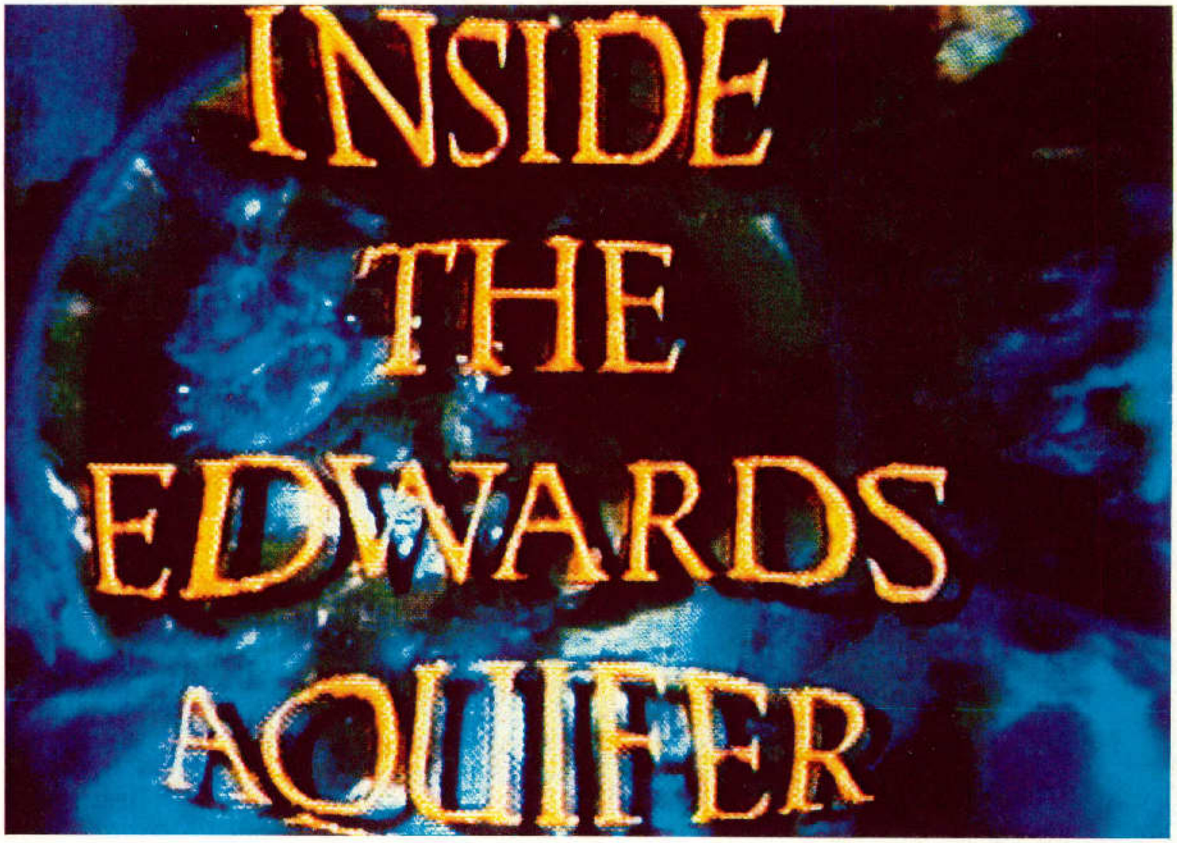

A Three Part Technical Film

High School Level
Teacher's Guide

Edwards Underground Water District

Inside the Edwards Aquifer

This film offers an opportunity for high school students and other interested parties to become more knowledgeable about the priceless Texas treasure, the Edwards Aquifer. Divided into three sections, the video gives a myriad of information that can be correlated to various disciplines, including geology, chemistry, biology, physics, environmental science, and Texas geography.

The most effective way for teachers to utilize the film is to show one section at a time over a period of a week or two. This guide provides you with a number of activities that can be used to reinforce information presented in each of the sections. In addition, a vocabulary list is provided for each individual section, rather than one long list at the end.

The Edwards Underground Water District's Division of Information and Education has additional materials available for use in the classroom, as well as a technical resource library that is open to the public. The EUWD Speakers' Bureau is also available for presentations to classes studying the Edwards Aquifer.

The activities in this booklet were were written by area high school teachers and the Education staff at the EUWD.

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Description of the Three Sections

The first section of the film discusses the location of the aquifer, its boundaries, and the three zones of the Edwards Aquifer system. Also addressed is the concept of artesian pressure, and some of the terms used to describe water movement. In addition, this introductory section gives a description of possible sources of contamination to the aquifer. Close-up looks at how water levels and water movement are measured wrap up Section One.

Section Two of the film investigates the inner workings of the Edwards Aquifer. It addresses how the aquifer is recharged, leading into the question of how much water is actually in the aquifer. The movement of water within the aquifer is discussed by comparing the origins of water in two adjacent springs. The last portion of this section investigates the complexity of water movement within the aquifer with a close look at the Knippa Gap.

The third section examines the geologic origins and structure of the aquifer. The porosity and permeability of the different layers of Edwards Limestone determine the amount of water and storage capacity of the Edwards Aquifer. Suggested ways of increasing the capacity and possible linkage to another aquifer are studied. Section Three wraps up with a description of the unique biology of the Edwards Aquifer, which contains some of the purest natural water in the world.

Section One - Vocabulary

Artesian aquifer - one type of aquifer in which two impermeable layers surround one permeable water-bearing layer; the water is confined and stored under pressure and will rise above the top of the aquifer when penetrated by a well

Artesian zone - area where the Edwards Aquifer is buried in the subsurface and under pressure; one of the three zones which makes up the Edwards Aquifer region; it underlies and supplies water to six counties

Aquifer - a permeable underground rock formation that contains significant amounts of water

Darcy's Law - a mathematical formula used to determine water flow rate through rock aquifers

$$\text{permeability} \times \frac{\text{change in height}}{\text{change in distance}}$$

Downdip block- the rocks on a *downthrown* side of a fault (rocks further from the original fault than adjacent rocks that are closer to the fault, or updip)

Drainage area - upper watersheds in the hill country where rainwater runs off into creeks and streams which then flow over the the recharge zone, replenishing the aquifer

Flux - the rate of movement through a unit cross-section

Fresh/Saline Water Interface (Bad Water Line) - the southern boundary of the aquifer region which separates fresh water from saline water

Groundwater divide - a point from which water moves in opposing directions in an aquifer

Head - the elevation to which water rises at a given point because of pressure

Hydraulic gradient - the rate of change of total *head* per unit of distance of flow at a given point and in a given direction

Impermeable - material that will not permit liquid or water to flow through it

Index well - a primary observation well generally reflecting water level conditions in the area

Non-point source pollution - pollution that can not be traced to one particular source

Permeable/Permeability - ability of a porous rock to transmit water

Recharge zone - where Edwards Limestone is exposed at the surface and water enters the aquifer primarily through cracks in the streambeds

Saline Water - water containing significant amounts of salt and other minerals, typically characterized by a foul smell

Transmissivity - a measure of the aquifer's ability to move or transmit water; high transmissivity areas can have much greater volumes of water flowing through them in a given period of time than areas of low transmissivity

Unconfined area ("water table") - the recharge zone of the aquifer where water moves under the force of gravity

Updip block- the rocks on an *up-thrown* side of a fault (rocks closer to the original fault than adjacent rocks that are further from the original fault, or downdip)

Water table ("unconfined area") - the upper surface of the zone of saturation in the unconfined area of the aquifer

Lesson 1: Geography of the Edwards Aquifer Region

Objective: Students will locate the three hydrologic/physiographic areas of the Edwards Aquifer region, and identify political boundaries within the region.

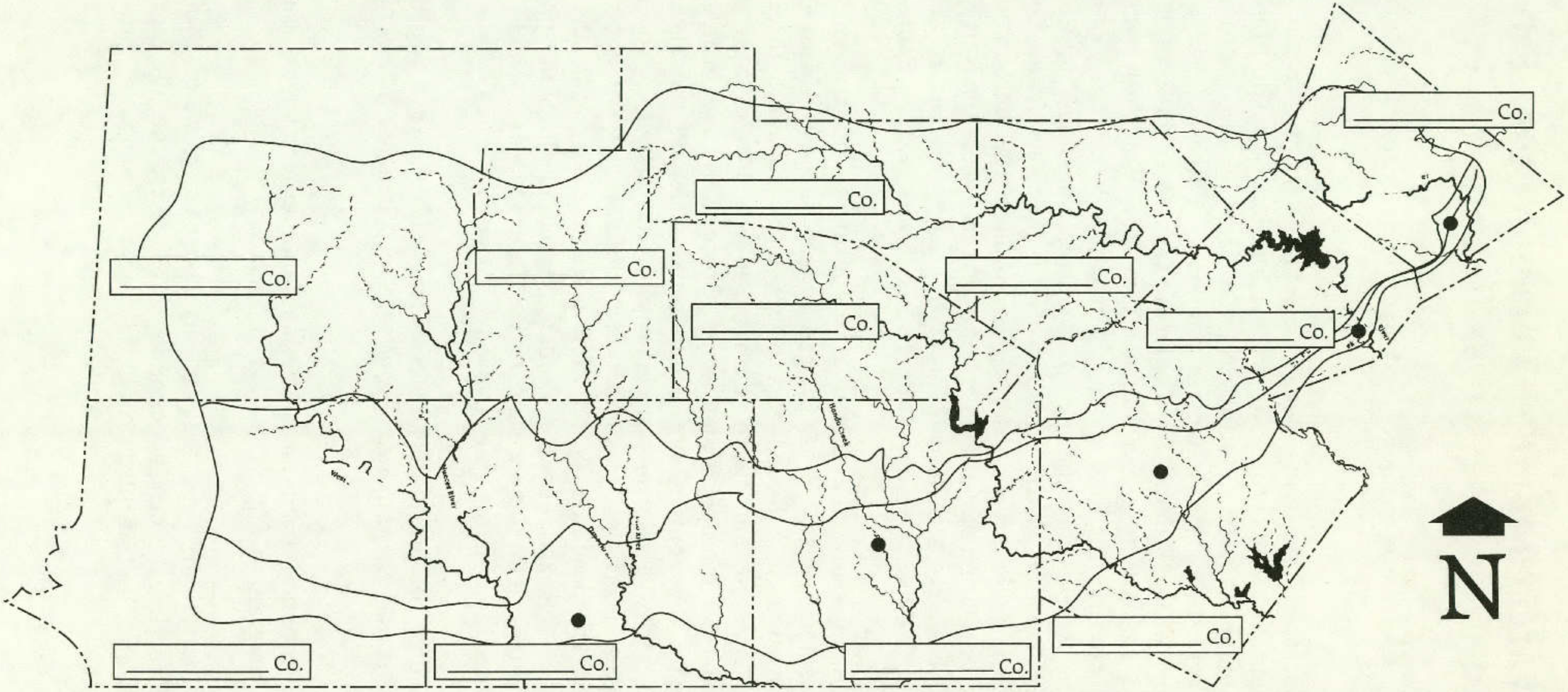
Background information: The Edwards Aquifer region extends 176 miles from the town of Brackettville in Uvalde County in the west to the town of Buda in Hays County to the east. There are three hydrologic/physiographic areas within the aquifer region: the **Drainage Area (Edwards Plateau)**, the **Recharge Zone (Balcones Fault Zone)**, and the **Artesian/Reservoir Area (Gulf Coastal Plain).** The 4,400 square mile **Drainage Area**, commonly known as the **"Hill Country"** is located on the **Edwards Plateau**. Many spring fed rivers and streams originate from the porous Edwards Limestone of the water table aquifer and flow south into the **Recharge Zone**. The **Recharge Zone** separates the **Edwards Plateau** to the north and the **Gulf Coastal Plain** to the south. The 1,500 square mile **Recharge Zone** is located in the **Balcones Fault Zone,** where the Edwards and associated limestones are exposed at the surface. Recharge dams built in this area help collect runoff from the **Drainage Area** and funnel it directly into the aquifer. The **Artesian/Reservoir Area** consists of a band of Edwards and associated limestones confined between two relatively impermeable layers of rock. Since the water is under pressure, wells that have been drilled in the artesian area come close to or flow to the surface and provide most of the water for the San Antonio region. At the southern and eastern edge of the **Artesian Area** is a boundary between fresh and saline water known as the "Fresh-Saline Water Interface" (formerly known as the "Bad Water Line"). Here, water movement is very slow, with the water remaining in contact with limestone and gypsum for a longer time, allowing more minerals such as calcium, sulfates, and iron to dissolve. Total dissolved solids may reach concentrations greater than 1,000 milligrams per liter.

