GK-12 Field Workshop – Edwards Aquifer Hydrogeology
Environmental Science Institute
The University of Texas at Austin

Photo by: David Johns, City of Austin, WPDR

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A Note on the Guidebook and Supplemental Materials

This guidebook is accompanied by a CD containing a copy of the guidebook and all materials that are linked in the text of the guidebook. At the beginning of each section of the guidebook you will find links to lessons relating to that stop on the field trip. We suggest that you do as many lessons as possible before going on the field trip as they provide a good background for the materials covered at each stop. Within each section of the guidebook, you will find links to additional (often interdisciplinary) readings related to each stop. Please feel free to print out additional copies of the guidebook and supplemental materials as needed, but please cite the source.

-Brian Cowan
Guidebook Editor

<u>Stop 1: Barton Springs</u>

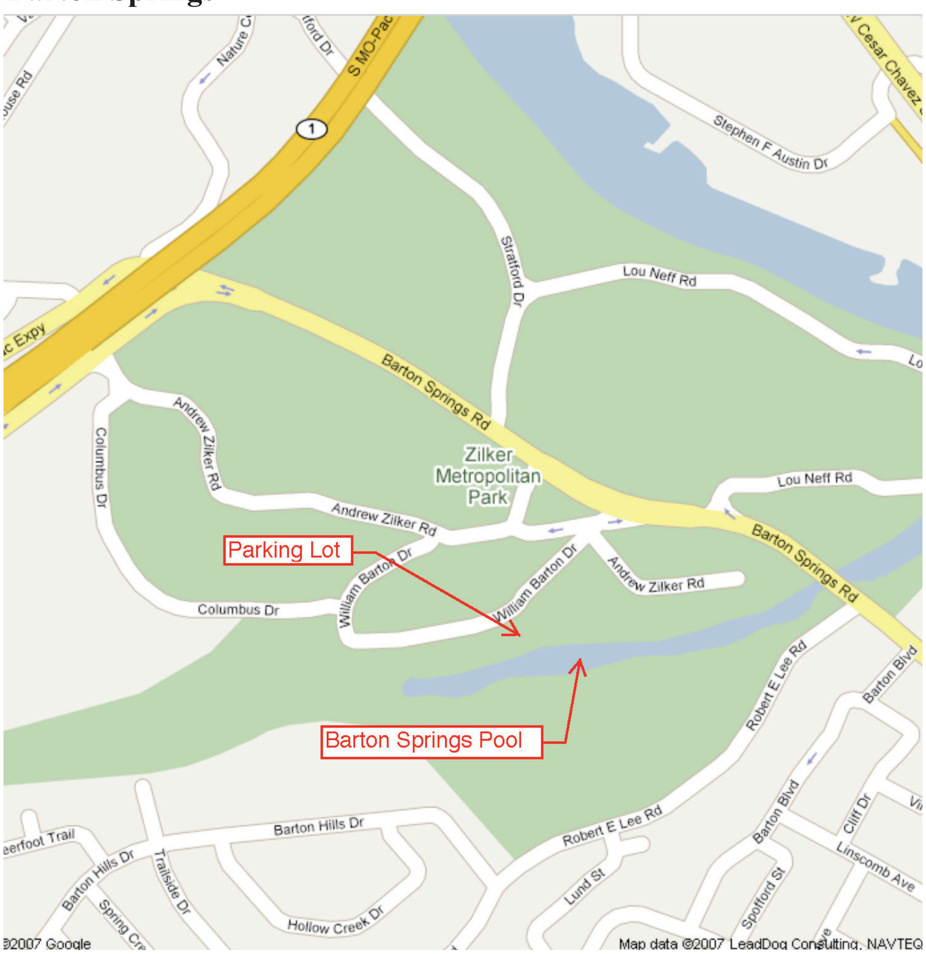
Objectives:

- **Understand the influence of geology on Barton Springs.**
- **Examine impacts of urbanization on water quality and quantity**
- **Examine aquatic life at Barton Springs.**

Related Lesson Plans

- Students visit http://www.esi.utexas.edu/outreach/groundwater/ for an introduction to aquifers and groundwater with an emphasis on the Edwards Aquifer.
- *The Water Cycle and Pollution* – students build models to that demonstrate how the various components of the hydrologic cycle (water cycle) are interconnected and what "powers" the hydrologic cycle. An extension activity allows students to simulate how surface pollution can contaminate an aquifer.
- *Park or Parking Lot* - students build models to help their city decide between building a park or parking lot while considering how the proposed land uses will affect erosion rates and contaminant levels in local streams.
- *SOS Interdisciplinary Guide* - interdisciplinary activities on the natural history, human history and current social issues pertaining to Barton Springs and Barton Creek. Prepared by an Austin social studies teacher and subjects include history, language arts/English, social studies and geography.

Direction to Barton Springs



Executive Summary

At this stop we will discuss the history of, and future challenges faced by Barton Springs; a place that is often referred to as the "Jewel of Austin". Zilker Park is home to Barton Springs, which collectively refers to four major springs in the vicinity of Barton Springs pool. Not only is Barton Springs a major attraction, it is also home to a federally-listed endangered salamander, Euycea sosorum, which is only found at the springs. Barton Springs is also the primary discharge point for the aquifer, and thus an ideal location from which to monitor the overall health of the aquifer and to monitor for changes in water quality as the Austin area continues to grow.

Today we will discuss how local geology, climate and human activities affect water quality and quantity at Barton Springs. Specifically, we will discuss how well pumpage rates have changed over time, groundwater flowpaths to the springs as delineated by dye tracing studies and how the water quality of the springs has changed over time.

Left: Photo of Barton Springs Pool taken from the South banks of Barton Creek in 1926. At that time, the water from Baron Creek flowed into the pool. A bypass tunnel was later installed to divert the normal flow and floods from Barton Creek around the springs. The tunnel lies beneath the sidewalk on the northern end of the pool.

Photo courtesy the Austin History Center, Austin Public Library, C01824

We have in our own city a remarkable natural water resource. Barton Springs, worthy of preservation and studious protection, is an area of beauty that provides wonderful natural swimming and recreation facilities that give pleasure to thousands of Austinites of all ages and visitors from all over the world. Barton Springs heads the list of our natural treasures and, as such, can indeed be called the soul of our city.

James A. Michener
March 1993

Barton Springs and Zilker Park receive a half-million visitors per year. Barton Springs and the natural landscape of the Hill Country is a major draw for people to move to the Austin area. Barton Springs is also home to a federally-listed endangered salamander, *Euycea sosorum*, which is only found at the springs (http://www.ci.austin.tx.us/salamander/). A second blind salamander, *Eurycea waterlooensis*, was recently discovered to inhabit the spring as well.

> Biology: Click here for an excellent short-paper on the endangered Barton Springs Salamanders by City of Austin Biologist, Liza Collucci.

The average flow of the combined Barton Springs is 53 cubic feet per second (cfs). During average flow conditions, water withdrawn from the aquifer by pumpage is about a tenth of Barton Spring's discharge. However, during low flow conditions, when the pumping demands are highest and the aquifer is not readily replenished by rainfall, the proportion of pumping to discharge may exceed 50%. During the drought of the 1950's, Barton Springs flow diminished to less than 10 cubic feet per second. Since that time, levels of pumpage have increased from about 0.66 cfs to an average exceeding 10 cfs (BS/EACD, 2001). Recent groundwater models suggest that under drought conditions similar to that of the 1950's, Barton Springs would flow only a few cfs or dry entirely, until replenished by rainfall (Scanlon and others, 1999). Pumpage can also dry portions of the **Recharge Zone** during drought periods when groundwater would otherwise be present (Slade and others, 1985).

Barton Springs actually consists of four springs, three of which were named after the daughters of the original owner, William Barton. The Main Spring, or Parthenia Spring, discharges into the Barton Springs pool near the diving board. Note the fault along which the main spring discharges (Figure 1.6). The thin bedded rock unit on the southwest side of the fault is the Regional Dense Member, n ear the contact with the underlying Grainstone Member. The Regional Dense Member can be examined along the small bluff across the main parking lot from the pool. The lower Georgetown Formation is exposed on the northeast side of the fault. The offset of the fault is greater than 40 feet but less than 70 feet.

> Social studies: Learn more about Barton Springs namesake, William Barton.
> Click here for an excerpt from *Barton Springs Eternal*

Zenobia Springs, located in the sunken gardens southeast of the main spring, is also called Old Mill Springs. A three-story tall flour mill was constructed on this site in 1879.

Eliza Spring, located behind the concession stand on the north side of the pool, discharges into the bypass tunnel for Barton Creek that lies under the sidewalk on the north end of the pool. Surface flow from upstream Barton Creek passes entirely through this bypass, except during periods of high floodwaters.

Upstream of the Barton Springs pool on the south bank is the Upper Barton Spring. This spring only flows when the other three springs flows combined exceed about 40 cfs.

Groundwater flow to Barton Springs is localized along two major flow paths (Figure 1.4), the Manchaca Flow Route and Sunset Valley Flow Route (Hauwert and others, 2002; BS/EACD , 2002). Both flow routes are strongly influenced by general fault trends. **Recharge** from Onion, Little Bear, Bear, Slaughter, and Lower Barton creeks generally follow the Manchaca Flow Route and discharge from Main, Eliza, and Old Mill Springs. Recharge from Williamson and Barton Creeks generally recharge either Cold Springs (on the Colorado River upstream of Mopac Expressway) or the combination of Upper and Main Barton Springs. Under moderate and high aquifer-flow conditions (where Barton Springs flows greater than 35 cfs) groundwater flow velocity along the major flow routes can exceed 4 miles per day. A dye tracer injected in Onion Creek in July 2002 traveled 17 miles to first arrive at Barton Springs only three days later. Under low aquifer-flow condition, groundwater flow velocities (as determined by the arrival time of dye at Barton Springs) diminished from about 1 mile to 0.6 miles per day across the aquifer. These initial tracer arrival times represent only the fastest component of groundwater flow, some recharge is stored in the aquifer for much longer periods of time. Nevertheless, the Edwards Aquifer is sensitive to water-quality changes far away.

The first recorded contamination of Barton Springs was documented in consulting reports to the City of Austin in 1922, as part of an assessment of possible drinking water resources:

> "The sanitary quality of the Barton Springs water has been a subject of interest for some time. Tests made in 1917 indicated a water of very good quality with only an occasional sample indicating the presence of E-coli. However, in a series of tests made in June and July 1922, Taylor and Schoch obtained a positive E-coli determination in every test. These tests were made daily on each spring and indicate that the flow from the Edwards formation is undoubtedly contaminated, at least intermittently, by surface water in the Hardscrabble country" (Burns and McDonnell, 1922).

Taylor and Schoch (1922) added, "The contamination is undoubtedly due to the many habitations on the Hardscrabble country, and the long distance that the water flows at a comparatively shallow depth below this surface." Thus it was early in the 1900's that bacterial contamination at Barton Springs was recognized, that it originated from "human refuse," that the source for this contamination was far away, and that Barton Springs was too sensitive too be relied on for a regular drinking water source without treatment.

A one year water-quality study, conducted from1981 to 1982 by the U.S. Geological Survey and the City of Austin, found that the constituents measured at Barton Springs indicated drinking water quality, except in association with rain events when levels of **indicator bacteria** and some other constituents rose significantly. Following a storm event, a single reading of an organic compound, diethyl phthalate was 120 micrograms per liter. When rainfall accumulations exceeded 1.5 inches or more per week, **indicator bacteria** counts "peaked during or shortly after each storm and then decreased sharply within several days after the storm" (Freeman, Schertz, Slade, and Rawson, 1984). **Turbidity** also increases sharply after rain events, creating a swimming hazard (Slade, Dorsey, and Stewart, 1986). As a result, Barton Springs pool is closed following larger rain events when the turbidity is high.

When discussing the quality of Barton Springs for swimming, it is important to recognize the following:

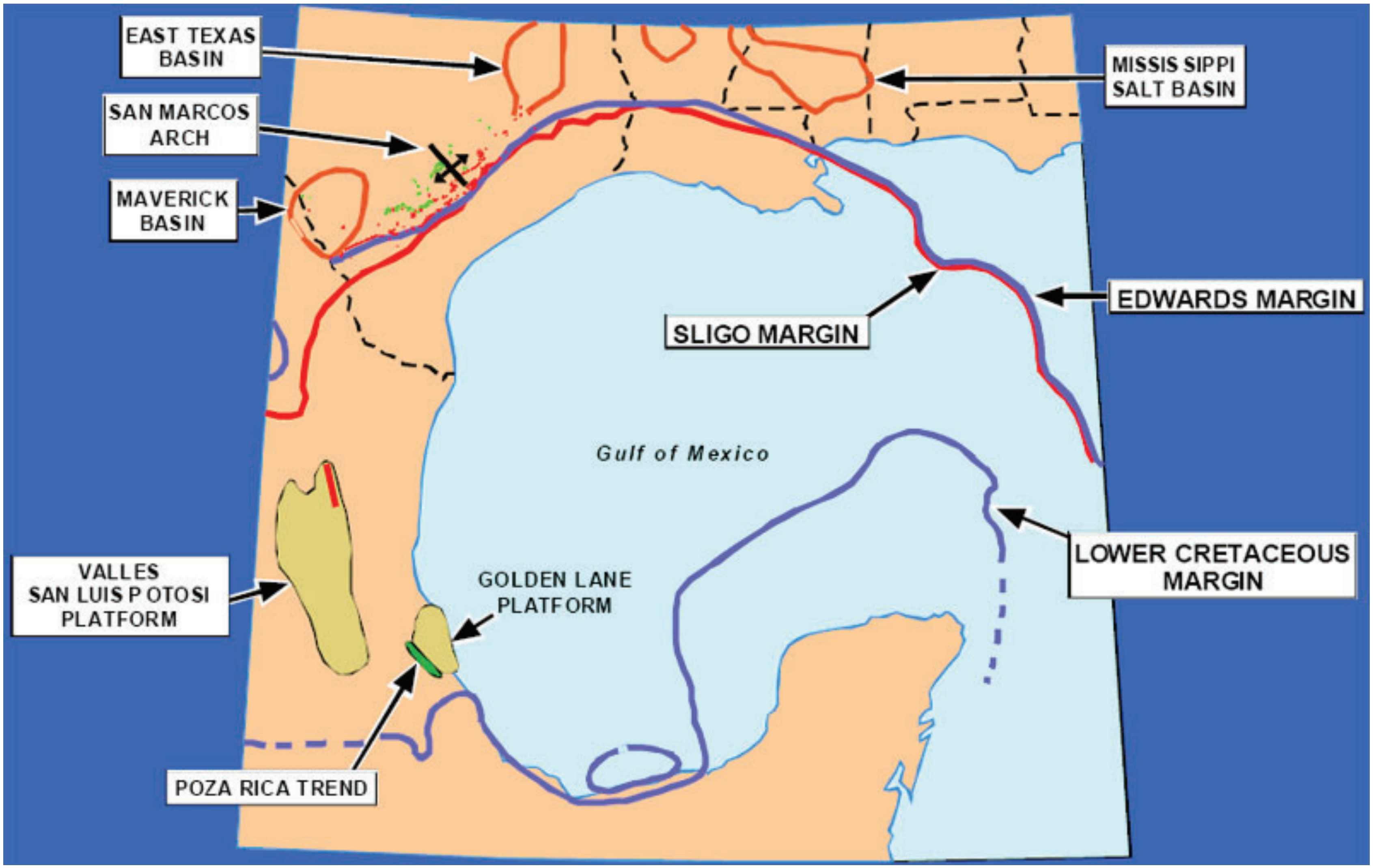
1) Water-quality standards for swimming are higher than standards for public water supply systems for many constituents such as **indicator bacteria**. The water quality of most natural swimming holes and swimming pools is not tested. State toxicologists suggest one of the best indicators for the safety of swimming at Barton Springs is to look at the number of incidences of acute health complaints from swimmers.
2) All or nearly all of the incidences of higher levels of constituents of concern in the water were measured at times of high **turbidity**, after large rain events when the pool is closed, or from known incidences of contamination which were identified and corrected (such as from a nearby leaking wastewater line). In many cases, these high normal levels of constituents are tied to sediments that settle to the bottom of the pool and are buried.
3) The upstream dam and the sidewalk bypass diverts water from upstream Barton Creek around the pool. Therefore, **hydraulic connection** between Barton Creek and the Barton Springs pool occurs though **recharge** in the creek bottom upstream of the pool (near the Loop 360 overpass) and through infrequent floods that overtop the dam.
4) Barton Springs and water bodies in the Austin area have seen more extensive water-quality sampling than most places in the world since 1978. Still, when considering water-quality assessments, it is important to recognize that each sample is tested for a limited number of constituents, they may not always reflect changes observed around rain events and other differing conditions, and that **detection limits** vary but generally have improved over time. Errors or differences in sampling techniques can lead to differing results. Samples that do not have associated verification and/or quality assurance samples are difficult to evaluate for accuracy. To further complicate the assessment, laboratories can, and do make errors, and some laboratories have been accused of fabricating results.

Currently, regular samples taken from Barton Springs show higher levels of **indicator bacteria** than in wells sampling the aquifer. This is because Barton Springs is the **down-gradient** discharge point for every possible contamination site in the aquifer, and groundwater flow along the major flow paths is too fast to significantly reduce contaminants. Although no longer a viable (untreated) drinking water source, the quality of Barton Springs appears to be excellent for recreation. However, the continued degradation of Barton Springs water quality with increasing urbanization is predictable, based on studies of urbanization both in the City of Austin and across the nation. Disturbance from **urbanization** is correlated to levels of **impervious cover** in most cases. Some land use types, such as golf courses and landfills, may produce poorer quality of runoff than their corresponding level of impervious cover might suggest.

The local newspaper has recently reported in early 2003 that an adjacent apartment complex overlay an abandoned landfill where coal tar wastes were supposedly dumped, contaminating an upstream tributary of Barton Creek and Barton Springs with polyaromatic hydrocarbons. However, further testing indicates the PAH contamination of the upstream minor creek tributary actually originates from a parking lot sealant containing coal tar, as was previously suspected by the City and verified with shallow borings across the apartment complex site. The bypass dam hydraulically separates the minor creek tributary and Barton Springs pool, so there is no indication that this tributary is contributing to contamination in Barton Springs pool except possibly during flooding when Barton Creek overtops the pool upstream dam.

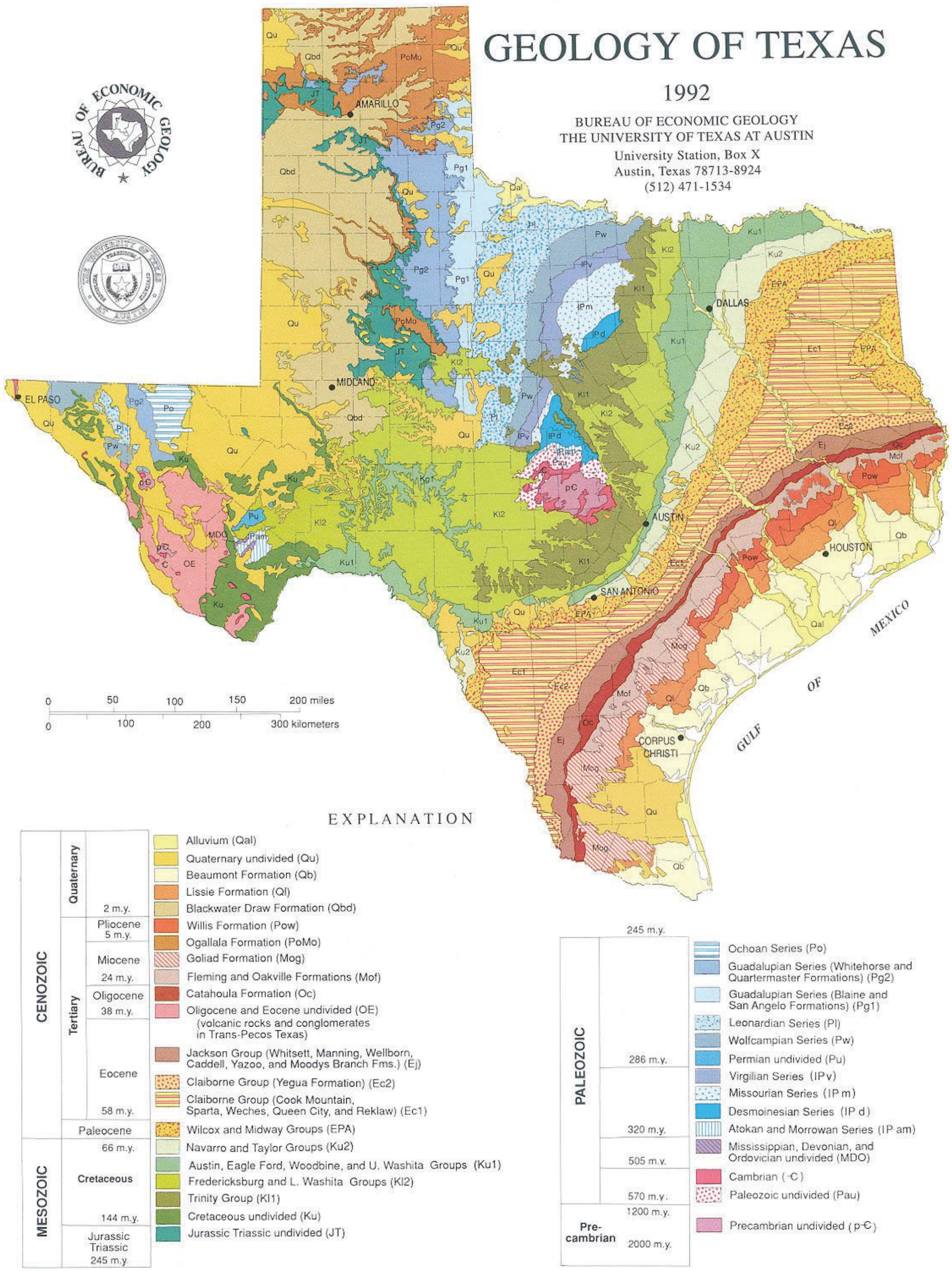
> Social Studies: Click here for links to several articles on perceived threats of pollution to Barton Springs.

