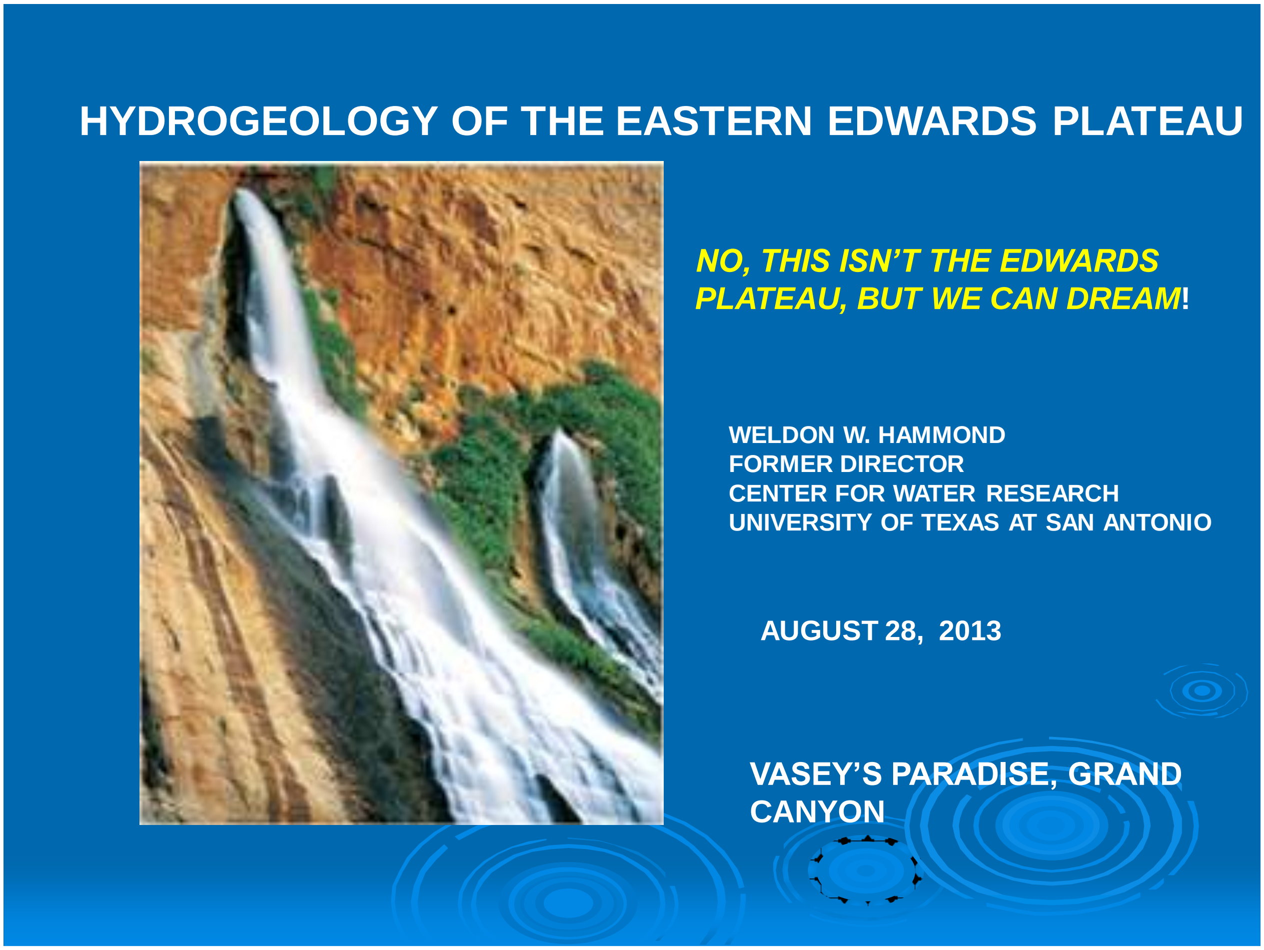

HILL COUNTRY CHAPTER

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TRAINING COURSE
HYDROGEOLOGY OF THE EASTERN EDWARDS PLATEAU
2013

INTRODUCTION

First let's look at the relative masses of water on a global scale, just to put the water picture into the proper perspective.

Water Masses At The Earth's Surface
(Source: Encyclopedia Britannica)

Reservoirs	Volume (in millions of cubic kilometers. One cubic kilometer equals 172,052,358 gallons)	Percent of Total
Oceans	1,370	97.25
Ice Caps and Glaciers	29	2.05
Deep Groundwater (700- 4,000 meters)	5.3	0.38
Shallow Groundwater (less than 750 meters)	4.2	0.3
Lakes	0.125	0.01
Soil Moisture	0.065	0.005
Atmosphere	0.013	0.001
Rivers	0.0017	0.0001
Biosphere	0.0005	0.00004
Total	1, 407.8	100

Interesting note…..as a comparison we have over 3,200 times more water that occurs as shallow groundwater than in all the rivers and lakes in the world combined.

FIGURE 1. WATER MASSES AT THE EARTH'S SURFACE

Ocean water is saline, water in the ice caps and glaciers is fresh water but in the "solid" phase and therefore not very usable. The amount of water in that occurs as soil moisture (vital for plant growth), in the biosphere (plant and animal material) and in the atmosphere is fairly trivial when we compare them with the total amount of water but very, very important in the grand scheme of the water world.

We have a finite amount of water on our planet. As our population grows so will our demand for water. Figure 2 is the population growth in Kendall County, one of the fastest growing areas in Texas. Kendall County's growth is primarily due to its proximity to the San Antonio metropolitan area. However, much of the eastern Edwards Plateau may experience similar population growth in the near future.

Population Growth

Kendall County	Population	% Change From Previous Decade
Census 2010:	33,410	40.7
Census 2000:	23,743	62.7
Census 1990:	14,589	37.2
Census 1980:	10,635	52.7

Census 1970:	6,964`	18.3
Census 1960:	5,889	8.6
Census 1950:	5,423	6.8
Census 1940:	5,080	-

FIGURE 2. KENDALL COUNTY POPULATION GROWTH

Water resources may well be the limiting factor for future growth potential

Climate

The climate of the eastern Edwards Plateau ranges from dry subhumid in the eastern half (Comal and Kendall Counties) to semiarid in the western half (Uvalde and Kinney Counties) (Thornthwaite 1948). Both areas are mesothermal (moderate amount of heat, with winters not cold enough to sustain snow cover). Summers are hot and typical of a continental climate regime.

Precipitation in the eastern Edwards Plateau is highly irregular, varying with location and with the time of year. Winter months are generally dry and precipitation is primarily light rain and drizzle. Normally precipitation increases significantly during April, May and June as thunderstorms become more frequent. Summers are quite uniform with hot daytime temperatures and only an occasional, isolated, afternoon or evening convective thunderstorm. Summer months are relatively dry. Precipitation generally begins to increase in September due to weather disturbances moving inland from the Gulf of Mexico.

Geomorphology

(Definition: the scientific study of landforms and the processes that shape them)

Streams in the upper reaches of the drainage basins typically have eroded headward into the Edwards Group and the underlying upper member the Glen Rose Limestone. Stream valleys immediately upstream from the Balcones Escarpment (the southern limit of the eastern Edwards Plateau and associated with the Balcones Fault Zone) are narrow with steep gradients and the beds of stream channels are either limestone outcrops or highly porous alluvium. These constricted stream channel reaches are subject to very high flood discharges with flood stages in excess of 12 to 15 meters. In their middle and lower reaches the major streams have incised their valleys into the lower member of the Glen Rose Limestone, forming broad valleys with extensive alluvial terraces, thick floodplain deposits and locally broad meanders.

