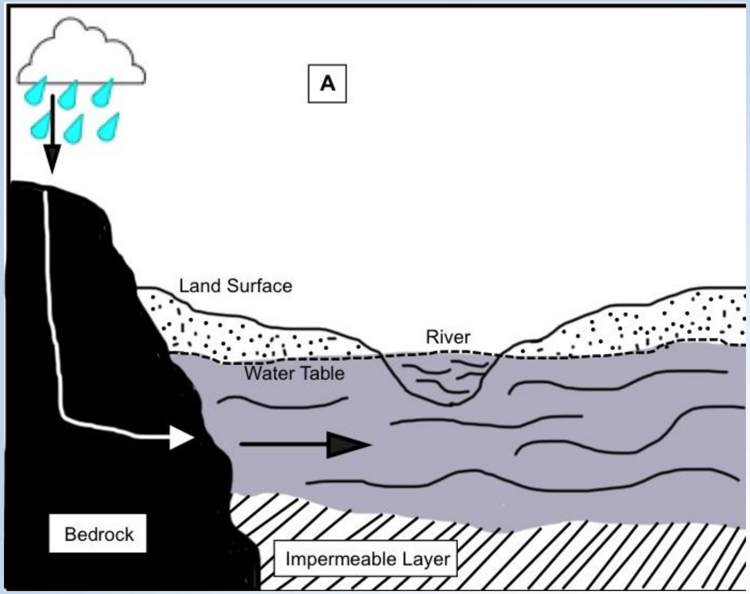
B. All flow to well from storage

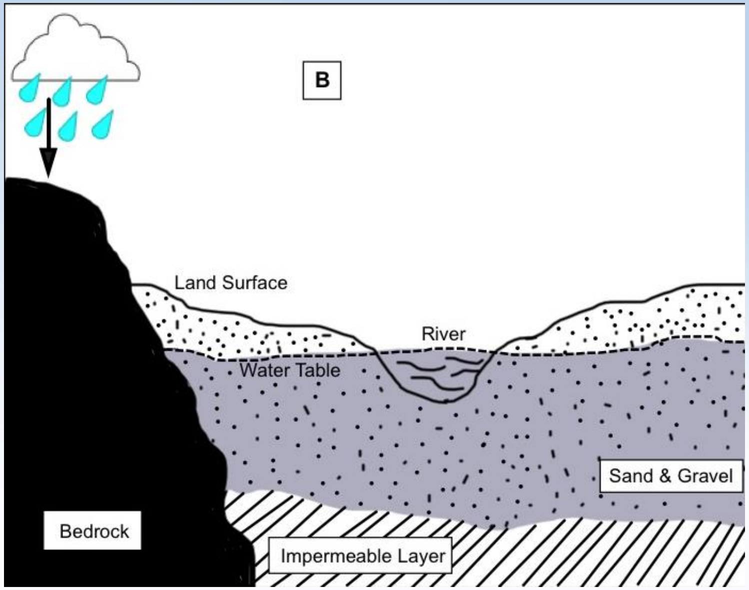
C. Changing gradients change flow system

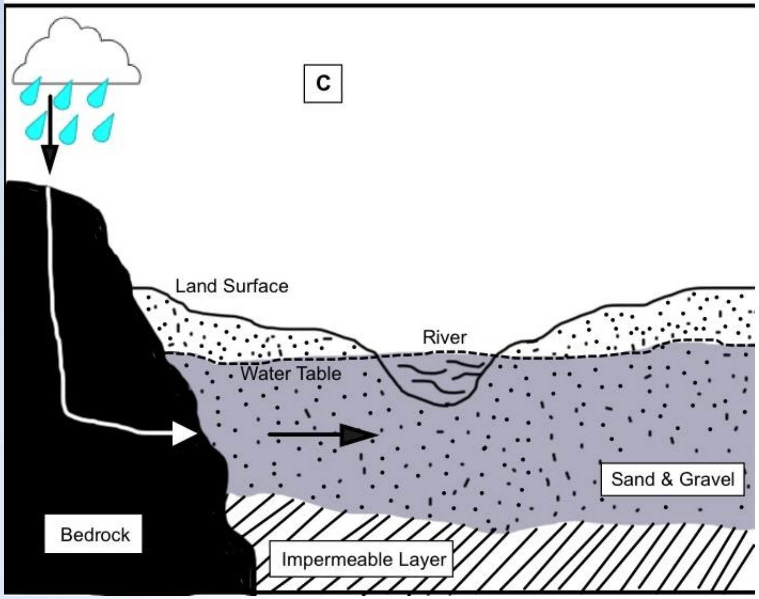
Extreme case - flow previously toward stream reversed