Materials: Copies of student map, classroom copies of the EUWD poster *Water Resources of the Edwards Aquifer Region*, colored pencils, and video: *Inside the Edwards Aquifer.*

Procedure: Using information from the video and poster, the students should identify the features listed on the map. Have students label all of the cities and counties. In conclusion, have the students shade in the three areas and make a legend.

Extensions: Have students write a descriptive report on each of the three physiographic zones. Have them identify which of the areas are most important in terms of protecting the quality of water in the Edwards Aquifer.

Geography of the Edwards Aquifer Region



In the Artesian/Reservoir Area, the water flows generally from west to east

The drainage basins of the Edwards Plateau act as funnels, collecting runoff from the Drainage Area into streams that cross the Recharge Zone.

KEY

Find and label: The eleven counties and 5 cities indicated on the map.

Use 3 colors or patterns to indicate the location of the 3 hydrologic regions.

Make a legend.

Lesson 2: Water Moving Through the Edwards Aquifer: A Cross-Section View

Objective: Students will identify geologic and hydrologic features on a cross-section diagram.

Background Information: All living things depend on water. Water is continuously recycled through the processes of evaporation, transpiration, condensation and precipitation. The Edwards Aquifer is a unique hydrologic system. It supplies nearly all of the water for municipal, domestic, and agricultural needs of the area. Rainfall in the **Drainage Area** infiltrates the water table aquifer and forms spring fed streams that flow downhill over relatively impermeable rock formations to the permeable **Recharge Zone**. Water in the streams, as well as rain falling in the area, enters the aquifer through fractures, faults, solution cavities and caves of the **Recharge Zone**. From the **Recharge Zone**, this groundwater flows through the porous, honeycombed Edwards formation to the **Artesian Area** where it is trapped between two layers of relatively impermeable rock. The upper layer is the **Del Rio Clay**. Beneath the **Edwards Limestone** is the **Glen Rose Limestone.**

Since the water is under pressure, the Edwards is considered an artesian aquifer. If the pressure is high enough, water is discharged on the surface. Most of the water enters from the west and is forced east where it may emerge through springs such as the San Antonio, San Pedro, Comal, and San Marcos Springs. Water can also be discharged through drilled wells. Some wells are drilled into a high pressure point within the aquifer, thus forcing the water to the surface without pumps - this is called a flowing artesian well. The complexity of the geologic formations makes it difficult to predict how deep a well must be drilled at any particular location to penetrate the aquifer. Water from wells and springs may be used to irrigate crops and lawns and then returns to the atmosphere by transpiration from vegetation. Or, it may flow to the Gulf of Mexico and eventually evaporate, thus completing the hydrologic cycle.

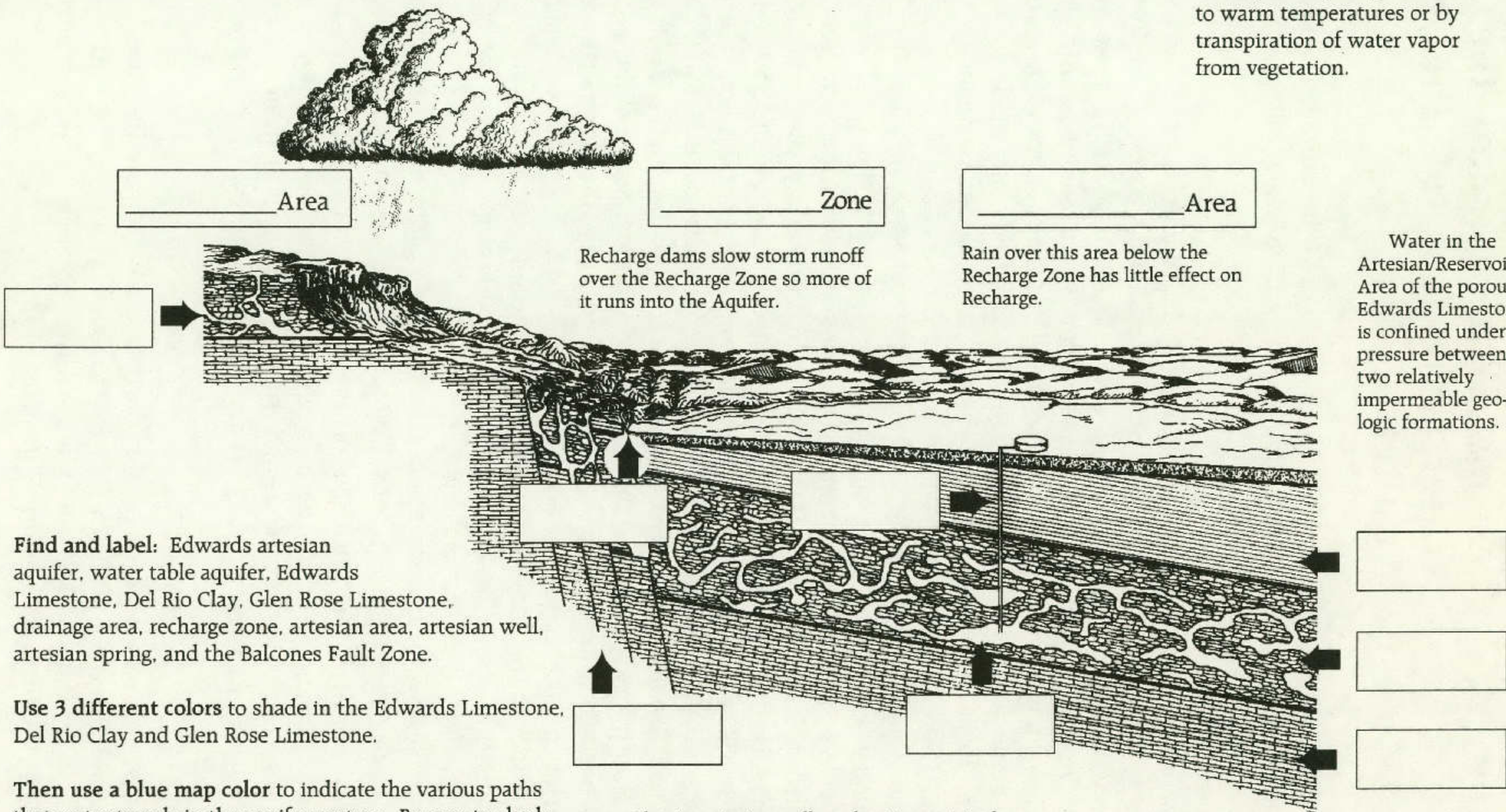
Materials: Classroom copy of the poster *Water Resources of the Edwards Aquifer Region*; video: *Inside the Edwards Aquifer*; map pencils, and copies of the student activity page.

Procedure: Using information from the video and the poster, have students identify and label the diagram using the terms provided.

Extensions: Using a terrarium, have the students construct a water cycle or groundwater model. Experiments can be conducted to determine the porosity and permeability of different sediments. Students could demonstrate how a well works.

Water moving through the Edwards Aquifer

About 85% of precipition falling on the area is lost back to the atmosphere by evaporation due to warm temperatures or by transpiration of water vapor from vegetation.



Water in the Artesian/Reservoir Area of the porous Edwards Limestone is confined under pressure between two relatively impermeable geologic formations.

Find and label: Edwards artesian aquifer, water table aquifer, Edwards Limestone, Del Rio Clay, Glen Rose Limestone, drainage area, recharge zone, artesian area, artesian well, artesian spring, and the Balcones Fault Zone.

Use 3 different colors to shade in the Edwards Limestone, Del Rio Clay and Glen Rose Limestone.

Then use a blue map color to indicate the various paths that water travels in the aquifer system. Be sure to shade in the water table aquifer, recharge streams and the artesian aquifer.

Flowing artesian wells and springs exist where hydraulic pressure is sufficient to force the water up through wells and faults to the surface.

Lesson 3: Testing Water from the Fresh/Saline Water Interface of the Edwards Aquifer

Objective: The students will investigate and identify the ions responsible for the "rotten egg" smell often found in the saline water south of the Edwards Aquifer.

Background information: Although the water of the Edwards Aquifer surpasses EPA quality standards set for drinking water, it is by no means "pure." Dissolved substances and gases give the water a pleasing taste, and in fact, can promote human health. Chloride compounds are added to the water to get rid of harmful bacteria. However, in the southern and eastern parts of the aquifer, high concentrations of some substances can affect the quality of the water. For example, iron (Fe) gives water a bad taste and leaves deposits in pipes and fixtures. Some compounds containing sulfur (S) give water a bad odor.

At the southern and eastern edge of the artesian area of the Edwards Aquifer is a boundary known as the Fresh/Saline Water Interface. Here water movement is slowest, and the water remains in contact with limestone and gypsum a long time, allowing more minerals such as calcium sulfate and iron to dissolve. The total dissolved-solid concentration increases from about 350 milligrams per liter on the fresh water side, to 3000 milligrams per liter on the saline water side. A few miles south of the fresh/saline water interface, the water contains even more total dissolved-solids. Concentration is as much as 5000 milligrams per liter. For many purposes, the dissolved-solids concentration is a major limitation on the use of water. Use your map to identify the southern and southeastern boundaries of the fresh water zone of the Edwards Aquifer which is defined by a contour line that represents a 1000 milligram per liter total dissolved-solids. This transition zone is known as the Fresh/Saline Water Interface, formerly known as the "Bad-Water Line."

In the following investigation, samples of water will be qualitatively analyzed for the presence of sulfate ions $(SO_4)^{-2}$. The formation of a precipitate will positively confirm the presence of the sulfate ion $(SO_4)^{-2}$ in the aqueous solution. Remember that there are other substances dissolved in the water, but only the sulfate ion will be tested for in this investigation. Consult chemistry laboratory manuals for simple analytical procedures to test for calcium, chlorine, and so on.

Materials: A class copy of the current EUWD bulletin (one is provided to every high school library.) Retrieve from the back a copy of the map "Location of water-quality data-collection sites--wells, springs, and streams--sampled during 1972-90"; Video: *Inside the Edwards Aquifer.*

Materials (cont.):

Lab materials:

1) A reference solution known to contain the sulfate ion - 200 ml 0.1 M $FeSO_4$ (iron (II) sulfate, 5.6 g $FeSO_4.7\ H_20$/200ml)
2) Tap water
3) Saline Water (if possible, get a water sample from below the Fresh/Saline Water Interface)
4) A control (distilled water known not to contain the sulfate ion)
5) Test reagent solution, in a dropper bottle - 50 ml 0.1 M $BaCl_2$ (1.2g $BaCl_2.2H_20$/50 ml)
6) 4 small test tubes

Procedure: Using the materials listed, have the students complete the investigation: *Sulfate Ions in Your Drinking Water?*

Extensions: Using the current EUWD Bulletin, Appendix B - Water Quality, determine the highest and lowest dissolved sulfate (mg/ml) for the test sites in your county. Find the location of these test sites using the last three digits of state well-numbering system on the map: Location of water-quality data-collection sites--wells, springs, and streams--sampled during 1972-90.

Sulfate Ions in Your Drinking Water?

1. Wash four test tubes thoroughly with tap water and rinse twice with distilled water.

2. Label the four tubes: (R) reference sample (TW) tap water, (C) control, and (S) saline water.

3. Add 2 ml of the designated sample to each tube. Remember to carefully rinse the graduated cylinder with distilled water between samples.

4. Add three drops of barium chloride ($BaCl_2$) test solution to each of the four test tubes. Mix the test tube contents thoroughly. Record your observations. The confirming test you observed for $(SO_4)^{-2}$ can be represented as follows:

Barium ion	+	Sulfate ion		Barium Sulfate
(test solution)	+	(reference solution)	=	(precipitate)
$(Ba)^{+2}$		$(SO_4)^{-2}$	=	$BaSO_4$

5. In your conclusion, explain your observations in regards to the presence or absence of the sulfate ion. Compare the relative amounts of precipitate of the reference solution to the tap water and saline water.

Lesson 4: Determination and Comparison of Total Dissolved Solids

Objective: The students will carry out a microscale evaporation of various samples of water in order to compare the relative amounts of nonvolatile solids contained in the samples.