Vegetative regions

Hill and Vaughan (1898) divided the Edwards Plateau into three physiographic elements; (1) flat-topped summits (uplands), (2) breaks or slopes and (3) streamways and described the corresponding vegetative types.
The xerophytic nature and dwarfing of the uplands plants in the Edwards Plateau is similar to the pinyon-juniper pigmy forests and submontane shrub association of west Texas and western North America. The uplands contain primarily juniper, oak and bunch grass with lesser amounts of Mexican juniper, live oak, shin oak, Texas oak, blackjack, prickly pear, yucca and mesquite. Along the extreme eastern margins of the Plateau, the sand, marls and clays present in the Walnut Formation and the basal nodular member of Edwards Group support a much denser growth, in distinct contrast to the sparse vegetation of the thin calcareous lithosols of the Glen Rose Limestone and the Edwards Group. Van Auken (1980) reported no significant differences between plant communities living on the Glen Rose Limestone and the Edwards Group. The floodplains of the larger rivers and their tributaries contain mesic forests of live oak, elm, cedar elm, hackberry, pecan and cypress along with scattered occurrences of walnut, sycamore and red mulberry plus numerous other species.

Geology

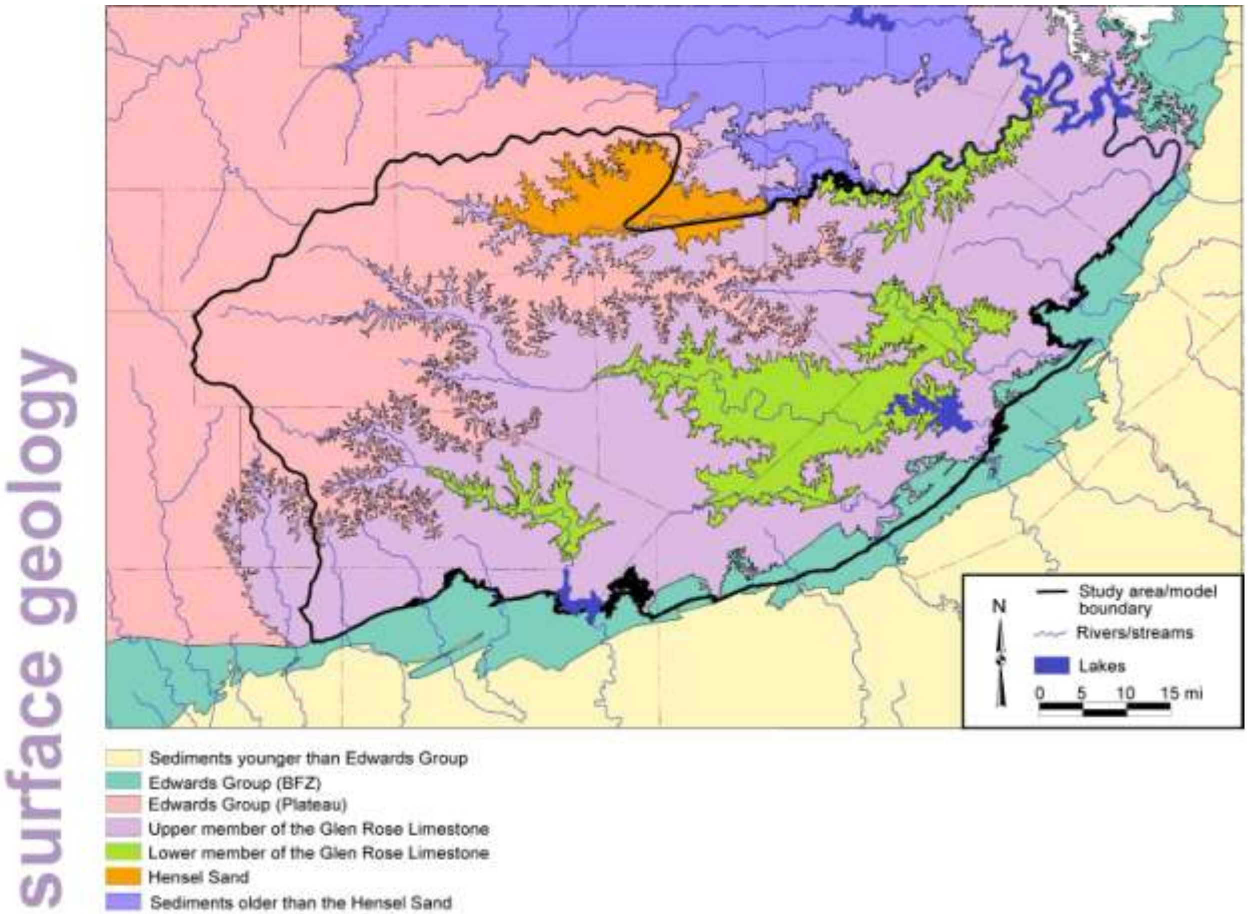


FIGURE 3. SURFACE GEOLOGY (modified from TWDB Report 273

Rock of Cretaceous and Quaternary Systems are exposed at the surface in the eastern Edwards Plateau. Cretaceous formations (older than 65 million years) outcrop at the surface in the eastern Edwards Plateau. These rocks, primarily limestone and dolomite, with some sandstone and shale, were deposited some 145- 65 million years ago in an open shallow, shelf edge marine environment.

The Trinity aquifer in the Hill Country is comprised of sediments of the Trinity Group and is divided into lower, middle, and upper aquifers based on hydraulic characteristics of the sediments (Barker and others, 1994).

Geologic Formations in the Eastern Edwards Plateau that are capable of yielding groundwater (from oldest to youngest)

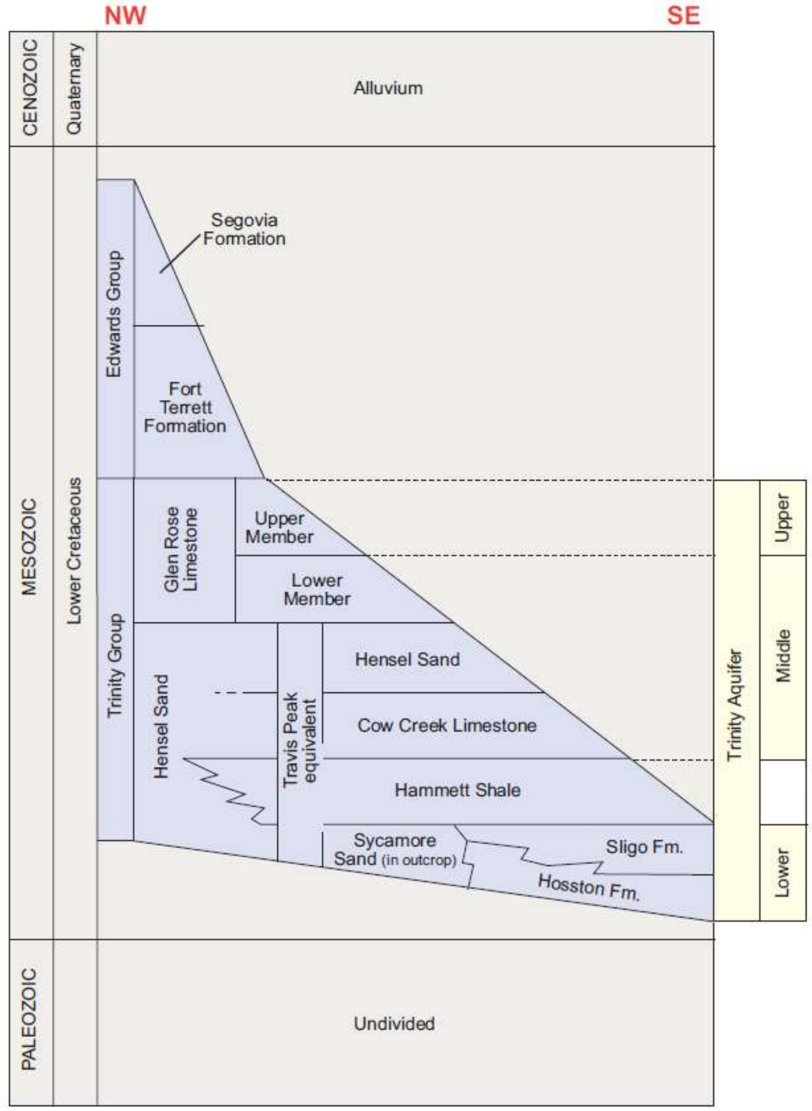


Figure Stratigraphic and hydrostratigraphic section of the Hill Country area (after Ashworth, 1983; Barker and others, 1994).

