
*Photo credit: James Volosin*

# The State of the Pedernales:
# Threats, Opportunities and Research Needs

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**Summary**
The Pedernales River is an iconic Hill Country river, running 106 miles through rolling limestone hills before eventually joining the Colorado River at Lake Travis. The Pedernales drains nearly 820,000 acres across 8 counties. During dry periods, the Pedernales River provides up to 23% of the surface water entering Lake Travis, which the city of Austin relies on for drinking water, energy production, and recreation. The Pedernales and its associated watershed area provide critical habitat for several endemic species, and the river provides important scenic, recreational, and cultural value to Central Texas.

This report summarizes the research, conservation, and stewardship efforts that have been completed or are currently active in the Pedernales River watershed. Understanding the river's unique characteristics, the diverse land uses that take place within the watershed, and the wide variety of stakeholders interested in the its long-term sustainability will inform efforts moving forward. There are already a variety of organizations, agencies, business, and individuals invested in the future health and protection of the Pedernales River. Coordinating efforts between these groups will ensure efficiency, enhance community outreach and education efforts, and improve our overall understanding of the river.

This report first summarizes some of the physical, geological, hydrological, ecological, historical, cultural, and demographic characteristics of the Pedernales watershed and its stakeholders. This summary comes from programmatic reports and scientific journal articles that have been written about the river and the wider Edwards Plateau region. The review goes on to list research needs, challenges to the health of the river, and opportunities for collaboration. Existing and ongoing efforts are then summarized with a list of organizations and agencies that are actively working within the watershed.