Figure 1.1: Location map of Gulf of Mexico region, showing regional setting of Lower Cretaceous shelf-margin carbonates



http://www.searchanddiscovery.net

Figure 1.2: Geologic map of Texas.



http://www.lib.utexas.edu

Figure 1.3: The Barton Springs Segment of the Edwards aquifer

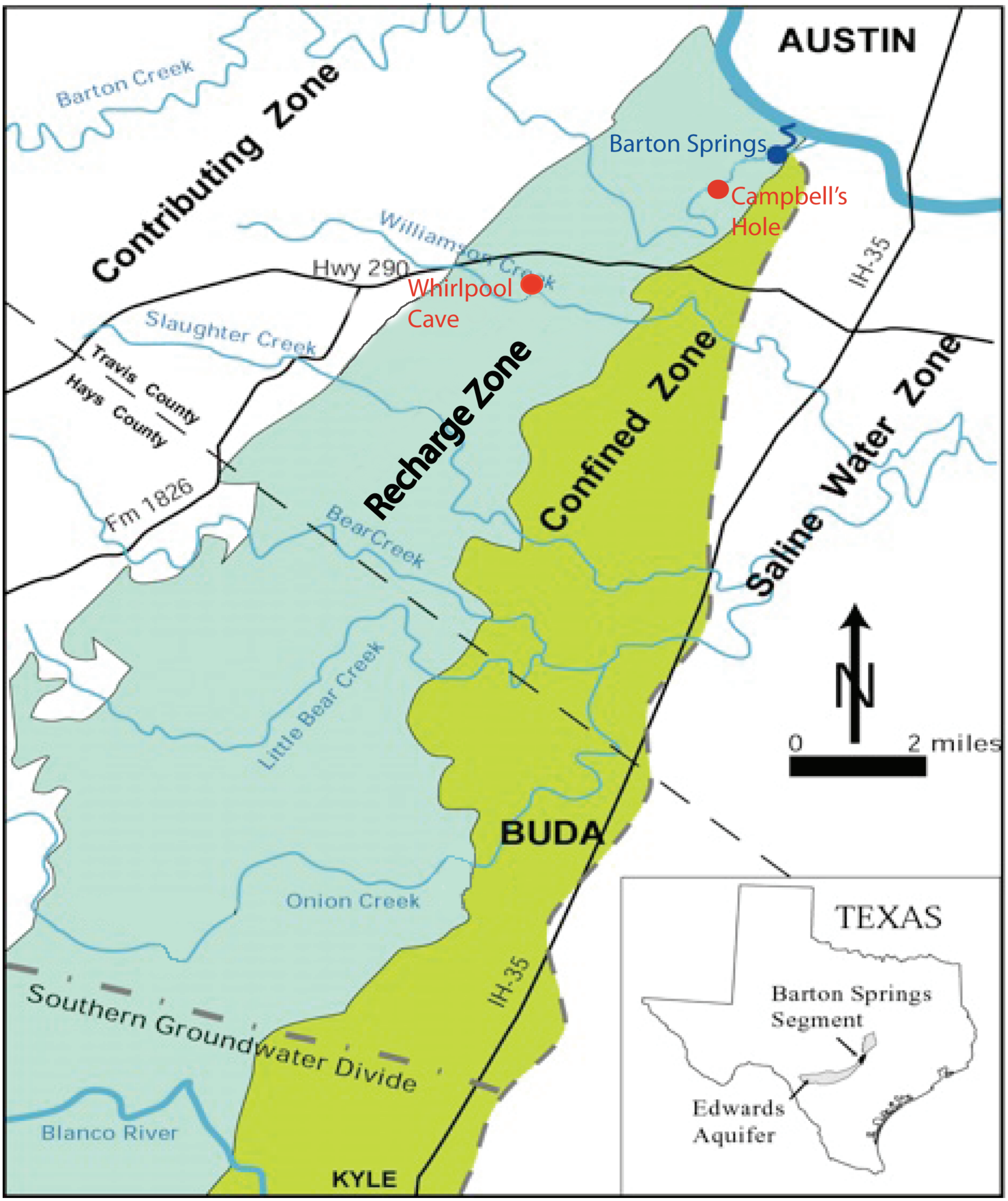
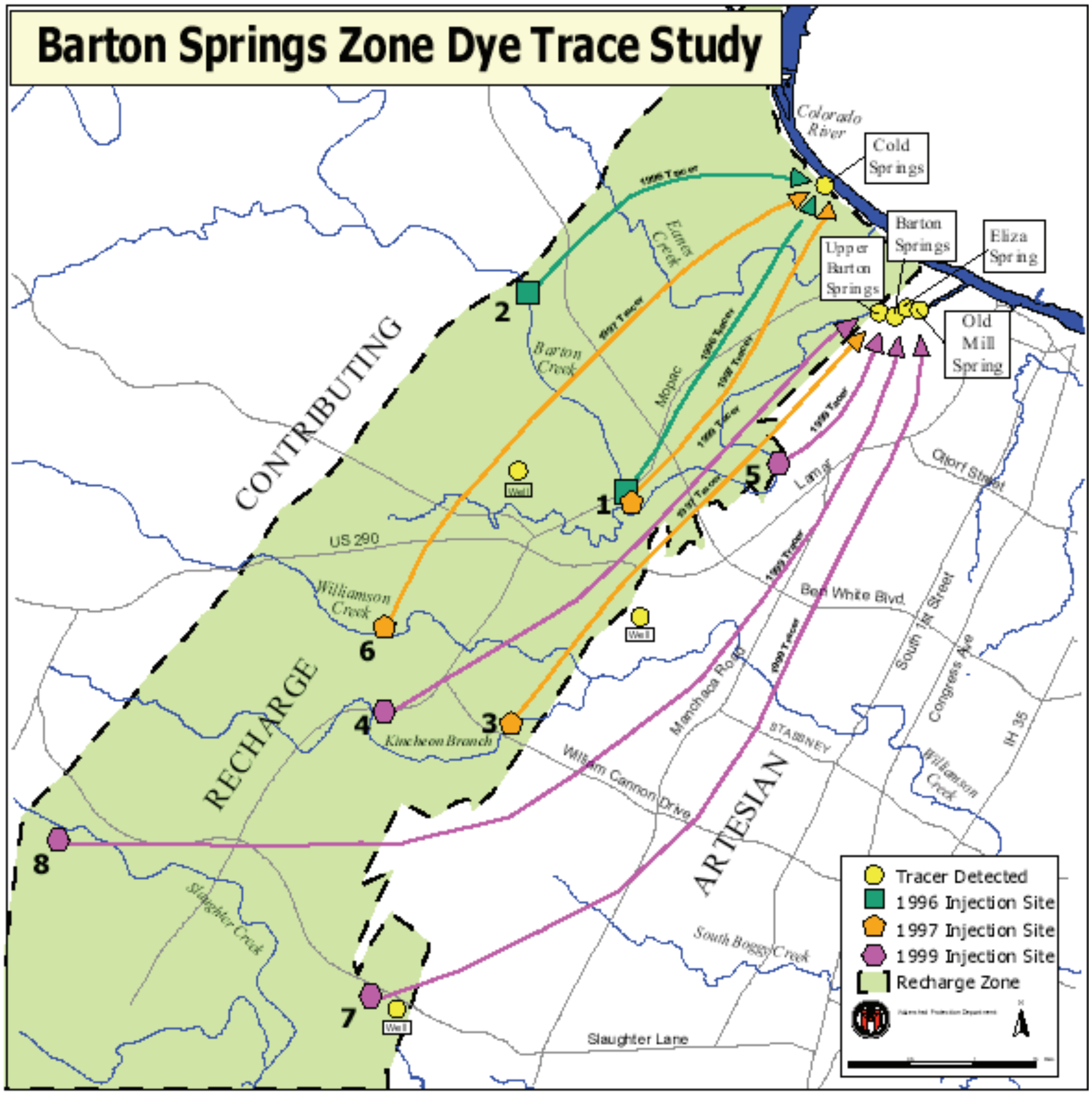


Figure Modified From City of Austin, WPDR

Figure 1.4: Map of dye tracing studies conducted in the Barton Springs Segment of the Edwards aquifer



Dye Input Number on Map	Dye Input Location	Aquifer Conditions	Miles Traveled	Days	Rate (miles/day)
1	Mopac bridge	Dry	3.2	5	0.6
1	Mopac bridge	Wet	3.2	0.8	4.1
2	Lost Creek area	Dry	2.7	5-6	0.5
3	Kincheon Branch	Wet	4.5	1	3.6
4	Whirlpool Cave	Wet	5.5	3	1.5
5	Westhill Driv	Wet	1.8	0.4	4.1
6	Brush Country Road	Wet	5.2	8	0.7
7	Brodie Sink	Wet	7.4	1-2	3.7
8	Midnight Cave	Wet	8.3	7-8	1.1

Figure & Data from City of Austin, WPDR

Figure 1.5: Aerial view of Barton Springs in downtown Austin

Figure 1.6: Geology of Barton Springs Pool

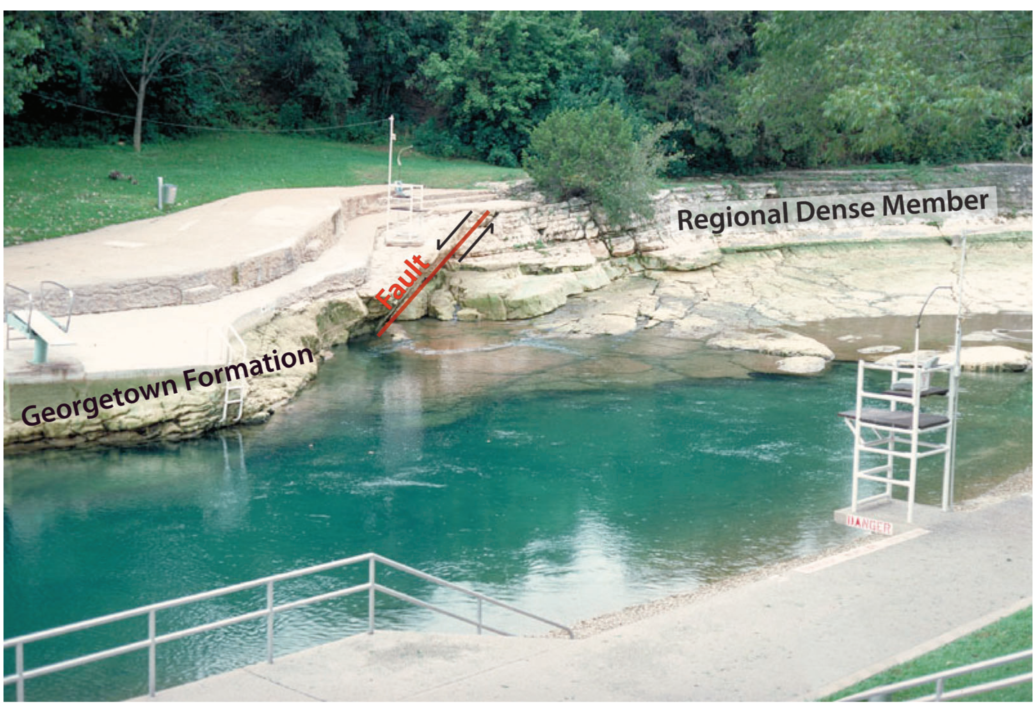


Photo Modified from http://edwardsaquifer.net/

Figure 1.7: Satellite photograph of Barton Springs and Campbell's Hole

Stop 2: Campbell's Hole

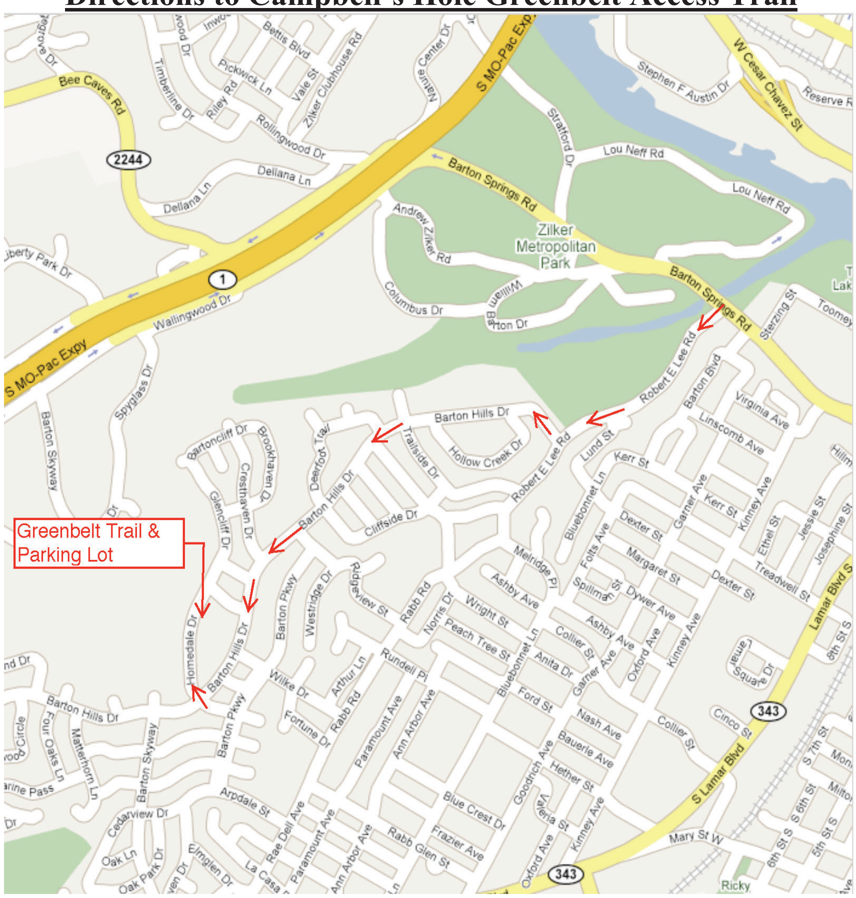
Objectives:

- **Understand the depositional setting of the Edwards Group.**
- **Examine fossils in the Edwards Group.**
- **Understand the roles of the different zones of the Barton Springs segment of the Edwards Aquifer.**

Related Lessons

- *Porosity & Permeability*- Two lessons that allow students to understand how water flows underground and that various earth materials (including the rock units at Campbell's Hole have different porosity and permeability values.
- *What is a watershed*- After some classroom preparation, this lesson is completed in the filed as students walk to Campbell's Hole. Students examine various characteristics of a watershed and how humans have impacted that watershed.
- *SOS Interdisciplinary Guide* - interdisciplinary activities on the natural history, human history and current social issues pertaining to Barton Springs and Barton Creek. Prepared by a Austin social studies teacher and subjects include history, language arts/English, social studies and geography

Directions to Campbell's Hole Greenbelt Access Trail



Directions to Campbell's Hole From the Barton Hills Access Trail

This stop is easily accessible for school groups from the rear of Barton Hills Elementary (see map above, 2010 Homedale Road) or from the Spyglass Road access east of Loop 1 Mopac Expressway and Bee Caves Road. Some elementary school classes have enjoyed walking the mile from Barton Springs Pool to Campbell's Hole. For our field trip, we will enter via the Barton Hills access trail. Take the right fork just past the trailhead and follow that trail to the bottom of the hill (use caution as the trail is steep and unpaved). Before reaching Barton Creek at the bottom of the hill, take the right fork and continue on the wooded trail that follows along the east bank of Barton Creek (see photo below).

A short distance down the trail, you will reach another fork. Continue to the right across the small wooden bridge (see photo below).

Shortly after crossing the wooden bridge the vista opens to see the cliff at Campbell's Hole (see picture below), a popular inner-city recreational swimming/kayaking spot when the creek is flowing.

Crossing Barton Creek is not advisable when strongly flowing! Check flow conditions on the USGS website for Barton Creek at Loop 360 (Colorado River watershed) at:
http://waterdata.usgs.gov/tx/nwis/uv/?site_no=08155300&PARAmeter_cd=00065,00060
or
http://waterdata.usgs.gov/tx/nwis/current/?type=flow (for all the flow stations in Texas, including Barton Springs). If river discharge at Loop 360 is 30 cubic feet per second (cfs) or higher, you should strongly consider not entering the creek. Always rely on your best judgment! When the creek is strongly flowing, the site we visit today can be accessed from the Barton Hills access point by walking downstream along the banks instead of through the creek channel. Be aware this site may not be accessible during flooding conditions. Always check the weather forecast and remember that Barton creek is subject to flash flooding during heavy rain events!

<u>*Executive Summary*</u>

Campbell's Hole, a popular swimming hole in South Austin, is a wonderful place to view the rock units that make up the upper third of the Edwards Aquifer. The rocks, which are exposed on a large cliff, were laid down approximately 100 million years ago when a shallow inland sea covered much of Texas. At least five informal hydrostratigraphic units of the Edwards Aquifer are distinguishable (from top to bottom): the Georgetown Formation, the Leached and Collapsed Members, the Regional Dense Member, the Grainstone Member, and the Kirschberg Member. Today we will discuss the different depositional environments that theses units were formed in and how that affected the characteristics of each unit and fossils found within them. We will also discuss how faulting and the makeup of the rock units themselves influence groundwater flow in the Edwards Aquifer.

Left: Photo of Barton Creek near Campbell's Hole in April. Campbell's Hole is a popular recreation spot for swimmers and kayakers when the creek is flowing.

Photo from Wikipedia Commons

"Rocks are records of events that took place at the time they formed. They are books. They have a different vocabulary, a different alphabet, but you learn how to read them."

John McPhee
Geologist

Campbell's Hole cliff shows a nice cross section of the rocks making up the upper third of the Edwards Aquifer (Figure 2.6). The Edwards Group (Figure 2.1) was originally named the Barton Creek Limestone because of its excellent exposure of this unit. Turn of the century geologist Robert Hill mapped the individual beds in this exposure to better understand and correlate the Edwards Group (Figure 2.2).

The rock units exposed at the surface in South Austin were deposited during the Cretaceous period, roughly 100 million years ago. Texas was a much different place during the Cretaceous. A shallow inland sea covered most of Texas. During the Early to Middle Cretaceous the marine waters were very shallow in a lagoon extending for hundreds of miles across central Texas. A large reef front laid midway between current Austin and Houston, receiving the force of high-energy waves and restricting circulation of marine waters over central Texas (Rose, 1972). As a consequence, the central Texas marine waters were generally tranquil with a relatively high salinity, resembling the modern Caribbean with its warm, clear waters and reef growth. Shelled organisms were capable of incorporating minerals from the water into their shell structure. The most common minerals in this environment, **carbonates**, include the common and sometimes clear mineral **calcite**. As water levels gradually rose during the Cretaceous period, shells, carbonate sands, and minerals precipitated directly from the restricted marine water and built up into sequences of material several hundred feet thick. Periodically, shorelines and islands became exposed in the Early to Middle Cretaceous of central Texas. In the Zilker Park botanical gardens, remains of freshwater reeds, turtle shell, and dinosaur footprints were uncovered, suggesting the proximity of shoreline and freshwater during that specific interval (upper Regional Dense Member of Person Formation, Edwards Group;

Dinosaur footprints are commonly found in the rocks of the Trinity Group across central Texas (Lockley, 1999; Lockley and Hunt, 1995). In the Cretaceous rocks of the Big Bend area, the remains of the largest flying creature to ever live, the reptile *Quetzalcoatlus*, were found and are now displayed at the UT Texas Memorial Museum (http://www.tmm.utexas.edu/exhibits/pterosaur/index.html). Later in the Cretaceous the marine waters deepened considerably and underwater volcanoes became very active. The remnants of two volcanoes can be seen in the Austin are. The ash deposits of one of these volcanoes can be viewed across the street from Saint Edwards University in the Blunn Creek preserve (just west of Oltorf and IH 35). The second volcano remnant is Pilot Knob, which appears as a prominent hilltop just south of Bergstrom airport on Highway 183. A water tanks now stands on top. In the rock intervals of the Georgetown Limestone, Del Rio Clay, and Austin Chalk that overlie the Edwards Group, remains of large swimming reptiles are found in the Austin area, such as mosasaurs, (http://www.tmm.utexas.edu/exhibits/mosasaur/index.html) and pleisosaurs (http://www.tmm.utexas.edu/exhibits/scratching/plesio.html). The remains of these swimming reptiles can be viewed at the Texas Memorial Museum.

Here at Campbell's Hole, at least five informal **hydrostratigraphic units** of the Edwards aquifer are distinguishable (Figure 2.3): the Georgetown Formation, the Leached and

Collapsed Members, the Regional Dense Member, the Grainstone Member, and the Kirschberg Member (Small and others, 1996). Each of these units are primarily **limestone**. These **hydrostratigraphic** units have differing characteristics and fossils that reflect differing conditions under which the rocks were laid. The **hydrostratigraphic** units also differ in their influence on groundwater flow. The most **permeable** of these units are the Leached and Collapsed Members and the Kirschberg Member, and this fact is reflected by the presence of caves in the Campbell's Hole cliff specifically within these layers.

> Social Studies: Learn more about the Greenbelt environmental and political issues. Click here for an excerpt from *Barton Springs Eternal* and click here for an article from the *Austin Chronicle*.

From the Barton Hills trailhead we will start in the Georgetown Formation. Although part of the Edwards Aquifer, the Georgetown Formation was deposited under deeper marine water and different conditions than the rocks of the underlying Edwards Group. The lower Georgetown is typically nodular, meaning it weathers into smaller fragments, and has a yellow or orange oxidized color on fresh surface. In many **outcrops** (including this one), the Georgetown can appear to be just as hard and massive as the Edwards Group. It consists of a **fossiliferous packstone** containing the rounded **brachiopod** *Kingena*, pectins, and abundant oysters shells including *Gryphea* and *Arctostrea carinata* (see fossil guide in appendix for pictures). Further along the path, an orange-stained surface indicates the contact with the underlying Leached and Collapsed members of the Person Formation, Edwards Group. After the Edwards Group was laid down and **lithified** into rock, it was exposed and eroded. In fact, the upper 100 feet of the Edwards Group, seen 20 miles south of here in Hays County, is missing at Campbell's Hole. The Leached and Collapsed Members of the Edwards Group are typically more massive, tan to light brown **wackestones** containing some chert horizons and fossils of *Toucasia.* Some of the more soluble and permeable layers of the Person are largely recrystallized as **sparites**. The more visually distinctive **hydrostratigraphic** unit observed on the cliff is the thin-bedded Regional Dense Member. It is a mudstone with very few fossils, however, iron-stained burrows and mudcracks are commonly observed in this rock unit (Figure 2.5).

Groundwater flow is also influenced by structural features such as faults and fractures. During the Miocene Period (roughly 10 million years ago), intense fracturing and faulting occurred along a relatively narrow band known as the Balcones Fault Zone. Faults are fractures along which one side moved relative to another, as evidenced by an offset in rock layers across the fracture, **slickenlines** or **slickensides** (Figure 2.4) on the fault surface, **breccia** (consolidated broken or crushed rock fragments), or unusual mineralization (such as the appearance of large calcite crystals). The faults associated with the Balcones Fault Zone are generally oriented northeast-southwest and strongly influence the flow of groundwater in the Edwards Aquifer.

At Campbell's Hole bluff, a major fault is distinguishable by a thicker line of vegetation and lack of continuity of the rock layers (Figure 2.3 and Figure 2.6). The thin bedded

Regional Dense Member can be visually followed on either side of the fault and appears to be offset about 30 feet. We will look up close at the fault to see distinctive fault features.

Over 50 million years of erosion exposed the geologic units underlying the Edwards Group, the Glen Rose Formation of the Trinity Group, on the west side of Austin. The upper portion of the Glen Rose Formation consists of alternating **marls** (clay-rich limestone) and more massive limestone beds. It is considerably less permeable to water, thus creeks flowing across upper Glen Rose Formation tend to gain flow from perched springs rather than lose flow to the underlying rock. As a result, the watersheds of Barton and Onion Creeks gain considerable flow from this **contributing zone**.

The **recharge zone** of the Barton Springs segment of the Edwards aquifer is roughly five miles wide and extends roughly 20 miles long, from the Colorado River south to the Buda and Kyle areas (Figure 1.3). Within the **recharge zone**, rocks of the Edwards Group and overlying Georgetown Limestone are exposed at the surface. Fracturing associated with the Balcones Fault Zone and preferential dissolution of the rocks by rainwater, produced voids that store underground water. An **aquifer** is a porous rock that can produce sufficient quantities of water of useable quality.

