Gretchen Miller, Ph.D., P.E., P.G.
Presentation to the Lost Pines Groundwater Conservation District, April 2025

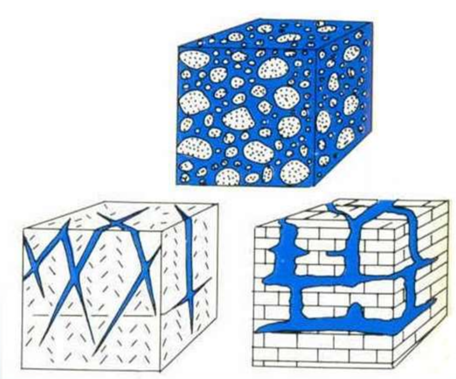
Groundwater and Aquifers 101

LREWATER.COM

ROCKY MOUNTAIN | MIDWEST | SOUTHWEST | TEXAS

1

WHAT IS GROUNDWATER?



- **Water found in void spaces of subsurface geologic features**
  - Between grains of sediments and sedimentary rocks like sandstone
  - In fractures of hard rock like granite
  - In dissolution features of carbonate rocks like sandstone
- **When void spaces are filled, the media is "saturated"**
  - Difference matters for flow behavior

2

THEN WHAT IS AN AQUIFER?

- **A water bearing geologic formation**
  - Or system of formations
  - Usually with significant quantities of water
  - Frequently limited to those with qualities fit for drinking or irrigation
- **Formations are distinct rock units extensive enough to be mapped**

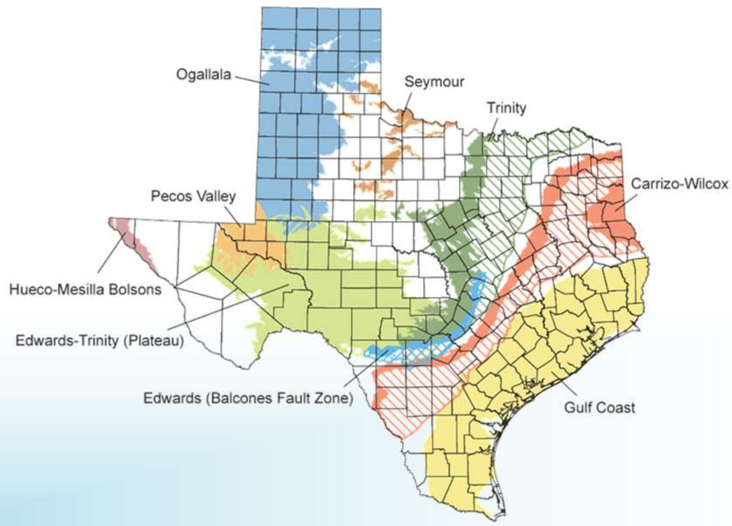
Illustration from Utah Geological Survey

3

AQUIFERS IN TEXAS

4

MAJOR AQUIFERS OF TEXAS



From George et al . (2011) *Aquifers of Texas*

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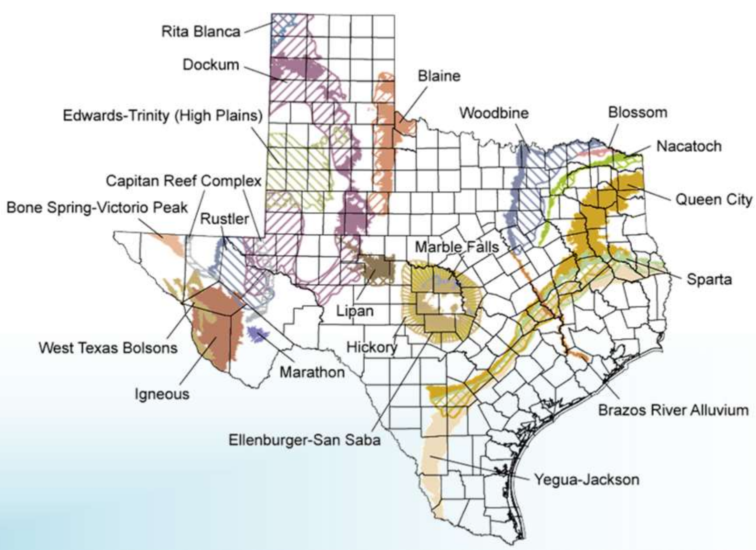
MINOR AQUIFERS OF TEXAS



From George et al . (2011) *Aquifers of Texas*

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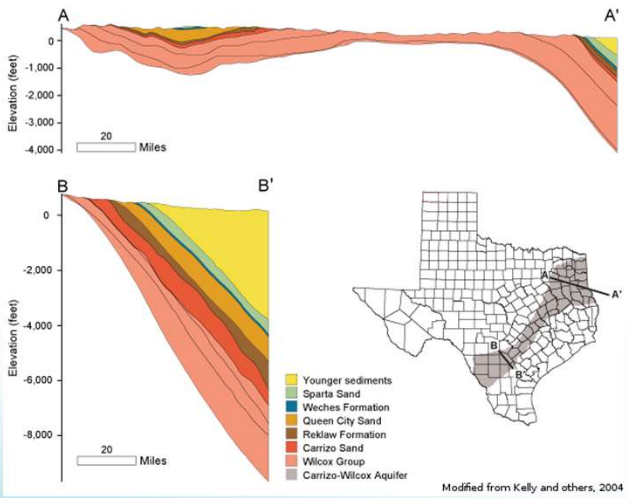
HOW ARE AQUIFERS DESCRIBED AND VISUALIZED?