Background: The Edwards Aquifer is likened to a "living thing" because the aquifer is still growing as more and more underground cracks, crevices, and honeycombed passageways are slowly enlarged by the dissolving action of water. When one sees the water from the aquifer, it is difficult to imagine the dissolved substances that give water its pleasant taste. Ultimately, if these substances are found in substantial amounts, they can affect the quality of the water. In a solution, atoms, molecules, or ions are thoroughly distributed, with the result that the mixture has the same composition and properties throughout. By carefully removing the solvent (water), the remaining nonvolatile substances (solutes) can be easily seen.

Materials: Video - *Inside the Edwards Aquifer*

Hot plate
2" x 2" piece of foil
Plastic dropper, narrow stem
Forceps

Water Samples: Distilled Water
Tap Water
Well Water

Procedure: Break students into groups.
Given the materials listed, groups will complete the activity: *Is Something Floating in my Glass?*

Extension: Repeat the experiment using bottled waters from different parts of the country, as well as from other countries. Rank the various water samples in order from the lowest TDS to the highest TDS. If an analytical balance is available, develop a laboratory procedure to quantitatively determine a comparison of the mass of the dissolved substances.

Is Something Floating in My Glass?

Procedure:

1. Obtain a 2" x 2" piece of foil. Place it on the table shiny side up and smooth it with your fingers.

2. Using forceps, place the foil shiny side up onto the hot plate at low heat.

3. Place one drop of each water sample onto the foil about 0.5 cm apart. (Keep in mind where each water sample is located on the foil.)

4. Allow the water to evaporate.

> *Note: If the water spits and splatters, the hot plate is too hot. Lower the heat and repeat experiment if necessary.*

5. After the water evaporates, remove the foil from the hot plate using the forceps. Describe and record your observations.

6. Compare the relative amounts of total dissolved solids on the foil.

(Laboratory Procedure adapted from: Thompson, Steven, *"The Chemistry of Natural Water,"* Chemtrek, Allyn and Bacon, 1990.)

Lesson 5: Simplified Artesian Pressure Model

Objective: Teacher or students can build a working model of the recharge area as it affects an artesian area, complete with a measurement well and three natural springs. The concept of artesian pressure will be demonstrated.

Background information: Groundwater in the water table of the "unconfined area" in the recharge zone is at atmospheric pressure and is under the force of gravity. But as the Edwards Limestone slants away from the surface, the weight of the overlying formation and the weight of the groundwater (62.4 lbs/cf) itself builds greater and greater pressure in the confined zone, or artesian area. What is called "head" in hydraulics is the combination of elevation and pressure, and it is a description of how high the water will rise at a given point due to pressure. Water moves from higher head to lower head, that is, from a higher potential energy state to a lower one. But water doesn't necessarily move from a higher pressure area to a lower pressure area. To clarify, in the recharge zone, one may use the term "uphill" for water that lies higher or farther north. But in the artesian zone, where the water is confined and under pressure, the terms "updip" and "downdip" are used. A working model of this principle and the artesian principle in general will demonstrate this concept.

Materials: (1) one piece of pegboard, 1/4" thick x 3' x 4', or any similar dimension that can hold, suspend and spread out the "devices" in this model
(2) two quart sized, clear, plastic containers (one with a lid)
(3) four 18" sections of aquarium tubing
(4) aquarium cement
(5) one 14" piece of glass tubing to serve as a "measurement well" in the artesian zone container
(6) tie-downs to fasten all devices to the pegboard
(7) adjustable pinch clamps to control the flow from the springs tubing
(8) water inflow, and work area appropriate for the discharge of water

Procedure: Drill holes in the plastic containers as shown in the drawing (page 16). Insert the aquarium tubing pieces into the holes and cement in place. Drill a hole in the lid of the "artesian container" and insert the glass tubing to a point just below the lid. Cement in place. Allow all these cemented pieces to dry and set overnight before mounting them on the pegboard. Now follow the drawing for the mounting of all devices. The three tubes leading out of the artesian zone represent the three natural spring regions in San Antonio, New Braunfels, and San Marcos. The container in the upper left represents the recharge zone and must be kept full of water (unless there is a drought). If there is no water shortage, all springs will be kept operating. But with a decline of water in the recharge zone, the artesian springs will progressively cease to operate. The glass tube in the artesian zone will measure the rise and fall of water pressure.

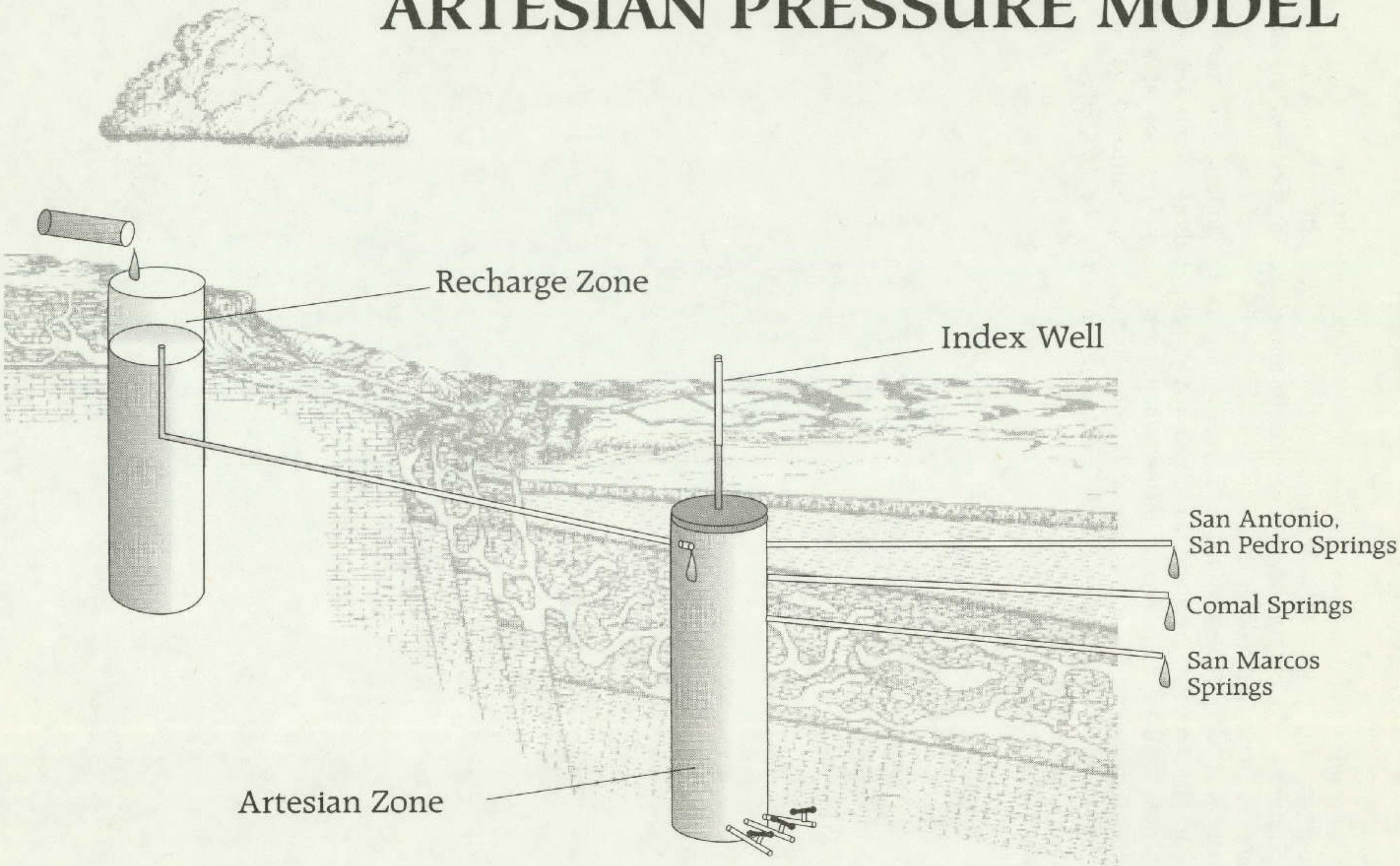
Extensions:

(1) Have a student(s) paint a cross-section of the Edwards system on the pegboard (use the EUWD poster: *Water Resources of the Edwards Aquifer Region* as a guide). This painting should closely match the locations of all the devices mounted here (see diagram).

(2) The model can also represent the effect of pumping by adding one more drilled hole in the artesian area and adding a triple gang valve. Keep the valves closed until you have regulated your inflow, then open the valves one at a time to see effects of pumping on the index well and springs (also indicated on diagram). Have students identify groups that could possibly be the large "pumpers" represented by the triple gange valve.

(See page 16 for model diagram.)

ARTESIAN PRESSURE MODEL



Natural Springs

Section Two - Vocabulary

Acre foot - the volume of water that would cover one acre of land to a depth of one foot - 325,851 gallons (also - the approximate amount of water that would serve the needs of one family for one year)

Balcones Fault Zone - the area bounding the Edwards Plateau to the south, having extensive cracks and faults caused by the force of crustal movement

Cubic feet per second - unit used to measure the amount of recharge to the aquifer; one cfs is equivalent to 448.8 gallons per minute

Hydrology - the science that deals with global water: its properties, circulation, and distribution, on and under the earth's surface and in the atmosphere, from the moment of its precipitation until it is returned to the atmosphere through evapotranspiration or is discharged into the oceans

Non-porous - lack of void space in the rock which reduces its ability to hold water

Outcrop - that part of a geologic formation or structure that appears at the surface of the earth

Porosity (porous) - the ratio of void space to particles; a larger ratio would hold more water

Recharge - process by which water is added to an aquifer

Strata (plural of **Stratum**) - a layer of sedimentary rock, visually separable from other layers above and below; a *bed*

Subsurface - the zone below the surface, whose geologic features are interpreted on the basis of drill records and various kinds of geophysical evidence; formed or occuring beneath the earth's surface

Void space - an opening or space in a rock or a soil, capable of holding water

Lesson 6: Porosity in Edwards Limestone

Objective: Students will measure the volume of water that the honeycombed Edwards Limestone can hold and learn to appreciate the concept of porosity of this rock formation.

Background information: How much water is in the Edwards Aquifer is a complex question. The U. S. Geological Survey has estimated it to be in the range of 25 to 50 million acre-feet. This estimate is based on the total volume of the geologic unit, which is the thickness of the water-bearing Edwards Limestone multiplied by an average porosity then multiplied by the area it underlies. But it is not easy to guess the aquifer's average porosity, since the aquifer is comprised of open caverns and microscopic pores, all with varying degrees of interconnectedness. In this activity, an investigator can measure the volume of an irregular object (a mass of limestone rock with many pores) by the water displacement method.

Materials: Samples of very porous limestone rock "about" 1 liter in size (you will need to obtain at least one rock per group); large beakers (2 liter or larger) that will hold the rocks; water sufficient to cover the rocks in the beaker; waterproof, thin, plastic bags. Video: *Inside the Edwards Aquifer*.

Procedures: (**Note:** You many want to ask students to bring in samples of limestone for this investigation. If not, you may find this lesson more suitable to do as a teacher presentation rather than a student-oriented group activity.)

Divide the students into groups or pairs. Have students proceed with the activity: *How Much Water Will Limestone Hold?*

Encourage students to determine why there is such a big difference between the readings. The second measurement will be less than the first because the water has entered the pores and cavities of the rock. The difference between the two readings is the volume of water that this one particular rock will hold if permitted to do so. For example, if the first volume is 600 ml and the second volume is 500 ml, the difference is 100 ml of water that entered the porous rock. This is 1/6 the volume of the rock sample or 16.6%. This amount is much higher than the aquifer's porosity estimated by the geologists, which is 2 - 4%. Not all Edwards Limestone is as porous as the selected samples typically used in this activity, but the concept of porosity is well demonstrated.

Extensions: 1) Students can use different samples and then determine an average for the water-holding capacity of limestone. 2) Have students put the sample into a large lab sink and, with a rubber hose on the sink faucet, put the hose end into a cavity and carefully turn on the faucet. Watch where the water comes out. There will be many surprises. Try numerous cavities. You may even get wet.

How Much Water Will Limestone Hold?

1) Put water into the beaker (about 1/2 to 2/3 full). Take a reading and record it: ______________ml

2) The rock used should be cleaned of all soil from all pores if it has not been done. Carefully put the rock into the thin plastic bag without tearing holes in it. Place the bag covered rock into the beaker of water and let the water push the plastic bag over the pores and cavities of the rock. Take another reading of the water level and record it.
______________ml

3) Carefully remove the bag covered rock from the beaker and remove the bag from the rock. Place the same rock into the beaker of water, read the water level, and record it: ______________ml

4) Subtract these last two readings: ______________ml

What does this figure mean?