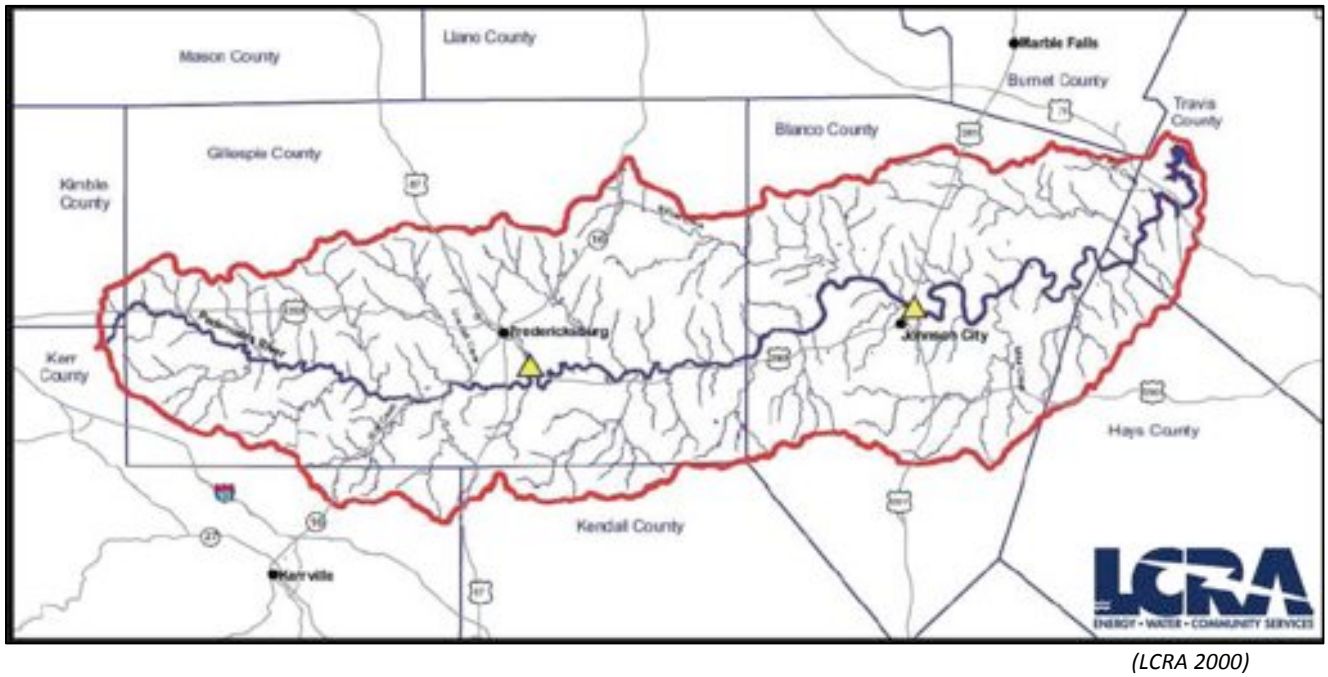
**Table of Contents**

## Introduction

The Pedernales River runs 106 miles through the Texas Hill Country and Edwards Plateau ecoregion and is an important tributary of the Colorado River. The headwaters of the Pedernales are spring-fed and originate in southeastern Kimble County. The river flows in an easterly direction through Gillespie County, into Blanco County, and ultimately into the Colorado River in Travis County. In all, the river passes through four counties[1] and has a drainage area of more than 819,200 acres. The Pedernales watershed extends into eight counties,[2] and the river has a number of important tributaries along its reach.[3] Most tributaries are highly intermittent, but there are several perennial streams that provide important surface water to the main stem (TNC 2007).

The Edwards Plateau ecoregion is capped by a thick layer of limestone rock that has dissolved over time to form the largest continuous karst area in the United States (Bowles and Arsuffi 2006). The region is home to a wide array of plant and wildlife species, including numerous endemic species found nowhere else in the world (TNC 2007). Many of these species are rare, including 19 plants, 34 fish, at least six salamanders, and several insect species associated with river habitats (LCRA 2012). The diversity of species documented in the area is a result of the wide variety of habitats found in the in the uplands, riparian, river, spring, and karst systems of the Edwards Plateau.

**Figure 1: Map of the Pedernales**




*(LCRA 2000)*

[1] Blanco, Gillespie, Hays and Kimble counties.

[2] Blanco, Burnet, Gillespie, Hays, Kendall, Kerr, Kimble, and Travis counties.

[3] Important tributaries include Barons Creek, Cypress Creek, Hamilton Pool, Heinz Creek, Live Oak Creek, Town Creek, and Williams Creek (The Meadows Center 2013).

## Natural and Cultural History

The Pedernales watershed, like most of the Edwards Plateau, was most likely composed of a mixture of grassland prairie, savannah, forest, and brush land until the mid-1800s, when the first German settlers arrived. Fire management provided an important component of the ecology of the region, and brush such as Ashe juniper was confined to areas that were not reached by fire—primarily in deep ravines and canyons (LCRA 2000).

The first written accounts of the Pedernales River watershed come from the 17th century when Spanish explorers were just beginning to enter the area. For the most part, those explorers chose to stay out of the Edwards Plateau region because of heavy "brushwood" found at the edges of the hills in what is now Comal County, as well as conflicts with Native Americans (Weniger 1984).

By the early-19th century, German settlers were making their way deeper into the Pedernales River watershed area establishing towns and permanent settlements. These early pioneers sent accounts of a broad forested valley around the Pedernales, rich mesquite prairies, and untouched oak stands. The first report of grass in the area came from J.W. Benedict, reporting from Blanco County near Johnson City of grasses "3 to 4 feet high" (as cited in Weniger, 1984). Reports of wild buffalo in the Pedernales watershed indicated a rangeland that could support roaming grazers, but it was likely broken by brush land and denser forest in the ravines that were unscathed by fire.

Fire was commonly referenced by early Central Texas pioneers and became widely suppressed as permanent developments were established in the area. The suppression of fire coupled with intense overgrazing dramatically altered the landscape of the area, and favored the growth of woody plants over grasses (LCRA 2000).

The name Pedernales comes from the Spanish term that was used to describe the flint rocks that characterize the riverbed (Smyrl 2013). Archeological evidence of human habitation in the Pedernales watershed can be traced back to 10,000 years BC.