East of the recharge zone, the Edwards Group and Georgetown Limestone are buried progressively deeper underneath clays, **shales**, and less permeable **limestone** units as faults generally drop further down to the east. In this area, known as the **artesian zone**, the water-levels of the Edwards aquifer can rise above the top of the aquifer in a well. In some flowing artesian wells located in low elevations, groundwater actually rises directly to the surface without mechanical pumping. Generally east of Congress Avenue and Interstate 35, groundwater is very slow moving and restricted in the Edwards Aquifer and is highly saline due to the long period of **residence**. This eastern boundary of the Edwards Aquifer is known as the "bad-water line" or **saline-water line** (Figure 1.3).

In this field trip we focus on the Barton Springs segment of the Edwards aquifer, but there are other segments that are much larger. Also included in the Balcones Fault Zone (BFZ) is the San Antonio segment that extends from the Kyle area to San Antonio and west to Del Rio. The northern segment of the BFZ portion of the Edwards Aquifer extends from the Colorado River north through Salado to the Waco area. The largest portion of the Edwards Aquifer is the often overlooked Edwards Plateau segment, which covers large portions of central and west Texas.

> Social Studies: Learn more about the early Native Americans and Spanish inhabitants of the Barton Creek Watershed. Click here for an excerpt from *Barton Springs Eternal*.

Figure 2.1: Hydrostratigraphic units of the Edwards aquifer Region

Hydrogeologic subdivision				Group, formation, member	Thickness (Feet)	Porosity / permeability type
UPPER CRETACEOUS	UPPER UNITS			Navarro Group, Upper Taylor Marl undivided and Escondido Formation	200 - 580	Low porosity / low permeability
				Anacacho Limestone and Pecan Gap Chalk	300 - 500	Southern Bexar Co. has some water bearing strata
				Austin Chalk	200 - 350	Minor aquifer that is locally interconnected with the Edwards Aquifer
	UPPER CONFINING UNITS			Eagle Ford Group	30 - 50	Low permeability
				Buda Limestone	40 - 50	Low porosity / low permeability
				Del Rio Clay	40 - 50	None / primary upper confining unit
LOWER CRETACEOUS	EDWARDS AQUIFER			Georgetown Formation	2 - 20	Low porosity / low permeability
		EDWARDS GROUP	PERSON FORMATION	Cyclic and marine members, undivided	80 - 90	Laterally extensive; secondary porosity/ water - yielding
				Leached and collapsed members, undivided	70 - 90	Porosity developed along fractures or faults, permeable beds of collapse breccia, burrow biomicrities, honeycombed and laterally extensive, one of the most permeable
				Regional dense member	20 - 24	Negligible porosity and low permeability; vertical barrier
			KAINER FORMATION	Grainstone member	50 - 60	Cavernous, honeycombed layer and interparticle porosity
				Kirschberg evaporite member	50 - 60	One of the most permeable. Boxwork porosity in breccia or by burrowed zones
				Dolomitic member	110 - 130	Porosity developed along fractures or faults, honeycombed and laterally extensive, and water yielding
				Basal nodular member	50 - 60	No permeability in subsurface
	Lower confining unit			Upper member of the Glen Rose Limestone	350 - 500	Relatively impermeable

From Maclay and Small (1976)

Figure 2.2: Measured geological section of Barton Creek at Campbell's Hole, Deep Eddy (Cold Springs) Bluff and Bee Creek

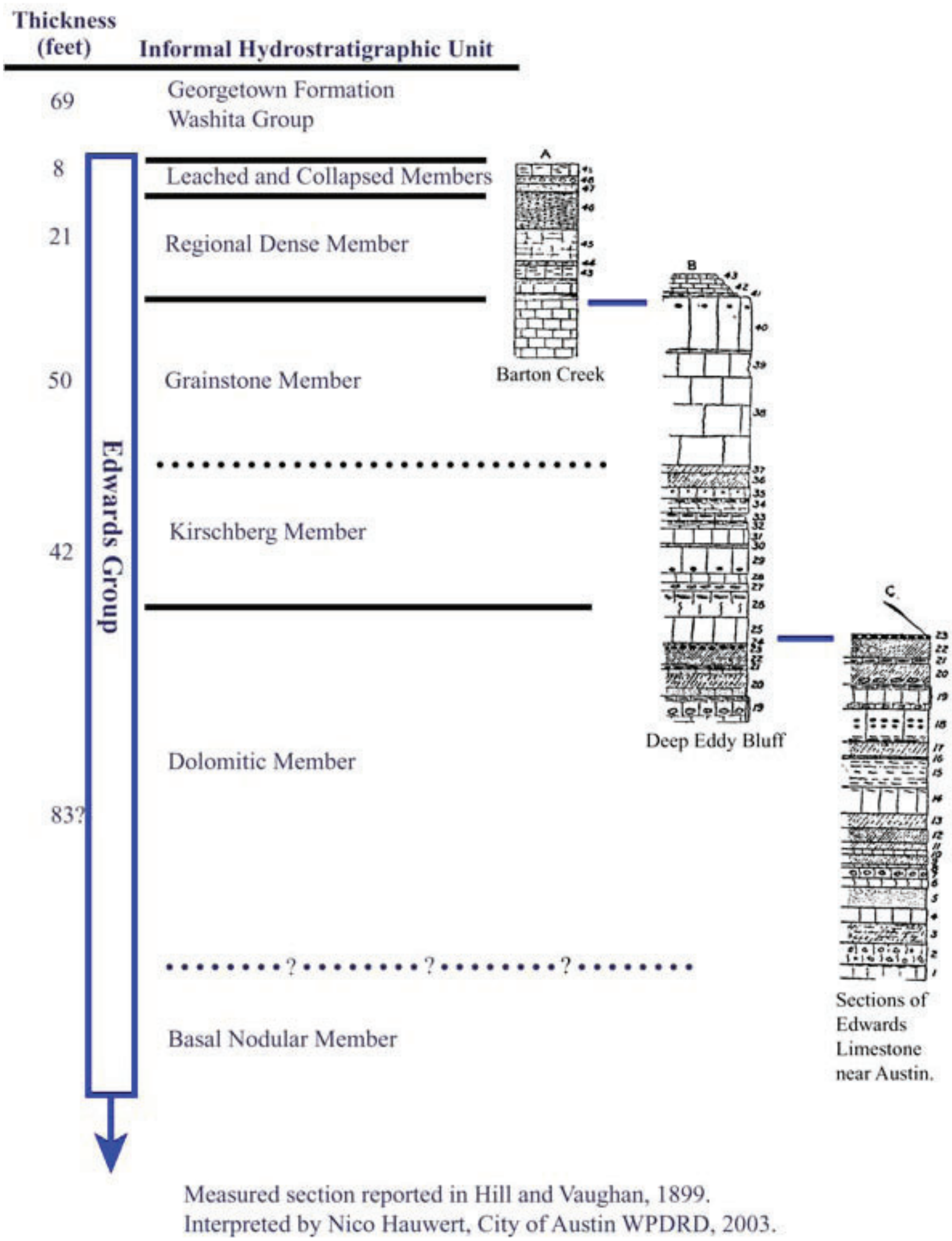
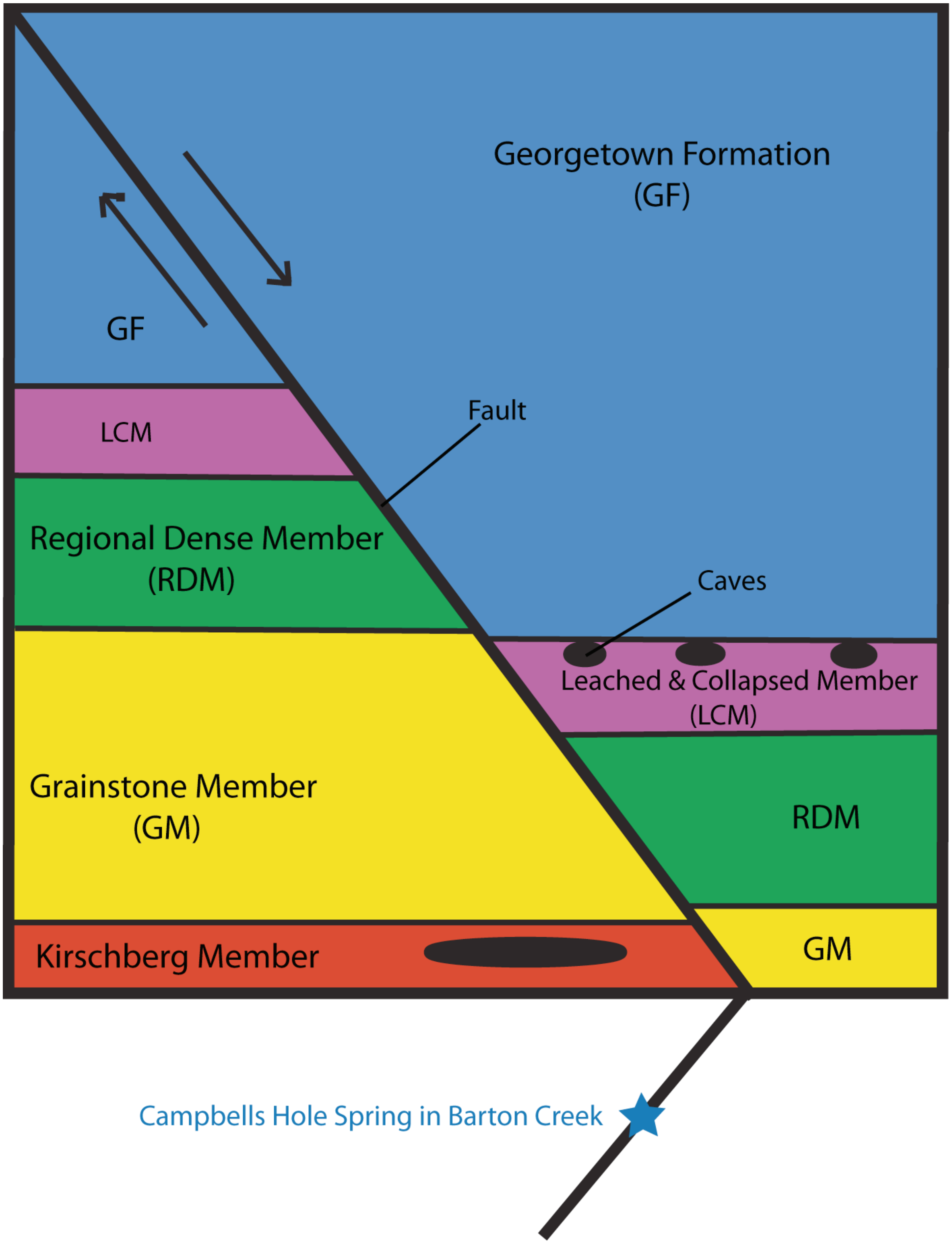


Figure 2.3: Slickenlines on rocks along the fault zone at Campbell's Hole. Slickenlines indicate that rocks have moved past one another along a fault plane.

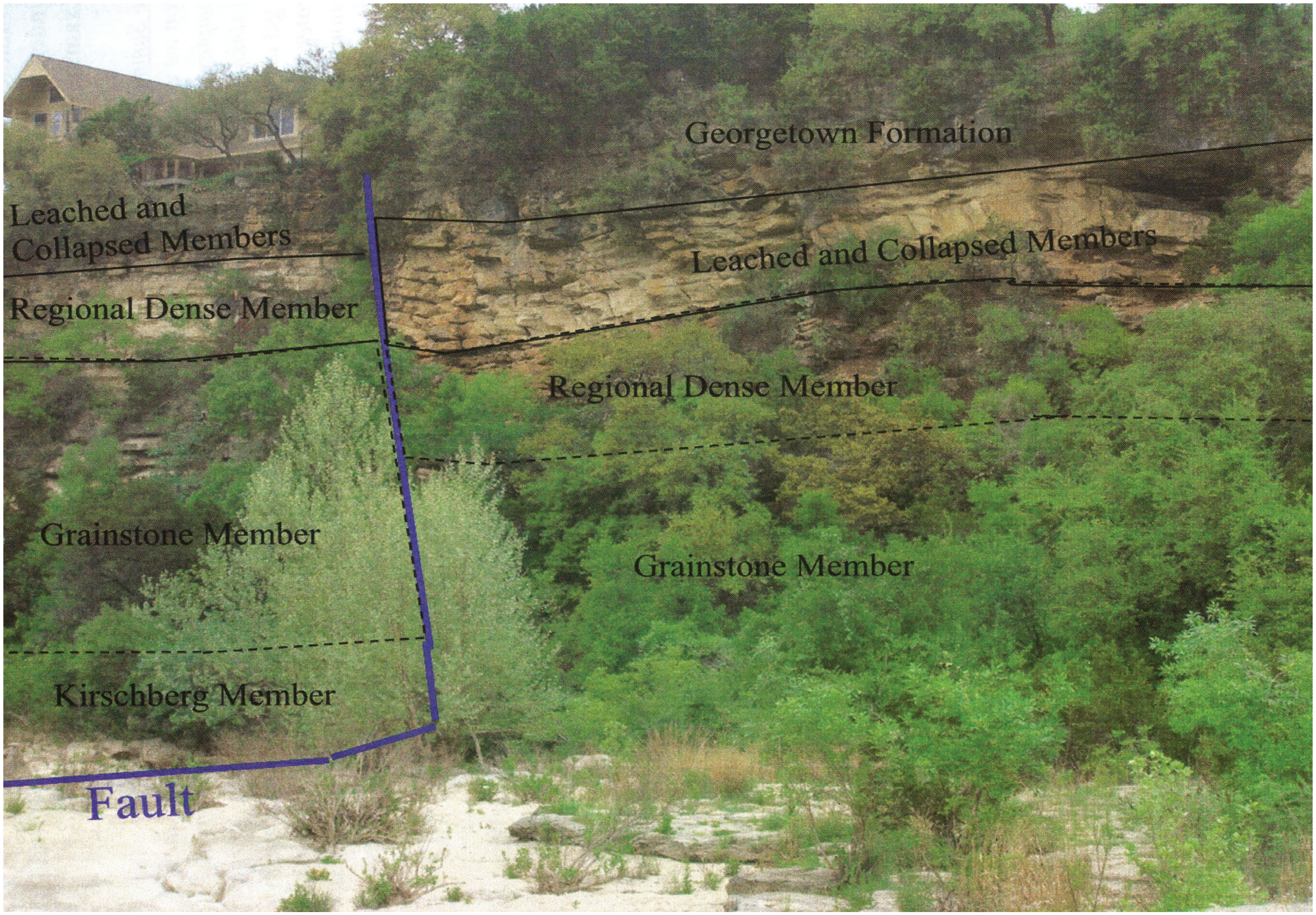
Figure 2.4: Fossilized burrows in the Regional Dense member at Campbell's Hole

Figure 2.5: Sketch of geologic features on Campbell's Hole bluff on Barton Creek



Prepared by Nico Hauwert, City of Austin, WPDR, 2003)

Figure 2.6: Geologic Interpretation of Campbell's Hole Outcrop



<u>Stop 3: Whirlpool Cave</u>

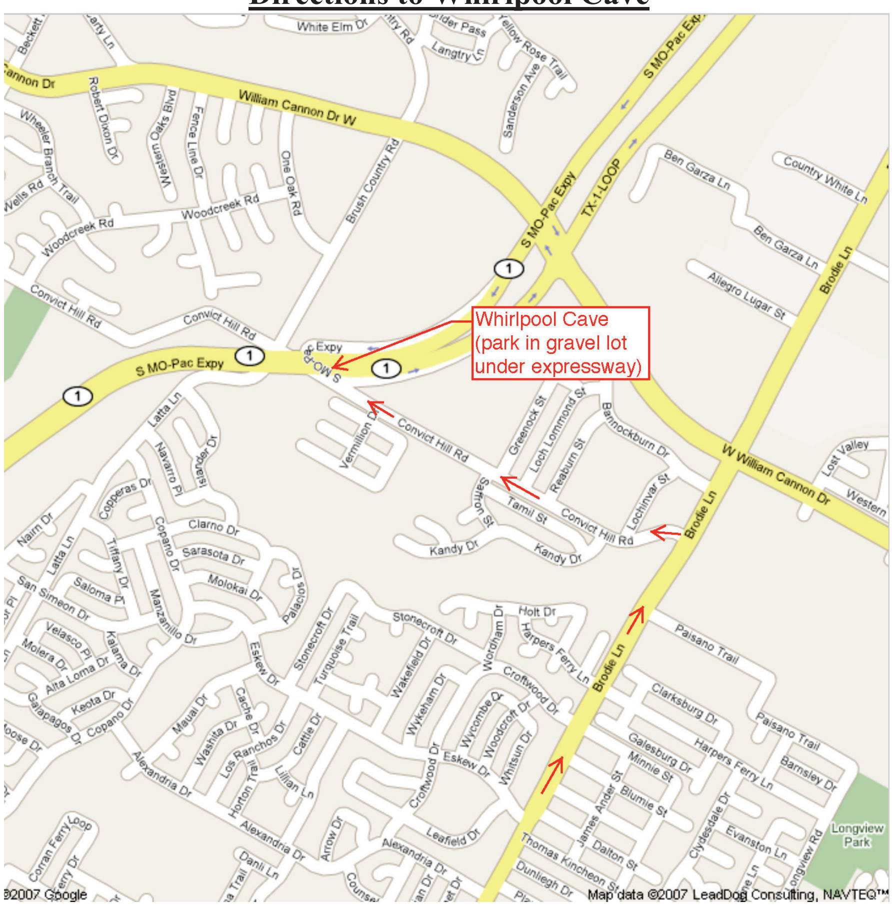
Objectives:

- **Discuss how karst aquifers form**
- **Discuss the vulnerability of karst aquifers to pollution due to rapid groundwater recharge through caves and sinkholes like this one.**
- **Take CO_2 measurements (outside and inside the cave) and discuss seasonal fluctuation of CO_2 in Austin caves.**

Related Lesson Plans

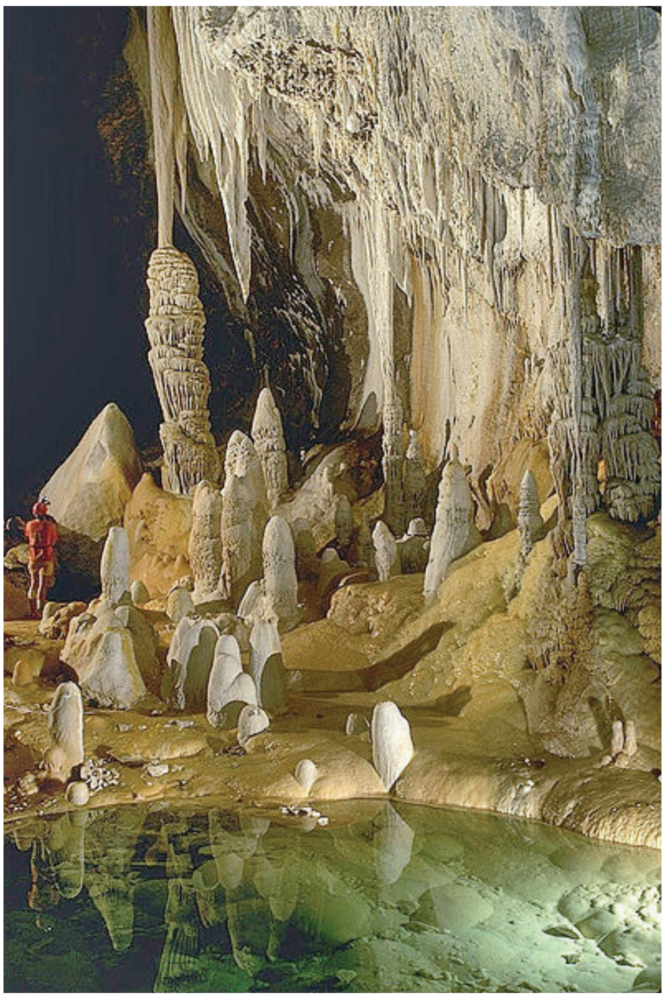
- Students visit http://www.esi.utexas.edu/outreach/caves/ for an introduction to caves and karst with an emphasis on the Edwards Plateau region.
- *<u>Cave Formation and Water Movement in Karst</u>*- Students build models that demonstrate how water creates caves and karst landscapes.
- *<u>Learning to Live With Caves and Karst</u>*- An excellent collection of short readings and lessons on caves and karst. Including how caves form, the cave ecosystem, cave art, the economic importance of caves and how living on karst landscapes affects humans.

<u>Directions to Whirlpool Cave</u>



Executive Summary

At this stop we will discuss how karst aquifers (like the Edwards) are formed and how these highly complex landscapes evolve through time. We will discuss internal drainage sinkholes and how these sinkholes affect runoff and groundwater recharge. We will also see first-hand the erosive power of water on limestone in Whirlpool Cave, one of the most visited "wild caves" in the Austin area. Today we will only be traveling a short distance into the cave, to a large room called the Travis County room. We will be able to see the results of limestone dissolution first hand, and discuss how polluted water might quickly reach the aquifer by flowing through large cavities such as Whirlpool Cave. We will also discuss some unique scientific research projects that have been conducted in Whirlpool Cave and other caves in the Austin area.



Left: Photo of Lechuguilla Cave in New Mexico. Is the deepest cave in the United States and is considered by most cavers to be on of the most pristine caves in the world. Lechuguilla Cave is only open to scientific research, exploration and surveying trips and to National Park Service management trips.

Photo from Wikipedia Commons

Take nothing but pictures. Leave nothing but carefully placed footprints. Kill nothing but time.

The Caver's Creed

Formation of Karst Aquifers

Karst aquifers, such as the Edwards aquifer, are formed when slightly acidic waters dissolve away limestone to form voids within the rock. The acid responsible for this weathering is typically **carbonic acid,** and is formed when carbon dioxide and water come into contact. In most **karst** aquifers, **carbonic acid** is produced in the soil as infiltrating water is enriched in carbon dioxide gas that is given off by bacteria as they consume organic debris in the soils. Over time, this process forms cavities and caves within the limestone rock. For a great animation of how caves form visit http://www.pbs.org/wgbh/nova/caves/form.html.

As a **karst** aquifer matures, more of its rainfall runoff is directed underground. This creates a very efficient **internal drainage** system, where water can flow into caves and sinkholes rather than into streams and lakes. In the vicinity of the nearby Goat Cave Nature Preserve, many large and overlapping **internal drainage sinkholes** insure that little surface runoff contributes to the major creeks, except during unusually heavy rain events. In the Edwards aquifer, solution cavity development seems to be controlled by the geologic units (rock layers) that form the aquifer. In the less permeable rock units, such as the Georgetown Formation, the Regional Dense Member, the water tends to cut downward through the rock forming vertical shafts. In the more permeable rock units, such as the Kirschberg (the unit that much of Whirlpool cave is formed in), the water tends to cut laterally forming more horizontal passages. In Whirlpool Cave, we will see how the geologic units control whether the cave passage is vertical or horizontal.