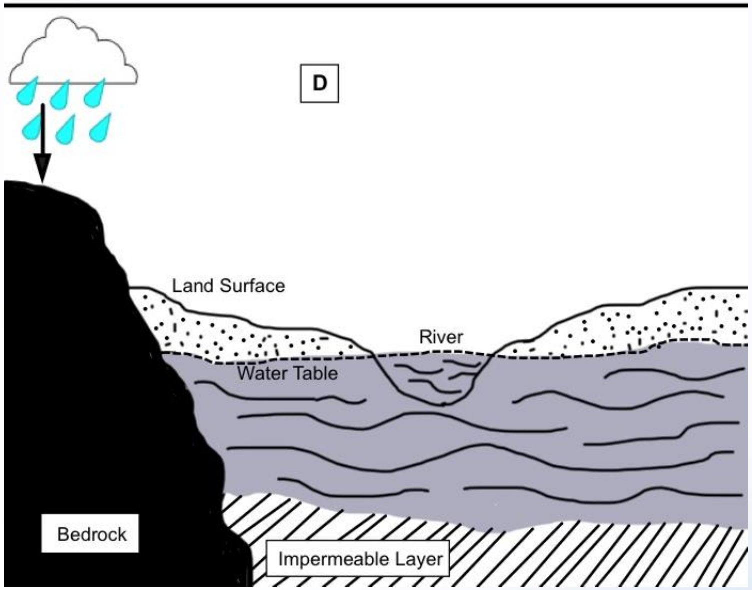


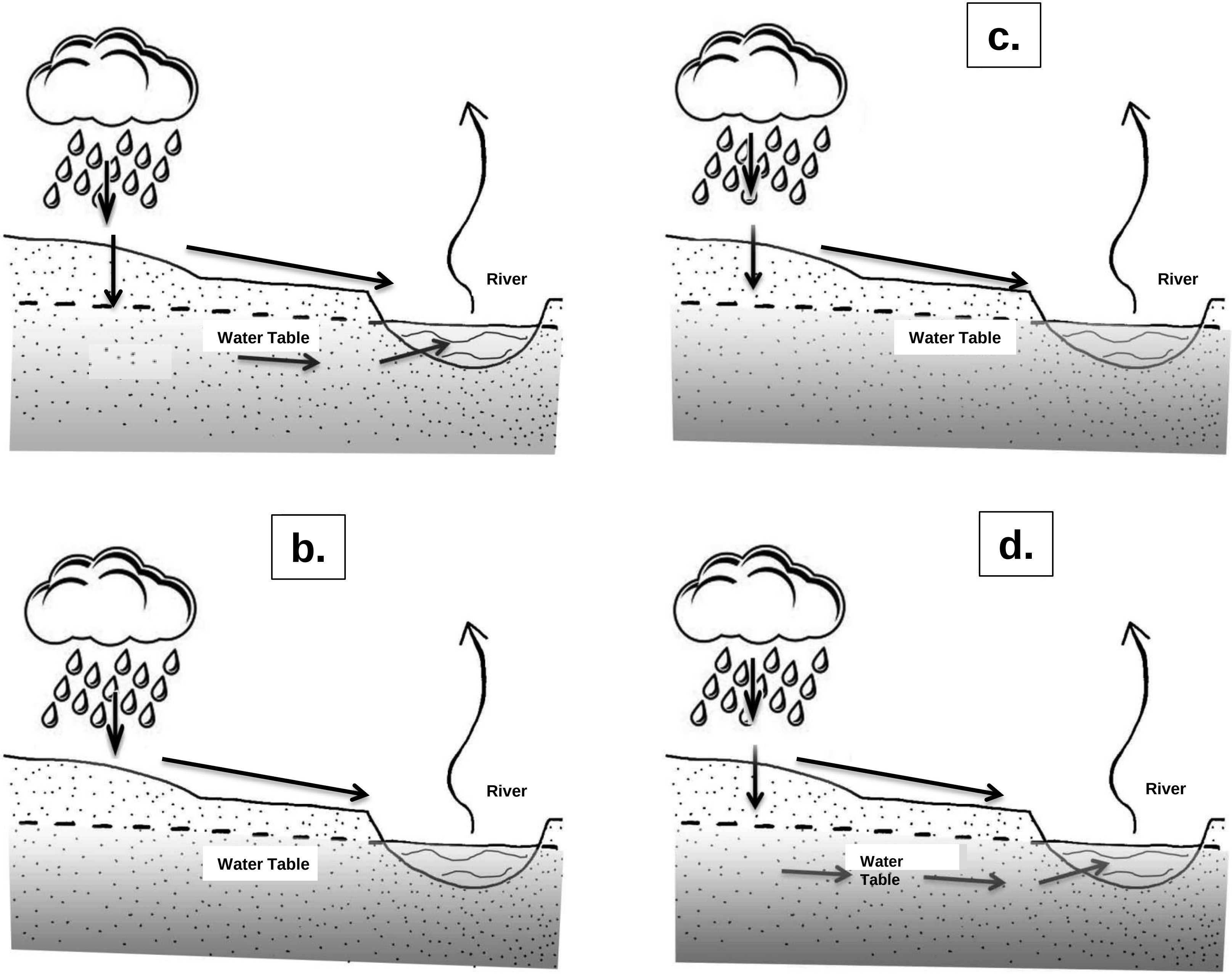

a.
Land Surface
River
Water Table
Bedrock
Clay
b.
Land Surface
River
Water Table
Sand and Gravel
Bedrock
Clay
c.
Land Surface
River
Water Table
Sand and Gravel
Bedrock
Clay
d.
Land Surface
River
Water Table
Bedrock
Clay