- **Carrizo-Wilcox Example**
  - From *Aquifers of Texas*
  - Note formation names
- **Cross-section**
  - With vertical exaggeration
  - In multiple locations
- **Plan/map view**

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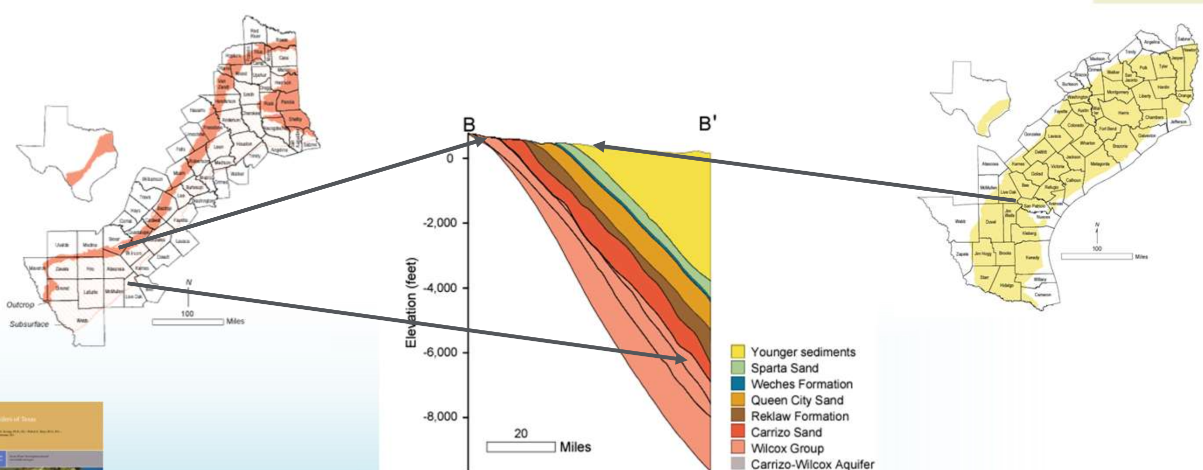
WHAT DOES SUBCROP MEAN?



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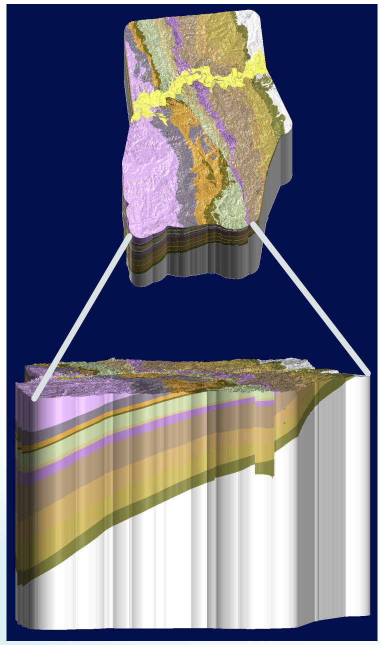
AQUIFERS OF LOST PINES GCD

LPGCD Geological Model

- L1_Colorado River Alluvium
- L2_Yegua-Jackson
- L3_Cook Mountain
- L4_Sparta Sand
- L5_Weches
- L6_Queen City Sand
- L7_Reklaw
- L8_Carrizo Sand
- L9_Wilcox, Calvert Bluff
- L10_Wilcox, Simsboro
- L11_Wilcox, Hooper
- L12_Midway Group
- L13_Undifferentiated Cretaceous
- Unknown



Outcrop

Subcrop

Fault

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WHAT OTHER ~~JARGON~~ *KEY TERMS* DO WE NEED TO KNOW?

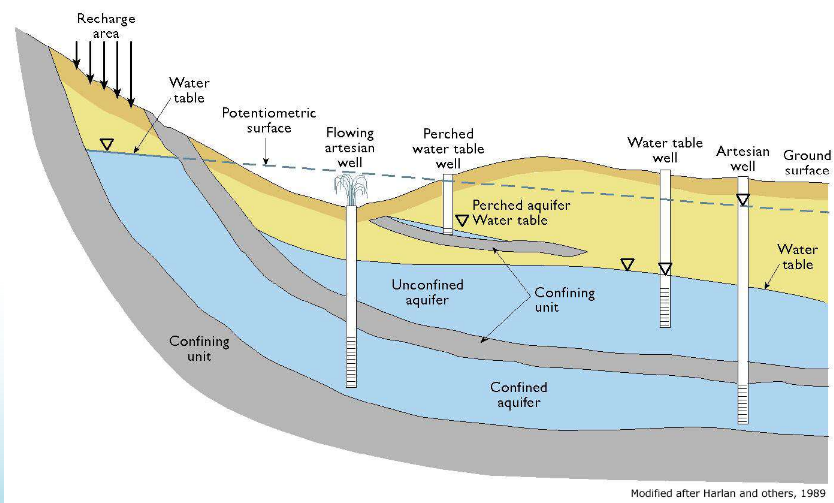

Image from Colorado Geological Survey

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AQUIFERS OF LOST PINES GCD

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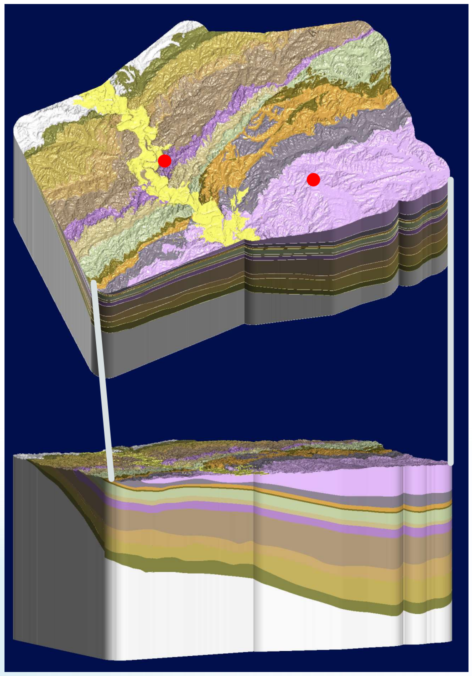