Whirlpool Cave

Whirlpool Cave is located on a 4.4 acre preserve that is managed by the Texas Cave Management Association (www.tcmacaves.org). The cave entrance, located just east of Mopac expressway within the bed of West Williamson Creek, is marked by a large concrete structure that is used to stabilize the entrance and protect the cave from trespassers. The cave is located within the Grainstone Member and the Kirschberg Member of the Edwards Group, which we were able to see outcropping at Campbell's Hole. The cave passages stretch over 1,300 feet in length, but only reach a depth of approximately 50 feet at its deepest points (Figure 3.1). As you enter the cave you will crawl down a series of short drops, which quickly descend through the Grainstone Member, a less permeable geologic unit. Most caves located within the Grainstone Member are more vertical, like this portion of Whirlpool Cave. At the bottom of these drops you will enter the more permeable Kirschberg Member, which the remaining 1,200 feet of passage lies within. You will notice that the cave passages become much more horizontal from that point on, which is typical of cave passages within the Kirschberg Member. Today we will travel to the Travis County Room, which is the largest known room in Travis County.

Whirlpool Cave has served as a unique classroom for educating the public about caves, troglobites (cave dwelling creatures) and the environmentally sensitive nature of karst aquifers, such as the Edwards Aquifer. In fact, the Texas Cave Management Association and the City of Austin regularly escort school groups into the cave. In addition to being an invaluable education tool, Whirlpool Cave has served as a natural laboratory for scientists as well. The Barton Springs/Edwards Aquifer Conservation District and the City of Austin have long been interested in increasing their understanding of recharge and groundwater flow routes to local springs and wells. This knowledge is invaluable in helping to protect our water resources, particularly Barton Springs. In 1999, as part of an ongoing study, a non-toxic fluorescent dye was injected into Whirlpool Cave. That dye quickly traveled through the aquifer and was detected at Barton Springs three days later. This dye trace demonstrated that pollutants can flow through the aquifer very rapidly and be discharged into Barton Springs. Whirlpool cave is also part of an ongoing study of the fluctuations of carbon dioxide (CO_2) concentrations in several caves around Austin.

Most caves in the Edwards Aquifer region have elevated levels of CO_2 due to the degassing of CO_2 rich drip waters as they enter the cave. As water travels though the soil it becomes enriched in dissolved CO_2 gas. This is the same process responsible for creating carbonic acid, which dissolves limestone and forms caves. The CO_2 rich water then moves downward until reaching the aquifer, or in some cases, a cave. When the CO_2 rich water enters a void (such as a cave) the CO_2 dissolved in the water escapes from into the air, increasing the CO_2 concentration of the air. When that CO_2 escapes from the water, it also causes a chemical reaction that is responsible for the deposition of cave formations.

A recent study by researchers at the University of Texas at Austin has shown that CO_2 levels within Austin area caves vary seasonally. The highest levels of CO_2 are detected in the summertime, when the outside air becomes much warmer and more buoyant than cave air, allowing CO_2 to build up in the cave air. In the winter, the cooler outside air becomes denser than the cave air and thus the cave air begins to ventilate as the cooler air flows into the cave. This ventilation causes CO_2 levels within the cave to decrease.

> Geology: Click here for a short paper on cave CO_2 and ventilation written by UT Austin scientists.

Karst, Caves and the Environment
Most caves in the Austin area, like Whirlpool Cave, are now gated to protect the caves and the public alike. A number of local cave rescues have left some members of the public calling for the filling in of local caves out of public safety concerns. Some local property owners have filled in caves on their property for various reasons, including (1) to discourage trespassing to the caves, (2) to fill in potential traps for cattle, (3) to utilize sinkholes as stock ponds for cattle, (4) to conceal recharge features in order to avoid potential regulation or controversy, and (5) to legally fill in **sinkholes** or disconnect them from their drainage areas in advance of proposed development as approved by regulatory agencies or through a grandfather clause. Unfortunately the need to protect the public from injuring themselves in caves, to protect the caves and their inhabitants and the need or desire to fill **sinkholes**, has resulted in (1) much of the public not realizing that they live over a sensitive **karst** aquifer and (2) large areas of important **recharge** sources

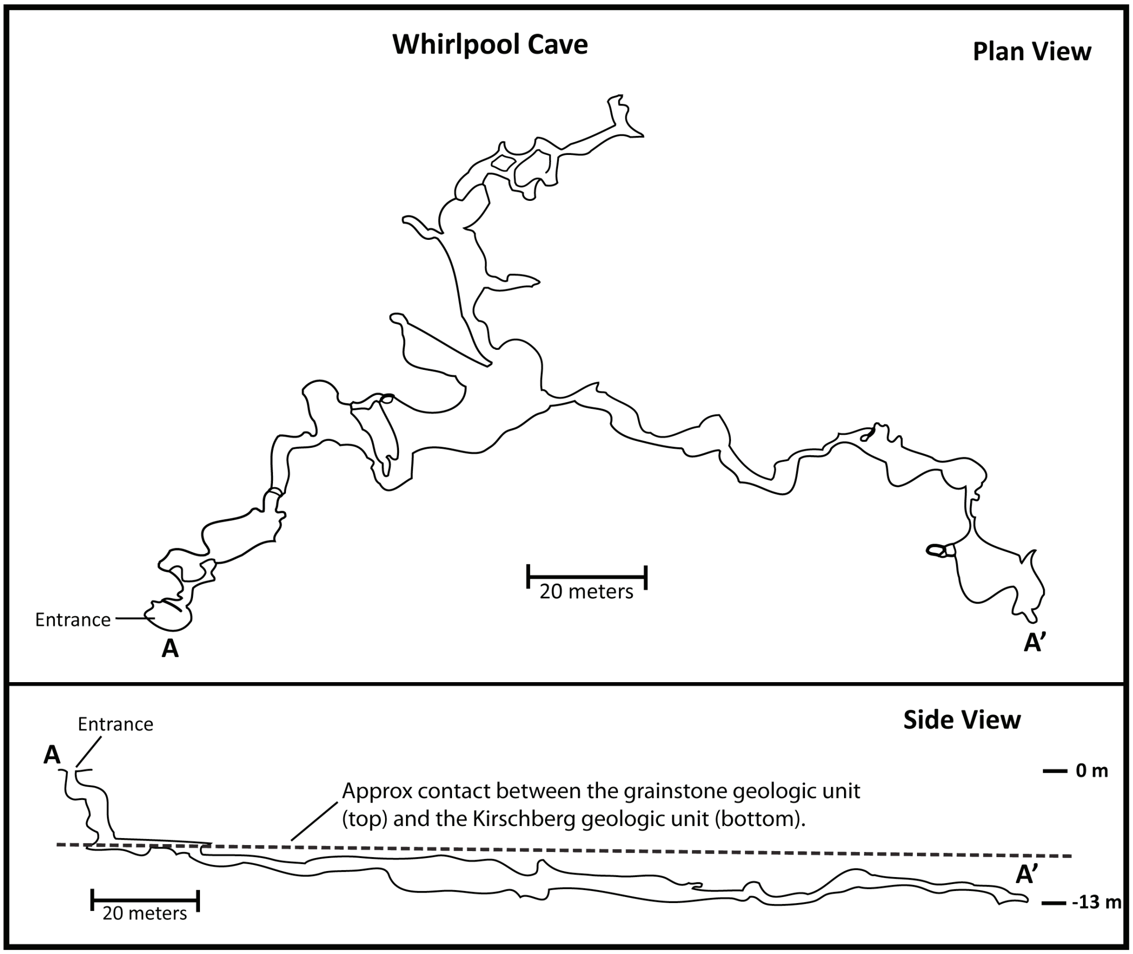
being disrupted. **Karst preserves** such as this provide the public an opportunity to safely view natural **karst** landscape and help retain some of the original runoff that once contributed to aquifer **recharge**.

As previously discussed, land-disturbance activities can contribute fine-grained sediments to the creeks, which in significant volumes can plug these recharge features. The timing of creek flow may also affect the amount of water available for recharge. Flashy creek-flows, typical of urban areas with high **impervious cover**, can overwhelm recharge features, encouraging the rejected water to runoff the recharge zone. The intensity and distribution of rainfall, and particularly the amount of **impervious cover** within the drainage, can influence the amount of rejected recharge. Finally, recharging sinkholes are often plugged to make way for growing urban areas.

> Social Studies: Click here to read an article about urbanization and the Edwards Aquifer Recharge Zone. Click here to read about the political debate surrounding the Longhorn Pipeline and other oil pipelines running through Austin.

The Longhorn Oil Pipeline runs nearby, across the Blowing Sink Preserve. Originally transporting crude oil pipeline from west Texas to coastal refineries by Exxon, this line is preparing to transport refined petroleum hydrocarbons products in the reverse direction. Most of the pipeline section crossing the **Recharge Zone** of the Barton Spring segment was refitted with new pipe, a grouted trench with cement cap, and leak detection system. However, there are still grave concerns about the potential for a catastrophic spill and impacts to the aquifer.

Figure: 3.1: Map of Whirlpool Cave located in the Recharge Zone of the Edwards Aquifer in South Austin. Note how the geometry of the cave changes from vertical in the Grainstone geologic unit (located above the dashed line) to horizontal in the Kirschberg geologic unit (located below the dashed line).



Web Resources

Web Resources
City of Austin Earth Camp teacher resources
http://www.ci.austin.tx.us/watershed/ec_main.htm

Cave Life
http://www.utexas.edu/depts/tnhc/.www/biospeleology/explore.htm

Barton Springs/Edwards Aquifer Conservation District website
http://www.bseacd.org/

The Edwards Aquifer Authority (San Antonio segment) website
http://www.edwardsaquifer.org/pages/resources.asp

Edwards Aquifer Homepage (by Gregg Eckhardt). This site has a "Newsflashes" page, but nothing new has been added since December. There is a lot of information about the aquifer.
http://www.edwardsaquifer.net/

Recent Articles on Perceived Threat to Barton Springs from Nearby Tributary
Recent articles in a local newspaper have expressed concerns that Barton Springs is hazardous for swimming due to contamination from a small tributary to Barton Creek immediately upstream of the pool. Read the articles below and see what you conclude.

An overview of the perceived threat by the City of Austin:
http://www.ci.austin.tx.us/watershed/bs_summary2.htm

Austin American Statesman: "Toxic Waters: An Austin Treasure at Risk"
http://www.statesman.com/specialreports/content/specialreports/bartonsprings

Austin Chronicle:
"Austin at Large: The Toxic Agenda" About incorrect statements in Austin American Statesman
http://www.austinchronicle.com/issues/dispatch/2003-01-24/pols_atlarge.html

"Impaired Judgement" About SOS Alliance efforts list Barton Springs as "impaired waterway"
http://www.austinchronicle.com/issues/dispatch/2003-01-31/pols_feature2.html

City of Austin Public Information on Austin American Statesman Concerns of Barton Springs
http://www.ci.austin.tx.us/news/2003/2003bartonsprings.htm

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Glossary of Terms

Aquifer- a permeable formation that stores and transmits groundwater in sufficient quantity to supply wells.
Artesian zone- an aquifer containing water under pressure.
Brachiopod- any mollusk-like, marine animal of the phylum Brachiopoda, having a dorsal and ventral shell; a lamp shell
Breccia- rock composed of angular fragments of older rocks melded together.
Calcite- a common mineral consisting of crystallized calcium carbonate $CaC0_3$; a major constituent oflimestone
Carbonates- sediment or a sedimentary rock formed by the precipitation of organic or inorganic carbon from an aqueous solution of carbonates of calcium, magnesium, or iron. Limestone is a carbonate rock.
Carbonic acid- a weak, unstable acid, H_2C0_3, present in solutions of carbon dioxide in water.
Chert- a sedimentary form of amorphous or extremely fine-grained quartz, partially hydrous, found in concretions and beds.
Contributing zone- a zone of the Edwards aquifer where runoff from the land surface feeds streams that flow over relatively impermeable limestones until they reach the recharge zone.
Fossiliferous- bearing or containing fossils, as rocks or strata.
Hydrostratigrapbic unit- a division of rock layers where rocks with similar hydraulic properties are grouped together
Impervious cover- a groundcover that is incapable ofbeing penetrated by water.
Indicator bacteria- bacteria that are used to assess the microbiological quality of water.
Internal drainage- an area of land in which no runoff flows to a creek, stream or lake but instead becomes groundwater recharge.

Karst- an area of irregular limestone in which erosion has produced fissures, sinkholes, underground streams, and caverns.
Limestone- a sedimentary rock consisting mainly of calcium that was deposited by the remains of marine animals
Lithified- to change sediment to stone or rock.
Marls- a crumbly mixture of clays, calcium and magnesium carbonates, and remnants of shells
Outcrop- a portion ofbedrock or other stratum protruding through the soil level.
Packstone- a sedimentary carbonate rock whose granular material is arranged in a selfsupporting
framework, yet also contains some matrix of calcareous mud.
Permeable- capable of being penetrated (by water).
Recharge- the processes by which ground water is absorbed into the zone of saturation.
Recharge Zone- highly faulted and fractured zone ofthe Edwards aquifer where limestones outcrop at the land surface, allowing large quantities of water to flow into the Aquifer
Residence- the period of time water spends in contact with a particular material (i.e. bedrock or soil)
Saline-water line- a delineation given to the zone within the Edwards aquifer where the concentration of dissolved solids reaches 1,000 parts per million or more.
Shale- a fine-grained sedimentary rock consisting of compacted and hardened clay, silt, or mud. Shale forms in many distinct layers and splits easily into thin sheets or slabs.
Sinkbole- a depression in the ground communicating with a subterranean passage (especially in limestone) and formed by solution or by collapse of a cavern roof
Slickenlines or Slickensides- a polished, striated rock surface caused by one rock mass sliding over another in a fault plane.
Sparites- a nonmetallic, readily cleavable, translucent or transparent light-colored

mineral with a shiny luster, such as feldspar
Turbidity- muddiness created by stirring up sediment or having foreign particles suspended
Urbanization- the removal of the rural characteristics of a town or area, a process associated with the development of civilization and technology. Demographically, the term denotes redistribution ofpopulations from rural to urban settlements
Wackestones- carbonate rocks which are matrix-supported; i.e., there are more than 10% grains, but the fine grain clay size matrix essentially surrounds the grains.

Lessons and Readings for Each Stop

Below you will find the lessons and readings for each stop of the field trip. Direct links can be found in each section of the guidebook above. Simply click the link and you will be taken to the selected lesson.

To print lessons: Select File→ Print → then select the pages that you wish to print. For example entering 1-10 would print pages 1-10 of the document or entering 1,3,5,7 would only print pages 1, 3, 5 & 7 of the document.

Barton Springs Lessons & Readings

Environmental Science Institute
UNIVERSITY OF TEXAS AT AUSTIN

The Water Cycle and Pollution

Objective: In this lesson, students construct and observe a fully functioning model of the water cycle and how contaminants move through the surface water/groundwater system
Length of Lesson: Multi-day
Grade Level: 5th

The Lesson:

I. Materials

clear Tupperware container with clear lid (approx. 9x4x6)
potting soil
small pebbles (washed)
squirt bottle
food coloring
seeds or small plants (optional)

II. Engagement

To engage the students, ask them probing questions about the Water Cycle, but do not use the term "Water Cycle". Write the students answers on the board. Through discussion arrive at a definition for the Water Cycle and a simple drawing of the water cycle.

Example Question	**Possible Student Responses**
Where does rain come from?	The clouds
Where do clouds come from?	Ocean, lakes, outer space
Where does rainwater go?	Lake, river, ocean, underground, glacier

III. Background

Water is in constant movement on, above, and below the surface of the Earth. This process is known as the "Water Cycle" or the "Hydrologic Cycle". As the word "cycle" implies, there is no beginning or end to this movement of water. A the water moves through the various components of the Hydrologic Cycle, it takes on three of the states of mater, liquid, vapor, and solid. These processes happen on several time-scales ranging from "in the blink of an eye" to hundreds of thousands of years.

Although the balance of water on Earth remains fairly constant over time, individual water molecules may travel large distances over relatively short amounts of time. For example, the water molecules in the apple that you ate yesterday may have fallen as rain on the other side of the globe last year, or maybe a dinosaur drank it many millions of years ago.

Source: http://ga.water.usgs.gov/edu/watercycle.html

IV. Procedure

Students will be divided up into groups and follow these steps to construct their own Water Cycle models:

a. Cover bottom 2/3 of the Tupperware container with a layer of washed pebbles approximately one inch deep.
b. Cover the layer of washed pebbles with a layer of potting soil that is approximately one inch deep.
    i. Optional: Plant a few seeds (grass, herbs, etc) in the potting soil or transplant a small plant into the potting soil.
c. Pour water into the uncovered portion of the Tupperware container until 1 inch depth is achieved.
d. Secure lid (ensure that lid seals completely) and place in window or other area of classroom that receives direct sunlight.
e. Students record observations daily. Encourage students to sketch the changes that they observe.
f. After a few days discuss the observed changes with the class and what the changes in the models may represent in the "real world".
    i. Condensation on lid represents clouds and rain
    ii. Water in uncovered 1/3 of the container represents oceans/lakes/rivers
    iii. Water in the pebble matrix represents groundwater
    iv. Plants represent vegetation
g. Ask students "What caused your Water Cycles to work?"
    i. Ask leading question until students arrive at the conclusion that energy from the Sun drives the water cycle.

V. Extension

1. Place food coloring on the surface of the potting soil and tell the students that it represents pollution. It is best to place it near side wall of the container so the students can watch it flowing downward into the aquifer.
2. Spray the **soil** surface with a water bottle while telling the students that the mist represents the rain.
3. Have students observe the food coloring move through the soil and pebbles (aquifer) and then into the standing water (ocean/lake/rive).
4. Explain to students that the food coloring moved through their Water Cycle models much the same as water pollution moves through the environment.

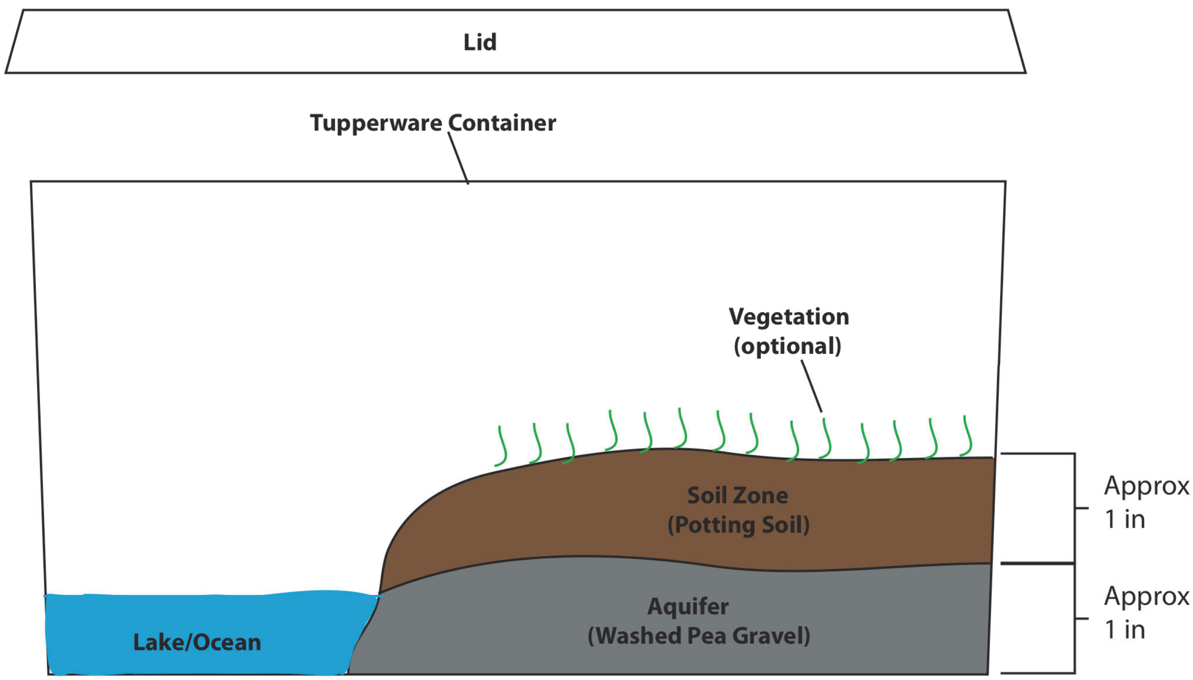
VI. Enrichment

a. Allow students to explore the U.S. Geologic Survey's Water Cycle summary website at http://ga.water.usgs.gov/edu/watercyclesummary.html.
b. Make a class mural to show the water cycle.
c. Allow students to "surf" their watershed at www.**epa**.gov/surf/
    i. Highlights Include: Citizen based "Adopt a Watershed" groups in your area, maps of your watershed, EPA assessments of your watershed's health, real-time USGS stream data (typically flow and sometimes pH, temperature, conductivity, etc.)

d. Take a hike through a local watershed with your students. Point out rivers, lakes/streams, springs, and other hydrologic features and discuss how they are connected to the water cycle.

VII. Figure

Side-view of a Completed Aquifer Model



Park or Parking Lot?

Graduate Fellow: Brian Cowan

Objective: Students will learn the difference between pervious and impervious cover and how impervious cover affects runoff rate, erosion rate and water pollution.

Time Allotment: 60 minutes

Materials:

Medium baking pans	Plastic cups (2 per group)	Sand
Sod/clumps of grass	Food coloring/dye	Tin foil
Graduated cylinder	Scissors/knife	Garbage bags

Engage: Engage the students by telling them that the city they live in is experiencing major flooding problems every time it rains. As a result of the flooding, many stream banks are eroding at an alarmingly fast rate, putting several homes and businesses in jeopardy of falling into area creeks. A local philanthropist has just donated a large piece of land (located downtown) to the your city, and City Counsel members are trying to decide how to use that land. The choices have been narrowed down to a large parking lot, which will help ease the current parking shortage downtown, or a park with hiking trails, gardens and a large lawn for picnicking. Counsel members have hired your students to conduct a study to determine how each type of land use (a parking lot or park) will affect the current flooding and erosion problem.

Exploration: Explain what pervious and impervious cover is and have the students list examples of each on the board. Ask students what types of cover they would expect to see in a park and a parking lot.

Each group of students will then use the materials provided to construct two models; one representing the parking lot and the other representing the park. See instructions below.

Once the models are complete, have the students hypothesize on what will happen to water that "rains" down on each model. Use a plastic or Styrofoam cup with four holes poked through the bottom as a "rain maker". "Rain" a set amount (i.e. 400 ml) of water onto each model by pouring the water into the rain maker. Have the students measure the amount of runoff generated by each model and observe the relative amount of erosion that occurred (represented by sand that was washed away) in each model. Have students answer the questions and give their recommendation on the sheet provided. On the board or overhead projector, create a graph of the volume of runoff collected from each experiment by each group.

Note: Cover desks with plastic sheeting or garbage bags that have been torn open. Have lots of paper towels available during the lab and during cleanup.

Explanation: This laboratory, in which students create working models demonstrating the differences between pervious and impervious cover, and how urban land planning and land-use can affect erosion rates and the magnitude of flooding events. Discuss how different land uses affect runoff rates (and thus flooding and erosion) and come up with a class recommendation for the City Counsel…should the city build a parking lot or a park? Why?