5) What is the percentage of the total porosity of the rock sample? Figure this out by dividing your reading without the plastic bag by the reading with the plastic bag. (Your answer will be in a fraction - make sure you convert it to a decimal!)

______________%

6) How does the porosity of your rock sample compare to the estimated porosity of the entire Edwards Aquifer? Why does your sample have such a significantly higher percentage of porosity than the aquifer?

7) Why is it so difficult to determine the exact amount of water stored in the Edwards Aquifer?

Lesson 7: Measuring Porosity

Objective: Students will be able to determine the percentage of pore space in a sample of sediment.

Background Information: One of the main variables associated with the behavior of any aquifer is its porosity or the amount of empty space available within the rock. Porosity can vary from 0% in some igneous and metamorphic rocks which are not aquifers to about 47% in some clay deposits. Porosity in the Edwards Aquifer as an average for the whole formation has been estimated at between 2% and 4%. Because of the difficulty in studying porosity in solid rock, we will explore the concept using unconsolidated sediments.

Materials: sand samples (sorted), sand samples (unsorted), clay, 2 graduated cylinders (the wide/low form 25 ml are best), small beakers, a pencil and copies of the student data page, Video: *Inside the Edwards Aquifer.*

Procedure: Prepare the sand samples for the students. If you have screen sieves available, run the sand through them until you have at least two samples of different grain sizes. The sieves that came with the ESCP program are more than adequate for this. Otherwise, use the sand as it comes. Make sure it is dry. If you want to include some clay, you can secure pure samples from ceramic shops, either as liquid slip, which you will have to allow to dry out, or as blocks which will have to be dried and ground up. Once the samples are ready, have the students complete the following steps:

1) Using one of the graduated cylinders, measure 25 ml of the sand sample. Pour the measured sand into a small beaker. Record the volume.
2) Measure 25 ml of water in the other cylinder. Add water carefully to the sample you measured until the sample is saturated and the top surface is just wet. Record the volume of water used.
3) Dispose of the sample in a bucket, wash and dry the beaker.
4) Repeat steps 1-3 for any other sand samples available.
5) Calculate the percent porosity by dividing the volume of water you added to the sand by the measured volume of the sand, and multiplying that answer by 100. Do this for all samples. If you are doing this in groups, you may want to collect class data and compare results.

Extensions: Students may be asked to bring in their own samples. Working with soils may be difficult as there is some difficulty getting them dry. You can extend this activity by asking students what will happen if clay is added to the sand, then rerunning the investigation to find out.

MEASURING POROSITY

Procedure:

1) Using one of the graduated cylinders, measure 25 ml of the sand sample. Pour the measured sand into a small beaker. Record the volume.
2) Measure 25 ml of water in the other cylinder. Add water carefully to the sample you measured until the sample is saturated and the top surface is just wet. Record the volume of water used.
3) Dispose of the sample in a bucket, wash and dry the beaker.
4) Repeat steps 1-3 for any other sand samples available.
5) Calculate the percent porosity by dividing the volume of water you added to the sand by the measured volume of the sand, and multiplying that answer by 100. Do this for all samples.

Example: Sand volume measured: 25 ml Water volume measured: 6 ml

6 / 25 = .24 X 100 = 24%

DATA TABLE

Sample Number	Sand Volume	Water volume	Porosity %
1.			
2.			
3.			
4.			
5.			

Questions:
1. Which sample presented the highest porosity? The lowest?

2. Were your results consistent with the other results in the class?

3. Was there any difference between samples with large grains and those with small grains? (If you had sorted samples.)

4. Was there any difference between samples that were sorted and those that were not?

Lesson 8: Measuring Permeability

Objective: Students will be able to relate permeability to porosity and understand that they are not identical.

Background Information: An important variable contributing to transmissivity is permeability, or the ability of water to flow through the void spaces (porosity). Permeability is a relative measure of the degree of interconnectedness between the pores and void spaces. It can also depend on how large the interconnections are. In clays with porosity values above 40%, the permeability may be essentially zero because the holes in the clay are so small and so poorly connected that the water gets stuck in the clay and cannot move. The Edwards Aquifer, while it only averages 2-4% porosity, has some very large cavities and billions of cracks, cavities and tiny pores. Its interconnections allow water to move. Unconsolidated sand has an even higher permeability.

Materials: Aquifer simulator** (prepared ahead of time), rubber hose, funnel, graduated cylinder, stopwatch, ringstand, clamps, filter paper, pencil and copies of the student activity sheet. Samples could include sand, gravels, clays, etc. **The aquifer simulator is a 30 cm length of 1" diameter PVC pipe or plexiglass pipe, two -#5 one hole rubber stoppers, two -3" pieces of glass tubing and two discs of filter paper. Insert the glass tubing in each of the rubber stoppers, cut a small disc of filter paper and place it on top of one stopper and insert the assembly into the PVC tube. Fill the tube with a sediment sample. The filter paper will keep the sand/clay from coming out the glass tube. If you set up several of these in advance, you can have different samples (include clays).

Procedure: The apparatus should be set up as follows:
1) Clamp the funnel to the ringstand.
2) Attach rubber tubing to the funnel.
3) Attach the simulator to the tubing and clamp it to the stand.
4) Attach rubber tubing to the bottom of the simulator.

Students should then follow these steps: Saturate the system with water. Pour water into the funnel until water begins to emerge. Stop pouring and wait until the water drips only about once every 2-3 seconds. Catch the water in a beaker or cylinder. Place an empty graduated cylinder at the bottom of the system. Pour water into the funnel and collect a full cylinder of water at the bottom. Use the stopwatch to record the time required to fill the cylinder, beginning at the moment you start pouring. Record your data. Repeat step 2 twice and take an average of the three trials. Repeat all steps with a different sample.

Extension: Provide a simulator that has been filled with clay, plaster of paris, concrete or mortar. Ask the students to identify the substance inside the tube and why its behavior is so different.

MEASURING PERMEABILITY

Procedure: The apparatus should be set up as follows:
Clamp the funnel to the ringstand. Attach rubber tubing to the funnel. Attach the simulator to the tubing and clamp it to the stand. Attach rubber tubing to the bottom of the simulator. Then follow these steps:

1. Saturate the system with water. Pour water into the funnel until water begins to emerge. Stop pouring and wait until the water drips only about once every 2-3 seconds. Catch the water in a beaker or cylinder.
2. Place an empty graduated cylinder at the bottom of the system. Pour water into the funnel and collect a full cylinder of water at the bottom. Use the stopwatch to record the time required to fill the cylinder, beginning at the moment you start pouring. Record your data.
3. Repeat step 2 twice and take an average of the three trials.
4. Repeat all steps with a different sample.

Data Table

Sample #_______

Trial:	Volume Collected:	Time:
1.		
2.		
3.		
Average:		

Sample #_______

Trial:	Volume Collected:	Time:
1.		
2.		
3.		
Average:		

Questions:
1. Were there any significant differences among your trials?
2. Were there any differences between your group's results and those of others for the same sample?
3. How do you account for the differences, or the uniformity?

Lesson 9: Recharge and the River Basins of the Edwards Aquifer Region

Objective: Students will identify the three major river basins whose rivers and streams flow through the Edwards Aquifer recharge area, and explain how these basins affect the amount of water in the aquifer.

Background information: One of the questions asked about the Edwards Aquifer is how much water enters the aquifer each year as recharge. This amount varies according to the amount of rainfall each year, and where it falls. The drainage area of the Edwards Aquifer includes the watersheds where rainwater runs off to streams to recharge the aquifer. Rain that falls on the counties of Edwards, Real, Bandera, Kerr and Kendall flows overland in streams until it reaches the recharge zone. In the recharge zone, the water disappears into cracks in the streambeds and enters the aquifer.

To answer the question of how much water enters the aquifer each year as recharge, scientists have two sets of gages on major rivers and streams that flow through the recharge area. One gage above the recharge zone measures the volume of water flowing at a point upstream. A second gage downstream of the recharge area measures the volume of water in the stream at that point, if any. The difference in volume between the two gages is the approximate amount of recharge from that stream. Some rivers and streams add more recharge than others. All the streams and rivers in the **Nueces River Basin** contribute about 57% of the recharge, the **San Antonio River Basin** with its smaller creeks contributes 34%, and the **Guadalupe-Blanco River Basin** contributes 9%.

Materials: 1) copies of the activity sheet and map: *Recharge to the Edwards Aquifer by Basin;* 2) map colors or markers; 3) classroom copy of the latest Bulletin from the EUWD (available in your school library), or copies of the table: "Estimated Annual Recharge to the Edwards Aquifer by Basin, 1934 to Present" (found in the EUWD Bulletin); 4) Texas maps

Procedure: Using information from the video, maps and table, students should identify the features listed on the activity page and answer the questions.

Extensions: Using the information from the latest bulletin from the EUWD, find the table that gives the Estimated Annual Recharge to the Edward's Aquifer by Basin, 1934 to present. Answer the following:

1) Compare the recharge for Medina Lake and the Guadalupe-Blanco River Basin for the years 1956 and 1981.

2) Determine the years which show the highest and lowest TOTAL recharge.

3) Investigate the amount of recharge from two different basins for a particular decade. How does the average for the decade compare to the total average given on the table? What are possible reasons for deviations if any?

Recharge to the Edwards Aquifer by Basin

Instructions for map activity:

1) Using the EUWD map/poster *Water Resources of the Edwards Aquifer Region*, draw in the boundary lines for the three areas of the Edwards Aquifer region: Drainage Area, Recharge Zone, and Artesian/Reservoir Area.

2) Using a gold map color, lightly shade in the Drainage Area. Using a grey map color, lightly shade in the Recharge Zone. Use a light blue to indicate the location of the Artesian/Reservoir Area.

3) Locate all the streams, creeks and rivers of the Nueces River Basin. (Hint: the mouth of the Nueces River separates San Patricio & Nueces Counties.) Color these red. With a marker or map pencil, darken the streams, creeks, and rivers as they pass over the DRAINAGE and RECHARGE areas.

4) With a yellow pencil, repeat the instructions for the San Antonio River Basin. (Hint: the mouth of the San Antonio River separates Calhoun & Refugio Counties.)

5) With a green pencil, repeat the instructions above for the Guadalupe - Blanco River Basin. (Hint: the mouth of the Guadalupe River also forms the boundary between Calhoun & Refugio Counties.)

6) Review the video, *Inside the Edwards Aquifer*, and/or information in the EUWD Bulletin to determine the recharge contribution of the following; then, using your map activity and the map/poster, *Water Resources of the Edwards Aquifer Region*, identify which major river basin these smaller streams are a part of:

Rivers, Streams and Creeks	Percent Recharge	Major River Basin
Nueces & West Nueces	________________	________________
Frio & Dry Frio	________________	________________
Sabinal	________________	________________
Creeks between the Sabinal and Medina Rivers	________________	________________
Medina River	________________	________________
Salado Creek (area between the Medina River and Cibolo Creek)	________________	________________
Cibolo Creek and Dry Comal	________________	________________
Blanco	________________	________________
Guadalupe	________________	________________

Recharge to the Edwards Aquifer by Basin (cont.)

7) What relationships can you identify between the three major river basins? Why might these recharge rivers and streams be important to downstream users? How would the building of additional recharge dams affect these downstream users?

8) Which counties have major springs emerging from the Edwards Aquifer? How do you think these counties feel about increased or unlimited pumping to the west of them? How does this relate to recharge?

9) Which river basins rely on spring waters that emerge from the Edwards Aquifer? Would households and businesses along these river basins be concerned about continual flow from these springs?

10) Which of these various streams and rivers do you think contribute the best quality water to the aquifer? Which of these major basins may have potential water quality problems in the future and why?

11) Water from these recharge streams eventually reaches coastal estuaries. Locate and label the bays these three major river systems feed. Discuss how the quality and quantity of water in these streams affect the delicate balance in these estuaries. Would the residents along the coast be effected in any way by these basins? How?