Confined Aquifer

Unconfined Aquifer

Confining Layer

Recharge Area

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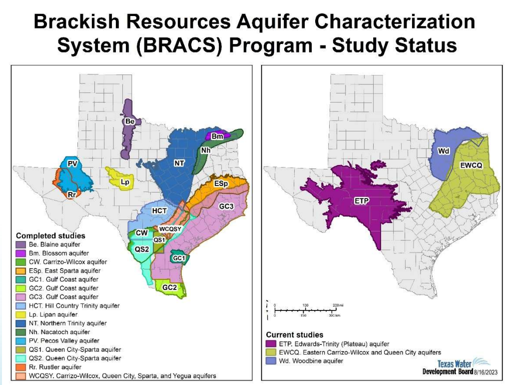
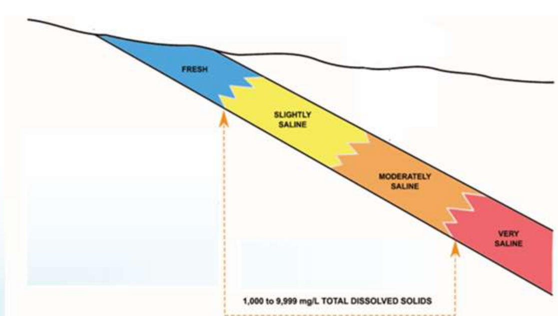
DOES THE WATER IN AN AQUIFER NEED TO BE DRINKABLE?





Images from TWDB

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WATER STORAGE AND MOVEMENT IN AQUIFERS

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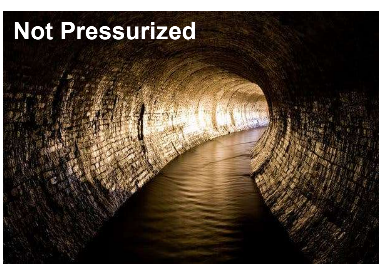
WHAT EXACTLY IS A WATER TABLE?



- **Idea captures the water level in an aquifer**
  - If the aquifer is *not pressurized*, the water level in a well indicates the interface between the saturated and unsaturated zone
  - If the aquifer is *under pressure*, the water level in a well indicates the pressure or, as a shorthand, the hydraulic head
- **Think sewer vs. water main**
  - Sewer illustrates water table
  - Main break shows potentiometric surface
- **A water table is not flat**

Images from the New York Times and the Guardian

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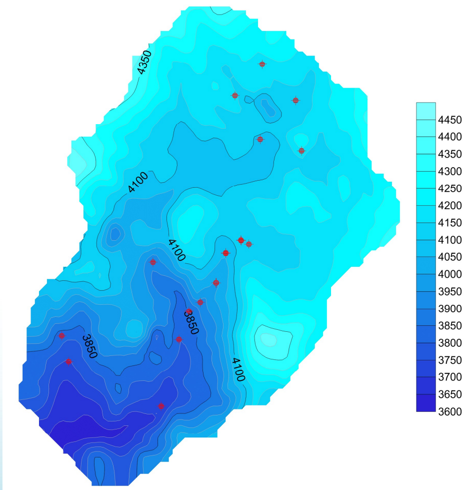
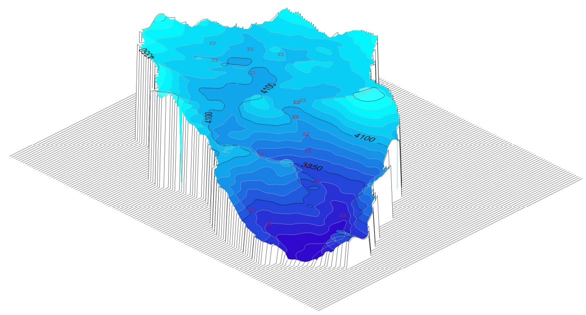
CONTOUR PLOTS SHOW WATER TABLE OVER SPACE





Images from Golden Software

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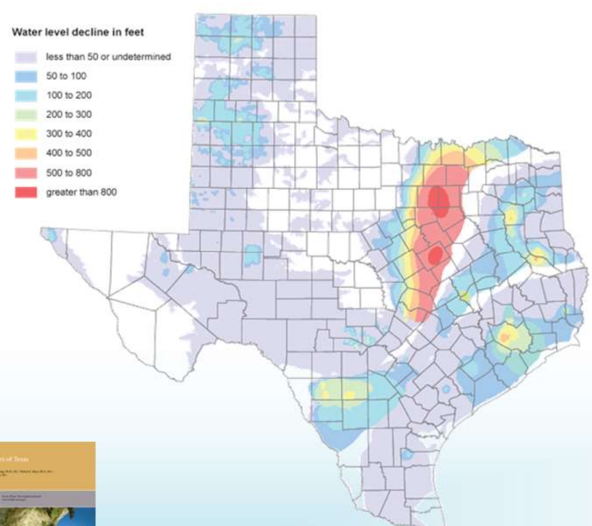
WATER TABLES OF TEXAS