Elaboration: Tell students that the type of ground cover can affect how much pollution flows into local streams, lakes and ever the aquifer. To simulate polluted runoff, place a few drops of food coloring or dye on each surface (pervious and impervious). Now repeat steps 6-10. Have a class discussion about what types of pollution runs off the streets in their neighborhoods and city. Ask the students to suggest ways to stop the pollution from reaching streams, lakes and aquifers.

Evaluation: Students have used the scientific method to hypothesize about rainfall on watersheds and flooding. They have used control and experimental watersheds (natural and altered by man) to test their hypotheses and can draw conclusions from their results. By formalizing the scientific method in written form the students can review and evaluate their own mastery of the concepts and vocabulary involved in this lab. Review the scientific method process with the class so that students can check their work.

Model Construction

1. **Place a book under one end of the baking pan to create a gentle slope**
2. **Line the upper half of the pan with ~ ½ inch of sand**
3. **Bend the lower edge of the pan so that all water draining from the sand will flow out of the pan at one collection point.**
4. **Place a piece of sod or clump of grass on top of the sand at the uppermost end of the pan (this represents the park/pervious cover)**
5. **Poke 4-5 small holes in the bottom of a plastic or Styrofoam cup (this will simulate rain when water is poured in)**
6. **In another cup, measure out an appropriate amount of water to be poured into the rainfall cup at the start of the experiment.** ***Note: use the same volume of water for both experiments so that students can compare volumes.***
7. **Have one student hold the rainfall cup over the pervious cover and another student pour a pre-measured volume of water into the rainfall cup. A third student will start a timer when the water is poured into the rainfall cup.**
8. **Using three separate cups, have students collect water at three intervals: 0-30 seconds, 30-60 seconds and 60-90 seconds. Caution them to be careful not to spill the water or mix up the cups. Be sure to label the cups to avoid confusion!**
9. **After the experiment, have the students record the volume of water collected in each cup.**
10. **Have one student from each group write their results on the board.**
11. **Set up the second baking pan in the same manner as the first, but replace the grass/sod with a sheet of tin foil (this represents the parking lot/impervious cover).**
12. **Repeat steps 6-10**

Park or Parking Lot?

Background
The (your city) City Counsel has a big decision to make and they need YOUR help! A large piece of land was donated to the City of (your city) by a wealthy philanthropist, and the City Counsel must decide how to use the donated land. The City Counsel is concerned the growing problem of erosion in the city. They have narrowed down the possible choices to just two; a parking lot or a park. Your job is to find out which type of land-cover (parking lot or park) will cause the least amount of erosion so that the City Counsel can make an informed decision. Good luck, we are counting on you!

Vocabulary
Land cover-
Pervious cover-
Impervious cover-
Runoff-
Erosion-

Hypothesis
Which type of land use (parking lot or park) will cause the most erosion? Why?

Data Collection
<u>Park/Pervious Cover (grass)</u>

Time	**Volume of water Collected**
30 seconds	
60 seconds	
90 seconds	

<u>Parking Lot/Impervious Cover (tin foil)</u>

Time	**Volume of water Collected**
30 seconds	
60 seconds	
90 seconds	

Review Questions
1) A parking lot is an example of impervious cover. What are two more examples of impervious cover?

2) What should the City Counsel do with the donated land: build a park or a parking lot? Why? *Hint: Remember that erosion is a BIG problem in (your city)!*

Save Our Springs Interdisciplinary Unit
For Middle Schools in the Austin Area

By Alex Hendrix, 7th Social Studies, AISD

Background:

The Environmental Science Institute at the University of Texas at Austin has been instrumental in providing local educators with workshops, lectures, resources and opportunities for professional development. The purpose of this teacher's guide is to provide middle school educators with the resources needed to create their own interdisciplinary project that could be implemented in either the 7th or 8th grade core subject areas, especially science, social studies and English. The goal is illustrate the natural and human history of Edwards Aquifer and its importance in sustaining life in Central Texas. The culminating activity is a hike down the Barton Creek Greenbelt, identifying plants, recharge and discharge points of the aquifer as well as fault lines, fossils and evidence of human activity.

English/Language Arts Activities:

Engagement: "**The Unforseen**" Film (http://theunforeseenfilm.com/blog/about/)
This film could be shown as an introduction to the larger interdisciplinary project that students will explore in their English, Social Studies and Science classes, basically it would serve as a "hook" to tap students interest in the issues facing Barton Springs, and the Edwards Aquifer.

After viewing the video, students have a discussion on the importance of the integrity of the water of Barton Springs. Next, students write a review of the movie, discussing examples of the various opinions on the conservation issues facing the springs.

Barton Springs Eternal: Soul of a City Turk Pipkin (editor)
(ISBN-13: 9781881484059)
This is an excellent resource that includes many short readings and essays including the natural history, human history and cultural importance of the springs. This book provides students with easy to read and interesting articles, students could be assigned separate readings from the book to share with the class at large. Quotes from Roy Bedichek, John Henry Faulk, J. Frank Dobie, Susan Bright, Ann Richards and many others provide excellent discussion opportunities for the classroom setting.

Social Studies Activities:

There are any number of lessons to create about the human history the Edwards Aquifer and more specifically around the Barton Creek area. The Barton Springs/Edwards Aquifer Conservation District (http://www.bseacd.org/) created an excellent curriculum supplement, its called, "The Barton Springs Segment of the Edwards Aquifer Unit of Instruction Secondary Social Studies Curriculum Supplement", their phone number is 512.282.8441. This packet includes teachable activities for the social studies classroom.

Again, the book Barton Springs eternal provides a number of readings about the human history, the archaeology of Barton Creek, the Lipan Apache, Tonkawa and other Native Americans use of the creek, including the harvesting of acorns as well as flint, or churt, embedded in the limestone, which was used for tool making, and traded with tribes along the Gulf of Mexico coast.

The University of Texas at Austin Liberal Arts College maintains as excellent resource for human history at http://www.texasbeyondhistory.net/plateaus/index.html
This website is a wonderful tool for both teachers and students.

Mapping:
Google maps, and Google Earth are easy to use interactive mapping tools that teachers and students can use to explore the many geospatial relationships in the Austin area such as the location of the zones of the Edwards Aquifer and the the existence of impervious cover and green space. Also, the Save Our Springs Alliance (sosalliance.org) has numerous maps projecting current growth and new highways and their impact on the aquifer. Students map out the hike with google maps before the hike, and then create another map after the hike that illustrate their discoveries along the trail, and included in the their map.

Science Activities:
The Environmental Science Institute at the University of Texas at Austin maintains numerous resources, and teachable activities about the Edwards Aquifer. Science teachers should explore the following websites to select the appropriate activities and resources to teach students about karst aquifers and Barton Springs.
http://www.esi.utexas.edu/outreach/caves/
http://www.esi.utexas.edu/outreach/groundwater/
http://www.esi.utexas.edu/outreach/ols/lectures/Mahler/index.html

The Hike:
After completing activities in English, Social Studies and Science, it is important to provide students with a field component. One way to is arrange to have the school busses drop off students at the entrance to Barton Creek on Highway 360, and then have the busses meet you and your students at the end of the hike at Zilker Park (Barton Springs). This easy 3 mile walk provides opportunities for students to explore first hand the Barton Creek ecosystem. Students should take a composition notebook and journal their discoveries. They should look for birds, insects, wildlife, native and non-native plants, fault lines along the cliffs, especially near Campbell's Hole, as well as caves, springs and evidence of anthropogenic activitity. Students could also create a poem, haiku or short prose about the experiences of the 5 senses they observed while hiking along the creek. Here is the suggested route:
http://maps.google.com/maps/ms?ie=UTF8&hl=en&msa=0&msid=106889945736424422044.00046eda7660e48de57ae&ll=30.250319,-97.79789&spn=0.043374,0.090895&z=14

Extensions:
The Save Our Spings Ordinance is a historical example of democracy in the the city of Austin. The Save Our Springs Alliance maintains an informative website
http://sosalliance.org/

about the natural and human history as well as historic and current issues facing the Edwards Aquifer.   There are no shortage to current issues facing decision makers at the local, state and federal levels, all affecting the integrity of the Edwards Aquifer. These issues provide students an opportunity to view these controversial issues from many different perspectives, the conundrum so brilliantly portrayed in the Unforseen film, the introductory activity. Students should understand and appreciate the complexities of resource conservation and the role of we the people.

The Salamanders of Barton Springs

"In terms of richness of troglobitic species, [Edwards Aquifer] is apparently either the most diverse or one of the most diverse subterranean aquatic ecosystems in the world" (Longley, 1981). San Marcos Spring, Texas has been identified as one of the top twenty hotspots for subterranean biodiversity in the world (Culver and Sket, 2000). Within the 48 contiguous United States, Hays County, Texas, with 26 species of stygobites (aquatic, cave-dwelling organisms), has the most diverse community of stygobytes, while Travis County, Texas has 35 troglobitic (terrestrial, cave-dwelling) species, the second most diverse community of troglobites (Culver et al., 2000). The Edwards Aquifer-Balcones Escarpment region is more diverse than previously believed, with over 59 single-county endemic species (Culver et al., 2000). The high number of endemic species and high biodiversity is a result, at least partially, of habitat fragmentation and isolation (Chippindale, 1995; Gibert and Deharveng, 2002). As of 2000, only 24 of the known cave-dwelling species in the United States received federal status, and 11 are found in Texas, highlighting the susceptibility of these species to changes in the aquifer (Culver et al., 2000).

The Barton Springs Segment of the Edwards Aquifer is host to the only confirmed localities of *Eurycea sosorum*, Barton Springs Salamander, and *Eurycea waterlooensis*, Austin Blind Salamander. *Eurycea sosorum* is found at the spring mouths of Eliza Spring, Barton Springs Pool, Old Mill Spring and Upper Barton Spring within Austin, Texas. Although *Eurycea waterlooensis* is also found at the mentioned spring mouths, excluding Upper Barton Spring, they are rarely seen at the surface and exhibit stygobitic (aquatic, cave-dwelling) characteristics. *Eurycea sosorum* received federal status under the Endangered Species Act while *Eurycea waterlooensis* has received candidate status with a priority of 2 (out of 10). These species are monitored at the spring sites once a month for population stability (Table 1), obvious health issues, and to track ecological changes (i.e. algae cover, invertebrate presence/absence, sediment depth, etc.).

Descriptive Statistics from Salamander Counts, 2003 to April 3, 2008

TOTAL COUNTS	*Mean*	*Std Dev*	*Std Error*	*Minimum*	*Maximum*
Eliza Spring	333	218	31	3	898
Barton Springs	66	77	12	1	300
Upper Barton Spring	8	7	1	0	29
Old Mill Spring	21	20	3	0	67

ESTIMATED DENSITY/SQ FT	*Mean*	*Std Dev*	*Std Error*	*Minimum*	*Maximum*
Eliza Spring	0.415	0.277	0.04	0.001	1.123
Barton Springs	0.027	0.029	0.005	0	0.112
Upper Barton Spring	0.016	0.014	0.003	0	0.059
Old Mill Spring	0.015	0.015	0.002	0	0.05

Table 1. Most current statistics from City of Austin WPDRD salamander counts.

Both species are neotenic (aquatic stage only), lungless (respiration through external gills and skin) salamanders, dependent on the quality and quantity of groundwater. Controls on pumping from the aquifer are imperative to the survival of these species as over-pumping could dry up the springs under certain conditions. In addition, increases in development can increase pollutant runoff and degrade water quality of the springs. The

City of Austin has a captive breeding facility where City biologists conduct research on these species and maintain a healthy captive population in the event of a crisis such as a catastrophic spill. There are many factors complicating the conservation of *E. sosorum* and *E. waterlooensis*, but the City of Austin is dedicated to maintaining the delicate balance between urbanization and conservation.

Eurycea sosorum

Eurycea waterlooensis

Some resources to learn more about these species:
http://www.cityofaustin.org/splash/default.htm - Splash! Exhibit at Barton Springs Pool – free interactive learning center and customized field trips
http://www.digimorph.org/specimens/Eurycea_waterlooensis/whole/ - CT generated animations of a *Eurycea waterlooensis* skeleton
http://www.amphibiaweb.org/index.html - Website dedicated to amphibians –source for images and some general knowledge of specific species – not always up to date

Please feel free to contact Liza Colucci for additional information.
Liza.Colucci@ci.austin.tx.us   512-974-2669

William "Uncle Billy" Barton

1782–1840

In 1837, when William Barton and his family settled at the large freshwater spring that would later bear his name, his nearest neighbor was Reuben Hornsby, eleven miles away at Hornsby's Bend. The Barton party had moved to Texas nearly ten years earlier with Stephen F. Austin and had "taken their league" near Bastrop. But later, when another family moved within earshot, old man Barton decided to pull out and moved upriver to a more private spot. So, when William Barton's eldest son, Wayne, returned victorious from the Battle of San Jacinto, Texas was a free republic, the Mexican general Santa Anna was a prisoner, and the Barton family was on the move.

All told, there were three springs grouped within a short distance of the cabin Barton built overlooking the main hole of Spring Creek (as it was known then). Old man Barton named these springs after his three daughters, Parthenia, Eliza, and Zenobia. The names never stuck, however, and the place has been called Barton Springs ever since. These three springs remain today as Barton Springs pool, the nearby Elks Pit (fenced off near the current concession stand), and the Sunken Garden (downstream from the pool on the south bank).

If Barton had any designs on solitude at his new home, they were to be dashed by greater designs on the sleepy settlement of Waterloo, which lay just across the river. Waterloo, Texas, wasn't so much a town in those days as a frontier outpost, with a few small cabins and a single large one surrounded by a split-log stockade for Indian protection. Indian raids were a real threat to the Texas settlers in those days, just as the settlers' encroachment was a real threat to the continued existence of the Indians. Uncle Billy Barton came to be known as a great Indian fighter as the following story was passed down through generations. The version here is adapted

One month after brothers William and Elisha Barton each received headright grants from the Mexican government and purchased 4,428 acres for $155, an exultant Elisha wrote of his purchase to family back in South Carolina:

Brother, such land as it is you never saw. It is a high, dry, healthy country and much healthier than any part of Alabama. . . .

There are a great many deer in this colony. I can see at one sight sometimes more than 300. There are {also} many good buffalo, and wild cows run at this time within ten miles of where I live. There is an enormous sight of wild horses within four miles of where I live.

Brother William and his family are here and he has got him just as much land as I have.

Brother, I never expect to see any of you again, still I will write to you as much as once a year, if I should live. I can, at almost any time, send a letter from here to the United States by someone that is passing. I am living 15 miles above where William lives, five miles below where the St. Antone Road crosses it. . . .

So no more but remains your brother till death.

Farewell,
Elisha Barton
May 2nd, 1831

AUSTIN HISTORY CENTER/AUSTIN PUBLIC LIBRARY

One of the earliest known photos of Barton Springs (circa 1870)

from Frank Brown's *Annals of Travis County and the City of Austin.*

William Barton's son was late returning from a journey to Bastrop one day so old man Barton took his gun and climbed a small hill to scout downriver in the direction of his son's travels. As Barton passed a thicket, a handful of Indians suddenly rose up and fired, just nicking the rim of the old man's hat.

Mr. Barton returned fire and wounded one of the Indians. The rest of the party then charged upon him whooping and yelling. The aging Barton turned heel and ran for his life, knowing full-well his attackers would soon overtake him and that he must act quickly. Barton's escape route took him toward the lip of the hill he had climbed previously and it was here that he lit upon a desperate but courageous strategy. In full view of his gaining pursuers, Barton reached the edge of the hill and stopped suddenly. Then, in plain view of the Indians, he began shouting in a loud voice while beckoning with one hand to unseen reinforcements just below the embankment—outside of the Indians' line of sight. "Here they are boys, come quick!" Barton yelled, pointing his other hand at his surprised attackers. The Indians fell for the trick and bid a retreat from the wrath of the unseen forces. Barton quickly fled in the opposite direction, running as fast as his old legs could take him toward his cabin by the Springs. By now a small group of Barton's guests had heard the commotion and stood guard by the cabin. As they watched, the old man ran out of the woods at full-gallop and dropped in complete exhaustion into their midst, saying "Boys, it's a good thing it wasn't one of you or you would have surely been killed."

Spring Creek is a stream of eighteen miles in length, which enters the Colorado from the west, one mile above the City of Austin. It rises in the mountains, and after running a few miles, almost disappears: but about one mile from the river, at a place called Barton's springs, it is again supplied by water, by four large springs, which supply a stream of sixty feet in width and four feet deep, and runs with a brisk current to the river. A company are about erecting a mill at this place. A portion of the land towards the head of this creek is broken and hilly, but of rich quality, and well supplied with timber. It has extensive, rich, and beautiful valleys, and some excellent table land upon the hills. Towards the mouth it runs through a country beautifully undulating, rich and agreeably interspersed with woodland and prairie.

George W. Bonnell
Topographical Description of Texas, 1840
Bonnell came to Texas in 1836 to fight in the revolution. He began this report as the commissioner of Indian Affairs under Sam Houston.

When stories of Barton's dangerous outpost made their way to the Texas government at Washington on the Brazos, soldiers were posted at the Springs for the family's protection. "In no time," wrote Brown, "Uncle Billy wrote President Houston to come get his blasted soldiers or he would sic the Indians on them. (It was more trouble to keep the soldiers away from his daughters than it was to fight the redskins.)"

On April 13, 1839, the Republic of Texas began the search for a new capital city, and a survey committee selected the town of Waterloo. In a letter to Mirabeau B. Lamar, the selection committee cited Waterloo's central location in the new republic plus its abundance of fine water, fertile land, building stone, and other "desideratims of health." Included in their praise was nearby Spring Creek (at Barton Springs), which afforded "the greatest and most convenient flow of water to be found in the Republic."

Indeed, William Barton's spring was soon to furnish that convenient flow to the city of Austin, whose records reveal that in December 1839, Barton agreed to "give possession of stream of water from my Big Spring" to furnish power for a sawmill. It was the first of various mills to take advantage of the dependable flow, so marking the dawn of the industrial era in the new republic. But before the pulsing spring was ever harnessed, Uncle Billy Barton died on April 11, 1840. His body was buried near his springs and later moved by his family to a less public spot in nearby Round Rock.

Tragedy at Barton Springs

On the first day of August 1842, George M. Dolson and John R. Black, two young men then residing at Austin, concluded to go to Barton creek to bath in the cool water. Friends warned them, before leaving, of the danger attending the trip, as Indians were numerous in the country about Austin and made frequent incursions in to the village and its vicinity in quest of booty and scalps. They expressed themselves as feeling safe, remarking that they were mounted on fleet horses and could easily out run the ponies of any Indian marauders that might be encountered. . . . Dolson and Black crossed the river at the ford near the mouth of Shoal creek . . . and proceeded to the creek, near the spring, about half a mile above its mouth. About two hours after leaving town their horses came back riderless, swimming the river above the ford. One of them had an arrow sticking in the rear of the saddle. The worst was feared. The few men then in the village organized a searching party and went to the creek. There they found the dead bodies of the two men, not far apart, showing they had been ambushed, killed outright, scalped and stripped of their clothing. . . . These two young men were noble specimens of manhood, beloved by all, and their untimely and tragic end was the source of sincere sorrow to the little community, who could not well afford to spare them.

Frank Brown
Annals of Travis County and the City of Austin
1875

Campbell’s Hole Lessons & Readings

Name______________________________ Class period ____ Date _____

Porosity

Objective: Students will measure the pore volume in a one liter sample of sand, rocks and soil.

Time Allotment: 55 minutes

Materials: two 2-liter soda bottles (1 model bottle, 1 collection bottle), nylon screen, 1000 mL of sand, 1000mL of water, 2 large plastic containers, lab table with sand, rock, and soil

Background: **Porosity** refers to open spaces for water to move through materials (such as sand, rocks, marbles, or molecules). These spaces are called pores. Each material has a unique number of pores, or pore volume, which cause the water to move through it at different rates. The sand, rock, and soil in this activity represent an **aquifer.** An **aquifer** is the porous rock structure that holds water underground. If we know the **porosity** of our aquifer and how big the **aquifer** is we calculate the volume of water store in that **aquifer.**

Procedures:

1. Write your hypothesis.
2. Put the screen into the model bottle and put the cap on the bottle
3. Fill your model bottle with sand to the 1000 mL mark
4. Fill your collection bottle with water to the 1000 ml mark and record below as your **start volume**
5. Slowly pour the water from the collection bottle into the sand, rock, or clay in the model bottle until you see water standing on the surface of the sand, rock, or soil
6. Read the remaining volume of water in the collection bottle and record it below as the **finish volume**
7. Remove the cap from the model bottle and let the water drain into the container. Transfer as much sand, rock, or soil as possible to the sand, rock, or soil container
8. Complete the calculations below, share your calculations with the other lab tables

Research Question: Which substrate (sand, rock, or soil) has the highest porosity?

Hypothesis: I think that…____

Data/Calculations:

Start volume - Finish Volume = Pore Space Volume

1. Start volume __________ - Finish volume __________ = _________mL

2. Pore volume in a liter of sand _______________
   Pore volume in a liter of rock _______________
   Pore volume in a liter of topsoil ______________

(Pore volume / Total volume) x 100% = porosity (%)

3. sand: _____________ / 1000mL x 100% = ____________%
   rock: _____________ / 1000mL x 100% = ____________%
   soil: _____________ / 1000mL x 100% = ____________%

Conclusion:

Which substance has the highest pore volume? _______________

Why? ____

____

____

____

References: ESI: Edwards Aquifer Hydrogeology CD; ESI: Outreach Lecture Series (20) CD, Dr. J. M. Sharp; Soda Bottle Hydrology (DOE/EM-0215)

Name_____________________________ Class period ____ Date _____

Permeability

Objective: Students will measure the permeability of water through sand, rocks, and soil and compare the results.

Time Allotment: 55 minutes

Materials: two 2-liter soda bottles (1 model bottle, 1 collection bottle), nylon screen, 1000 mL of sand, 1000mL of water, 2 large plastic containers, lab table with sand, rock, and soil

Background: How does water move through materials such as rocks? **Permeability** is the measure of how easily water can flow through a material (like rocks, soil, or an **aquifer.**) We pump our drinking water from the **groundwater** in an **aquifer**, the layer of porous rock or soil under the earth's surface which collects water. As we pump water out of an **aquifer** more water will flow in to take its place during **recharge. Recharge adds water** to the **groundwater system** when rainfall, melting snow, surface water, or water from a creek or lake **soak in through the soil and rocks.** Since water flows slowly in rock, **recharging the aquifer** takes time.

Procedures:

1. Write your hypothesis
2. Place the screen on the spout of the model bottle
3. Put 1000 mL of sand, rock, or soil into the model bottle and insert the screened end of the model bottle into the collection bottle
4. Slowly pour water into the model bottle. Try to keep the water 100 mL above the sand, rock, or soil
5. When the water starts to come out of the model bottle and into the collection bottle START TIMING THE FLOW
6. When the collection bottle reaches 1000 mL stop pouring the water and STOP TIMING and RECORD THE TIME in the data table below
7. Average the time and complete the calculations USING THE AVERAGE TIME
8. Share your data for your substrate (sand, rock, or soil) with the other lab groups and answer the questions

Research Question: Which substrate (sand, rock, or soil) has the highest permeability?