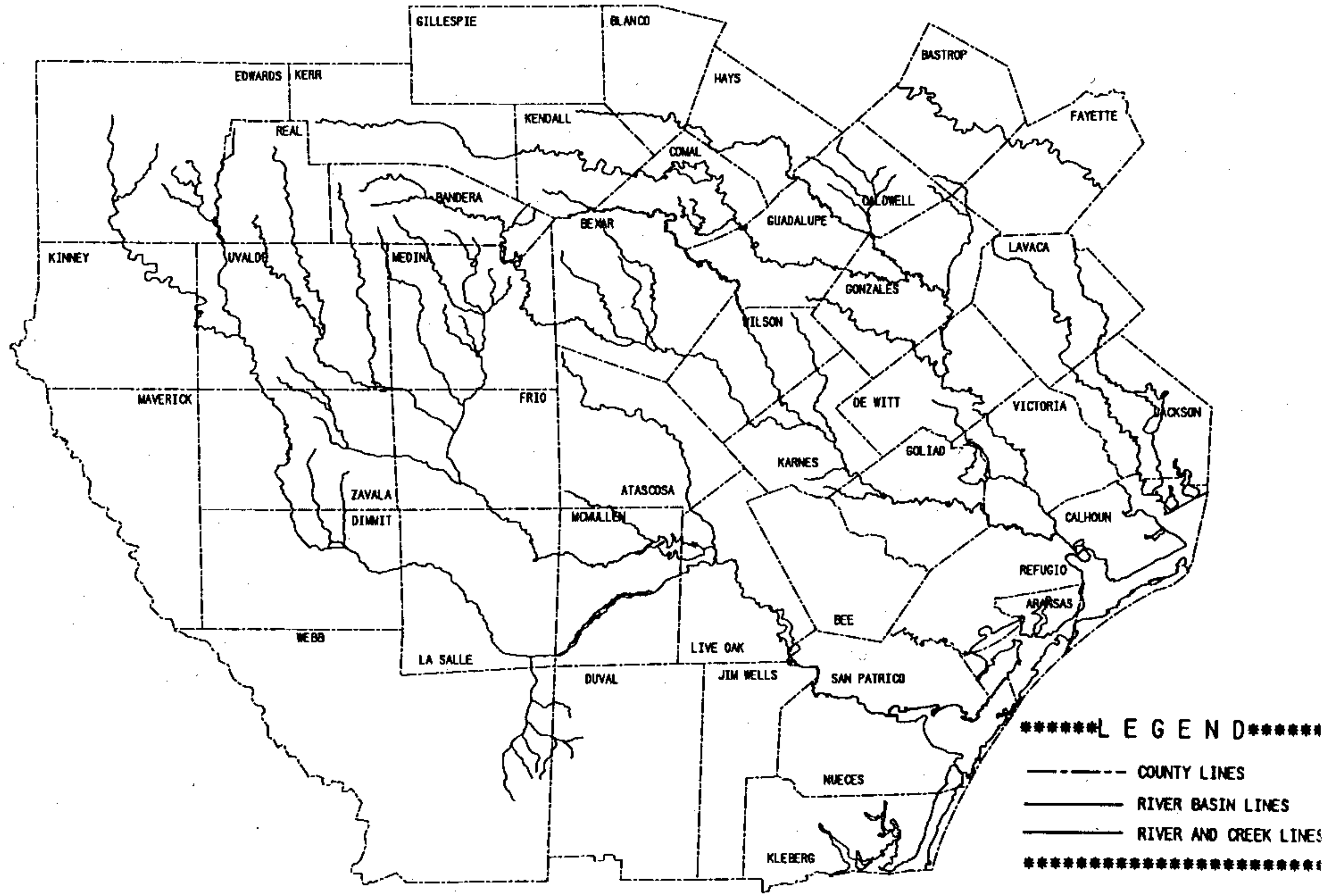
ENRICHMENT:

12) Using information from the EUWD Bulletin, generate a series of line graphs portraying yearly recharge, and discharge by type (spring discharge, irrigation pumpage, municipal pumpage). What kinds of relationships can you deduce from the graphs? What relationship do you see during periods of heavy rainfall? What types of problems could arise during periods of drought?

13) What is the average annual recharge from information out of the EUWD Bulletin? How many years during the period of record (1934-1990) has the recharge been less than average?

14) What are your opinions or impressions about using average recharge as a means of determining water usage from the aquifer?

RECHARGE AND RIVER BASINS



Section Three - Vocabulary

Basal nodular - one strata member of the Kainer Formation of the Edwards, characterized by marine deposits, massive nodular wackestones with permeability

Collapsed and Leached (members combined) - members of the Person Formation of the Edwards, characterized as intertidal and supratidal deposits that are permeable due to collapsed breccias and leached, burrowed wackestones

Cretaceous time period - geologic time period approximately 65 to 135 million years ago when the sediment that formed the geologic units of the Edwards Aquifer were deposited (see Appendix A for Geologic Time Chart)

Cyclic and Marine (combined) - members of the Person Formation, characterized as a very permeable and productive unit which consists of rudistic-bearing wackestones, packstones, and shell-fragment grainstones (contains cavernous openings)

Dolomite - a mineral consisting of a calcium magnesium carbonate found in crystals and in extensive beds

Evaporite - one of the sediments that are deposited from aqueous solution as a result of extensive or total evaporation; in the Edwards, it is a member of the Kainer formation

Formation - a body of rock strata that consists dominantly of a certain lithologic type or combination of types - formations may be combined into groups or subdivided into members

Grabens - an elongated, relatively depressed crustal unit or block that is bounded by faults on its long sides (these are the fault blocks that are relatively lower)

Grainstone - a mud-free grain supported carbonate sedimentary rock

Horst - an elongated, relatively uplifted crustal unit or block that is bounded by faults on its long sides (these are the fault blocks that are relatively higher

Kirschberg Evaporite - member of the Kainer Formation characterized as highly leached which contains well-developed secondary porosity that resembles boxwork

Member - a lithostratigraphic unit of subordinate rank, comprising some specially developed part of a formation

Miocene Epoch - time period when the Balcones Fault Zone was created through the uplift of the Edwards Plateau, 60 million years after the Cretaceous time period (see Appendix A for Geologic Time Chart)

Mudstone - a sedimentary carbonate rock whose framework is mud-supported and contains less than 10% grains

Packstones - a sedimentary carbonate rock whose granular material is arranged in a sulf-supporting framework, yet also contains some matrix of calcareous mud

Regional Dense Member- one member of the Person Formation, characterized as dense shaly mudstone which is nearly impermeable with no dissolution openings.

Wackestones - a sedimentary carbonate rock whose framework is mud-supported and contains more than 10% grains

(Note: Mudstones, Wackestones, Packstones and Grainstones are part of a specified classification system for carbonates. Created by Dunham, 1962)

Lesson 10: Paleogeography

Objective: Using the background information presented, students should be able to work out the paleogeography of the Edwards Aquifer.

Background Information: The Edwards Aquifer is part of a much larger and more complex sequence which geologists call the Edwards Group. To a geologist, a Group is a related sequence of formations. The basic unit of discussion is the formation. A formation is defined as a recognizable or mappable rock unit. Formations are defined clearly by their upper and lower boundaries in the rock column. They are described completely according to their characteristic appearance, fossils etc., and they are named for some geographic feature in the area where they are first studied.

In a single formation there may be a wide range of variation in appearance. The Edwards Group may be subdivided into two formations which are then subdivided into a total of nine members, all of which are mappable on the surface and in the subsurface. Faults have interrupted and complicated the sequencing of events.

If we were able to go back some 115-120 million years, we could fly over the Lower Cretaceous Sea which varied greatly in depth of water and was full of life. It is the variations in the lifeforms that we will use to work out the appearance of the surface. The remains of these lifeforms will be the basis of this activity.

The fauna of the Edwards Aquifer region during the Cretaceous period included:

Rudistic Clams: Very unusual clams found only in the Cretaceous. They lived in reefs like corals, and looked something like horn corals. Their shells tended to dissolve. Genera (groups) found: Toucasia, Monopleura, Caprina, Chondrodonta, Captinuleoidea and Eoradiolites.

Echinoids: Sea urchins. There may have been two kinds. The round regular urchins, like Goniopyguys, are most likely found in the reefs while the heart shaped urchins, related to Hemiaster, are found burrowed in the mud flats.

Oysters: The major form is commonly known as Exogyra texana or Ceratostreon texanum. It would have lived in the mud flats or other shallow water, but not in the reefs. Its form is a flat spiral form with a grooved surface. Another one that might be found is Gryphaea. This one is sometimes called "devil's toe nails."

Ammonites: Relatives of the Nautilus that is still alive today, ammonites were free swimming predators and would most likely have fed anywhere. They are most often preserved in the mud flats behind the reefs.

Background Information (cont.):

Paleogeographic Environments (existing during the Cretaceous period):

***Reefs*:** Located in shallow water, separating open ocean and less deep waters. Dominated by corals in warm water. Animals of the Cretaceous reefs in central Texas included clams, snails, and a few echinoids. This environment is characteristic of the environments of the Stuart City Reef and the Devils River Trend.

Back Reef Flats/Mud Flats/Lagoons: Muddy bottoms with some harder surfaces. Animals varied with oysters, echinoids and a large variety of shallow water forms. Burrowers and fillings were also found in this environment. This environment is characteristic of much of the deposits found in the San Marcos Platform.

***Evaporite Lagoon*:** A shallow restricted submerged area in which the sea lacked free access and the water tended to evaporate away during the summer. The water was extremely salty and not many things lived it it, but there were often gypsum deposits.

Materials: Video: *Inside the Edwards Aquifer*; student copies of descriptions and map activity; transparencies of student map activity and answer sheet.

Procedure: Students are to take the map which contains the letters representing the fossils and other data derived from a single time/geologic surface. They are to correctly shade in and place boundaries around the three environments listed above. When they have completed that task they should answer the questions associated with the map.

Extensions: Students can be asked to draw a block diagram of the map area, labeling the structural features mentioned in the film. They can be asked to research and report on Rudists ammonites and echinoids, either as large groups or by genus (i.e. Toucasia). Students could be asked to explain why the reefs did not contain corals as a dominant element.

Fauna and Environments of the Cretaceous Period

The fauna of the Edwards Aquifer region during the Cretaceous Period included:

Rudistic Clams: Very unusual clams found only in the Cretaceous. They lived in reefs like corals, and looked something like horn corals. Their shells tended to dissolve. Genera (groups) found: Toucasia, Monopleura, Caprina, Chondrodonta, Captinuleoidea and Eoradiolites.

Echinoids: Sea urchins. There may have been two kinds. The round regular urchins, like Goniopyguys, are most likely found in the reefs while the heart shaped urchins, related to Hemiaster, are found burrowed in the mud flats.

***Oysters*:** The major form is commonly known as Exogyra texana or Ceratostreon texanum. It would have lived in the mud flats or other shallow water, but not in the reefs. Its form is a flat spiral form with a grooved surface. Another one that might be found is Gryphaea. This one is sometimes called "devil's toe nails."

Ammonites: Relatives of the Nautilus that is still alive today, ammonites were free swimming predators and would most likely have fed anywhere. They are most often preserved in the mud flats behind the reefs.

Paleogeographic Environments existing during the Cretaceous Period:

***Reefs*:** Located in shallow water, separating open ocean and less deep waters. Dominated by corals in warm water. Animals of the Cretaceous reefs in central Texas included clams, snails, and a few echinoids. This environment is characteristic of the environments of the Stuart City Reef and the Devils River Trend.

Back Reef Flats/Mud Flats/Lagoons: Muddy bottoms with some harder surfaces. Animals varied with oysters, echinoids and a large variety of shallow water forms. Burrowers and fillings were also found in this environment. This environment is characteristic of much of the deposits found in the San Marcos Platform.

***Evaporite Lagoon*:** A shallow restricted submerged area in which the sea lacked free access and the water tended to evaporate away during the summer. The water was extremely salty and not many things lived it it, but there were often gypsum deposits.

PALEOGEOGRAPHY

Instructions: 1) Locate and circle the locations of the four cities found on the puzzle map: X1 (San Antonio); X2 (San Marcos); X3 (Uvalde), and X4 (Austin). 2) Using three different colored markers, shade in the areas that represent the fossil fauna or mineral deposits of ancient Cretaceous seas, using the codes below.

Environment	Fauna description	Fauna (if any)	Mineral (if any)	Code
Reefs (color red)	Rudistic clams	Chondrodonta		B
		Caprina		C
		Eoradiolites		E
		Monopleura		M
		Toucasia		T
	Echinoids	Goniopyguys		G
Back Reef Flats/ Mud Flats/ Lagoons (color blue)	Oysters	Exogyra		F
		Gryphaea		D
	Ammonites	Ammonites (Oxytropidoceras)		O
		Burrowers		Y
	Echinoids	Hemiasters		H
		Clams and snails		Z
Evaporite Lagoon (color yellow)		little if any	gypsum	A
			mud cracks	Q

Questions:

1) Locate and outline the Devils River Trend, the San Marcos Platform, the Stuart City Reef and the Kirschberg Evaporite Lagoon (part of the Comanche Shelf.)