- **Water table idea lets us track changes in aquifers over time**
  - Typically represented as water level declines or drawdown
  - Can be applied to changes over large regions
  - Or at an individual well

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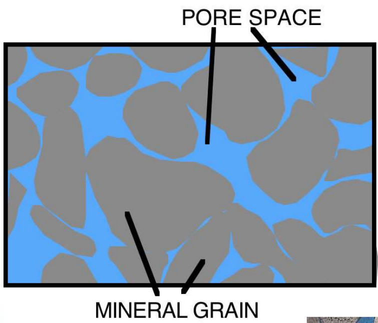
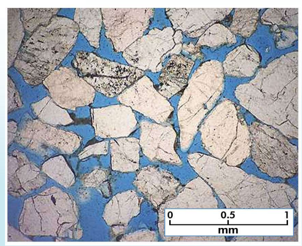
WHERE DO AQUIFERS STORE THIS WATER?





- **Porosity is the space available for water storage**
  - Between grains (primary)
  - In fractures and cavities (secondary)
- **Multiple terms for storage properties**
  - Specific yield (unconfined)
  - Specific storage (confined)
  - Storativity (both)

From U. Pittsburgh; U. Wisconsin

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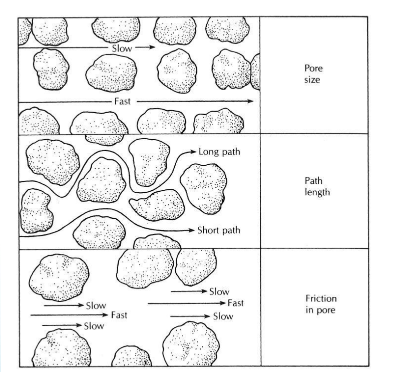
HOW DO AQUIFERS MOVE THIS WATER?



- **Water flows downhill**
  - From high pressure to low pressure
  - From high head to low head
  - Along a gradient
- **Friction opposes motion**
  - Air resistance, sand paper, pavement
  - Plastic vs. cast-iron pipe
- **Hydraulic conductivity (K) represents idea of friction in aquifer materials**
  - Higher values mean less friction

Image from Fetter (2001) Contaminant Hydrogeology

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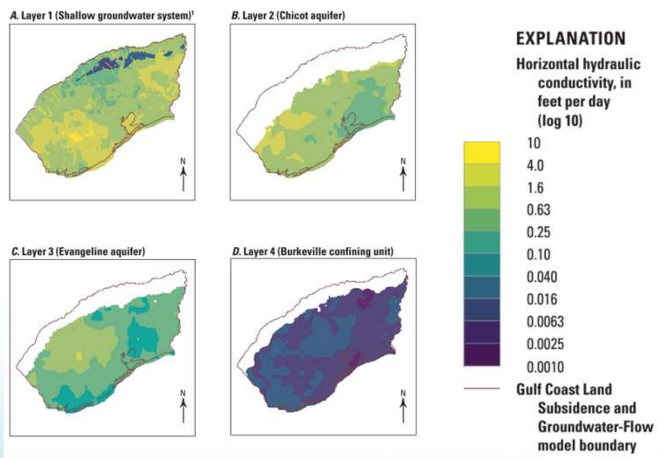
HYDRAULIC CONDUCTIVITY OF TEXAS



- **Used to model behavior of an aquifer**
  - Important GAM input
  - Needed for calculating well drawdown
- **Close cousin of transmissivity**
  - T = K * aquifer thickness

Images from Ellis et al. (2023) *USGS PP1877*

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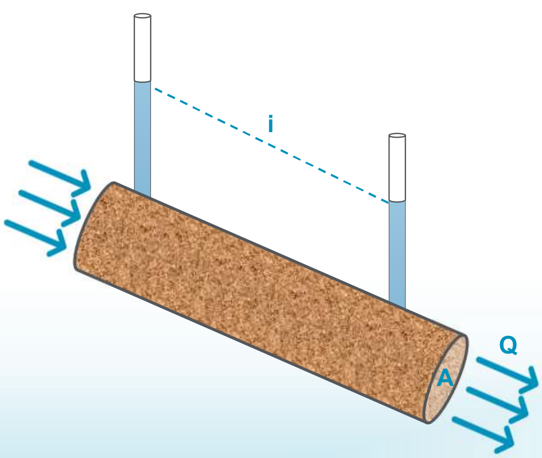
DARCY'S LAW COMBINES FRICTION AND PRESSURE



- **Flow rate is proportional to conductivity, gradient, and area**

$$Q = KiA$$

- **Flow increases with**
  - Higher conductivity (K)
  - Higher pressure gradient (i)
  - Larger area (A)

$q_x = -K_x \frac{\partial h}{\partial x}$, for Re < 10

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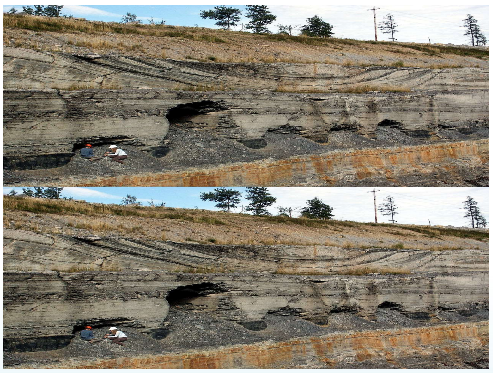
WHAT ARE SEDIMENTS?