Hypothesis: I think that…____________________________________
____

Data Table:

	Trial 1	Trial 2	Trial 3	Average
Sand				
Rock				
Soil				

Calculations:

Permeability flow = liters per minute = 1 liter/time for 1 liter to flow (minutes)

Sand : 1 liter / __________minutes = ________________liters per minute
Rock : 1 liter / __________minutes = ________________liters per minute
Soil : 1 liter / __________minutes = ________________liters per minute

Conclusions:

1. Which substrate (sand, rock, or soil) had the **greatest** permeability?
____

2. Which substrate (sand, rock, or soil) had the **least** permeability?
____

3. What is the relationship between porosity and permeability?
____
____
____
____

References: ESI: Edwards Aquifer Hydrogeology CD; ESI: Outreach Lecture Series (20) CD, Dr. J. M. Sharp; Soda Bottle Hydrology (DOE/EM-0215)

Middle School Lesson Plan #1

GRADE(S): 6^{th}, 7^{th}, 8^{th}

TOPIC: Watershed Management

TITLE: Just What IS a Watershed?

OVERVIEW: The student will observe the elements of a local watershed and begin to develop an appreciation for the need to protect watersheds as valuable resources. The student will observe the interdependence of a variety of factors on a watershed. These factors include local geology, the ecology of the watershed, and the effect of man's influence.

TEXAS ESSENTIAL KNOWLEDGE AND SKILLS:

Science, 6^{th} Grade

(a) Introduction

(2) As students learn science skills, they identify components of the solar system including the Sun, planets, moon, and asteroids and learn how seasons and the length of the day are caused by the tilt and rotation of the Earth as it orbits the Sun. Students investigate the rock cycle and identify sources of water in a watershed. In addition, students identify changes in objects including position, direction and speed when acted upon by force.

(b) Knowledge and Skills

(6.1) Scientific processes. The student conducts field and laboratory investigations using safe, environmentally appropriate, and ethical practices. The student is expected to:

(A) demonstrate safe practice during field and laboratory investigations

(6.2) Scientific processes. The student uses scientific methods during field and laboratory investigations. The student is expected to:

(B) collect data by observing and measuring

(C) analyze and interpret information to construct reasonable explanations from direct and indirect evidence

(D) communicate valid conclusions

(E) construct graphs, tables, maps, and charts using tools including computers to organize, examine, and evaluate data

(6.14) Science concepts. The student knows the structures and functions of Earth systems. The student is expected to:

(B) identify relationships between groundwater and surface water in a watershed

Mathematics, 6^{th} Grade

(b) Knowledge and Skills

(6.11) Understanding processes and mathematical tools. The student applies Grade 6 mathematics to solve problems connected to everyday experiences, investigations in other disciplines and activities in and outside of school. The student is expected to:

(A) identify and apply mathematics to everyday experiences, to activities in and outside of school, with other disciplines, and with other mathematical topics

(C) select or develop an appropriate problem-solving strategy from a variety of different types, including drawing a picture, looking for a pattern, systematic guessing and checking, acting it out, making a table, working a simpler problem, or working backwards to solve a problem

(6.12) Understanding processes and mathematical tools. The student communicates about Grade 6 mathematics through informal and mathematical language, representations, and models. The student is expected to:

(A) communicate mathematical ideas using language, efficient tools, appropriate units, and graphical, numerical, physical, or algebraic mathematical models

Social Studies, 6th Grade

(b) Knowledge and Skills

(6.6) Geography. The student understands the impact of physical processes on patterns in the environment. The student is expected to:

(B) describe and explain the physical processes that produce renewable and nonrenewable natural resources such as fossil fuels, fertile soils, and timber

(C) analyze the effects of physical processes and the physical environment on humans.

(6.7) Geography. The student understands the impact of interactions between people and the physical environment on the development of places and regions. The student is expected to:

(B) identify and analyze ways people have modified the physical environment

(6.22) Social studies skills. The student communicates in written, oral, and visual forms. The student is expected to:

(B) incorporate main and supporting ideas in verbal and written communication

(C) express ideas orally based on research and experiences

(D) create written and visual material such as journal entries, reports, graphic organizers, outlines, and bibliographies

(E) use standard grammar, spelling, sentence structure, and punctuation

Science, 7th Grade

(b) Knowledge and Skills

(7.1) Scientific processes. The student conducts field and laboratory investigations using safe, environmentally appropriate, and ethical practices. The student is expected to:

(A) demonstrate safe practice during field and laboratory investigations

(7.2) Scientific processes. The student uses scientific methods during field and laboratory investigations. The student is expected to:

(B) collect data by observing and measuring

(C) organize, analyze, make inferences, and predict trends from direct and indirect evidence;

(D) communicate valid conclusions

(E) construct graphs, tables, maps, and charts using tools including computers to organize, examine, and evaluate data

(7.12) Science Concepts. The student knows that there is a relationship between organisms and the environment. The student is expected to:

(A) identify components of an ecosystem

(7.14) Science Concepts. The student knows that natural events and human activity can alter Earth systems. The student is expected to:

(C) make inferences and draw conclusions about effects of human activity on Earth's renewable, nonrenewable, and inexhaustible resources

Mathematics, 7th Grade

(b) Knowledge and Skills

(7.7) Geometry and spatial reasoning. The student is uses coordinate geometry to describe a location on a plane. The student is expected to:

(A) locate and name points on a coordinate plane using ordered pairs of integers

(7.9) Measurement. The student solves application problems involving estimation and measurement. The student is expected to estimate measurements and solve application problems involving length (including perimeter and circumference), area, and volume.

(7.13) Understanding processes and mathematical tools. The student applies Grade 7 mathematics to solve problems connected to everyday experiences, investigations in other disciplines and activities in and outside of school. The student is expected to:

(A) identify and apply mathematics to everyday experiences, to activities in and outside of school, with other disciplines, and with other mathematical topics

Social Studies, 7th Grade

(b) Knowledge and Skills

(7.10) Geography. The student understands the effects of the interaction between humans and the environment in Texas during the 19th and 20th centuries. The student is expected to:

(A) identify ways in which Texans have adapted to and modified the environment and analyze the consequences of the modifications

(7.21) Social studies skills. The student applies critical-thinking skills to organize and use information acquired from a variety of sources including electronic technology. The student is expected to:

(A) differentiate between, locate, and use primary and secondary sources such as computer software, databases, media and news services, biographies, interviews, and artifacts to acquire information about Texas

(7.22) Social studies skills. The student communicates in written, oral, and visual forms. The student is expected to:

(B) use standard grammar, spelling, sentence structure, and punctuation

(D) create written, oral, and visual presentations of social studies information

Science, 8th Grade

(b) Knowledge and Skills

(8.1) Scientific processes. The student conducts field and laboratory investigations using safe, environmentally appropriate, and ethical practices. The student is expected to:

(A) demonstrate safe practice during field and laboratory investigations

(8.2) Scientific processes. The student uses scientific methods during field and laboratory investigations. The student is expected to:

(B) collect data by observing and measuring

(C) organize, analyze, evaluate, make inferences, and predict trends from direct and indirect evidence;

(D) communicate valid conclusions

(E) construct graphs, tables, maps, and charts using tools including computers to organize, examine, and evaluate data

(8.6) Science concepts. The student knows that interdependence occurs among living systems. The student is expected to:

(C) describe interactions within ecosystems

Mathematics, 8th Grade

(b) Knowledge and Skills

(8.14) Understanding processes and mathematical tools. The student applies Grade 8 mathematics to solve problems connected to everyday experiences, investigations in other disciplines and activities in and outside of school. The student is expected to:

(A) identify and apply mathematics to everyday experiences, to activities in and outside of school, with other disciplines, and with other mathematical topics

(C) select or develop an appropriate problem-solving strategy from a variety of different types, including drawing a picture, looking for a pattern, systematic guessing and checking, acting it out, making a table, working a simpler problem, or working backwards to solve a problem

(8.15) Understanding processes and mathematical tools. The student communicates about Grade 8 mathematics through informal and language, representations, and models. The student is expected to:

(A) communicate mathematical ideas using language, efficient tools, appropriate units, physical, or algebraic mathematical models

Social Studies, 8th Grade
(b) Knowledge and Skills
(8.30) Social studies skills. The student applies critical-thinking skills to organize and use information acquired from a variety of sources including electronic technology. The student is expected to:
(C) organize and interpret information from outlines, reports, databases, and visuals including graphs, charts, timelines, and maps

RELATED ESSENTIAL KNOWLEDGE AND SKILL:

English Language Arts and Reading, 6th Grade
(b) Knowledge and Skills
(6.15) Writing/purposes. The student writes for a variety of audiences and purposes and in a variety of forms. The student is expected to:
(A) write to express , discover, record, develop, reflect on ideas, and to problem solve (4-8)
(C) write to inform such as to explain, describe, report, and narrate (4-8)

English Language Arts and Reading, 7th Grade
(b) Knowledge and Skills
(7.15) Writing/purposes. The student writes for a variety of audiences and purposes and in a variety of forms. The student is expected to:
(A) write to express , discover, record, develop, reflect on ideas, and to problem solve (4-8)
(C) write to inform such as to explain, describe, report, and narrate (4-8)

English Language Arts and Reading, 8th Grade
(b) Knowledge and Skills
(8.15) Writing/purposes. The student writes for a variety of audiences and purposes and in a variety of forms. The student is expected to:
(A) write to express , discover, record, develop, reflect on ideas, and to problem solve (4-8)
(C) write to inform such as to explain, describe, report, and narrate (4-8)

DID YOU KNOW?

Activities in watersheds are having an important effect on water resources. Everything that occurs in a watershed contributes to the availability of the water used daily, whether it be for drinking/cooking, for swimming/boating, or in manufacturing. Understanding the processes that occur in a watershed can help each student understand the need to protect watersheds as a valuable resources. Terms often encountered when studying a watershed include:

watershed - defined by EPA as a geographic area in which, sediments, and dissolved materials drain into a common outlet.
pollutant - material or substance that is unwanted and can cause contaminated impure air, water and/or soil.
point source pollution - condition were an unwanted material or substance enters the environment (air, water and/or soil) from a single, discrete point such as a pipe.
non point source pollution - unwanted material or substance(s) that enter the environment (air, water and/or soil) from an general area and not a discrete or designated point, often carried by runoff or groundwater seepage into water sources.
hydrologic cycle - the cyclic pathway water follows in nature from rainfall and other forms of precipitation through use and discharge back into environment to evaporation/transpiration and condensation back to precipitation.
ecosystem - the plants and animals that live in a given area and their relationships to each other and the water, air, and soil in that area.
erosion - soil moved away from the original location by wind or water action.
intermittent stream - a stream that contains water only part of the time. (Common in areas with low rain fall averages).

LEARNING EXPERIENCE:

GENERAL TIME FRAME: 5-7 hours depending on length of field trip and student responses.

Description: Students will visit a watershed area surrounding a local creek, stream, pond, or reservoir and identify components of the watershed ecosystem as well geological features. Students will record observations and write a short report about the watershed area visited. The report is to include the effect (or possible effect) of man's activities on the watershed.

Time Frame: 2-4 hour field trip plus three 45-minute periods

Materials:

1. Data on the last rain event including duration, location, and amount
2. Topographic maps of watershed and surrounding area
3. Forms for recording data and observations during the visit to the watershed
4. Disposable cameras (optional) - 1 for every 2 or 3 students
5. Meter stick

Advanced Preparation:

1. Determine the watershed area to be visited. Check with the district science coordinator, district environmental center (if one exists), and/or local nature museums or clubs for suggestions.
2. Arrange for access to the watershed area during the anticipated date and time of the field trip. Have alternative days and/or times planned should it become necessary.
3. Arrange for transportation.
4. Determine whether or not the field trip will extend into lunch and plan for sack lunches, etc.
5. Make sure all permission slips are returned and are signed by a parent or guardian before the field trip. Follow all other school/district requirements for field trips including the provision for additional adults to accompany the students.

Procedure:

Before the field trip

1. Divide students into teams of 2 or 3 individuals.
2. Go over safety procedures.
3. Use a meter stick to determine the length of each student's stride. This information will be used by the students as a method of measuring or estimating distances.
4. Review the hydrologic cycle with an emphasis on the recycling of water by nature.
5. Discuss the last rain event - how long ago, how much rainfall was received, and how that information could influence what is seen during the visit to the watershed.
6. Discuss the possible effects of point source and non-point source pollution on the watershed.
7. Discuss/review how to read a topographic map.
8. Review procedures on how to record data and observations in an orderly manner.
9. Remind students to wear appropriate clothing and shoes for the field trip.
10. Make sure all permission slips have been returned and are signed by a parent or guardian.

During the field trip students should record the following information. (Photographs often help in describing what was seen.)

1. Descriptions of types of plants observed, the occurrence (rare, occasional, common) of each plant or plant type, and where each plant or plant type was encountered (in the water or approximate distance from the stream, creek, lake, etc.).
2. Descriptions of any animals observed, how many seen, and where they were encountered (approximate distance for the stream, creek, lake, etc.).

3. Descriptions and approximate numbers of any fish observed.
4. Evidence of other animals - footprints, etc.
5. General type of geology observed in the area.
6. Color of soil and rocks.
7. Location of any standing water (particularly after a rain).
8. A description of the stream or creek bed including type of sides and whether the stream was shallow or wide.
9. A description of water clarity - was the water surface green, foam on the surface, an oily sheen on the surface, the water cloudy or clear?
10. If the bottom of the water can be seen, what covered the bottom of the stream/creek bed or lake shore - gravel, small rocks, large rocks, mud/silt, solid rock, or a combination of any of these materials.
11. Whether or not the water had an odor - if so, attempt to describe the odor.
12. Whether or not any trash or debris was seen in or near the water along with a description of the trash or debris.
13. Whether or not there are any pipes or openings that put water or other substances directly into the water.
14. A description of water movement - was the water gently flowing, were any pools seen, was the water barely moving or not moving at all (stagnant), was the water rushing pass (rapids)?

After the field trip

Using the information gathered on the field trip, each student or group of students will write a short report which covers the following information:

a. A description what was observed during the visit to the watershed.
b. A map of the area showing the location of the watershed.
c. Ideas about sources of any pollution (trash and/or debris) observed.
d. Ideas of ways the watershed could be protected to maintain it as a water resource.

Teacher Talk:

Water is a valuable natural resource needed for different activities. The activities include residential/ residential, recreational, and agricultural use as well as use in manufacturing, mining, and electric power generation. As the demand on Texas available water supplies grows, the need to protect existing water resources - in addition to conservation, recycling/reuse, and the development of new water resources - becomes increasingly important. Watersheds contribute to both surface and ground water supplies. They are important water resources in meeting the ever increasing demand for water.

Teacher Questions	Possible Replies
1. Why is it important to maintain the ground cover in a watershed?	1. Student answers will vary. Example: Maintaining the ground cover reduces possible erosion of the soil thereby preventing

Teacher Questions	Possible Replies
	increased run-off with the result of less water going through the soil to the groundwater.
2. Why is it important to protect a watershed as a water resource?	2. Watersheds allow streams, creeks, ponds, lakes, etc. to be refilled with rain water. Watersheds also allow some of the water to be stored as ground water under ground.
3. What are some ways of protecting a watershed?	3. Student answers will vary. Examples of possible replies include keeping the ground cover in place, preventing dumping of trash or debris, and avoiding the discharge of harmful substances (pollutants) in the watershed.

RESOURCES:

Literature on water conservation by the Texas Water Development Board. View and order currently available brochures at http://www.twdb.state.tx.us/assistance/conservation/pubs.htm, contact Patsy Waters at patsy.waters@twdb.state.tx.us, fax an order form to (512) 936-0812, call (512) 463-7955, or write to:

Conservation
Texas Water Development Board
P.O. Box 13231
Austin, Texas 78711-3231

Maps of Texas River Basins, Aquifers, and Regional Reservoir Basin Maps are available on TWDB's website at **http://www.twdb.state.tx.us/mapping/index.htm**

State of Texas Water Quality Inventory by the Texas Commission on Environmental Quality: **http://www.tnrcc.state.tx.us/water/quality/**

Lesson plans and literature on water quality is also available from the Texas Commission on Environmental Quality at http://www.tnrcc.state.tx.us/admin/topdoc/index.html. Search for the following publications by number on TCEQ's website.

Lesson Plans and Resources for Teaching Environmental Sciences- GI 268
Water Education Team (WET) Instruction Handbook- GI 026
Land Use and the Water Cycle poster- GI 194
Conducting a Watershed Survey- GI 232
Watershed Owner's Streamwalk Guide- GI 218

For additional information, call (512) 239-1000, or write to:

Texas Commission on Environmental Quality
P.O. Box 13087

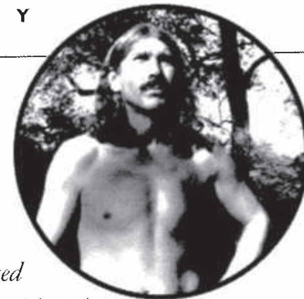
Austin, Texas 78711-3087

EXTENSIONS:

1. If there is an environmental center or nature museum in the area, invite a representative to speak to the students about the impact of man's activities on the watershed.
2. Instead of having each student write an individual report, divide the students into groups with 3 or 4 members. Have each group give an oral presentation to the class about what they observed on the field trip.

ORAL HISTORY

Joe Riddell



age 46

Joe Riddell has biked and floated most of Barton Creek over the past twenty years. He works as an attorney with the Texas Attorney General's Environmental Protection Division.

I started college in Austin in the summer of 1964, but it wasn't until 1973, the week after I took the bar exam, that a bunch of us took inner tubes down Barton Creek. It had been raining and the creek was flowing pretty good; I remember the waterfalls and floating through rapids. It was a fantastic trip.

Joe Riddell kayaking Barton Creek

LARRY KOLVOORD/AUSTIN AMERICAN-STATESMAN

I was hiking one day in the winter of 1973. I noticed some bulldozers were rough-cutting out a section of Barton Hills for a new subdivision. I saw that as a bad sign. I was concerned, and one thing led to another; I started finding out more and more about what was happening in the watershed.

I've come to learn that there is a contradiction between the role that the development community has forced upon the city and the protection of Barton Springs and the creek. I think when the city charter was amended in the fifties, it put a lot of the development questions out of the limelight and gave the responsibility to the planning commission rather than having subdivision authority remain in control of the city council. By isolating the development activities from the obvious political scene, the developers were able to make the city into a development machine. That is one of the functions of municipal government, to provide streets, housing, et cetera. But Austin's development community has pushed this narrow view upon the city council and particularly upon our city managers. To confront development now, as a citizen, one comes up against a great deal of history and momentum stacked against you.

Our city's responsibility to protect the public interest gives it the legal authority to forbid the urbanization of an aquifer recharge zone. Austin has just begun to realize that something profound needs to be done on a large scale, but many of our politicians still want to keep developers on the cutting edge. The problem is that they keep cutting, and now places like Barton Springs are on the edge.

When we start arguing the details of various ordinances, we often get away from the big picture of environmental protection. As it stands right now, the city has encouraged and subsidized development within the Barton Creek watershed, and as that development has occurred, the pollution has become more and more obvious and undeniable. There are current proposals to continue to allow development in the hopes it can be cleaned up by proposed engineering devices like filtering ponds. These are unproven experiments that fail to take into account a host of factors, like major floods, which are part of the geography and history of this area.

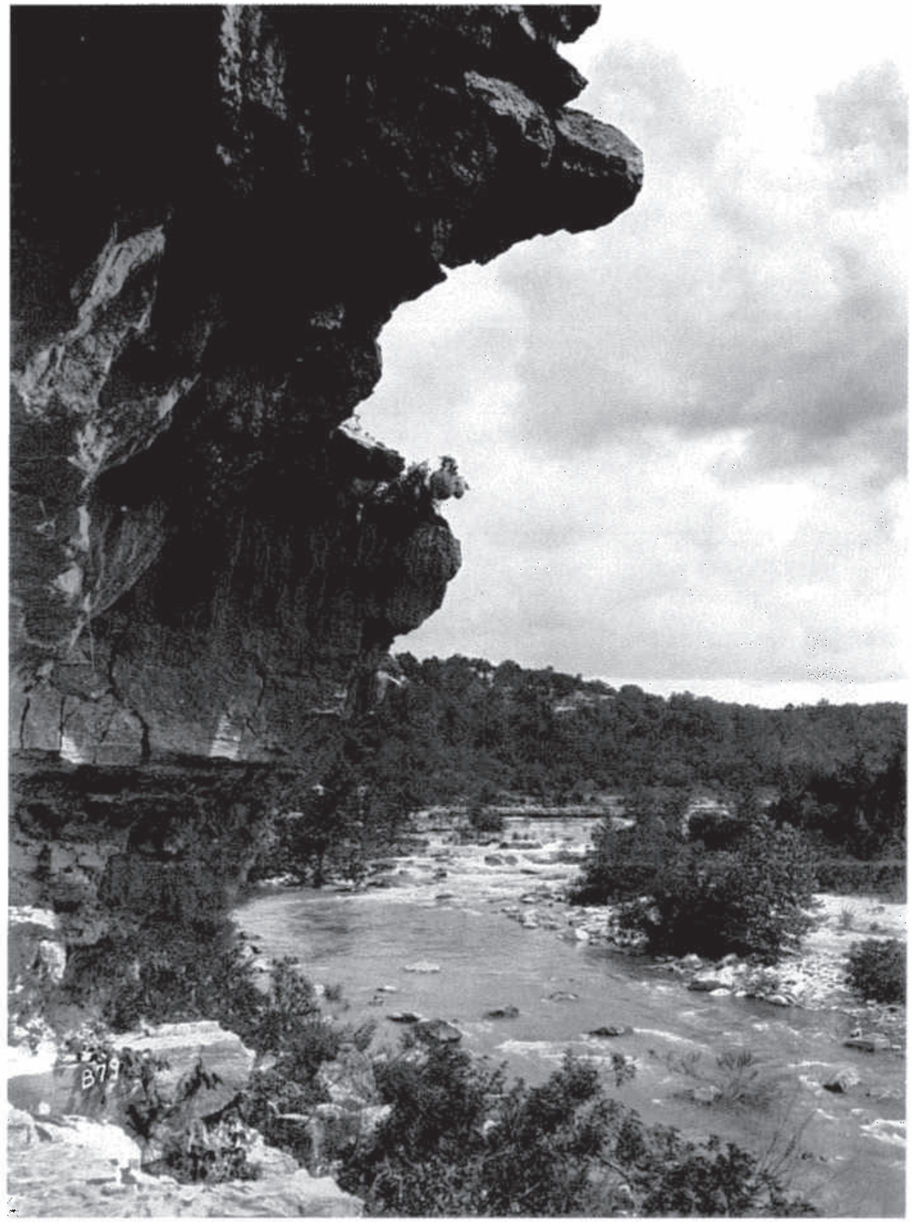
Until the debate can be moved away from technical arguments and center back on the value of the Springs and the risk to the aquifer, we'll continue to lose ground. When I was on the environmental board in the seventies, it became real clear to me that the people who shape the agenda and the discourse control the result of environmental battles.

I think this overall situation is going to get worse before it gets better. Eventually, I think Austin's demand for preservation of its aquifer and its beautiful creeks and springs will prevail over the drive of the developers and land speculators who are now urbanizing it.