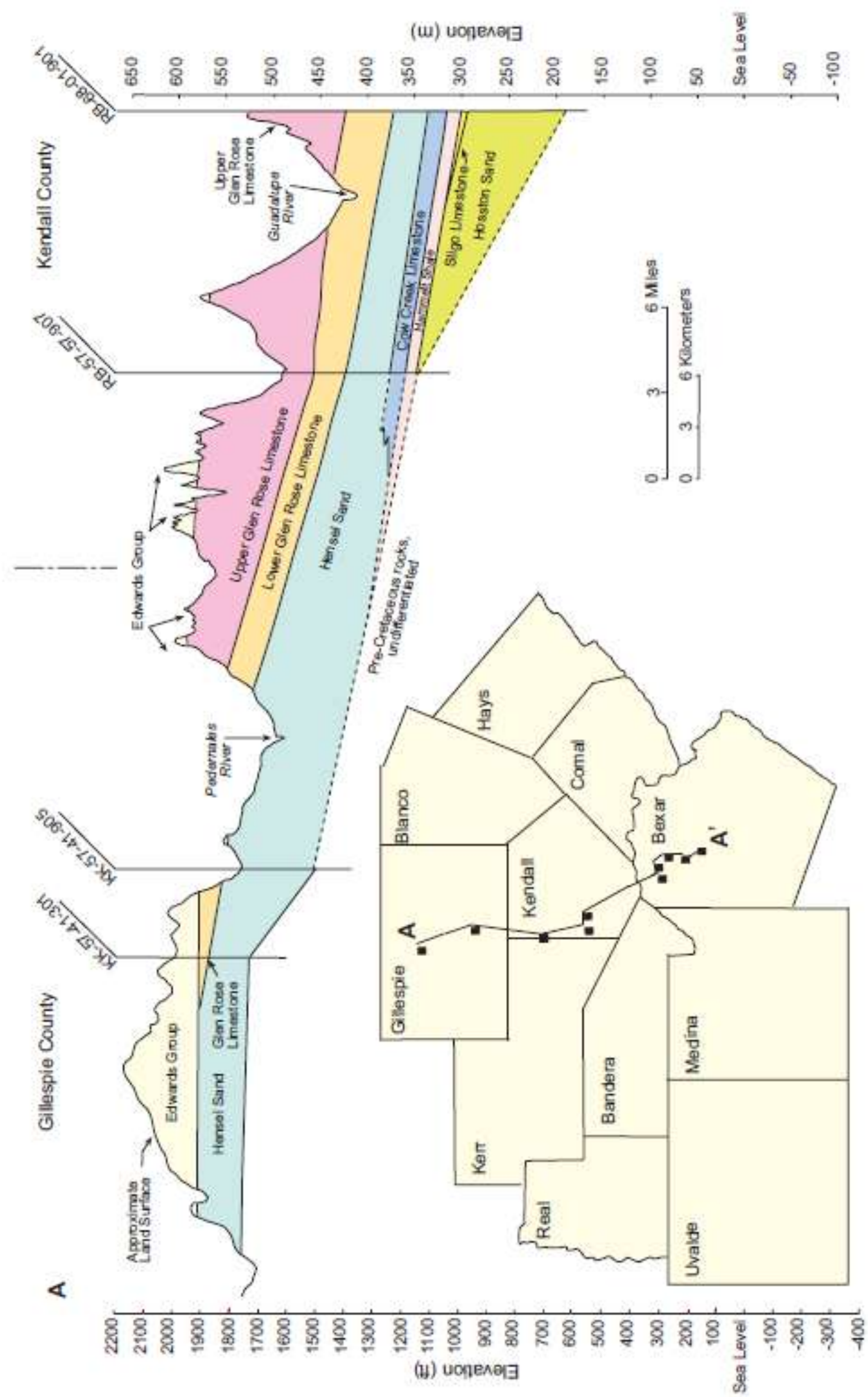
FIGURE 4. STRATIGRAPHY

The Lower Trinity aquifer consists of the Hosston and Sligo Formations in the subsurface and the Sycamore Sand in outcrop; the Middle Trinity aquifer consists of the Cow Creek Limestone, the Hensel Sand, and the Lower Member of the Glen Rose Limestone; and the Upper Trinity aquifer consists of the Upper Member of the Glen Rose Limestone.

Low-permeability sediments in the middle and upper parts of the Glen Rose Limestone separate the Middle and Upper Trinity aquifers. The Lower and Middle Trinity aquifers are separated by the low permeability Hammett Shale except where the Hammett Shale pinches out in the northern part of the study area (Amsbury, 1974; Barker and Ardis, 1996).The basal parts of the Hosston Formation, the Sycamore Sand, and updip parts of the Hensel Sand are mostly sand and contain some of the most permeable sediments in the Hill Country (Barker and others, 1994). The Cow Creek Limestone is highly permeable in outcrop but has relatively lower permeability in the subsurface due to the precipitation of calcitic cements (Barker and others, 1994). The oldest geologic unit exposed in Kendall County, the Cow Creek Limestone, crops out in the southeastern part of the county where the Guadalupe River has cut through the overlying strata. The Cow Creek is predominantly a massive, white, fossiliferous limestone. Locally, beds of sand, shale, and lignite occur in the lower and middle part of the Cow Creek. At places on the outcrop the thick limestone beds are honeycombed. The Cow Creek ranges in thickness from 55 feet in the subsurface to 25 feet in the outcrop. The Cow Creek yields small to moderate quantities of fresh to slightly saline water. Where the Cow Creek is thin the yield generally is less than 5 gpm (gallons per minute). The average yield of the wells tapping the Cow Creek was about 10 gpm. Recharge to the Cow Creek is primarily by inter-formational leakage from adjacent formations.

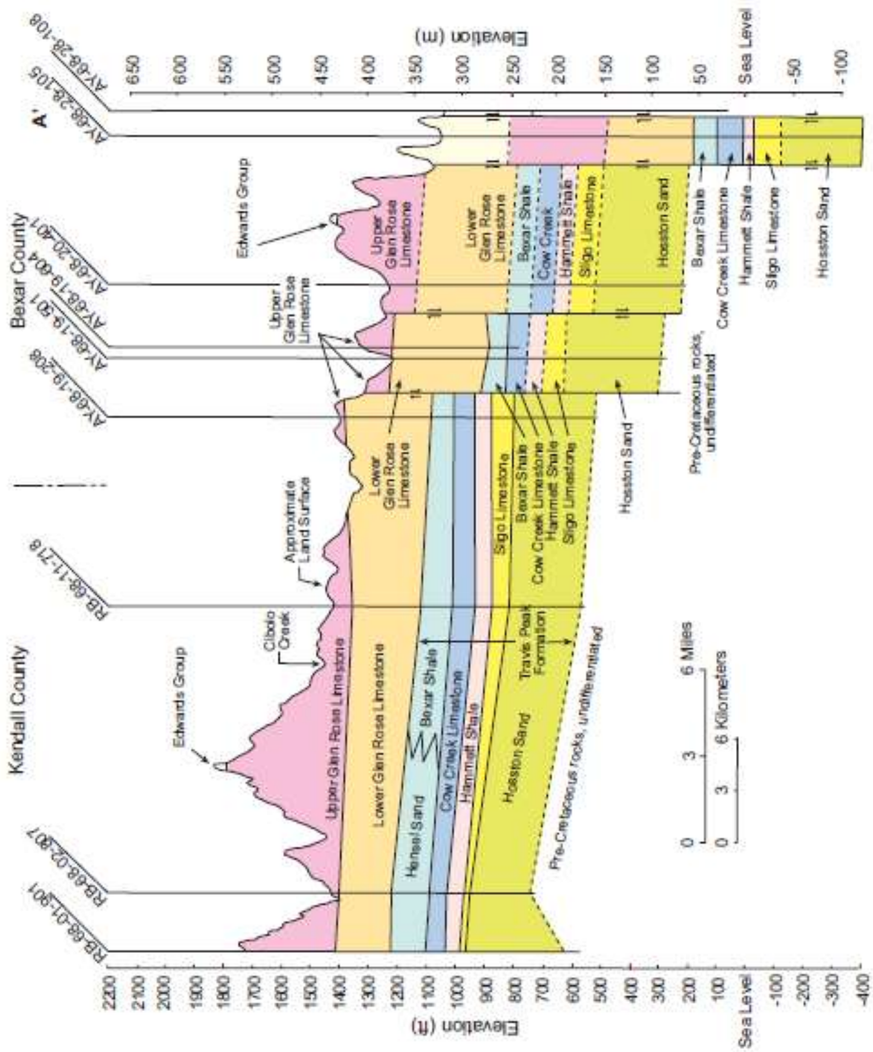
Similarly, the lower parts of the Glen Rose Limestone have higher permeabilities in outcrop and lower permeabilities at depth (Barker and others,1994). The Sligo Formation is a sandy dolomitic limestone that may yield small to large quantities of water (Ashworth, 1983).