- Former rocks
  - Pieces of eroded and weathered parent material
- Rocks in the making
  - Awaiting pressure and chemical changes to become sedimentary rocks
- Still "rocks"
  - Sediments can range from microscopic clay particles to granite boulders
  - Collection in one place is key to making a formation or aquifer

Image from M. Rygel, via Wikimedia Commons

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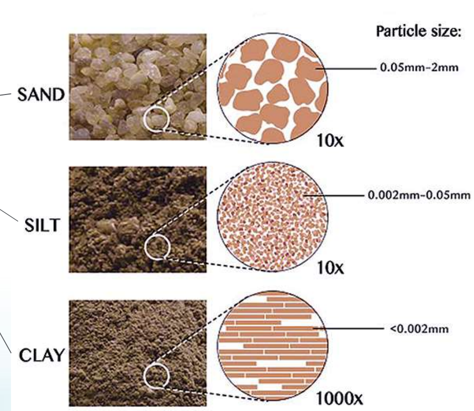
WHY DO SEDIMENTS MATTER FOR GROUNDWATER?

Table 3.2 **Representative Values of Hydraulic Conductivity for Various Rock Types**

Material	Hydraulic Conductivity (m/s)
SEDIMENTARY	
Gravel	3×10^{-4}–3×10^{-2}
Coarse sand	9×10^{-7}–6×10^{-3}
Medium sand	9×10^{-7}–5×10^{-4}
Fine sand	2×10^{-7}–2×10^{-4}
Silt, loess	1×10^{-9}–2×10^{-5}
Till	1×10^{-12}–2×10^{-6}
Clay	1×10^{-11}–4.7×10^{-9}
Unweathered marine clay	8×10^{-13}–2×10^{-9}
SEDIMENTARY ROCKS	
Karst and reef limestone	1×10^{-6}–2×10^{-2}
Limestone, dolomite	1×10^{-9}–6×10^{-6}
Sandstone	3×10^{-10}–6×10^{-6}
Siltstone	1×10^{-11}–1.4×10^{-8}
Salt	1×10^{-12}–1×10^{-10}
Anhydrite	4×10^{-13}–2×10^{-8}
Shale	1×10^{-13}–2×10^{-9}
CRYSTALLINE ROCKS	
Permeable basalt	4×10^{-7}–2×10^{-2}
Fractured igneous and metamorphic rock	8×10^{-9}–3×10^{-4}
Weathered granite	3.3×10^{-6}–5.2×10^{-5}
Weathered gabbro	5.5×10^{-7}–3.8×10^{-6}
Basalt	2×10^{-11}–4.2×10^{-7}
Unfractured igneous and metamorphic rocks	3×10^{-14}–2×10^{-10}



Left: Domenico and Schwartz 1998, Right: original source unknown

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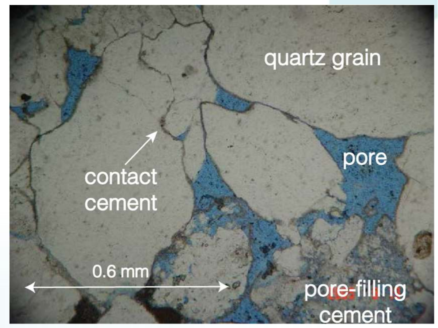
WHY DO SEDIMENTS *AND CEMENTING* MATTER FOR GROUNDWATER?

Table 2.2.1 Representative Values of Porosity (after Morris and Johnson[45])

Material	Porosity, percent	Material	Porosity, percent
Gravel, coarse	28[a]	Loess	49
Gravel, medium	32[a]	Peat	92
Gravel, fine	34[a]	Schist	38
Sand, coarse	39	Siltstone	35
Sand, medium	39	Claystone	43
Sand, fine	43	Shale	6
Silt	46	Till, predominantly silt	34
Clay	42	Till, predominantly sand	31
Sandstone, fine grained	33	Tuff	41
Sandstone, medium grained	37	Basalt	17
Limestone	30	Gabbro, weathered	43
Dolomite	26	Granite, weathered	45
Dune sand	45		

[a]These values are for repacked samples; all others are undisturbed.



Left: Todd and Mays, 2004, Right: Carcione et al. 2022

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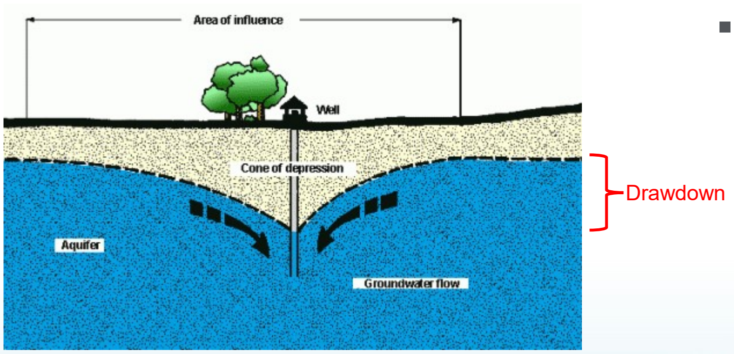
AQUIFER RESPONSE TO PUMPING

WHAT IS THE RELATIONSHIP BETWEEN PUMPING AND DRAWDOWN?