2) How is the paleoenvironment at the location of Uvalde different from that the other cities?

3) Sea level was not always the same over the map area. The evaporite lagoon was not always present. What reasons can you give for changes in the sea level?

Paleogeography Puzzle Map

```
C C  O  H  D F F F F F Y Y Z  A Q A A A A F F F F Z Z Y Z Y E Z Y X4
C C C F F F F F F F F F F F F A Q Q Q Q A A Z Z Z Z Z Z Z Z Z Z Z Z Z
 C C C H F Y Y Y O E F F F F A A A A A A A A F F F F F F F Z Y Y Y
  C  C C  D  D D  D D D D F A  Q  A  Q  A  Q A  D D D D D D F F F F
Z  C C C  D  D  D  D  D  D A Q Q Q Q Q Q Q Q Q A D D D D D DX2 D D D
 Z  C C C F F F F F H H H O A A A A A A A A A A H H H H O D D D D D
  Z  T T T F Y F Y F Y F Y F A Q  A  Q  A  Q A Y Y Y Y Y Y Y Y Y Y Y
  ZZ  T T T D D D D E D D D D A Q A Q A Q A Q  O H F F F F F F F F F
    Z  MTBCE F F F F F F FF  F  A  Q  A  Q F F F F F F F FF F F F F
     Z  MTBCE F F F F H H O  H  D D D D D D D D F F F F F F YY YY
     Z MTGBCE  ZZZZ  ZZZZ   ZZZZ    ZZZZ   YYYY YYYY YYYY YYYY YYYY
D     Z MTGBCE  ZZZZ ZZZZ ZZZZ ZZZZ FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
E          B B B    FF   E  FF  O   FF H  DD E   DD  DD    DD  DD  DD  D
E           M X3 T  F   Y   Y    Y    Y    Y   X1   Y    Y   Y     Y   T
P        Z   MBCGE  Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y
          F CTCTCT YYYYYYYY   YYYYYY   YYYYY Z Z Z Z Z Z Z Z Z Z Z T T
W          Z CTCTCT  D D D D D D D D D Y Y Y Y Y Y Y H H O F F F T T T
A           F CTCTCTC  DFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFDFTETETE
T           H EEEEEEE      F   F    F    F    F   F ETETETETETETETETET
E            Z EEEEEEE  F  F  F  F  F  F  F ETETETETETETETETETETETET
R             Y  EEEEE H O F D D D O H BBBBBBBBBBBBBBBBBBETETET Z
               Z EEEEEE BBBBBBBBBBBBBBTTTTTTTTTTTTTTTTTTGGEEE Y      DEEP
                EBCCCCBBBBCCCBBBCBBCBCBCBCTTGGGMMMMMMMMMMMM Y       WATER
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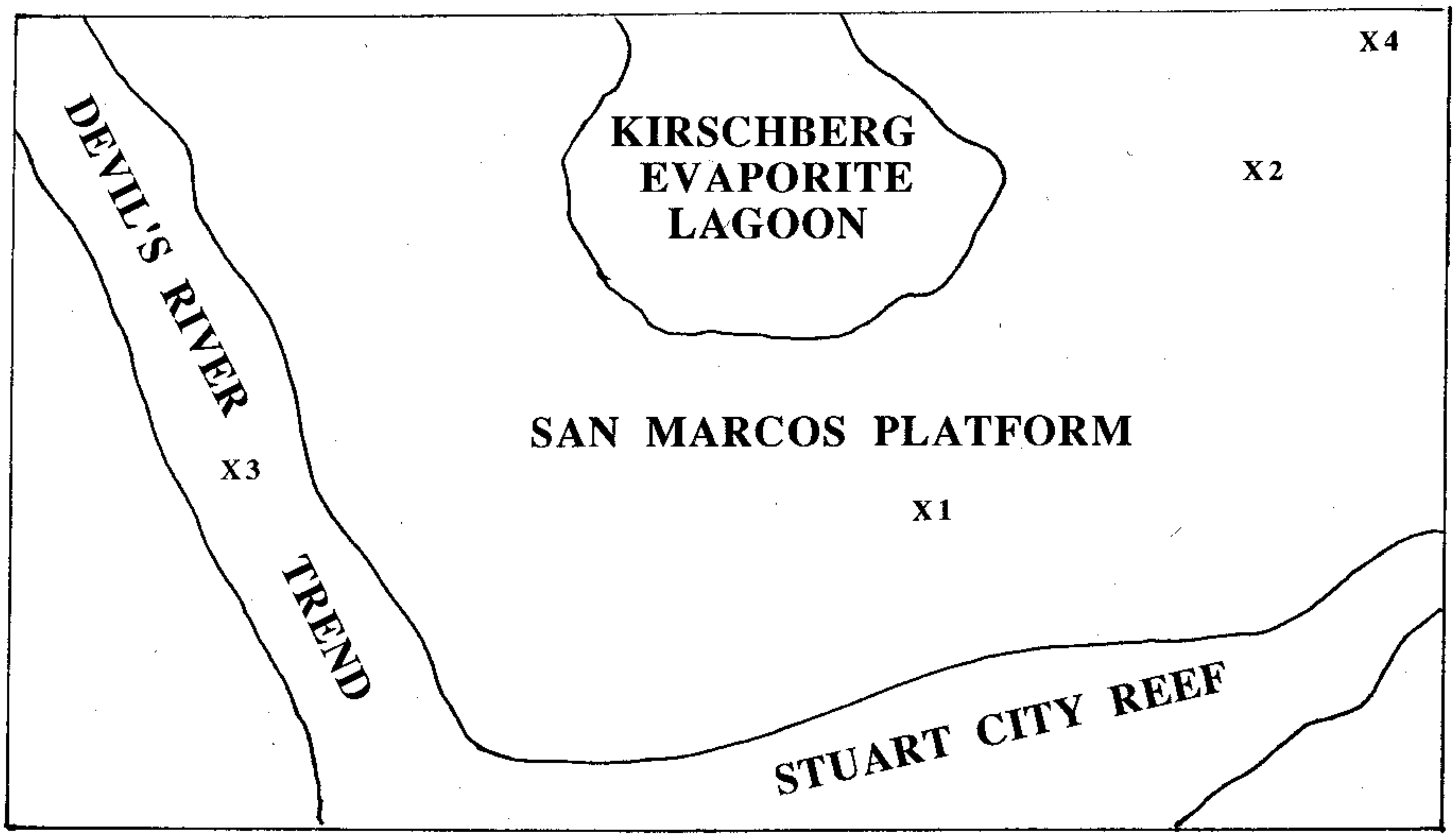
Paleogeography Puzzle Map Key

Transparencies of this can be made to overlay the students' puzzles.



Lesson 11: Geology Overlying, Within and Underlying the Edwards Limestones

Objective: Students will understand the complexity of the geology above, below and within the Edwards Limestones.

Background Information: The Edwards Limestones are extremely porous and permeable when compared to much less permeable layers above and below.

The science of Geology uses a specific classification system to distinguish one rock body from another. A Series is a unit of a geologic age. Series are subdivided into Divisions, which are subdivided into Groups, which are subdivided into Formations, which are subdivided into Members.

The Edwards Limestones are beneath younger, less permeable layers, known, in order from the surface down, as the Austin Group (Chalk), the Eagle Ford Group (Shale), and the Buda Limestones and Del Rio Clay of the Washita Group.

Within the San Marcos Platform of the Edwards Aquifer lie the Georgetown Formation of the Washita Group and two formations of the Edwards Group. The Edwards Group is divided into the Person Formation and the Kainer Formation, with each of these formations having various members. In the area known as the Devils River Trend lie some Edwards Facies rocks known as the Devils River Limestone. The rocks equivalent to the Edwards in the Maverick Basin are divided into the Salmon Peak Formation, the McKnight Formation, and the West Nueces Formation.

Underlying the Edwards Aquifer is the Glen Rose Limestone Formation, of the Trinity Group, which is an older, much less permeable formation.

The thicknesses of each of the formations and members differ from east to west within the region. The student description sheets give detailed descriptions of each of the formations and groups, along with estimates of thicknesses of the rocks within the region.

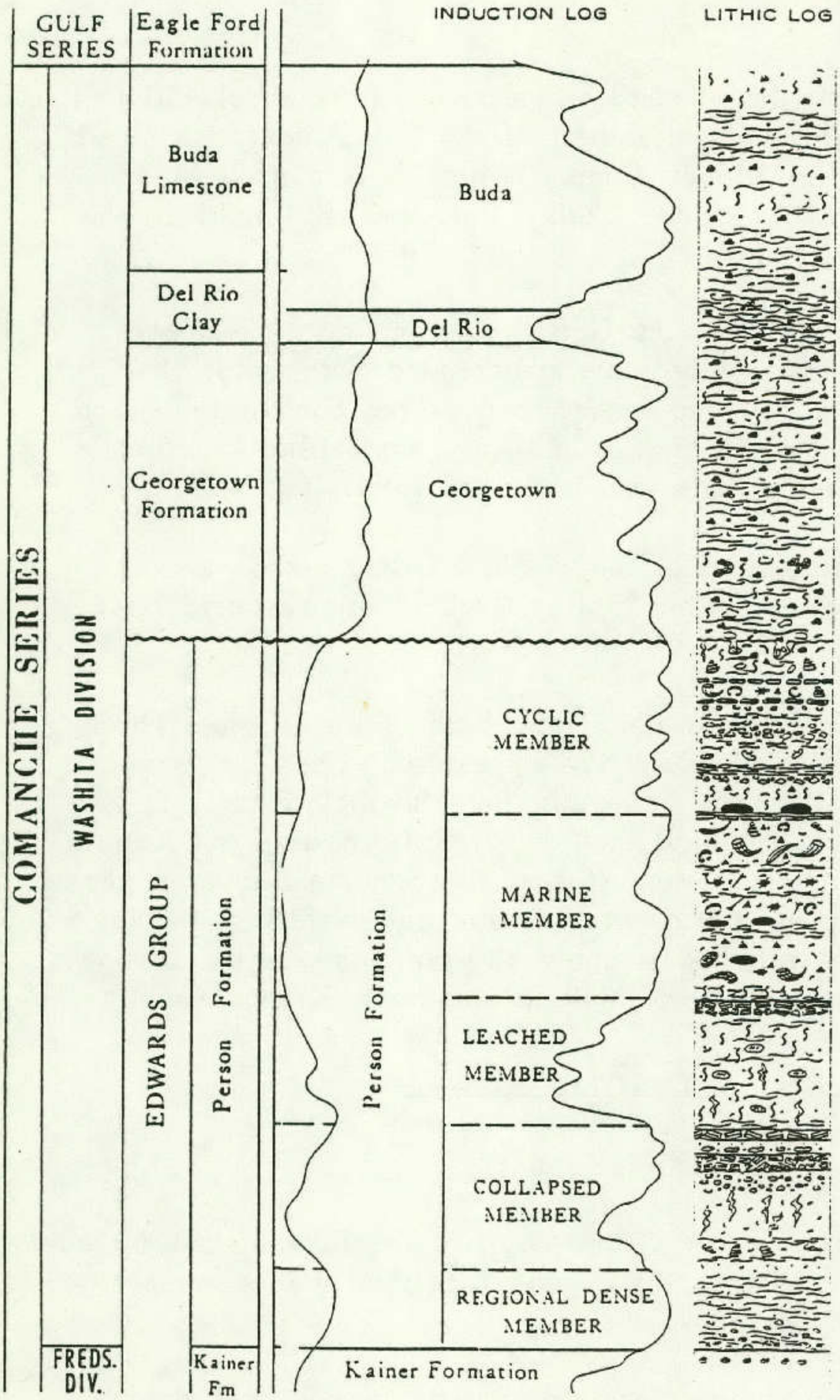
Materials: Group or individual handouts: *Geology of the Edwards Aquifer Region*; large sheets of butcher paper or paper for bulletin boards, markers, rulers.

Procedure: Break students into groups of two to four. Using information on the description sheets, students should draw a cross-section, or stratigraphic column, of the many Groups and Formations within the Edwards Aquifer system. This cross-section should be drawn to scale. Some of the drawings may be quite large - up to six feet! Make sure the students have enough room to spread out!