Today Austin is making decisions that will influence how long it's going to take before Barton Springs gets better and how much it's going to cost. Clearly, the conservative approach would be to restrain from more development on top of the aquifer.

We have great freedoms in this society, but we also have responsibilities to protect the collective safety and enjoyment of our greater community's future.

Editor's note: Since this interview in the spring of 1992, Joe says that he is encouraged by the clear mandate of the Save Our Springs victory. "The SOS message caught the ear of politicians at many levels of Texas government. Maybe things will be getting better sooner than I'd anticipated."



AUSTIN HISTORY CENTER/AUSTIN PUBLIC LIBRARY

Bluffs on Barton Creek

THE AUSTIN CHRONICLE
austinchronicle.com

News: November 2, 2007

http://www.austinchronicle.com/gyrobase/Issue/story?oid=556507

Watershed Redo

How redevelopment can save the springs ... or not

By Katherine Gregor

Austin, we still have a problem – the continued commercial pollution of our Barton Springs Watershed creeks as well as the Edwards Aquifer, a source of regional drinking water and Austin's beloved swimming pool. Heading toward a Nov. 8 City Council vote is a proposed solution championed by Council Member Lee Leffingwell – a newly designed ordinance that would amend the 1992 Save Our Springs Ordinance. It would apply to nearly 700 acres (200 tracts) of developed land, unless it gets curtailed to an even smaller pilot project.

Would these changes certainly result in a net reduction of aquifer pollution? And have the devilish details of the new ordinance been fully worked out to ensure the best possible environmental gain? Those worries – as with all things SOS – have triggered heated community debate. The good news: The city's Environmental Board and Planning Commission listened to citizen suggestions for strengthening the draft ordinance and incorporated many of those suggestions for final council deliberation. That's a city process working as it should.

While the legendary 1992 ordinance enacted important protections for Edwards Aquifer water quality – structural filters and site controls, impervious cover limits – it was applicable only to new development, not to properties already built out with shopping malls, offices, homes, and vast parking lots. A much-discussed example: the older, grandfathered shopping centers at the "Y" at Oak Hill, which continue to pollute week by week, year by year. Especially during hard rains, such pre-1992 developments disproportionately spill sediments and noxious contaminants (pesticides, lead, phosphorus, nitrogen, hydrocarbons) into creeks and eventually the aquifer.

This year, Barton Springs Pool has been closed a record number of days because a very rainy year caused flooding and washed unsafe levels of contaminants from upstream development into the springs and pool. While such pollution can be curtailed to a degree by on-site water-quality controls – such as special SOS Alliance ponds designed to filter out contaminants – the old developments have no such water-protection features. And the systems are so expensive (e.g., $1 million per site) that neither landowners nor the city say they can afford to install them.

Unless. Unless owners could make enough new money by redeveloping their land to pay for retrofitting it with new water-protection systems. For example, an ailing old Oak Hill "Y" sprawl-mall could be redeveloped as a nifty New Urbanist Town Center, with state-of-the-art water-quality improvements. That would please the Oak Hill Association of Neighborhoods, which wants better neighborhood services and stores. Indeed OHAN, which represents more than 20 member neighborhoods, has endorsed the proposed redevelopment ordinance. Theoretically, redevelopment also would prevent residents' driving the family gas-guzzler to better shopping elsewhere – another enviro plus. Leffingwell points to the current likelihood that Oak Hill residents will soon drive farther out to shop at the new Home Depot and HEB Supercenter now under construction in Dripping Springs (where the SOS Ordinance does not apply).

A major environmental motivation for the new amendment's proponents is to encourage the building of any new retail centers and apartment complexes on already-developed sites, rather than on "greenfield" raw land. (Greenfield development rules would not be affected by the new ordinance. All the protections of the SOS Ordinance in place would still apply.) The hope is that easing the rules on relatively close-in redevelopment will counter sprawl into the Hill Country. But whether market forces would actually work that way is open to much debate; as the SOS Alliance points out, a groovier New Urban Oak Hill Town Center could well attract new development all along both 290 and 71. They point to the reality that increased density of any kind means new sources of pollution. "Do your density somewhere else, not over the watershed," urges SOS' Colin Clark.

Tweaking the Terms

To tackle these problems and opportunities (and mitigate some of the noxious sentiments that settled in the environmental community after Proposition 2 failed last year), Leffingwell convened an advisory group 15 months ago. The open-invitation group met nearly weekly but informally; regular participants represented a cross-section of environmental, community, developer/business, and city environmental staff perspectives. Many of those involved in the process cited it as a model of pragmatic environmental action. SOS has criticized the lack of an official task force and publicly noticed process; Leffingwell responded from City Hall, "It was a lot more of a public process than a lot of things that go on around here."

Out of the advisory group's laudably collaborative work emerged the proposed new ordinance. In essence, the new Barton Spring Zone Redevelopment Ordinance proposes a give-get retooling. As with the new density-bonus system being proposed for Downtown ("Finding the Sweet Spot," Oct. 26), the new rules must be attractive enough to get owner-developers to voluntarily choose to use it. That market reality requires a balancing of interests – public and private, environmental and economic. If the new redevelopment terms don't work for developers, if owners lose too much land value, then neither redevelopment nor improved water-quality controls will result. Current pollution will continue unabated. For this reason Leffingwell, city staff, and the advisory group consulted extensively with landowners and developers to get their perspective and input. But as Leffingwell framed it, "This is an opportunity for redevelopment, not an incentive."

What landowners gain: the right to redevelop their land to current levels of impervious cover. Currently, the SOS Ordinance places limits of 15% to 25% on all new projects. But older, grandfathered commercial and office Barton Spring Zone properties have far more impervious cover; those with no water-quality controls average 58% impervious cover. The SOS impervious cover limit thus creates a huge disincentive to redevelop. As developer and advisory group member Terry Mitchell points out, an old shopping center with 80% impervious cover might have 150,000 square feet of ground-floor rentable space; at 15% impervious cover, a single-story center would be limited to around 28,000 square feet. That represents a huge loss in value. (Of course, retail zoning in place entitles heights of 60 feet; a five-story building with a 28,000-

square-foot footprint could total 140,000 square feet.)

If a redevelopment project, under the proposed rules, did not trigger a council review and vote (See "Strengthening the Ordinance," below), it would be administratively approved. This is a key reassurance to developers, for whom delay and uncertainty mean increased costs; it's an equally key fear of environmentalists, who want public review of every project. Leffingwell noted by e-mail, "Triggers laid out in the ordinance address both density (which is not addressed in the current SOS Ordinance) and compliance with neighborhood plans. If these triggers are exceeded, they would be treated as if they were zoning changes, and council approval by majority vote would be required. This requirement would be in effect even in the ETJ [land outside city limits], where zoning is not currently applicable."

Developers also would pay to conserve open space. Smaller sites that could accommodate only sedimentation/filtration ponds (rather than the much larger, more effective SOS ponds) would be required to buy, give, or fund mitigation land, which would be preserved as open space. The ordinance would establish a new fund, for acquiring property within a watershed that contributes to the recharge of Barton Springs. Projections indicate the fund could gain about $1 million a year from developers; fees would be assessed at a proposed (but debated) $15,000 per eligible acre.

Some folks, like the Oak Hill Association of Neighborhoods and developer Mitchell, think the new redevelopment ordinance is swell as written. Noted Dwain Rogers, OHAN president, "We have seen numerous properties in Oak Hill, originally developed 15 to 20 years ago, become 'frozen in time' by the impact of existing water-quality regulations. ... This results in properties that both continue to pollute the aquifer and do not evolve over time to meet the needs of Oak Hill."

But environmental groups (including the Sierra Club and Save Barton Creek Association) and the Austin Neighborhoods Council expressed reservations and urged further refinements after the draft ordinance was released in September. Most praised Leffingwell's leadership and said the concept had merit but called for significant refinements and greater community consensus on the new ordinance before it goes to a council vote and becomes law. Their advocacy led to the amendments recently incorporated by the city's Environmental Board and the Planning Commission. (See "Strengthening the Ordinance," below.)

As is its hard-line wont, the SOS Alliance led the opposition against the ordinance as written; it would strongly prefer no new (re)development or construction whatsoever over the watershed. Before enacting any new ordinance, said SOS, the city should first perform a "holistic analysis" of all potential Barton Springs Zone watershed pollution that could result from the redevelopment of about 200 eligible sites – including construction, vehicle, road, sewage, and other impacts. In response to the concern about construction-phase pollution, Leffingwell sponsored a proposal that passed at council Oct. 25. It directed the city manager to "evaluate and update the City's practices, capabilities, and available resources for review and inspection of construction phase erosion and sedimentation controls, inspection of water quality ponds, and enforcement of maintenance requirements."

The common hope is to craft a consensual, pro-environmental policy that's both sensitive and workable. Even the SOS Alliance was in a rare city-laudatory mood late last week, releasing a statement that praised the Planning Commission for incorporating (SOS' own) "great recommendation" to start with a pilot project, to prevent "an onslaught of high density development and grandfathered applications."

At this writing, the ordinance is scheduled for a Nov. 8 council presentation and vote. But in an Oct. 16 letter to the mayor, council, and commission members, the ANC had said: "The Austin Neighborhoods

Council requests additional consideration of the concerns expressed by the Environmental Board, our community and its environmental advocates. ... The hope is this would provide the Planning Commission and Council a better, more fully resolved ordinance with fewer objections and unanswered issues."

Thus far, that's what appears to be happening.

Imperversity

Open natural land is "pervious" – it permits rainfall to closely pervade/penetrate the soil and underlying rock material like limestone, which together with vegetation filters out many pollutants before the rainwater reaches the aquifer. The buildings, roads, and parking lots on developed land are "impervious" cover. During heavy rains, contaminants and sediments speedily run off impervious cover and end up in creeks, the aquifer, and Barton Springs.

Impact Facts:

SOS Ordinance Amendment, Barton Springs Zone

Eligible properties: up to 200

Eligible acreage: up to 700 acres

Size of properties: 86% are under 5 acres

Barton Springs Zone watershed affected: less than 1%

Maximum benefit: 10% reduction in toxic pollutants

Barton Springs Zone in Austin jurisdiction: 28.5%

Land uses in Austin Barton Springs Zone: commercial/multifamily, 8%available raw land, 23%preserved open space, 31%

This clay fragment from a human figurine was found by a seven-year-old boy near Barton Springs in 1946. The piece is believed to have followed the trade routes out of the Chiapas region of Mexico during the Teotihuacán culture (A.D. 300–600).

LEONARD VOELLINGER

Unearthing Questions

Leonard and Melissa Voellinger are professional archaeologists who have walked thousands of acres and recorded more than one hundred archaeological sites in the Barton Creek watershed. Their study of the creek's prehistoric habitation was used to support the first environmental legislation for the watershed, requiring the recognition and study of Native American sites prior to development.

The study of prehistory is elusive, like stalking a mountain lion known only by its tracks. From a few stones or pollen grains, we try to interpret the lives of those who walked these lands long before us. The artifacts shown here shape our understanding that Native Americans inhabited this area periodically for 8,000 to 10,000 years. But these rocks are mute to larger questions of the aboriginals' experience with this area. It is a popular notion these days, and not too hard to fathom, that these people appreciated a spiritual relationship with this great spring, but the day-to-day significance of these waters was probably more closely related to the variety and abundance of nearby resources.

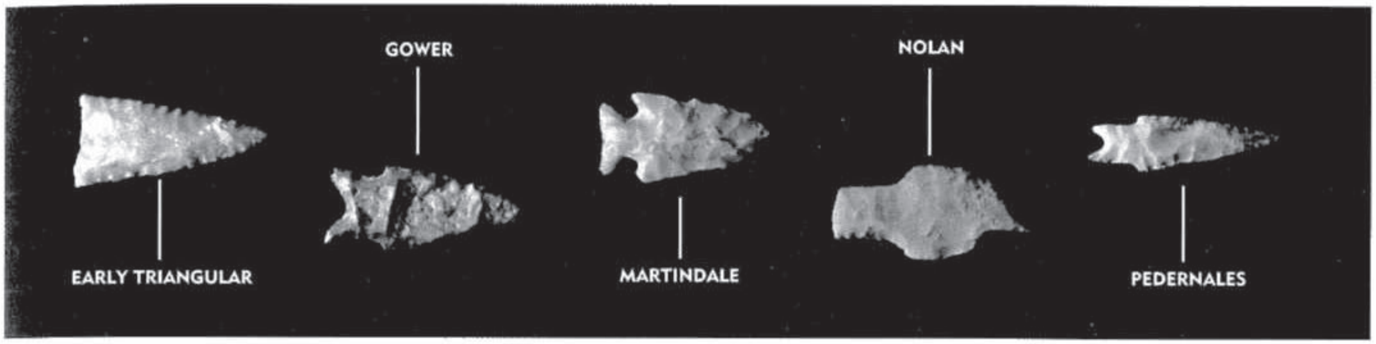
Historically, the karst topography along the edge of the Edwards Plateau has offered a rich harvest of acorns for the local hunter-and-gatherer cultures. Other bounty included the nopal cactus, mesquite, persimmons, Mexican plums, pecans, and agarita berries. This landscape was a veritable feast in the late summer and also harbored one of the densest populations of white-tailed deer in North America. Of course, all of these amenities depended on water, and the perennial supply at the springs and in the watershed helped further man's occupation. Meanwhile, the rich stores of gray Edwards chert contained within the limestone bluffs along the watershed also provided valuable raw materials for toolmaking and items to barter with the stoneless cultures of the coastal plains to the south and east.

Today, Native American habitation of this region is evidenced in a labyrinth of archaeological sites found throughout the Barton Creek watershed. These sites are diverse and reveal adaptive cultural changes through time. There are camps and rockshelters, as well as chert quarries and butchering sites. Notable among these areas are the burned rock middens widely believed to be by-products of acorn processing.

The earliest known excavations along Barton Creek were conducted in 1929 at Barton Springs by J. E. Pierce of the University of Texas. In a letter to a colleague, Professor Pierce wrote:

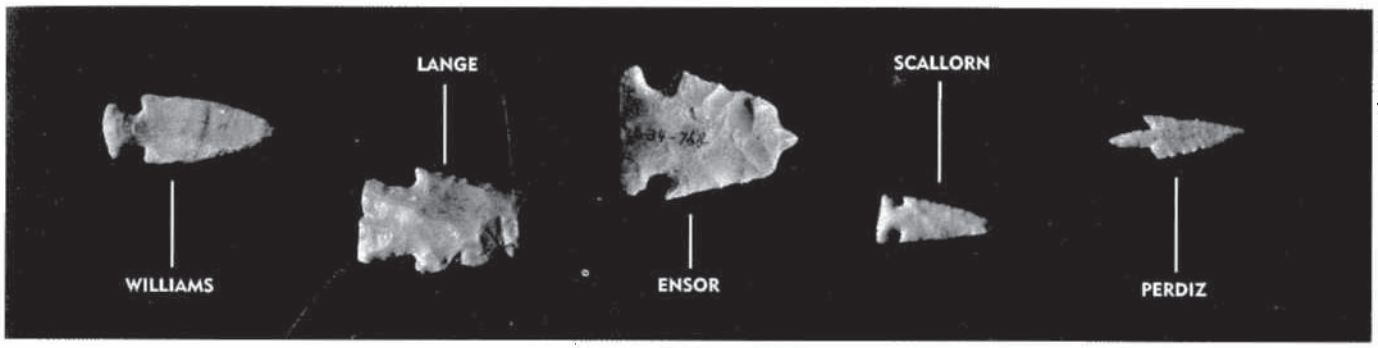
> Many interesting artifacts were found and many evidences of relatively settled village life, such as corn culture {probably acorn} implied by grinding stones, and pot shard (small in quantity), but the great quantities of river silt thrown down from time to time by the great floods . . . necessitates the moving of much material. This results in scanty returns from labor.
>
> Particularly fine specimens of blades were found at Barton Springs including . . . a curved skinning knife. One plaque of slate, probably from the Ozark mountains, is intricately carved with figurines and notched in a way indicating the keeping of records. On the whole, this place, as was to be expected of a site by such a spring and trees, gave evidence of more prolonged and more continuous occupation . . . than any place I have yet investigated with this fund. The magnificent collection of ceremonial flint axe blades which I obtained some years ago from the river bank in South Austin belongs to such evidence.

Since Pierce's excavations, the scientific methods underlying archaeological interpretation have come far. The modern, synergistic efforts of chemists, plant and animal taxonomists, geographers, paleontologists, and other scientists greatly aid archaeologists in developing an environmental framework for these sites as well as the types of activities that took place here. It is this multidisciplinary context that is so fragile and so susceptible to destruction. We know so little of this period, yet every year many more precious sites are



JOHN M^CCONNICO

These artifacts form a time line of Native American use of the Barton Creek watershed. Although popularly assumed to be arrowheads, the majority of these pieces are actually dart points, which were affixed to short shafts and hurled with an atlatl, or spear thrower. From left: The earliest point is similar to a Clovis point used about 10,000 years ago. The second point, a Gower, represents the Early Archaic, followed by a Martindale point, with its characteristic fish-tailed base. The fourth point is a Nolan, from the large, flat campfire hearths typical of the Barton Creek watershed. The Pedernales point is from the Middle Archaic, when burned rock middens (from acorn processing) became common in this area.



MARSHALL FRECH

From left: The Williams and Lange points mark the end of the Archaic. The Ensor point, which has been reworked into a drill, marks the transition from the Archaic into the Late Prehistoric period 2,000 years ago. The Scallorn point represents the development of the bow and arrow. The last piece is a Perdiz arrow point, which was used into the protohistoric period, after Cabeza de Vaca's sojourn in Texas.

permanently destroyed for highways, sewer lines, and development.

Today, Austin's most popular park (Zilker) lies square on top of layer upon layer of intact cultural strata representing perhaps 10,000 years of occupation. This site may one day prove to be one of the most significant in the United States for its ability to shed light on past lifeways.

It is indeed exciting to be working at the dawn of technologies that will allow humankind to know much more of our prehistory than ever before. In turn we also owe it to future generations to leave sizable areas like Zilker Park largely intact, for those generations will have the tools to know more than we now can. But amid all the technology and complexity we will use to study these areas, with each artifact I lift from the soil and weigh in the palm of my hand, I am poignantly reminded of the hunters who lived here and how we still remain--stalking.

The People Who Stay Together

Several tribes of Native Americans inhabited this area at the dawn of the Anglo conquests, including the Lipan Apache, the Comanche, and the Tonkawa. Of those, the Tonkawa were most localized to Austin, though they were generally nomadic and followed migratory game and other foods throughout the year. The name "Tonkawa" translates as "the people who all stay together," for the tribe was marked by the gathering of the remnants of various clans. Because of that, the Tonkawa often relied on sign language to communicate within their group.

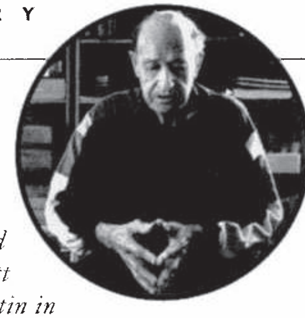
The last Tonkawa were moved out of this region and relocated in Oklahoma during the late nineteenth century. The tribe remains in existence today and is currently attempting to obtain land in the Central Texas area.

Gods and heroes were born out of springs, and ever afterward came and went between the above and below worlds through their pools. Every Pueblo had sacred springs somewhere near-by. There was every reason to sanctify them–physical, as life depended on water, spiritual, as they had natural mystery which suggested supernatural qualities; for how could it be that when water fell as rain, or as snow, and ran away, or dried up, there should be other water which came and came, secretly and sweetly, out of the ground and never failed?

Paul Horgan
Great River, the Rio Grande in North American History
1954

ORAL HISTORY

Emmett Shelton



age 88

Arrowhead hunter, lawyer, and Westlake land developer Emmett Shelton was born in South Austin in 1905.

We called it the blue hole. As kids we'd go barefooted from Congress Avenue through the Kinney pasture to the Springs. The Rabbs lived on the south side of the pool and their home was just south of where the springs come out. There was no dam there. We went in naked, of course, and there were fish. Somebody had put up a springboard, and the water was cold!

I graduated from Austin High in 1921, then went to Southwest Texas for college. I came to the university (Austin) in '25 and finished up my law degree in 1928.

I moved up into West Lake Hills in 1940. At one time I owned a contiguous tract of four thousand acres of land in this area. What is now Wild Basin I bought for four dollars an acre. I named it after an area in the Rocky Mountain National Park where I'd worked as a counselor in a camp. When I started buying, there wasn't a house or a road in the peninsula area. I offered it for sale, and I realized it wasn't fit for anything but residence. We didn't have any ordinances, so I restricted it by deeds. I built the roads in and started selling land in two- and three-acre tracts.

I once made a remark before the city council that when I died I wanted to be cremated and my ashes to be thrown over the hills in Westlake, and I hoped that most of my ashes would fall on treetops, not rooftops.

That's my background, and I'm proud that if I ever did anything worthwhile to nature, it is that the peninsula area of West Lake Hills is the most compatible between nature and man of any area that has been developed.

Barton Springs is a historical and archaeological monument. It ought to be preserved as near as possible to its natural state. It's an inspiration because it is one of God's jewels that people can understand. It's a creation. And that we've mistreated it there's no question, but man does mistreat most things.

It was beauty that we came out there for (as kids). They have sewer systems that run through there now; that's an awful thing to have happen. I don't care who was responsible for it, they were wrong, because sewers are human-made and subject to fracture.

Why didn't the people foresee the problem and buy the land when they could have gotten it cheap? The city very strongly encouraged development everywhere, and so you get out of trying to be an ecologist and developing land compatible with nature and you get your dollar element mixed in. I can tell you, whenever you get a dollar laying on the line, there's not good thinking taking place.

ERIC BEGGS

Emmett Shelton found this flint by Barton Springs on February 22, 1917. It is called a preform and is believed to have been used by Native Americans for trade purposes.

The Spanish

1528–1840

There is little doubt that Spanish expeditions visited the Colorado Valley during their sixteenth-century searches for gold. The first such exploration was probably that of Alvar Nuñez Cabeza de Vaca and three companions who survived a shipwreck off Galveston Island in 1528. They were enslaved by Native Americans for several years but eventually gained their freedom by aiding sick tribesmen. The Spaniards' shamanic reputation preceded them from tribe to tribe as they undertook a bizarre journey through this unknown land. Cabeza de Vaca's account indicates that his party may have crossed the San Saba hills above present-day Austin in 1534 before his party made its way to Mexico City in 1536.

The numerous expeditions that followed Cabeza de Vaca were sure to encounter the ancient thoroughfares that already crisscrossed the Texas landscape. These trails had been well worn by centuries of migratory herd animals and the Native Americans who pursued them. Two such trails bisected the area of San Antonio, one running north through New Braunfels and up through the present city of Austin. It was here that the natives often forded the Colorado River at the mouth of Shoal Creek, just downstream from Barton Creek and within a mile of Barton Springs. This ford was so well used as to be clearly visible when the original town of Waterloo (now Austin) was settled.

Spanish records indicate that in 1730 the missions San José de los Nazonis, San Francisco de los Neches, and Nuestra Señora de la Purisma Concepción d'Hanis were moved from East Texas along this same trail. A new site for the missions was chosen near the present-day Zilker Park. Their exact locations have never been uncovered, but there has been speculation about the origins of rock wall ruins located three miles upstream from the Springs.