- **Pumping creates a cone of depression**
  - Drawdown = Difference between original and new water level
  - Controlled by pumping rate, conductivity, nearby water sources
  - Drawdown predicted by Theis equation or MODFLOW model

From Raymond, 1988

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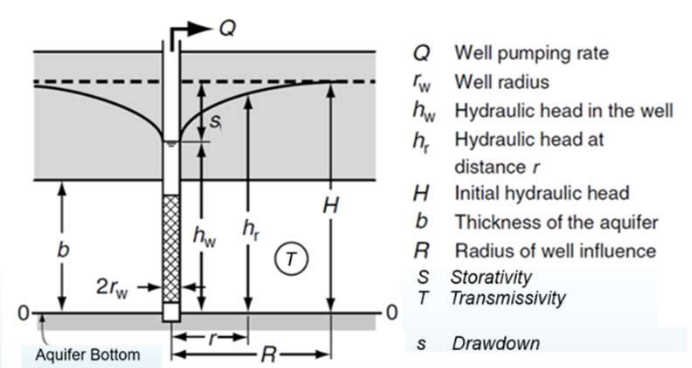
HOW IS DRAWDOWN PREDICTED?



- **Pumping creates a cone of depression**
  - Drawdown is a function of distance and time
    - Increases with time
    - Decreases with distance

$$s = \frac{Q}{4\pi T} \int_u^{\infty} \frac{e^{-y}}{y} dy$$

$$u = \frac{r^2 S}{4Tt}$$

Modified from Kresic 2009

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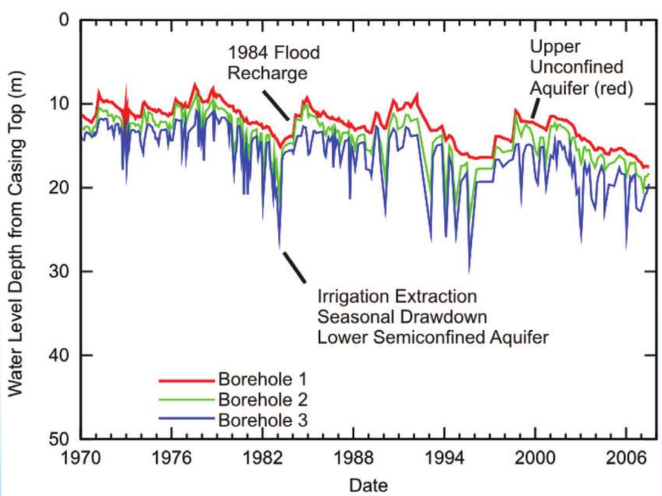
HOW DOES PUMPING IMPACT NEARBY WELLS?



- **Example of pumping impacts**
  - Well 3 (blue) – water extracted for seasonal irrigation
  - Well 2 (green) – nearby well in same aquifer is impacted
  - Well 1 (red) – well separated by semi-confining layer is also impacted

From Kelly and others, 2009

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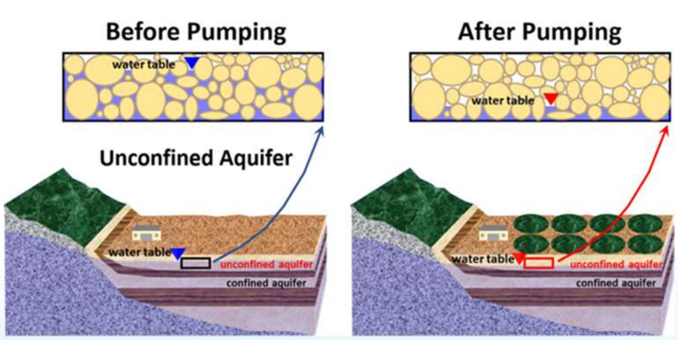
HOW DO CONFINED AND UNCONFINED AQUIFERS RESPOND DIFFERENTLY?



- **Unconfined aquifers –** Pores drained, water replaces air
- **Confined Aquifers –** Pressure relieved, grains can compress
- An equal decline of water levels in an unconfined aquifer yields more water than in a confined aquifer

Figure from Poeter and others, 2020

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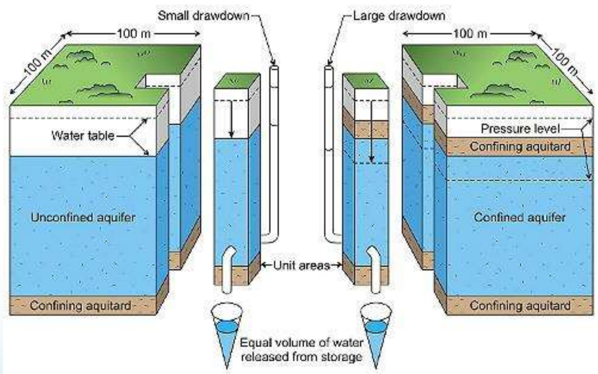
HOW DO CONFINED AND UNCONFINED AQUIFERS RESPOND DIFFERENTLY?