The Eastern Edwards Plateau is completely underlain by sediments of the Middle Trinity aquifer



Geologic cross section through the study area (after Ashworth, 1983, fig. 6).

FIGURE 5. GEOLOGIC CROSS SECTION



Geologic cross section through the study area (after Ashworth, 1983, fig. 6) *Continued*

FIGURE 6. GEOLOGIC CROSS SECTION

The Upper Trinity aquifer exists in most of the study area except where it has been eroded along and near the lower reaches of the Pedernales, Blanco, Guadalupe, Cibolo, and Medina rivers. In the western part of the study area, the Fort Terrett and Segovia Formations of the Edwards Group cap the Trinity aquifer sediments. The Edwards Group may produce large amounts of water where it is saturated and has high transmissivity (ability to transmit water). Headwater springs in the deep canyons along the perimeter of the Edwards Plateau issue from the Edwards aquifer where streams have intersected the water table in the Edwards aquifer on the plateau.

Hydrology

In the eastern Edwards plateau surface water and groundwater are mutually dependent water sources. Groundwater and surface water supplies are provided as a direct consequence of precipitation. As we shall discuss, flow in surface streams depends in part on groundwater. Much of the recharge to the aquifers is dependent on stream flow. This interdependence between groundwater and surface water and the lack of understanding of this relationship is reflected in the laws of the state of Texas concerning water supply wherein groundwater and surface water were considered to be independent entities.

We are going to separate the Hydrology section into:

Surface water
Groundwater

Surface Water

The major streams in the region are perennial (flow year around) whereas the majority of the tributary streams are ephemeral and are dry most of the year, flowing only after prolonged or intense rainfall.

The combination of steep slopes, narrow canyons, sparse scrubby vegetation and thin soils lead to frequent and sometimes dangerous flash flooding in all of the region's streams**.**

Base flow of the perennial streams is sustained almost entirely by groundwater and to a much lesser degree by discharges from waste-water treatment plants at each of the major towns or cities.

Drainage Basins

When studying the location of rivers and the amount of streamflow in rivers, a key concept is that of the river's "drainage basin" or "watershed". A drainage basin is the area of land where all of the water that falls in it and drains off of it goes to the same drainage point such as a small gulley or a river or the ocean. Drainage basins can be as small as a footprint or large enough to encompass all the land that drains water into rivers. An example of a large drainage basin would be the Colorado River which begins in west Texas and flows into Matagorda Bay on the Texas coast, where it enters the Gulf of Mexico. Or, it can be as small or smaller than a stream such as Kendall Creek in southern Kendall County

A drainage basin is an area of land that drains all the streams and rainfall to a common outlet such as the outflow of a reservoir, mouth of a bay, or any point along a stream channel. The word drainage basin is sometimes used interchangeably with watershed or catchment. Ridges and hills that separate two drainage basins are called the drainage divides. The drainage basin consists of surface water--lakes, streams, reservoirs, and wetlands--and all the underlying groundwater. Larger drainage basins contain many smaller watersheds. It all depends on the outflow point…. all of the land that drains water to the outflow point is the watershed for that outflow location. Watersheds are important because the stream flow and the water quality of a river are affected by events, human-induced or not, happening in the land area "above" or upstream from the river-outflow point

Precipitation Collection

Most of the precipitation that falls within the drainage area of a stream's monitoring site collects in the stream and eventually flows past the monitoring site. Many factors, some listed below, determine how much of the stream flow will flow by the monitoring site. Imagine that the whole basin is covered with a big (and strong) plastic sheet. If a thunderstorm dumped one inch of rain, all of that rain would fall on the plastic, run down slope into gullies and small creeks and then drain into main stream. Ignoring evaporation and any other losses, and using a 1-square mile example watershed, then all of the approximately 17,378,560 gallons of water that fell as rainfall would eventually flow by the drainage basin-outflow point.

- To picture a drainage basin as a plastic-covered area of land that collects precipitation is overly simplistic and not at all like a real-world watershed. A career could be spent trying to model a watershed water budget (correlating water coming into a watershed to water leaving a watershed). There are many factors that determine how much water flows in a stream (these factors are universal in nature and not particular to a single stream):

Precipitation: The greatest factor controlling stream flow, by far, is the amount of precipitation that falls in the watershed as rain or snow. However, not all precipitation that falls in a watershed flows out, and a stream will often continue to flow where there is no direct runoff from recent precipitation.

Infiltration: When rain falls on dry ground, some of the water soaks in, or infiltrates the soil. Some water that infiltrates will remain in the shallow soil layer, where it will gradually move downhill, through the soil, and may eventually enter the stream by seepage into the stream banks. Some of the water may infiltrate much deeper, recharging aquifers. Water may travel long distances in the subsurface or remain in storage for long periods before returning to the surface. The amount of water that will infiltrate over time depends on several characteristics of the watershed.

Soil Types: Clayey and rocky soils absorb less water at a slower rate than sandy soils. Soils absorbing less water results in more runoff overland into streams.

Soil saturation: Like a wet sponge, soil already saturated from previous rainfall can't absorb much more ... thus more rainfall will become surface runoff.

Land cover: Some land covers have a great impact on infiltration and rainfall runoff. Impervious surfaces, such as parking lots, roads, and developments, act as a "fast lane" for rainfall - right into channels that drain directly into streams rather than infiltrating into the soil. Flooding becomes more prevalent as the area of impervious surfaces increase.

Slope of the land: Water falling on steeply-sloped land runs off more quickly than water falling on gently sloping land.

Evaporation: Water from rainfall returns to the atmosphere largely through evaporation. The amount of evaporation depends on temperature, solar radiation, wind, atmospheric pressure, and other factors.

Transpiration: The root systems of plants absorb water from the surrounding soil in various amounts. Most of this water moves through the plant and escapes into the atmosphere through the leaves. Transpiration is controlled by the factors such as temperature, evaporation rate, and by the characteristics and density of the vegetation. Vegetation slows runoff and allows water to seep into the ground.

Storage: Reservoirs store water and increase the amount of water that evaporates and infiltrates. The storage and release of water in reservoirs can have a significant effect on the streamflow patterns of the river below the dam.

Water use: Uses of a stream might range from a few homeowners and businesses pumping small amounts of water to irrigate their lawns to large amounts of water withdrawals for irrigation, industries, mining, and to supply towns and cities with drinking water.