Extensions: Students should attempt to draw this cross-section using information that exists for the area that they live in. Students can research and discover what type of life existed in the marine environment during the depositional period of each formation, and draw a lithic log to the side.

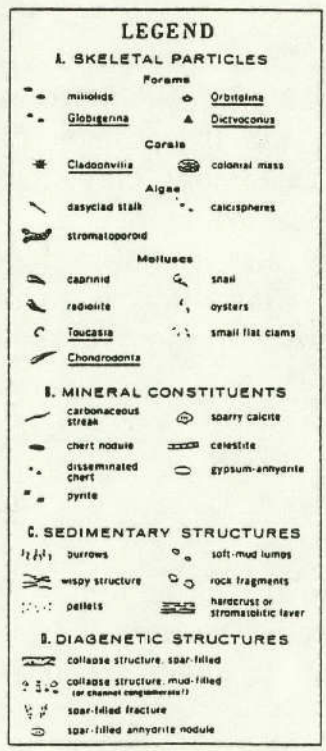
Example of Statigraphic Column

Teachers: This stratigraphic section depicts the type of drawing you want the students to generate using their descriptive reading: *Geology of the Edwards Aquifer Region.* Please note that this does not include the Austin Chalk, or Eagle Ford Shale (included in the reading). It is merely provided as an ***example***.



Students' charts should include the following groups, formations and members, listed from the surface down:

Group	Formations	Members
Austin	Austin Chalk	
Eagle Ford	Eagle Ford Shale	
Washita	Buda Limestone	
	Del Rio Clay	
	Georgetown	
Edwards	Person	Cyclic
		Marine
		Collapsed
		Leached
		Regional Dense
	Kainer	Grainstone
		Kirschberg Evaporite
		Dolomitic
		Basal Nodular
Trinity	Glen Rose	



Generalized columnar section Washita Division, Fashing-Person trend, south-central Texas.

(Adapted from: Bureau of Economic Geology, University of Texas at Austin, Edwards Group, Surface and Subsurface, Central Texas, Report of Investigation No. 74, by Peter R. Rose, 1978.)

Geology of the Edwards Aquifer Region

Overlying the Edwards Aquifer

The formations overlying the Edwards Aquifer are, in declining order, the Austin Group, Eagle Ford Group, and the Buda Limestone and Del Rio Clay of the Washita Group.

The Austin Group is a white buff, dense, chalky limestone. It is about 150 feet thick in much of the eastern area and central part of the San Antonio area and thickens to more than 1,000 feet in Kinney County, where it is a massive limestone in the lower part and thin-bedded chalky limestone and marl in the upper part.

The Eagle Ford Group is the basal unit of the Gulf Series or Upper Cretaceous. It is chiefly flaggy, calcareous, and sandy shale interbedded with hard, shaly limestone. It is about 35 feet thick in the eastern part of the San Antonio area and over 200 feet thick in the west where it is a flaggy, crystalline limestone and clayey, chalky limestone interbedded with layers of marl.

The Buda Limestone is the top formation of the Washita Group and is a very hard, dense, massive limestone. It is about 55 feet thick in the east and more than 100 feet thick in the west.

The Del Rio Clay overlies the Georgetown Formation, both of the Washita Group, within the San Marcos Platform, the Devils River Limestone within the Devils River Trend, and the Salmon Peak Formation within the Maverick Basin. It is a soft, sticky calcareous clay that is about 50 feet thick in the eastern and central part of the San Antonio area. In the western part of the San Antonio area, the Del Rio Clay also contains thin, flaggy beds of limestone interbedded with clay. The Del Rio Clay thickens to the west and is about 120 feet thick at the Uvalde-Kinney County line and more than 200 feet thick in southwest Kinney County.

Within the Edwards Aquifer

San Marcos Platform

The Georgetown Formation of the Washita Group overlies the Edwards Group on the San Marcos Platform. It is a dense, shaly, mud limestone and/or wackestone. The formation is about 20 to 30 feet thick.

The Edwards Group consists of two formations, the Person (upper) and the Kainer (lower). The Person Formation is about 180 feet thick and is divided into five units: The Cyclic Member, the Marine Member, the Collapsed Member, the Leached Member, and the Regional Dense Member. The Cyclic Member is not present or is not distinguishable within the aquifer. The Marine Member is a dense, lime mudstone about 80 feet thick. The Leached Member and the Collapsed Member are dense, variably recystallized lime wackestone and lime grainstones about 80 feet thick. The Regional Dense Member is the basal unit and is a dense, clayey, lime mudstone about 20 feet thick. The Kainer Formation is about 250 feet thick and consists of four members. The Grainstone Member is the upper member and is a well-cemented, miliolid lime grainstone about 60 feet thick. The Kirschberg Evaporite Member is stratigraphically below and is a recystallized, variably honeycombed, crystalline limestone about 50 feet thick. The Dolomitic Member is a variably recrystallized, honeycombed, crystalline, dolomitic limestone or crystalline dolomite. The Dolomitic Member is about 90 feet thick. The Basal Nodular Member is the lowest member and is a dense, shaly, lime wackestone about 50 feet thick.

Devils River Trend