- **Unconfined aquifers –** Pores drained, water replaces air
- **Confined Aquifers –** Pressure relieved, grains can compress
- An equal decline of water levels in an unconfined aquifer yields more water than in a confined aquifer

Figure from UNSW, 2017

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ABOUT THE LPGCD AQUIFERS

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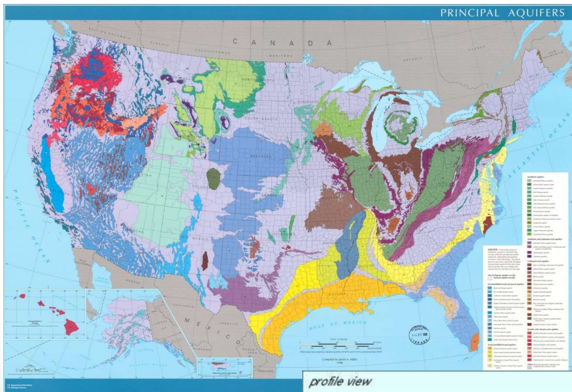
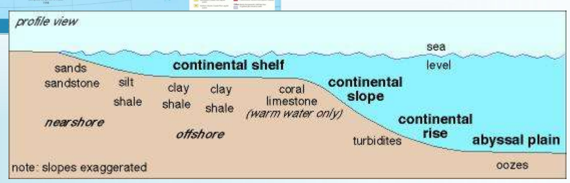
LPGCD AQUIFERS: “COASTAL” FORMATIONS



- **Coastal upland aquifer**
  - Unconsolidated to semi-consolidated sediments – i.e., not full-fledged rocks yet
  - Deposited at the margins between ocean and land
  - Change in particle size due to ocean level changes



From US National Atlas, Columbia University

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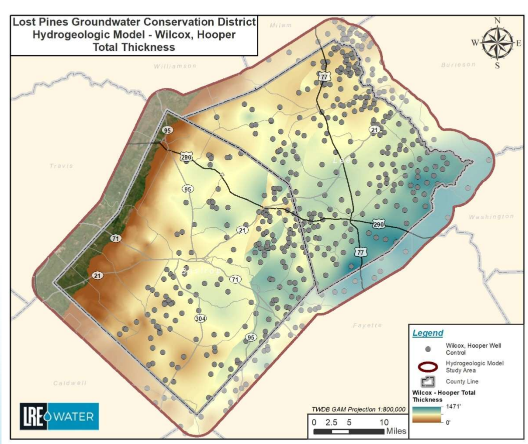
LPGCD AQUIFERS: LOWER WILCOX (HOOPER)



- **Carrizo-Wilcox (major aquifer)**
  - Oldest, deepest water-bearing layer
  - Bedding layers:
    - Sandstone formed/cemented with carbonate material (limestone pieces)
    - Lignite present (coal)
    - Shale (consolidated muds)
  - K = 0.04 - 6 ft/d (conductivity)
  - b = 1471 ft max (thickness)

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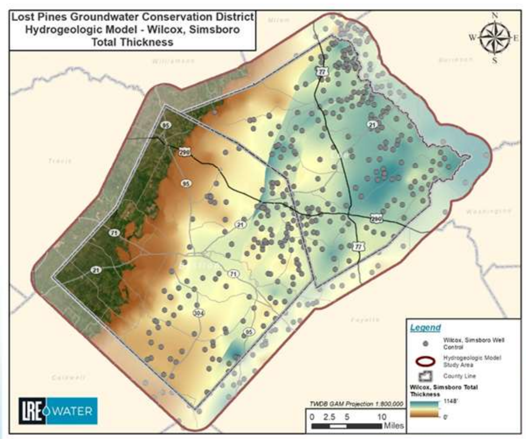
LPGCD AQUIFERS: MIDDLE WILCOX (SIMSBORO)



- **Carrizo-Wilcox (major aquifer)**
  - Second oldest, deepest water-bearing layer
  - Massive sandstone (no distinct layering)
    - Fine- to medium-grained
    - Well-sorted (grains same-sized)
  - K = 0.9 - 46 ft/d
    - Highest of LPGCD
  - b = 1148 ft max

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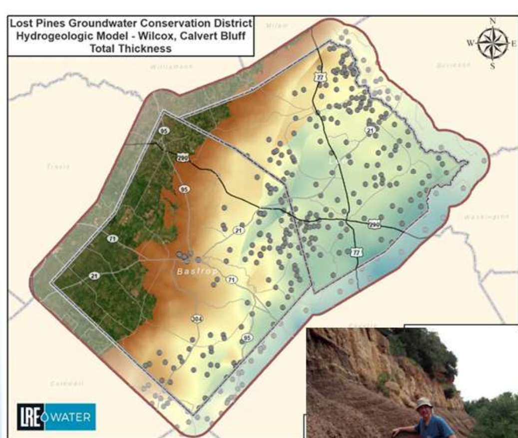
LPGCD AQUIFERS: UPPER WILCOX (CALVERT BLUFF)



- **Carrizo-Wilcox (major aquifer)**
  - Youngest Wilcox layer
  - Bedding layers similar to Hooper
    - Sandstone formed/cemented with carbonate material (limestone pieces)
    - Lignite present (coal)
    - Shale (consolidated muds)
  - K = 0.03 - 7 ft/d (conductivity)
  - b = 1924 ft max (thickness)