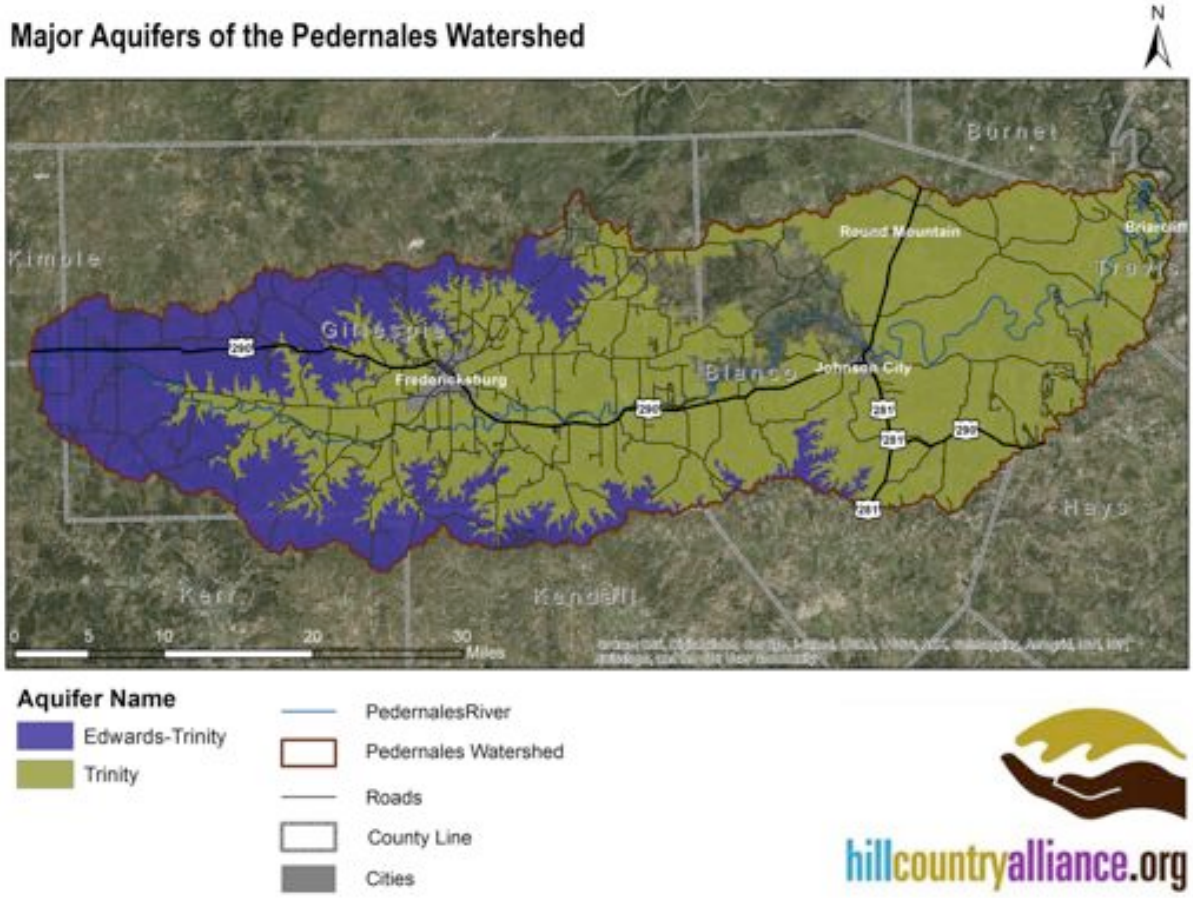
*Photo Credit: Rusty Ray*

## Geology, Topography and Drainage

The underlying geology of the Edwards Plateau region is essential to informing our understanding of how the Pedernales watershed functions. Geologic history determines the creation of soil, the resulting character and structure of plant life, the speed and nature of erosion, ground water recharge processes, and many other characteristics of the watershed (Lopes and Oliver 2008).