Fig 7. 3-DIMENSIONAL DRAINAGE BASIN REPRESENTATION

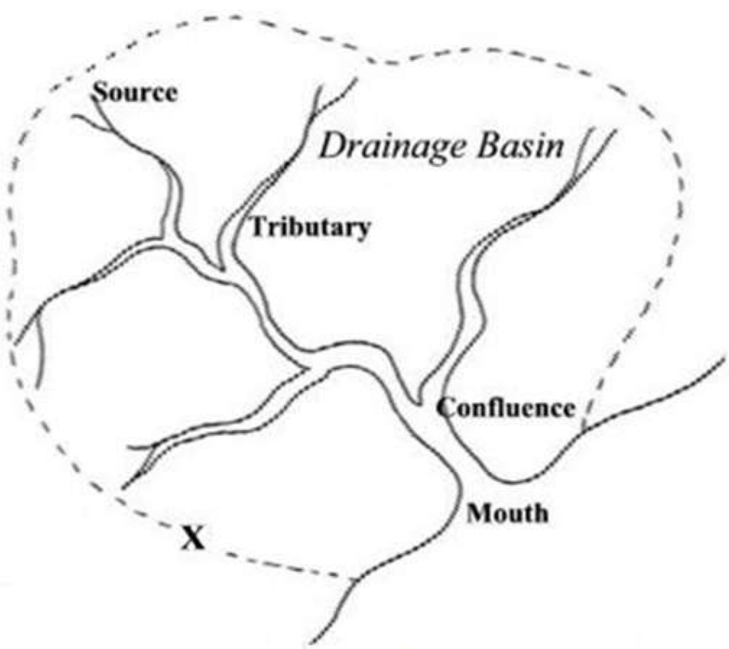


Fig. 8 Conceptual Drainage Basin

Surface Water Reservoirs

What hydrogeologic factors would be desirable for a reservoir?

1. Sufficient rainfall. Our average rainfall ranges from approximately 24 inches per year in the west in Uvalde County to approximately 32 inches in the east in Comal County. Compare with the average annual rainfall in Houston, Texas which is approximately 50 inches per year.

2. Yield of drainage basin.
   Drainage basin yield depends on many variables including

   a. Rainfall amount, distribution and intensity
   b. Antecedent moisture conditions (how much moisture was present in the soil before rainfall commenced)
   c. Topography (slope of land surface)
   d. Soil type
   e. Bedrock geology
   f. Vegetation
   g. Land Use
   h. Area of drainage basin

3. Deep, narrow reservoir site (reduce evaporation losses) Example:

Evaporation rates in Kerr County

Gross Evaporation = 73 in/year

Net Evaporation = 49 in/year

Evaporation minus Rainfall = Net Evaporation.

For every acre of water surface in a reservoir in Kerr County in an average year we would lose approximately 1,329,000 gallons of water to evaporation.

This is the reason we would like to have deep, narrow, reservoirs with minimum surface area but a maximum storage volume. Compare this with a reservoir in South Texas that is very wide but very shallow. We might have the same storage volume but a much greater evaporation loss.

4. Acceptable geology for reservoir construction. The reservoir site must have proper rock mechanics properties to withstand the dynamic loading response of dams and reservoirs as they are filled and drained. The site must have a little or no faulting, fracturing and minimal differential rock types. There should be minimal seepage losses to underlying bedrock.

   Most of our dams in this region are built on limestone which may have excessive porosity and permeability, solution cavities and differential vertical stress loading responses.

5. Environmental concerns. River valleys are our most productive lands from an agricultural perspective. They are also our most diverse in terms of vegetative species, animal habitat, presence of endangered species, etc. They are usually where significant historical and archeological sites are present.

Surface Water Summary: Most of the really good reservoir sites (and some really bad ones) in Texas have been utilized. I have been told that we could expect many long years of litigation if we ever decide to construct additional surface water reservoirs…. more on water rights restrictions later.

Surface Water

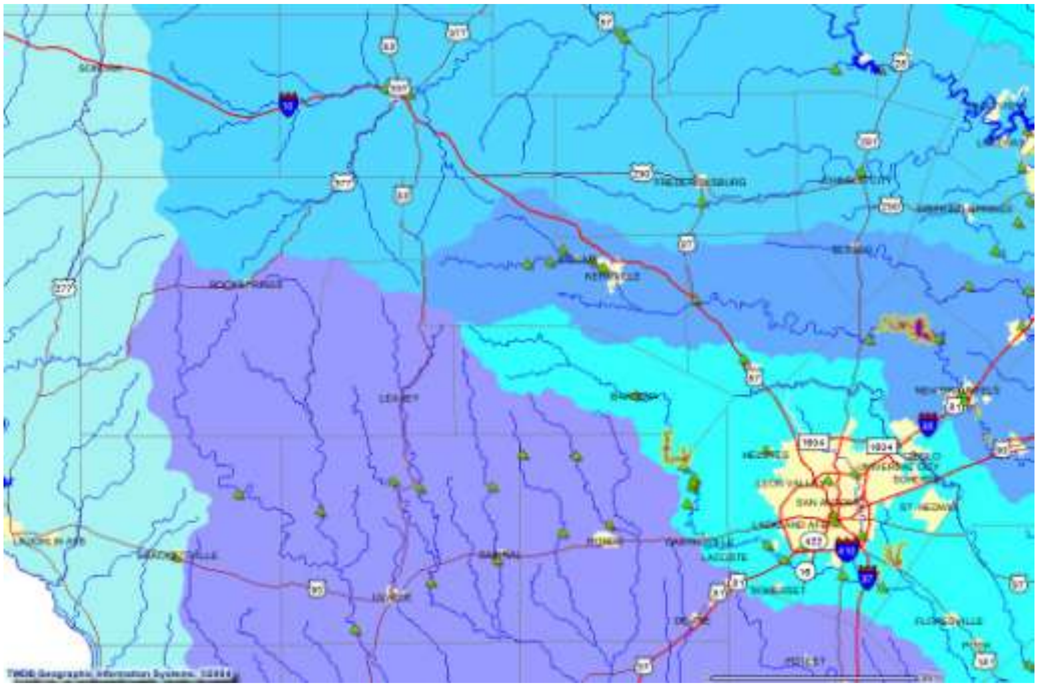


FIGURE 9. AREA STREAMS

Water volume and flow measurements.

All volumes and flow data are from U.S Geological Survey sources

Acre Foot. A volume of water. An old irrigation term. Amount of water required to cover one acre of land to a depth of one foot of water. Equal to 325,851 gallons.

Cubic feet per second. A flow rate. One cubic foot of water per second equals 7.48 gallons per second. You may also encounter flow rates in gallons per minute, cubic meters per second, etc.

Nueces River

No major reservoirs in the Plateau.
Long term median flow at Laguna (above Edwards aquifer recharge zone) is 72 cfs
Long term median flow at Uvalde is 25 cfs (below Edwards aquifer recharge zone)

Frio River

No major reservoirs in the Plateau.
Long term median flow at Concan is 49 cfs

Sabinal River

No major reservoirs
Long term median flow at Sabinal is 1.30 cfs

Hondo Creek

No major reservoirs.
Long term median flow near Tarpley is 13 cfs

Medina River

Medina Lake conservation capacity 254,823 acre-ft. Originally built in 1912 as a privately owned irrigation lake. Reservoir was built across several geologic faults. Leaks (from the Diversion Dam

reservoir) some 35,000 to 45,000 acre-feet per year into the subsurface. Reservior was built with insufficient drainage area.
Long term median flow at Bandera, Texas is 59 cfs.

Cibolo Creek

Boerne City Lake normal storage is 4,043 acre-ft, Formal name Upper Cibolo Creek Watershed Services Site 1 Dam.
Long term median flow 0.00

Guadalupe River

Canyon Lake Conservation Capacity is 378,781 acre-ft. The “Crown Jewel” in our surface water resources. Long term median flow at Kerrville is 56 cfs.
Long term median flow at Sattler is 253 cfs (above Canyon Reservoir).

What is missing here? In the eastern Edwards plateau we don’t have much surface water in terms of river flow nor do we have many large reservoirs.

HYDROGRAPH INTERPRETATION

A common way of analyzing the dynamics of surface runoff is by the use of a hydrograph.