The Devils River Trend refers to the belt of stratigraphically inseparable Fredericksburg and Washita rocks bordering the northern Maverick Basin. These Edwards Facies rocks are known as the Devils River Limestone and are chiefly recrystallized miliolid and shell fragment, lime grainstones, and wackestone about 450 to 600 feet thick.

Maverick Basin

The rocks equivalent to the Edwards in the Maverick Basin are divided into the Salmon Peak Formation, the McKnight Formation, and the West Nueces Formation. The Salmon Peak Formation, the upper unit of the Maverick Basin, is a dense, massive lime mudstone about 350 feet thick. The McKnight Formation is a thin-bedded lime mudstone and shale, about 100 to 200 feet thick. The West Nueces Formation consists of a lower nodular, lime wackestone about 60 feet thick and an upper massive, dense, lime mudstone about 60 feet thick.

Underlying the Edwards Aquifer

The Glen Rose Formation of the Trinity Group, which is the confining unit below the Edwards Aquifer, consists of beds of massive, chalky limestone alternating with beds of marly limestone.

(Adapted from: Texas Department of Water Resources Report LP-199: Identification and Tabulation of Geological Contacts in the Edwards Aquifer San Antonio, TX, by Ted A. Small, U.S.G.S. in cooperation with the San Antonio City Water Board.)

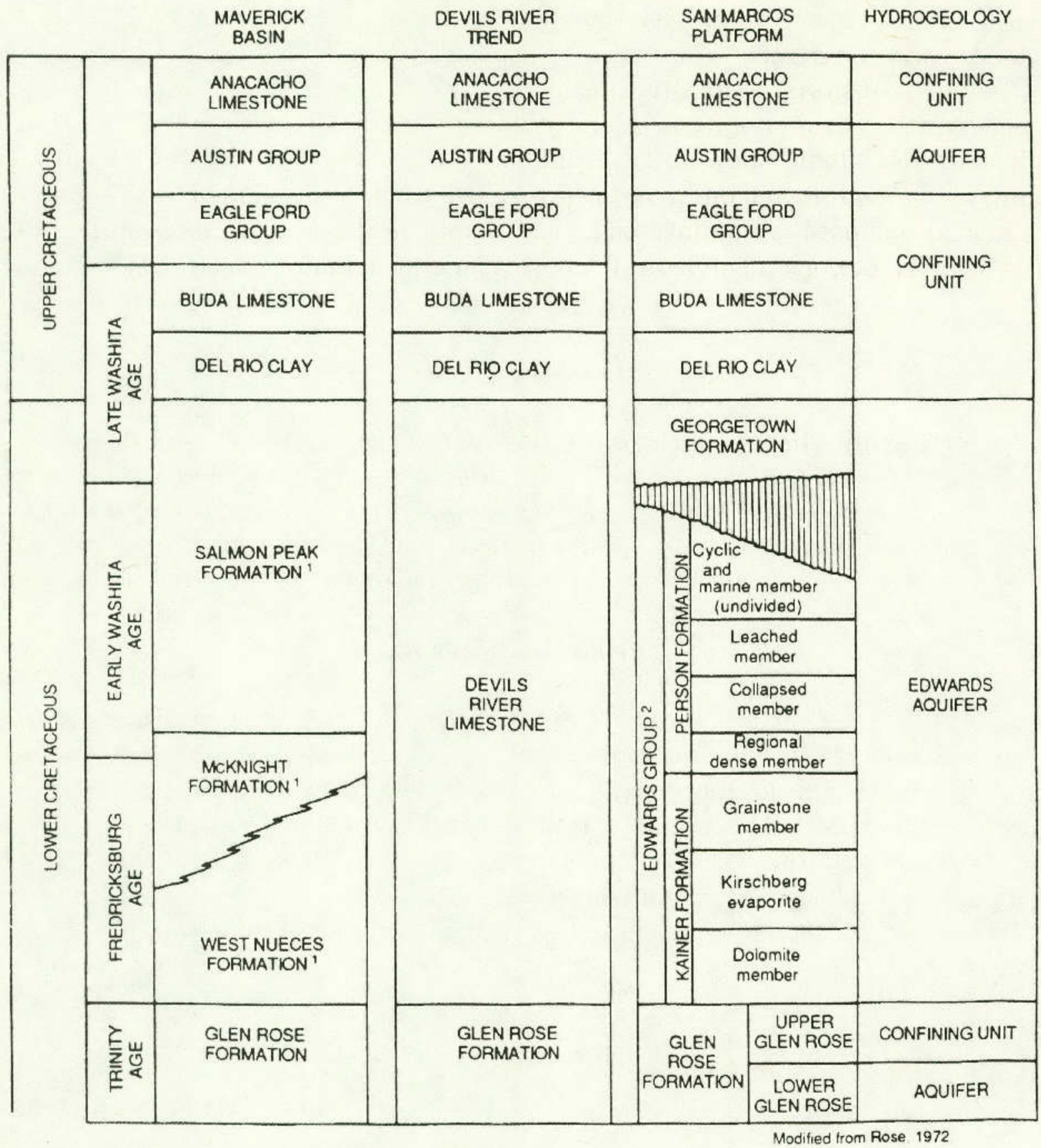
Appendix A

The Major Division of Geologic Time, and the Development of Life Forms As Shown By Fossils

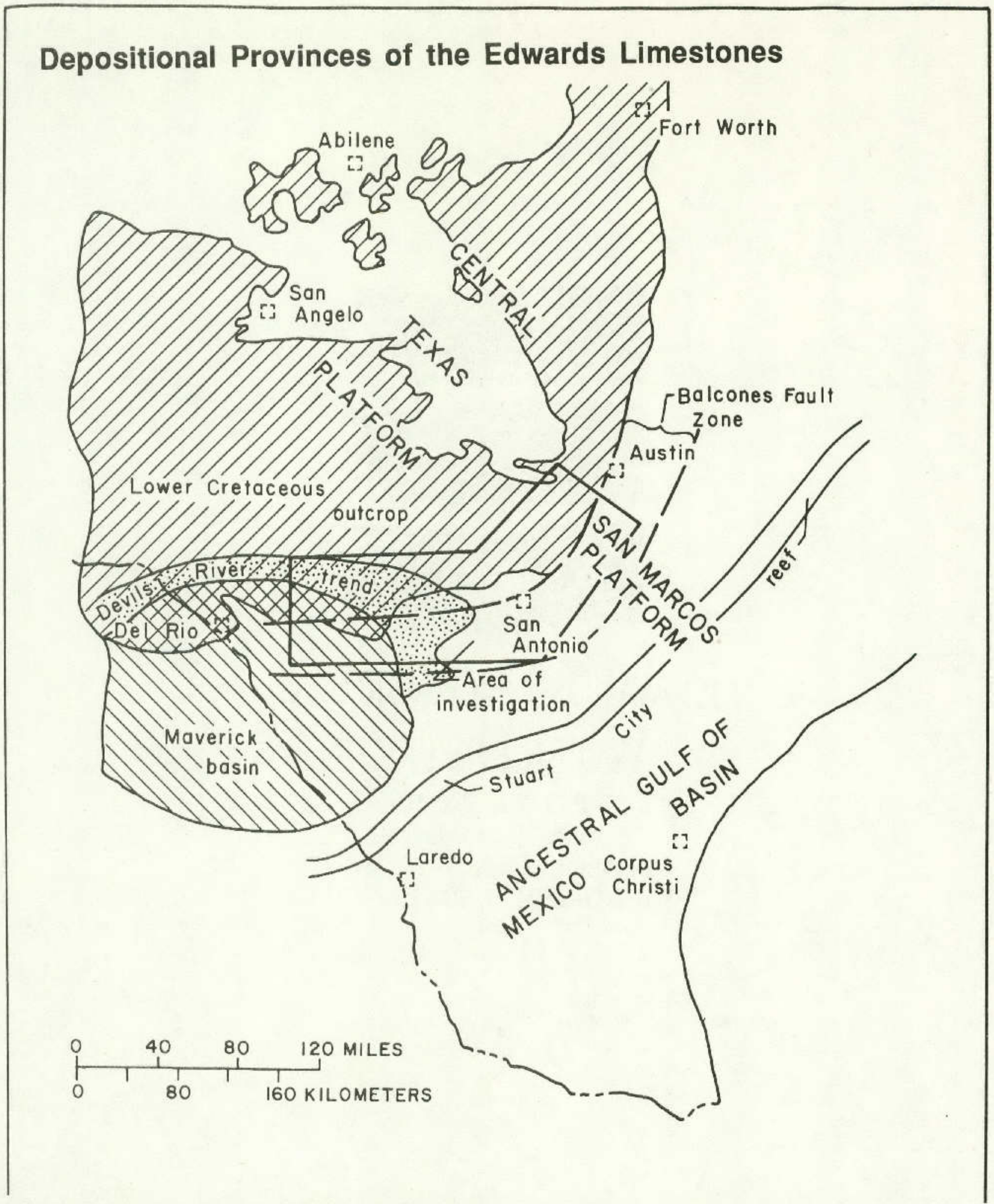
Era	System and Period			Distinctive Features	Million Years Ago
CENOZOIC	QUATERNARY			Early man; modern man in last 10,000 years	
					1.8
CENOZOIC	TERTIARY			"Age of Mammals"	
					65
MESOZOIC	CRETACEOUS		*Age of Reptiles*	First flowering plants; greatest development of dinosaurs & ammonites, followed by extinction	
					140
MESOZOIC	JURASSIC		*Age of Reptiles*	First birds, first mammals; abundant dinosaurs & ammonites	
					190
MESOZOIC	TRIASSIC		*Age of Reptiles*	First dinosaurs; abundant coniferous trees	
					230
PALEOZOIC	PERMIAN		*Age of Amphibians*	Extinction of trilobites and many other types of marine animals	
					280
PALEOZOIC	CARBON-IFEROUS	PENNSYLVAN-IAN	*Age of Amphibians*	Great coal forests; abundant insects, first reptiles	
					310
PALEOZOIC	CARBON-IFEROUS	MISSISSIPPIAN	*Age of Amphibians*	Sharks and amphibians; large primitive trees	
					345
PALEOZOIC	DEVONIAN		*Age of Fishes*	First amphibians and ammonites	
					405
PALEOZOIC	SILURIAN		*Age of Fishes*	First plants and animals on land	
					425
PALEOZOIC	ORDOVICIAN		*Age of Marine Invertebrates*	First fishes	
					500
PALEOZOIC	CAMBRIAN		*Age of Marine Invertebrates*	First abundant record of marine invertebrates; trilobites dominant	
					570
	PRECAMBRIAN			Very few fossils: primitive aquatic plants; oldest fossils (bacteria, algae) about 3,100 million years	

Appendix B

Correlation of Stratigraphic Units



(Adapted from: South Texas Geological Society, <u>Geology of the Edwards Aquifer, Descriptions and Recommendations</u>, January 1991.)



(Adapted from: U.S.G.S., the Texas Water Development Board, and the San Antonio City Water Board, Open File Report 76-627, Progress Report on Geology of the Edwards Aquifer, San Antonio Area, Texas and Preliminary Interpretation of Borehole Geophysical and Laboratory Data on Carbonate Rocks, by R.W. Maclay and T.A. Small, 1976.)

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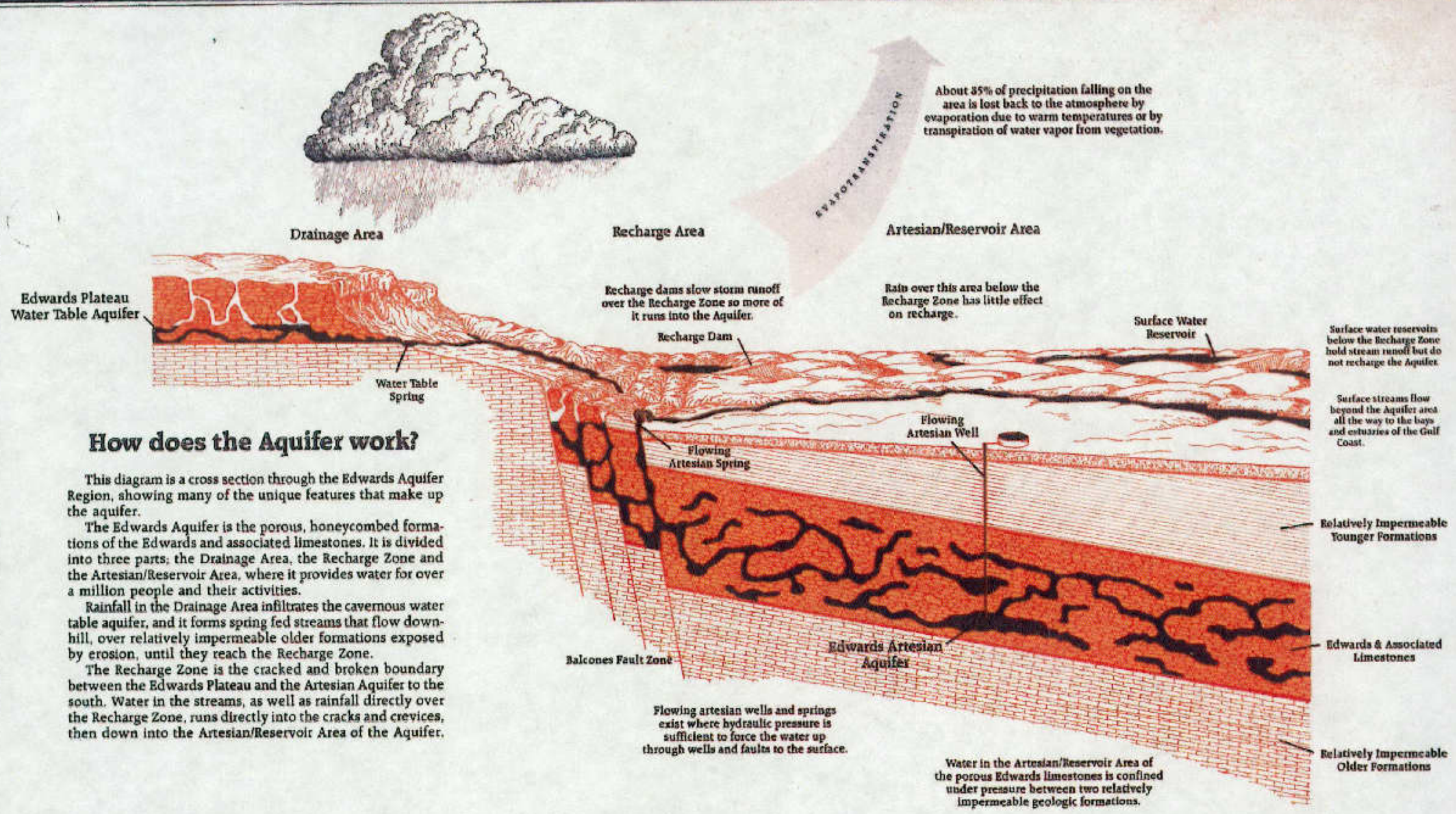
Special thanks for their help on the production of activities in this guide go to:

Rose Mary Castro, Fox Tech High School, San Antonio ISD
Ed Gildemeister, Jefferson High School, San Antonio ISD
Cy Firgens, MacArthur High School, Northeast ISD



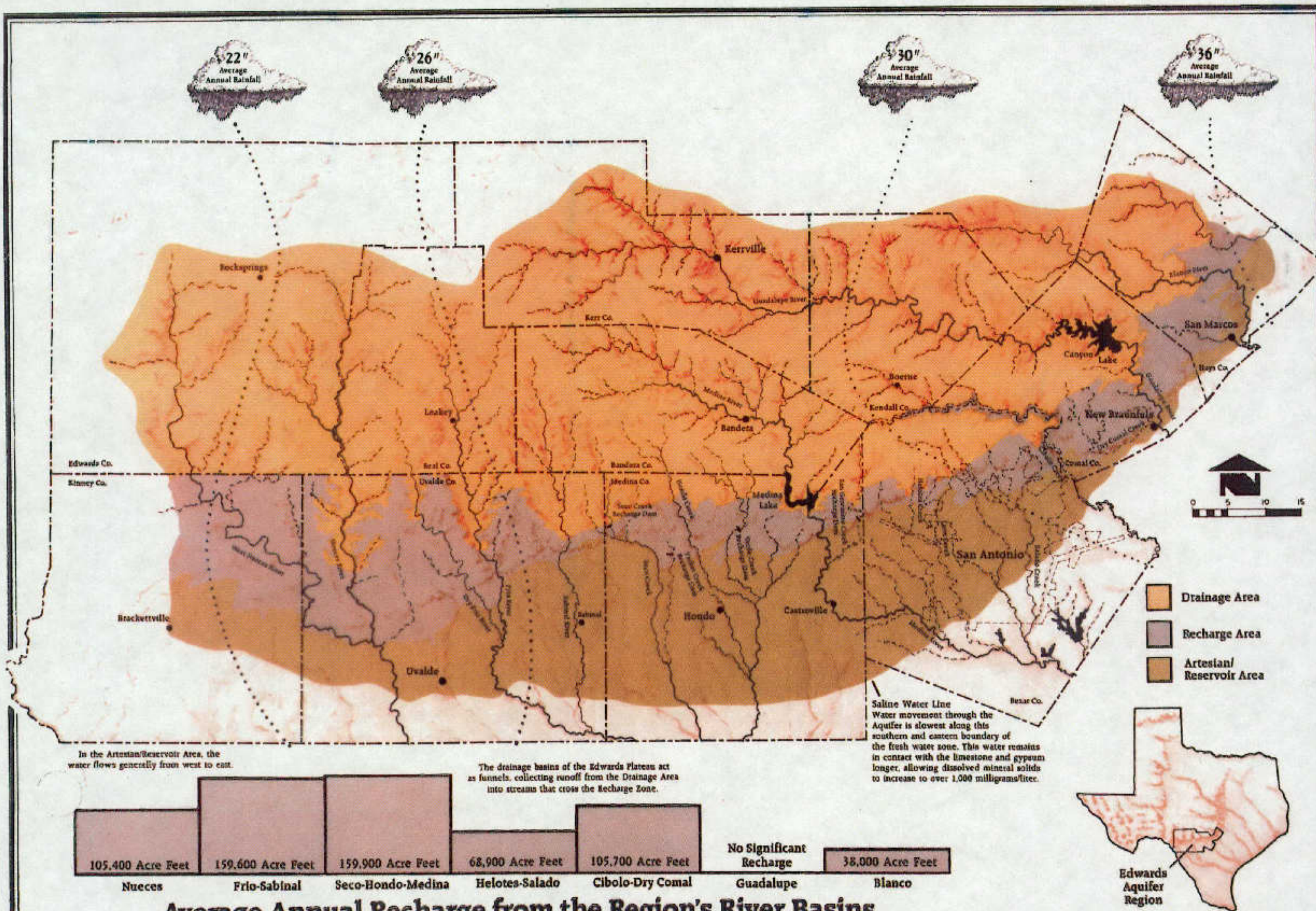
How does the Aquifer work?

This diagram is a cross section through the Edwards Aquifer Region, showing many of the unique features that make up the aquifer.

The Edwards Aquifer is the porous, honeycombed formations of the Edwards and associated limestones. It is divided into three parts; the Drainage Area, the Recharge Zone and the Artesian/Reservoir Area, where it provides water for over a million people and their activities.

Rainfall in the Drainage Area infiltrates the cavernous water table aquifer, and it forms spring fed streams that flow downhill, over relatively impermeable older formations exposed by erosion, until they reach the Recharge Zone.

The Recharge Zone is the cracked and broken boundary between the Edwards Plateau and the Artesian Aquifer to the south. Water in the streams, as well as rainfall directly over the Recharge Zone, runs directly into the cracks and crevices, then down into the Artesian/Reservoir Area of the Aquifer.



Average Annual Recharge from the Region's River Basins