A
Land Surface
River
Water Table
Bedrock
Impermeable Layer

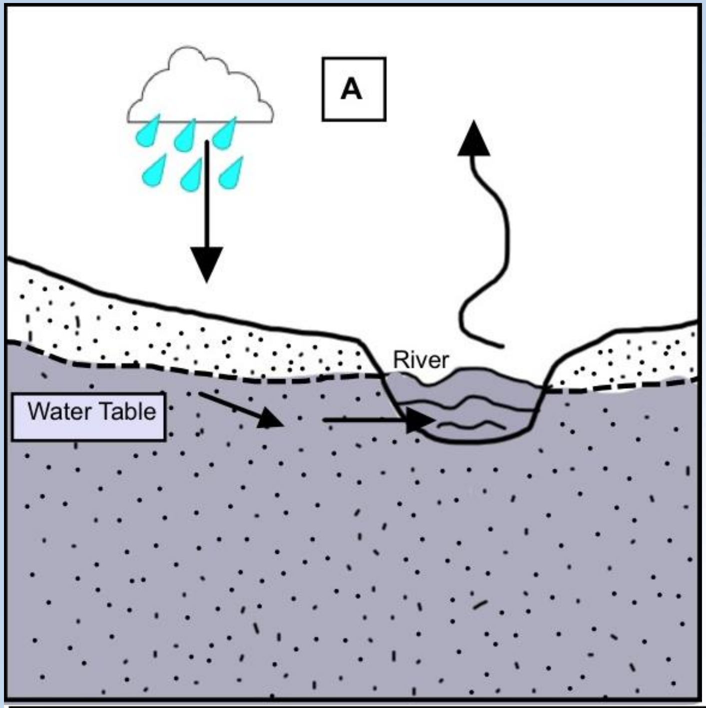

B
Land Surface
River
Water Table
Sand & Gravel
Bedrock
Impermeable Layer

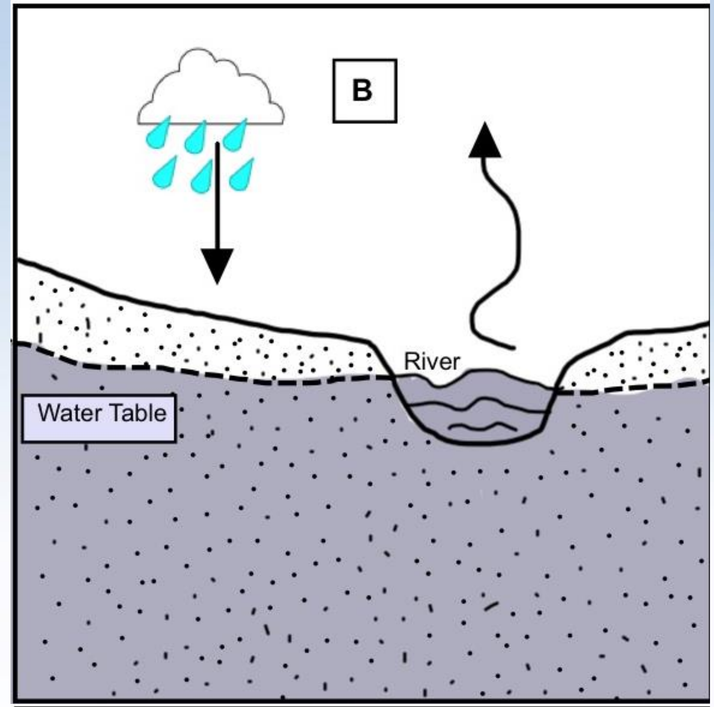

C
Land Surface
River
Water Table
Sand & Gravel
Bedrock
Impermeable Layer

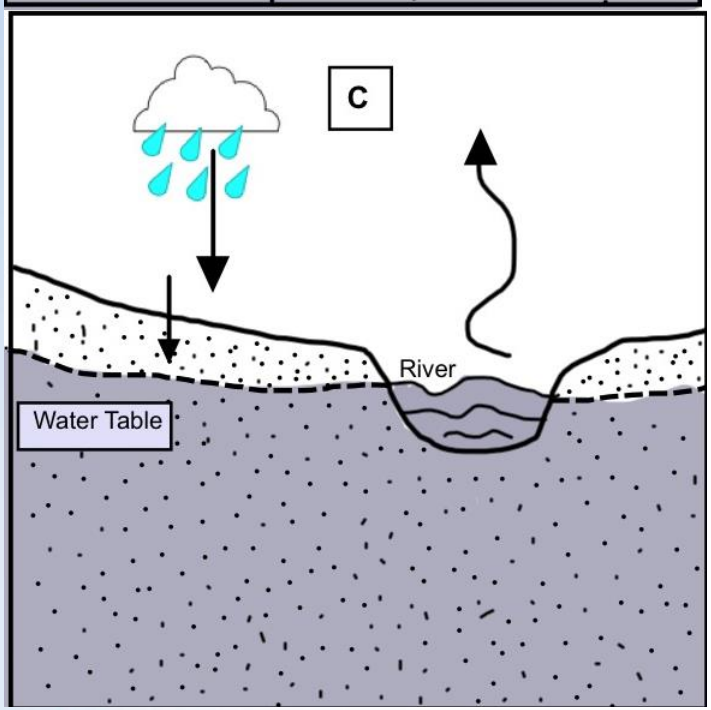

D
Land Surface
River
Water Table
Bedrock
Impermeable Layer

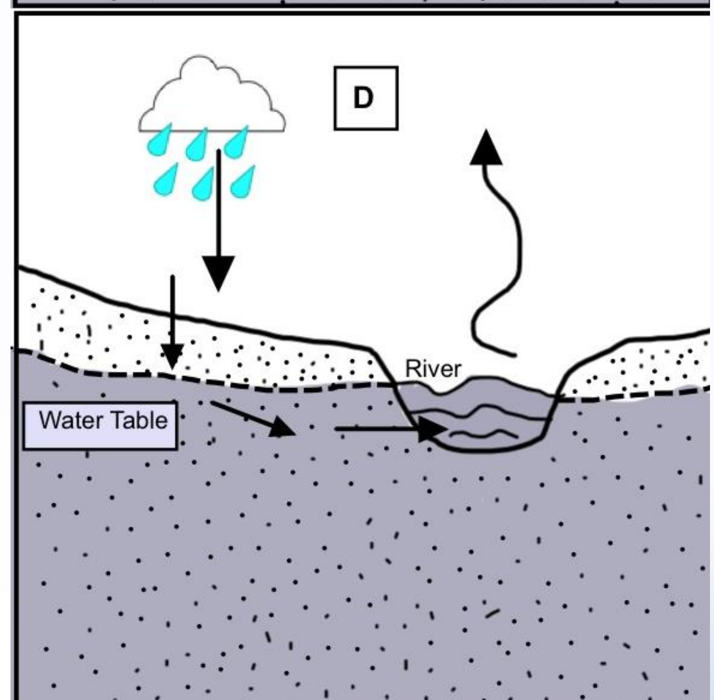


c.
River
Water Table
River
Water Table
b.
d.
River
Water Table
River
Water
Table


A
River
Water Table


B
River
Water Table


C
River
Water Table


D
River
Water Table

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http://cals.arizona.edu/arizonawet/

Arguably, there is no volume of ground-water use that can be truly free of any adverse consequence, especially when time is considered. The direct hydrologic effects will be equal to the volume of water removed, but those effects may require decades to centuries to be manifest. Because aquifer recharge and ground-water withdrawals can vary substantially over time, these changing rates can be critical information for improving management strategies.

Water Availability for the Western United States—Key Scientific Challenges
By Mark T. Anderson and Lloyd H. Woosley, Jr., USGS Circular 1261, 2005

In the Headlines

GW Depletion During Drought Threatens Future Water Security of the Colorado River Basin

Article Claims:

- GW accounted for 50.1 km^3 of total 64.8 km^3 FW loss; which means that the rate of depletion of GW storage far exceeded the rate of depletion of Lakes Powell and Mead.

Gravity Recovery and Climate Experiment (GRACE)

Using Gravity to Measure a Change in Mass.

Using Equation for Total Water Storage:

- Soil Moisture (from GLDAS)
- Snow Water Equivalent (from SNODAS)
- Surface Water (Powell & Mead dam releases, Precipitation from PRISM and evapotranspiration from MODIS all compared to GRACE)
- Solve for Groundwater Quantity