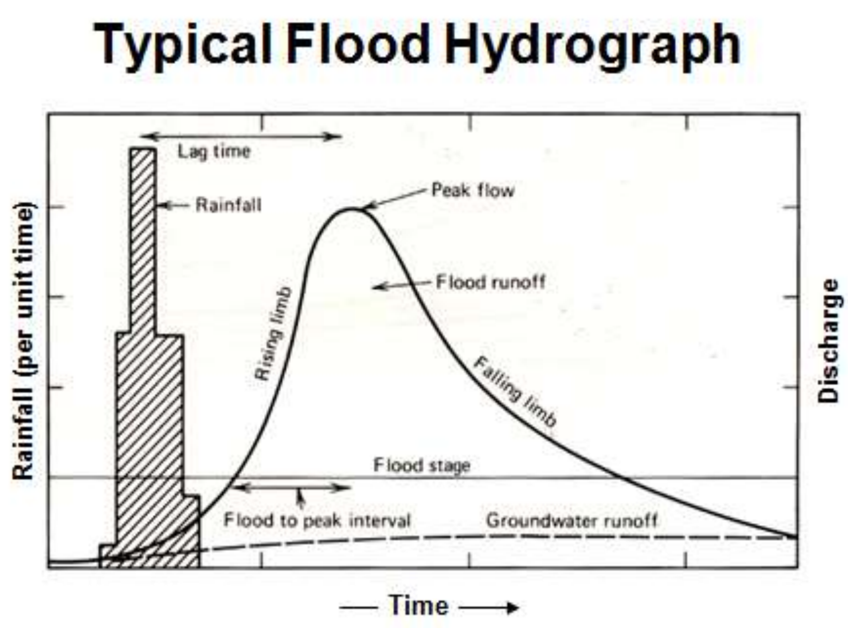
A hydrograph provides the rate of flow at all points in time during and after a storm event. Since a hydrograph plots volumetric flow rates against time, integration of the area beneath a hydrograph between any two points in time gives the total volume of water passing that point during the time interval.

Let’s take a real simple example and tear it apart.

We have a drainage basin and we know the size of that basin.

We have a gauging station to measure flood flow when our stream exits the drainage basin. All surface water in the basin must pass through our gauging station.

We have a rain storm. Let’s start the time that it begins to rain at zero.



From Baker and Costa (1981)

FIGURE 10. STREAM HYDROGRAPH

The vertical axis is discharge (cfs). The horizontal axis is time.

The rain begins, water runs down to the tributary streams and eventually into the main stream channel. As more and more surface water moves into the channel, the water level in the channel rises and we have more discharge (flow past our gauge).

Eventually the rain stops, the rate at which water moves to the channel slows down and our hydrograph curve begins to fall.

Notice that, for this stream, even before the rain started we had some flow, denoted by a dashed line at the gauging station. This is termed "Base Flow" and is the flow that is normally present in the channel. This flow is sustained by groundwater moving from the subsurface into the stream channel.

Surface Water Law in Texas.

Source: Texas Water Law, Texas A & M University

In Texas, water rights depend on whether the water is groundwater or surface water. Surface water belongs to the state of Texas. It can be used by a landowner only with the state's permission.

Riparian Doctrine. The riparian doctrine is based on English common law. These court-developed rules are used in deciding cases that involve water use conflicts. The basic concept is that private water rights are tied to the ownership of land bordering a natural river or stream. Thus, water rights are controlled by land ownership.

Riparian landowners have a right to use the water, provided that the use is reasonable in relation to the needs of all other riparian owners. Riparian owners retain the right to use water so long as they own the land adjacent to the water.

Prior Appropriation Doctrine. This doctrine, on the other hand, is controlled by statute. Applied in the western states, prior appropriation is not related to land ownership; instead water rights are acquired by compliance with statutory requirements. While the principles of riparian rights were appropriate in areas of England and the United States where rainfall averages 30 inches or more a year, these rights were not suited to the arid West.

During their early development, western states failed to control rivers and streams, and water was treated as though it belonged to no one. In the absence of any rules, people simply took water from streams and used it; that is, they appropriated it. When this practice became legalized, it became known as the Doctrine of Prior Appropriation.

When we speak of water rights we are usually referring to the base flow in a stream, not the flood flow. When the water rights were initially issued by the state, this region was under wetter than normal climate conditions, resulting in more base flow, As a result, most of our rivers are "oversubscribed".

Groundwater

As an introduction to this section, we need to see what water demands in the state of Texas are met by groundwater.

USES OF GROUNDWATER IN TEXAS

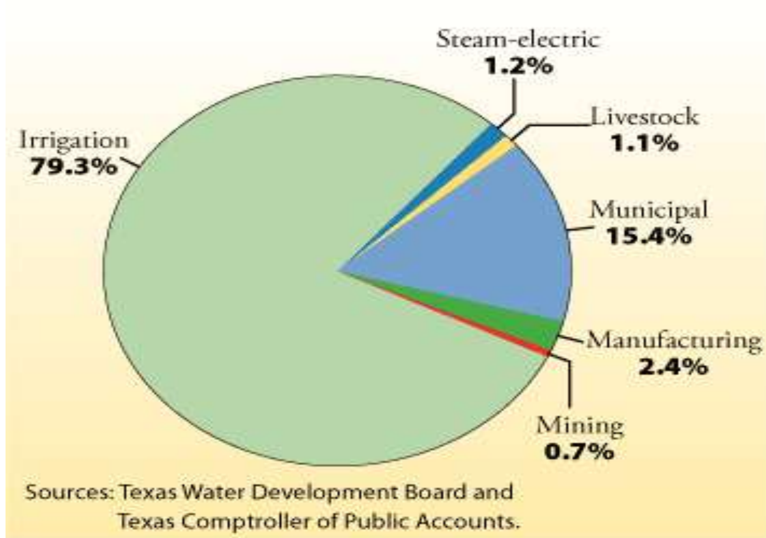


FIGURE 11. USES OF GROUNDWATER IN TEXAS

Back to the Hydrologic Cycle.
Most of the water in the subsurface has been supplied by way of the hydrologic cycle.

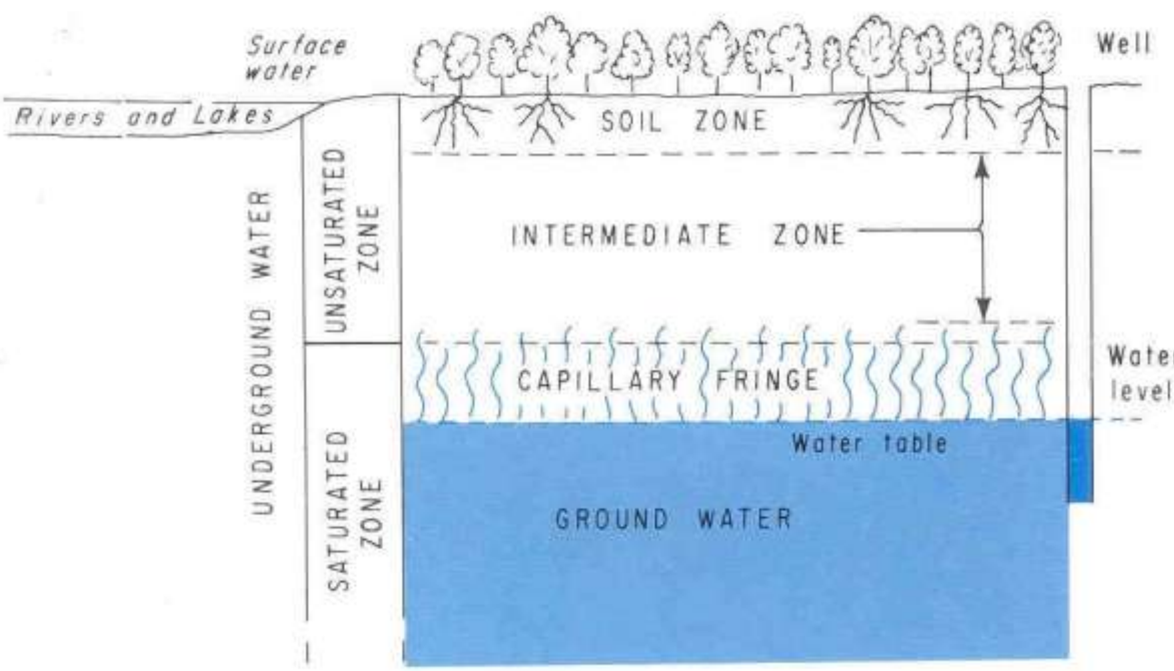


FIGURE 12. UNDERGROUND WATER

Groundwater is water that is located beneath the earth's surface. Groundwater occurs in pore spaces in rock and sediment and in the fractures of rock formations.