Photo from Yancey and others, 2013

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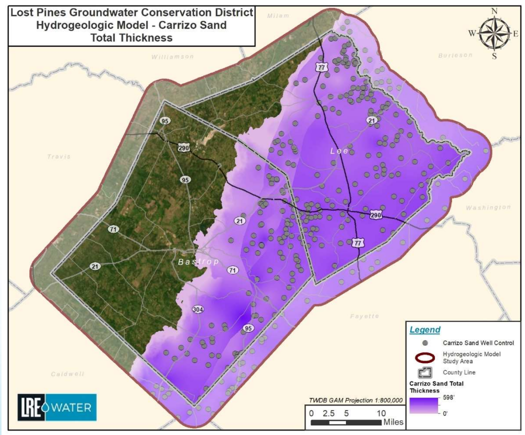
LPGCD AQUIFERS: CARRIZO



- **Carrizo-Wilcox (major aquifer)**
  - Fine to cross-bedded sand and some thin beds of sandstone and clay
  - K = 2 - 24 ft/d
  - b = 598 ft max

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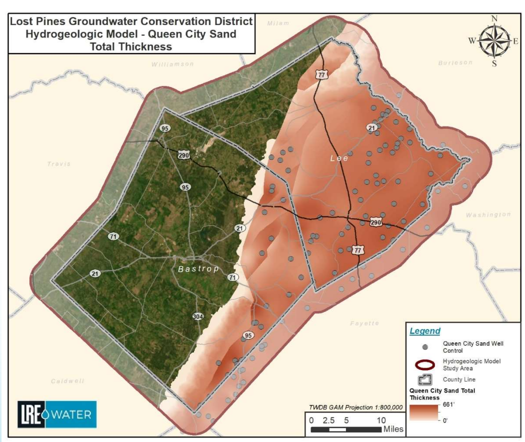
LPGCD AQUIFERS: QUEEN CITY



- **Minor aquifer designation**
  - Only some thin beds present
  - Fine to medium sand, clay
  - Some conglomerate – i.e., rocks containing other rocks
  - K = 0.6 - 10 ft/d
  - b = 661 ft max

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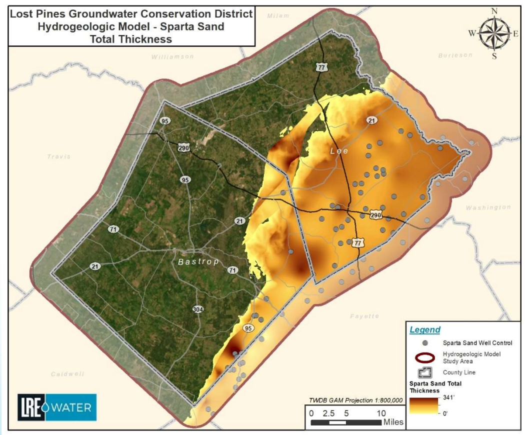
LPGCD AQUIFERS: SPARTA



- **Minor aquifer designation**
  - Fine to medium sand with some clay
  - K = 0.2 – 9 ft/d
  - b = 341 ft max

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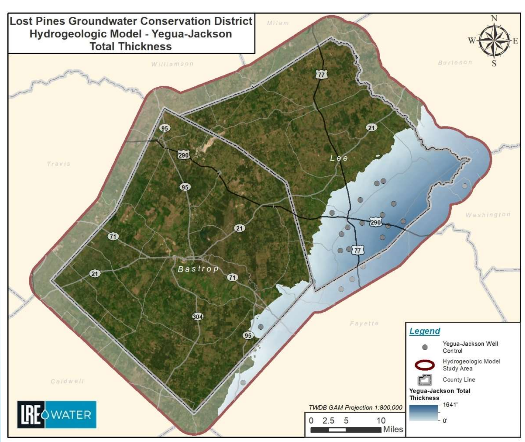
LPGCD AQUIFERS: YEGUA-JACKSON



- **Minor aquifer designation**
  - Yegua
    - Medium to fine sand, silt, clay,
    - Gypsum (calcium sulfate mineral)
    - Some lignite (coal)
  - Jackson
    - Clay, silt
    - Volcanic ash, tuffaceous sand (derived from volcanic ash)
    - Shale (consolidated clay)
  - K = 0.03 - 30 ft/d
  - b = 1641 ft max

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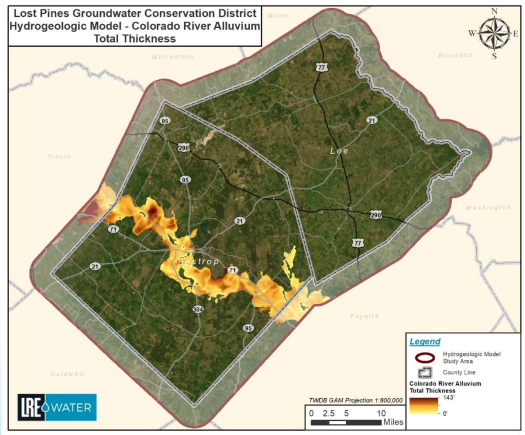
LPGCD WATERS: COLORADO RIVER ALLUVIUM



- **No aquifer designation**
  - River deposited sands, gravels, and clays
  - "Young" sediments
  - b = 143 ft
  - K = 75 ft/d

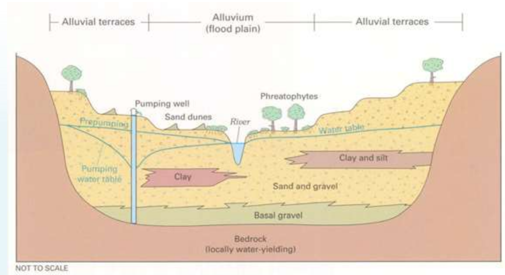


Image: USGS, 1996

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Q&A

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