In any event, the missions were occupied for less than a year before the friars moved on to San Antonio, and it was almost a hundred years before the territory came under the control of the Mexican government in 1821. Mexico then opened the land up to colonization by foreign immigrants, encouraging settlers with the promise of 177 acres of irrigable farmland and an additional league of pasture (4,428 acres) for each new family. Individual recruiters, well paid in prime land holdings, made their way up the Eastern Seaboard with glorious tales of the Texas heartland, and pioneer immigrants soon poured into the territory.

AUSTIN HISTORY CENTER/AUSTIN PUBLIC LIBRARY

The origin of these stone walls just upstream of Campbell's Hole on Barton Creek has never been fully explained. Speculation has arisen that they were stock pens associated with Spanish missions, but the Spanish built nearly all such structures in straight lines, and these walls are contoured.

An old Comanche Indian trail from Bandera County to Nacogdoches passed Barton Springs. They were a popular gathering place for Tonkawa, Apache, and Comanche Indians in historic times, and probably for their ancestors for thousands of years previously. Spanish explorers wrote that in 1714 wild horses were numerous here. Three Spanish missions were located at the springs from 1730 to 1731.

Gunnar Brune
Springs of Texas, Vol. 1

Vegetation occurrence and hydrologic function at field stops:

(adapted from "Recommended Land Management for the Water Quality Protection Lands" submitted by the Land Management Planning Group to the City of Austin Water/Wastewater Commission on May 19, 2001)

The quality of the water in the Edward's aquifer is partially dependent on native vegetation in both the Contributing and Recharge Zones of the aquifer. Vegetation serves to filter impurities from the water, protect and build soils, funnel water to the aquifer, and to provide shade and habitat for other native plants and for wildlife. A healthy mix of vegetation is of paramount importance to maintain high water quality in streams and the groundwater, whereas loss of vegetation often leads to a loss of soil and increased runoff and erosion, leading to resulting decrease in water quality and quantity.

In contributing zones, rangelands offer better opportunities for water to enter the aquifer because there are fewer impervious surfaces than in urbanized areas, but ranching activities have altered the natural hydrologic system. Beginning in the late 1800s, livestock overgrazing and the suppression of wildfires transformed the Hill Country landscape, and much of the soil profile was eroded and lost. Without wildfires, woody plants were allowed to take over where grasses once dominated. As a consequence, the balance between types of vegetation – specifically between grasses, forbs, and woody vegetation – was altered, and with it came significant changes to the groundwater regimen. These negative changes are not irreversible, however, and much research and experimentation has been done over the years to find the best ways of restoring the land to its original health.

Some studies indicate an inverse relationship between the presence of woody species and deep groundwater infiltration. This research suggests that the removal of woody vegetation (trees and brush) and the subsequent establishment of herbaceous vegetation (grass and forbs) in its place can increase the "water yield" in the contributing zone, hypothesizing that woody species intercept a large portion of annual rainfall in their canopies, a significant portion of which is lost to evaporation (Hollon, 2000; Wu et al., 2001). Hollon (2000) and Wu et al. (2001) indicate that the greatest amount of aquifer recharge is obtained by keeping woody plant canopy coverage below 15% to 20% in contributing zones. Another hypothesis proposes that this tree canopy keeps evapotranspiration low, thus increasing recharge. Additional studies are currently being conducted to discover further evidence to support one or the other of these opposing views.

Historical accounts describe the landscape in Central Texas becoming progressively woodier over the last 150 years (Smeins, 1982). While the exact mechanisms for this transition are still under debate, it is generally accepted to be a combination of the interacting effects of fire (or lack of it), grazing practice, and drought, all creating a mosaic of ecosystems. Fire, in many ecosystems, represents part of the dynamic equilibrium, which maintains the balance between productivity and decomposition (Pyne, 1982). Overall the historic vegetation pattern was probably one of a "moving mosaic" of different plant communities, ranging from regions that burned frequently to areas that rarely experienced fire, if ever. In contrast to native American Bison, grazing by cattle can have a dramatic effect on vegetation. The spread of mesquite (*Prosopis glandulosa*) throughout central Texas has been largely attributed to the ingestion of mesquite pods and consequent defecation of seeds. Finally, invasive species such as *Arundo donax* (Giant Reed), *Colocasia esculenta* (Elephant ear), and *Tamarix ramosissima* (Saltcedar) can present a threat to water quality when they dominate a system to such an extent that they reduce overall vegetation coverage, and thereby increase erosion or shade out native species more effective at capturing and holding rainfall.

Our field trip takes us to several sites of recharge, where woody species are more desirable. At these locations, the vegetation is described as oak/juniper woodlands. These stands of woody vegetation enhance hydrologic function by stabilizing river banks during flood events and filtering impurities from the water.

Campbell's Hole:

The vegetation on the banks of the streambed is mostly comprised of *Juniperus ashei* (Ashe Juniper) – the darker green trees – and *Populus deltoids* (Eastern Cottonwood) – the lighter green trees

However, a few other trees can be seen on the field trip as follows:

Salix nigra (Black Willow)

Cornus drummondii (Dogwood)

Fraxinus texensis (Texas Ash)

Ulmus crassifolia (Cedar Elm)

Quercus fusiformis (Live Oak)

Celtis laevigata (Hackberry)

Ilex vomitoria (Yaupon Holly)

Diospyros texana (Texas Persimmon)

Forestiera pubescens
(Elbow Bush)

Opuntia engelmannii
(Texas Prickly Pear)

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http://www.bio.utexas.edu/courses/bio406d/PlantPics_archive.htm

Whirlpool Cave Lessons & Readings

CAVE FORMATION AND WATER MOVEMENT IN KARST

AUTHOR: Corinne Wong

DATE TO BE TAUGHT: November 29 and 30, 2007

LENGTH OF LESSON: Two 45 min class periods

GRADE LEVEL: 8

SOURCE OF THE LESSON: Deep Down Underground (author Maragret Russell) 5E lesson plan and Sierra Nevada Recreation Corporation "Cavern Geology: Lesson 1: What is a Cavern?"

TEKS ADDRESSED:

§112.24. Science, Grade 8.

(a) Introduction.

> (7) Investigations are used to learn about the natural world. Students should understand that certain types of questions can be answered by investigations, and that methods, models, and conclusions built from these investigations change as new observations are made. Models of objects and events are tools for understanding the natural world and can show how systems work. They have limitations and based on new discoveries are constantly being modified to more closely reflect the natural world.

(b) Knowledge and skills.

> (1) Scientific processes. The student conducts field and laboratory investigations using safe, environmentally appropriate, and ethical practices. The student is expected to:
>
> > (A) demonstrate safe practices during field and laboratory investigations; and
> >
> > (B) make wise choices in the use and conservation of resources and the disposal or recycling of materials.
>
> (3) Scientific processes. The student uses critical thinking and scientific problem solving to make informed decisions. The student is expected to:
>
> > (C) represent the natural world using models and identify their limitations;
> >
> > (D) evaluate the impact of research on scientific thought, society, and the environment; and

(4) Scientific processes. The student knows how to use a variety of tools and methods to conduct science inquiry. The student is expected to:

(A) collect, record, and analyze information using tools including beakers, petri dishes, meter sticks, graduated cylinders, weather instruments, hot plates, dissecting equipment, test tubes, safety goggles, spring scales, balances, microscopes, telescopes, thermometers, calculators, field equipment, computers, computer probes, water test kits, and timing devices; and

(12) Science concepts. The student knows that cycles exist in Earth systems. The student is expected to:

(A) analyze and predict the sequence of events in the rock cycle;

(14) Science concepts. The student knows that natural events and human activities can alter Earth systems. The student is expected to:

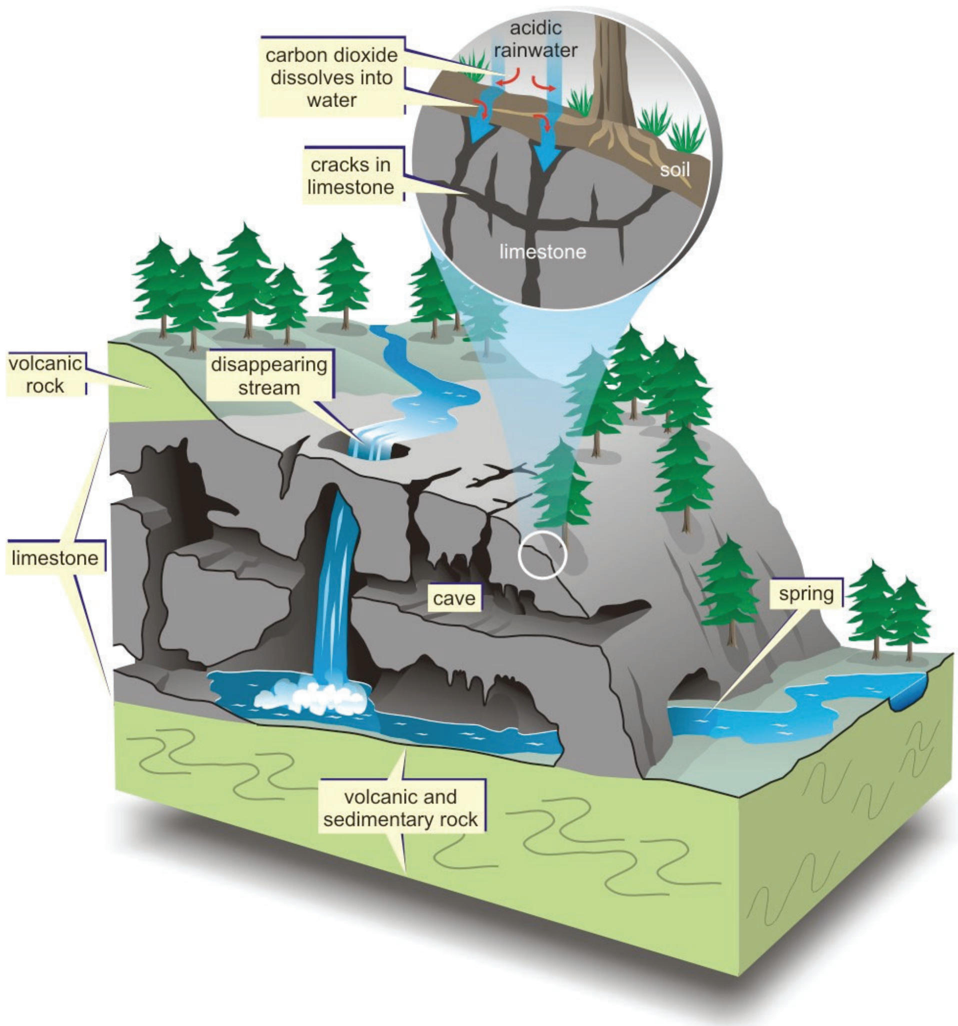
(A) predict land features resulting from gradual changes such as mountain building, beach erosion, land subsidence, and continental drift;

(C) describe how human activities have modified soil, water, and air quality.

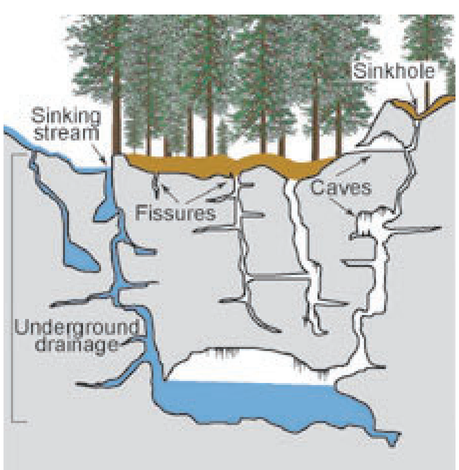
CONCEPT(S):

Some caves are formed by the dissolution of limestone rock - $CaCO_3 + CO_2 + H_2O \leftrightarrow Ca^{2+} + 2\,HCO_3^-$. Rainwater becomes slightly acidic when it dissolves CO_2 from the atmosphere and the soil it is infiltrating. This slightly acidic water dissolves the limestone. The rate of cave formation increases with the decrease of impermeable cover and increase in features such as sink holes, fractures, faults that increase the amount surface area exposed to infiltrating water.

Karst is a landscape characterized by surfacial and subsurface solution weathering of soluble bedrock, usually limestone. Characteristic karst features include: caves, sink holes, disappearing or emergent streams. Water management in karst areas is difficult because karst terrains can move large volumes of water faster than in non-karst terrains. Karst terrains have numerous macropores such as conduits, fractures, sink holes, caves, through which large volumes of water can move through quickly. This leaves karst aquifers vulnerable to contamination events. Also, karst terrains are heterogeneous and anisotropic, making predicting the direction and rate of water movement difficult.



web.mala.bc.ca/geoscape/Karst.htm



www.esi.utexas.edu/outreach/caves/karst.php

OBJECTIVES: Students will be able to:

1. Use a model to explain real phenomena.

2. How caves in carbonate terrains form.

3. Describe how water quality in karst terrains is vulnerable

SAFETY: Students should be instructed not to eat or drink any of the lab materials. Students should be warned that they are working with a weak acid and need to be careful not to get it in their eyes or on their clothing. The acid being used is lemon juice, so the risk of harm is minimal.

MATERIALS:
64 sugar cubes for each group
10 plastic cubs of the same size (dice?) for each group
1 clear plastic case with square edges (aprox. 5") for each group
toothpicks
plastic transfer pipettes
plastic cups
1/4 stick modeling clay for each group
piece of limestone for each group
lemon juice
litmus paper

Day 1

Engagement (10 min):

Warm Up (in journal):
Use a chair with an open back foldable chairs work best. Tell the students that cavers form grottos (groups) in which they meet to talk about and plan cave trips. A favorite recruiting activity for grottos is to have people climb through chairs – if you can make it through the chair, you might be ready to go caving!

Questions:

1. Can you fit through the hole in the chair (try it)?
    a. Use common sense about which students you allow to try this.

2. Do you think Ms. Abernathy can fit through the hole (for fun)?

3. What is a cave? (underground cavern large enough for a human to enter)

4. Have you ever been in a cave?

5. How do you think caves form? (open ended)

Model Cave:
Show students a pre-made model with a cave in it. Let them know that they will be making their own models.
Questions:
   a. How do you think I made this cave? Come up with a guess and discuss it with your partner.

Exploration (35 min):

I. Build models (15 min):
1. Have students make a 4x4x4 stack of cubes up against one corner of their clear cube. Let them know they can use any combination of sugar or plastic cubes.
2. Have students cover the surface with a thin ($1/16^{th}$ in.) layer of clay.
3. Teacher draw on white board a quick sketch of bedrock beneath a surface layer or bring in a cross section type picture.
4. Questions:
   a. What is a model? (something that represents something else)
   b. How might your model compare to the drawing on the board? (the clay is the surface, the cubes are the bed rock)
   c. What is the difference between the sugar and plastic cubes? (dissolvable, not)
   d. What is that representing in the real world? (more and less soluble rock/limestone; the different cubes could also represent different types of rocks (for example a clay layer or chert nodule or dolomitic bed) within the limestone. The whole point is that one rock is more soluble than the other)

II. Make predictions (5 min)
1. Have the students drop the acidic water on a sugar cube not a part of their model.
2. Questions:
   a. What happened when you dropped the acidic water on the sugar cube? (it dissolved)
   b. What does it mean to dissolve something? (a solid breaks apart into smaller, separate molecules and mixes with the solvent/water – for example, salt crystals (NaCl) break into Na and Cl in the water, making salt water)
   c. Can water move quickly through clay? (no)
   d. How can you get a cave to form in your model? (holes in the clay)
   e. Draw a sketch (in journal) of how you will make a cave and what it would look like. (open ended).

III. Create Caves! (10 min)
1. Give students time to test out their cave making methods (should involve poking holes in the clay and dripping water onto the surface).
2. Questions:
   a. Did what you say you were going to do work? Good question.
   b. What was the best method to make the cave the fastest?
   c. What does this represent in real life?

d. Did you observe anything you didn't expect?

e. Does your cave look like the one you drew?

f. Sketch your cave.

IV. Clean up! (5 min)

Day 2

Engagement (10 min):

Have a geologic map of Texas out with cave locations labeled with stars:

Questions:

1. Look on the map – what is the same about all the locations starred on the map? (limestone terrains)

2. Drop some lemon juice on the rock and record your observations (the rock will fizz as the weak acid is dissolving the limestone)

3. Why might that be occurring? (limestone is dissolving; if students do not get this, come back to it in the explanation part)

Explanation/Expansion (25 min):
Group discussion:
Teacher: You created a model of a cave system. What did this model show you? Save models from the previous day or recreate models so students have a visual

1. Review key ideas from yesterday (5 min):
    a. Model
    b. Parts of the model
    c. Dissolve
        i. Who remembers what we did with pH before this semester? (used pH to determine a mystery liquid)
        ii. What is the pH scale, check your notebooks?
        iii. What is pH value does an acid have?
        iv. What pH value does a base have?
        v. What is the pH of pure water? (7)
        vi. What do you think the pH of the lemon juice is? (acidic)
        vii. Have students test it with litmus paper
        viii. How might rainwater become acidic? (pick up CO_2 from the atmosphere and soil horizon)
        ix. What part of your model is acidic rainwater?

2. Student share – have each student group share their sketches (dotcam), keep a list of how students described cave formation (5 min).

3. Questions (5 min) – use student observations to guide questions
    a. Did the cave form uniformly – the same all throughout? (no)
    b. Where did it form the quickest? (beneath holes, spaces between cubes)
    c. If you had no idea about what the subsurface looked like, could you predict where the water would go and where the cave would form? (no)
    d. How did water get below the clay layer? (holes)
    e. When you had a hole, did water infiltrate quickly or slowly? (quickly)
    f. What could you do to slow, but not block water infiltrating the hole? (sponge, which would represent vegetation)
    g. If your water came from this area, would you want water to infiltrate fast or slow? (depends)
    h. In what situations would you want water to infiltrate slowly? (if there was pollution in the area. The more time water spends with the vegetation, soil, and rock, the more time for interactions to occur to naturally remediate some of the pollutants.)
    i. In what situations would you want water to infiltrate quickly? (In areas prone to drought, water infiltrating quickly would not be evaporated)
4. Relate to water management (12 min)
    Teacher: The rock you dropped lemon juice on this morning was limestone..
    Questions:
    a. What kind of rock are Texas caves found in? (limestone)
    b. Why do you think that is? (limestone dissolves)
    c. What does your model suggest about how water moves through limestone?
    d. Who has been to Barton Springs?
    e. Why is Barton Springs relevant to this lesson?
    Teacher: Have students work in their groups to come up with management advice for the area surrounding Barton Springs (ex: What should we do to make sure that Barton Springs always flows but has clean water). Have each group present their findings.

Evaluation (8 min):

1. Make a sketch showing how caves form. Label the factors that cause or enhance cave formation (hint, you should have the following labels: limestone, acidic rain water, CO_2, cave, surface/soil, fractures/cracks, holes/sink holes). If you are not comfortable drawing, use a paragraph to explain cave formation.

2. Describe how water movement in karst terrains makes groundwater resources vulnerable. (large volumes of water can move rapidly through the subsurface. Prediction of water flow paths is difficult)

Assessment Rubric

Exceeds Satisfaction – 1. Has a diagram with all of the components requested in correct relationship. 2. Mentions 2 of the 3 (large volume, rapidly, unpredictable)

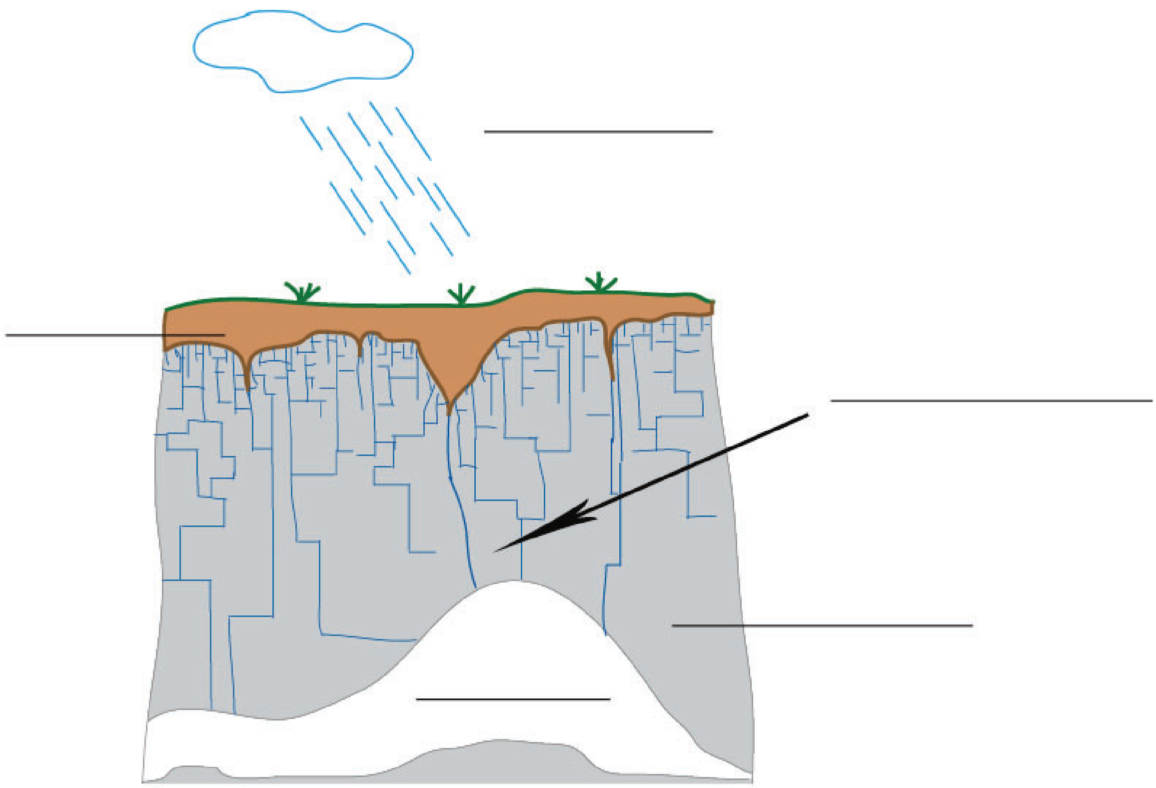
Satisfaction – 1. Has the cave depicted in the subsurface with water flowing to the cave via preferential pathways. Not everything is labeled. 2. Mentions 1 of the 3.

Does not meet satisfaction – 1. The sketch does not coherently indicate a cave or that water is flowing to the cave. No labels. 2. Does not coherently answer.

Modifications for students with special needs:

Alternative assessment:

Here is a diagram of cave formation, label the parts



A cave forms by water _____________ limestone.
The water is slightly ______________.

Answers:
A cave forms by water dissolving limestone.
The water is slightly acidic.

Show me what you learned! Name: ____________

1. Make a sketch showing how caves form. Label the factors that cause or enhance cave formation (hint, you should have the following labels: limestone, acidic rain water, CO2, cave, surface/soil, fractures/cracks, holes/sink holes).

If you are not comfortable drawing, use a paragraph to explain cave formation.

5. Describe how water movement in karst terrains makes groundwater resources vulnerable.