Aquifer
Rock or sediment that is capable of storing, transmitting and yielding economic quantities of water to wells and springs. Types of geologic materials in the eastern Edwards plateau that may function as aquifers include limestone, dolomite, sandstone, sand, gravel and soil.

Water Table
The surface in an unconfined aquifer below which all pore spaces are saturated with water.

Porosity and Permeability
Porosity is the open spaces in a rock that could contain water. Usually it is defined as the ratio of the volume of void spaces in a rock or sediment to the total volume of the rock or sediment. (a rock with a 10% porosity would have 10% void space and 90% solid rock). Pore space must be interconnected as "effective porosity" in order to be able to transmit water.

Permeability is the ability of a rock or sediment to transmit a fluid.

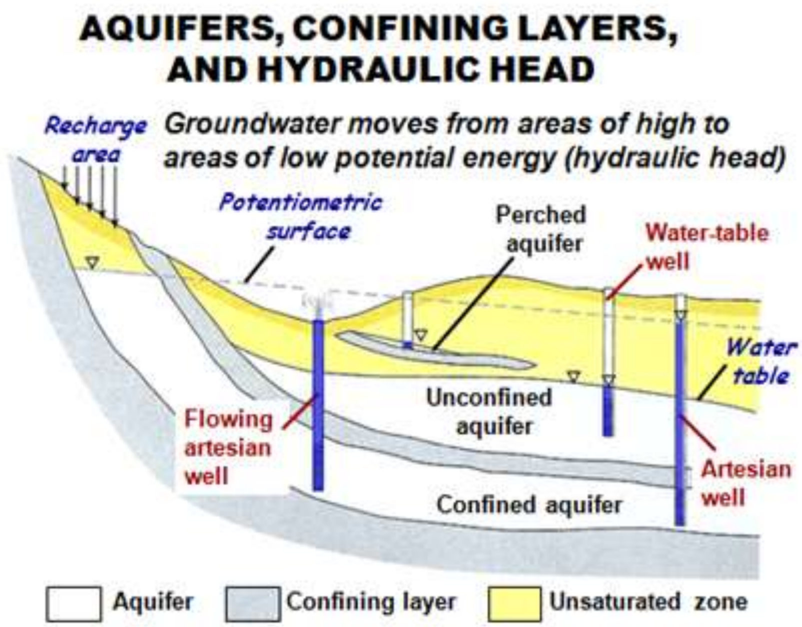


FIGURE 13. CONFINED AND UNCONFINED AQUIFERS

Unconfined aquifer
An unconfined aquifer is an aquifer in which there are no confining layers between the zone of saturation and the surface. The water table is free to move up or down in response to changes in recharge or to withdrawal. In a well drilled into an unconfined aquifer the water level in the well will rise to the level of the water table.

Confined aquifer
An aquifer that is overlain or capped by a confining bed. The confining bed has a much lower permeability than the material which makes up the aquifer. In a well drilled into a confined aquifer, the water level in the well will rise in response to the pressure which has built up in the aquifer. These aquifers are also referred to as "artesian aquifers".

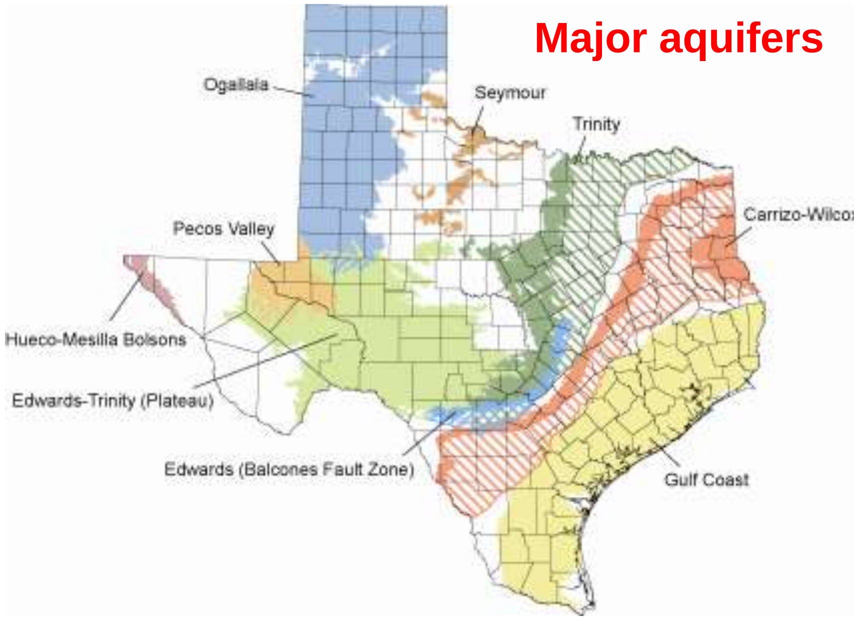


FIGURE 14. MAJOR AQUIFERS. Source: Texas Water Development Board

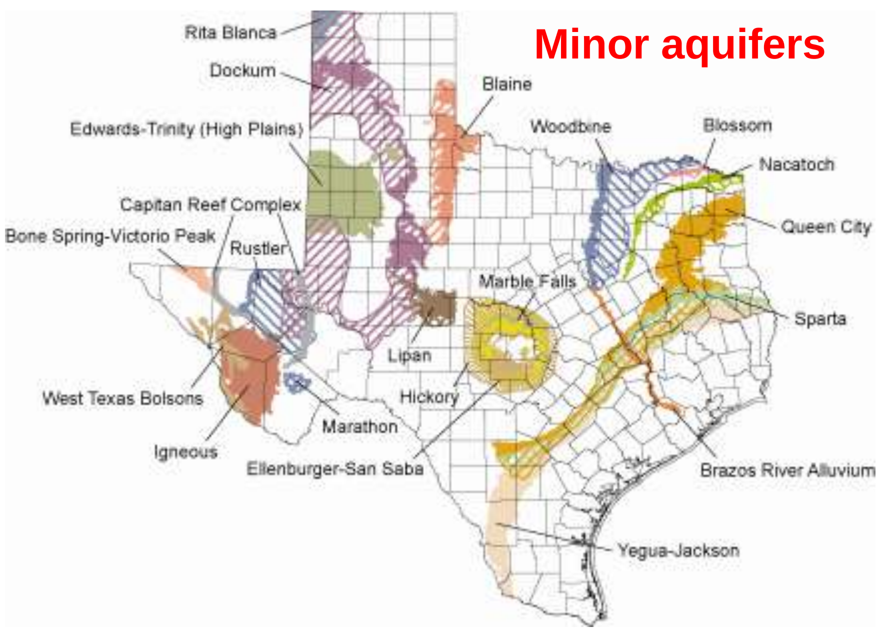


FIGURE 15. MINOR AQUIFERS. Source: Texas Water Development Board

System	Series	Group	Stratigraphic Unit	Hydrologic Unit	Approximate Maximum Thickness (feet)	Character of Rocks	Water-Bearing Properties
Quaternary	Recent and Pleistocene		Flood plain, terrace, and fan alluvium	Alluvium	50	Gravel, sand, silt, clay, caliche.	Yields small quantities of fresh water.
Cretaceous	Comanche	Fredericksburg	Edwards Limestone	Edwards and associated limestones	500	Hard, massive, cherty limestone.	Yields small to moderate quantities of fresh water in the northwestern portion of the study area.
			Comanche Peak Limestone		60	Marly, nodular limestone.	
			Walnut Clay		15	Marly clay and shale aggregate.	Not known to yield water.
		Trinity	Glen Rose Limestone: upper member	Upper Trinity	500	Alternating resistant and nonresistant beds of blue shale, nodular marl, and impure, fossiliferous limestone. Also contains two distinct evaporite zones.	Yields very small to small quantities of relatively highly mineralized water.
			Glen Rose Limestone: lower member	Middle Trinity	320	Massive, fossiliferous limestone grading upward into thin beds of limestone, dolomite, marl, and shale. Numerous caves and reefs occur in the lower portion of the member.	Yields small to moderate quantities of fresh to slightly saline water.
			Travis Peak Formation: Hensell Sand Member / Bexar Shale Member		300	Red to gray clay, silt, sand, conglomerate, and thin limestone beds grading downdip into silty dolomite, marl, calcareous shale, and shaley limestone.	
			Travis Peak Formation: Cow Creek Limestone Member		90	Massive, fossiliferous, white to gray, argillaceous to dolomitic limestone with local thinly bedded layers of sand, shale, and lignite.	
			Travis Peak Formation: Hammett Shale Member		80	Dark blue to gray, fossiliferous, calcareous and dolomitic shale with thinly interbedded layers of limestone and sand.	Not known to yield water.
			Travis Peak Formation: Sligo Limestone Member	Lower Trinity	120	Sandy dolomitic limestone.	Yields small to large quantities of fresh to slightly saline water.
			Travis Peak Formation: Hosston Sand Member		350	Red and white conglomerate, sandstone, claystone, shale, dolomite, and limestone.	
Pre-Cretaceous rocks						Black, red, and green, folded shale, hard massive dolomite, limestone, sandstone, and slate.	Yield moderate quantities of fresh water in the northern portion of the study area.

FIGURE 16. WATER BEARING UNITS. From Ashworth, TWDB

Recharge vs. Spring Flow

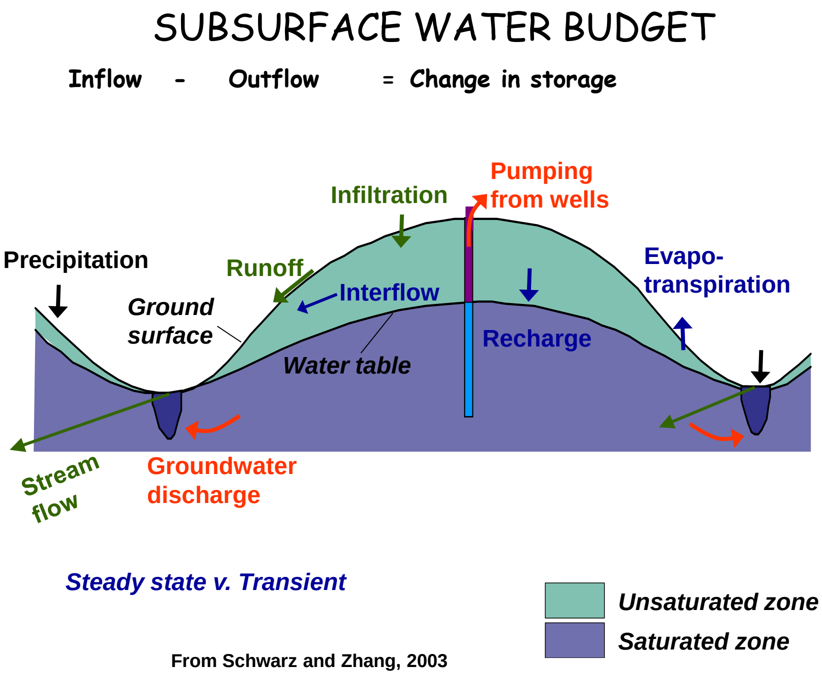


FIGURE 17. WATER TABLE AND BASE FLOW TO STREAMS

Think of the water table as an energy surface, the steeper the slope, the more energy and the greater movement of groundwater to the river.

Recharge.

The movement of surface water underground to the water table or into the recharge zone of a confined aquifer. Classic example is where a stream flowing over a streambed in fractured limestone loses water to the subsurface. We can even have rainwater falling on exposed bedrock and infiltrating downward, even with no major stream involved. If the bedrock is porous and permeable we can have recharge.

What happens if it doesn't rain and we do not receive recharge? Then the recharge is reduced, the ground water continues to move towards the river until there is no gradient or energy surface, the water table becomes flattened. Then we have no spring flow to the river.

Groundwater and surface water. Recharge and spring flow. This is the interdependence between groundwater and surface water that we spoke of earlier.

If we cause the water table elevation to fall (depletion of the aquifers), we decrease the spring flow and we decrease the flow of surface water in the river. If we decrease the amount of water available for recharge by overuse of surface water or poor management practices, we decrease the amount of groundwater.

We can use the Guadalupe River as an example. The Guadalupe River usually maintains a base flow even during periods of low rainfall. All of the base flow is derived from groundwater. Deplete the groundwater supplies and you decrease the spring flow which is sustaining the base flow of the river.

One more example. Let's look at Cibolo Creek in Boerne. Usually some flow present at Boerne except under extraordinary drought conditions. Go down the valley of the Cibolo approximately two miles below Boerne. The base flow of the Cibolo disappears. All of the base flow infiltrates underground in the streambed of Cibolo Creek.

Ground-water Law in Texas
Source: Texas Water Law, Texas A & M University

Water found below the earth's surface in the crevices of soil and rocks is called percolating water, or more commonly groundwater. Texas groundwater law is judge-made law, derived from the English common law rule of "absolute ownership." Groundwater belongs to the owners of the land above it and may be used or sold as private property. Texas courts have adopted, and the legislature has not modified, the common law rule that a landowner has a right to take for use or sale all the water that he can capture from below his land. The rule of capture was adopted by the Texas Supreme Court in 1904 in ***Houston & T.C. Ry. Co. v East***, **81 S.W. 279** (Texas 1904). Because of the seemingly absolute nature of this right, Texas water law has often been called the "law of the biggest pump." Texas courts have consistently ruled that a landowner has a right to pump all the water that he can from beneath his land regardless of the effect on wells of adjacent owners. The legal presumption in Texas is that all sources of groundwater are percolating waters as opposed to subterranean rivers. Consequently, the landowner is presumed to own underground water until it is conclusively shown that the source of supply is a subterranean river.
The state of the law with respect to ownership of subterranean rivers is not settled in Texas. Both stream underflow and subterranean rivers have been expressly excluded from the definition of underground water in Section 52.001 of the Texas Water Code.
The practical effect of Texas groundwater law is that one landowner can dry up an adjoining landowner's well and the landowner with the dry well is without a legal remedy. Texas courts have refused to adopt the American rule of "reasonable use" with respect to groundwater.

Exceptions to Absolute Owner Rule. There are five situations in which a Texas landowner can take legal action for interference with his groundwater rights:
* If an adjoining neighbor trespasses on the land to remove water either by drilling a well directly on the landowner's property or by drilling a "slant" well on adjoining property so that it crosses the subterranean property line, the injured landowner can sue for trespass.
* There is malicious or wanton conduct in pumping water for the sole purpose of injuring an adjoining landowner.
* Landowners waste artesian well water by allowing it to run off their land or to percolate back into the water table.
* There is contamination of water in a landowner's well. No one is allowed to unlawfully pollute groundwater.
* Land subsidence and surface injury result from negligent over-pumping from adjoining lands.

What is the latest word from the Texas Supreme Court on the rule of capture?

Some 95 years after the ***East*** decision, the Texas Supreme court reviewed the rule in ***Sipriano v. Great Spring Waters of America, et al., 1 SW3d 75*** (Texas 1999) [**Ozarka**]. The Ozarka case involved a claim by a domestic well owner that Ozarka's nearby pumping had dried up his well.

The landowner asked the court to protect his private-property interest in groundwater by imposing liability on Ozarka.

Many observers thought that the Texas Supreme court would modify the capture rule to protect rural homeowners and domestic users of water. They were wrong. The court unanimously affirmed the rule of capture. However, it suggested that it might change the rule in the future if the Texas Legislature did not adequately address groundwater over-pumping.

The Legislature's response was to strengthen the laws enabling citizens to manage this problem locally through groundwater conservation districts.

On February 24, 2012, the Texas Supreme Court issued its decision in the ***Edwards Aquifer Authority v. McDaniel**.* The ***McDaniel*** decision definitively settled an issue that had remained unresolved in Texas for more than a century, namely whether a Texas landowner has a vested property right, protected under the U.S. and Texas constitutions, in the groundwater in place under the landowner's property. The Court held that the landowner does have such a right, and that the state could not deprive the landowner of this right without paying adequate compensation as required by Article 1, Section17(a) of the Texas Constitution.

This opinion does seem to signal that Texas water law, one way or another, is going to change.