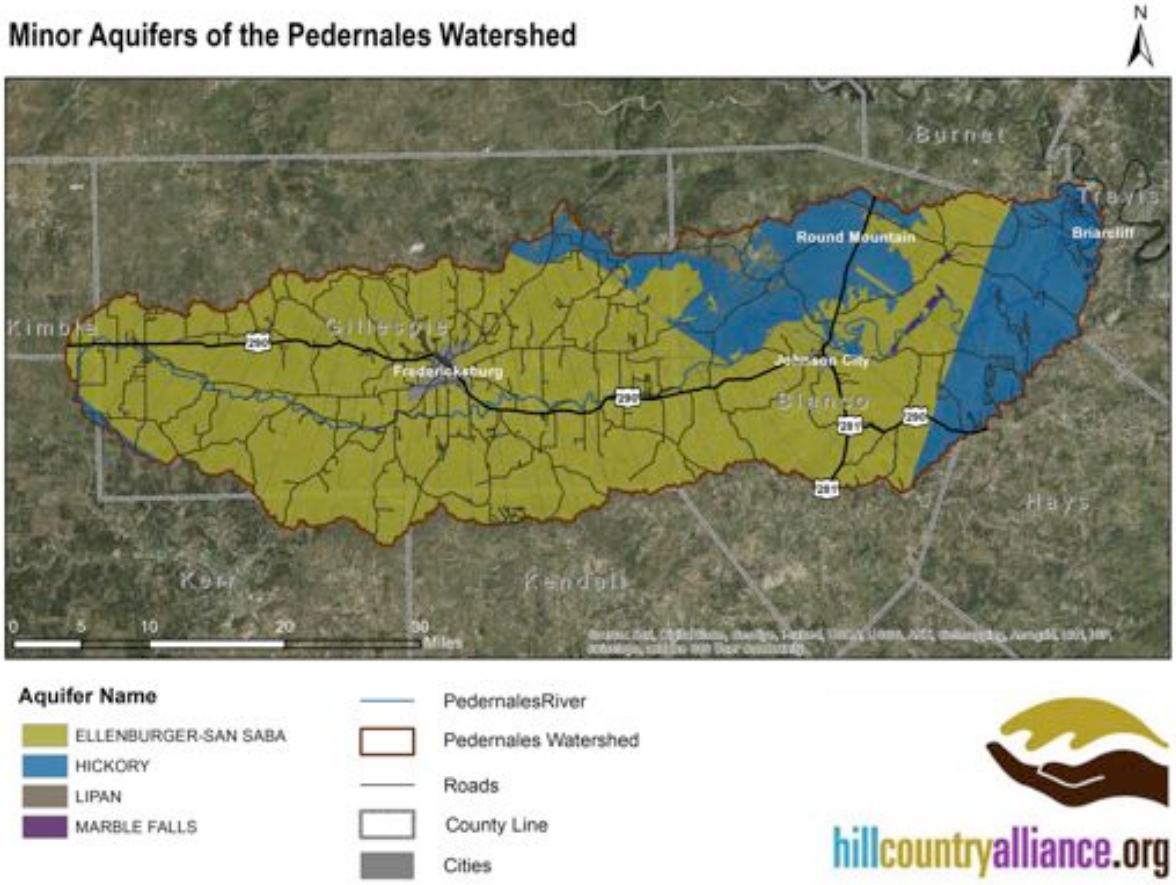
The Pedernales watershed sits atop both major and minor underground aquifers. Major aquifers are defined by the Texas Water Development Board as those that supply a large quantity of water in large areas of the state (Ashworth and Flores 1991). The Edwards Trinity and Trinity aquifers are the major aquifers that underlie a large part of the watershed (TNC 2007). In general, the majority of the uppermost surface layer of geology was deposited between 114 and 65 million years ago during the Cretaceous period—there has not been any major faulting in the Cretaceous strata in the Pedernales since it was deposited (Lopes and Oliver, 2008). Aquifers within the cretaceous strata include the Lower Trinity, Middle Trinity, Upper Trinity, and Edwards aquifers (LCRA 2000).

**Figure 2:**



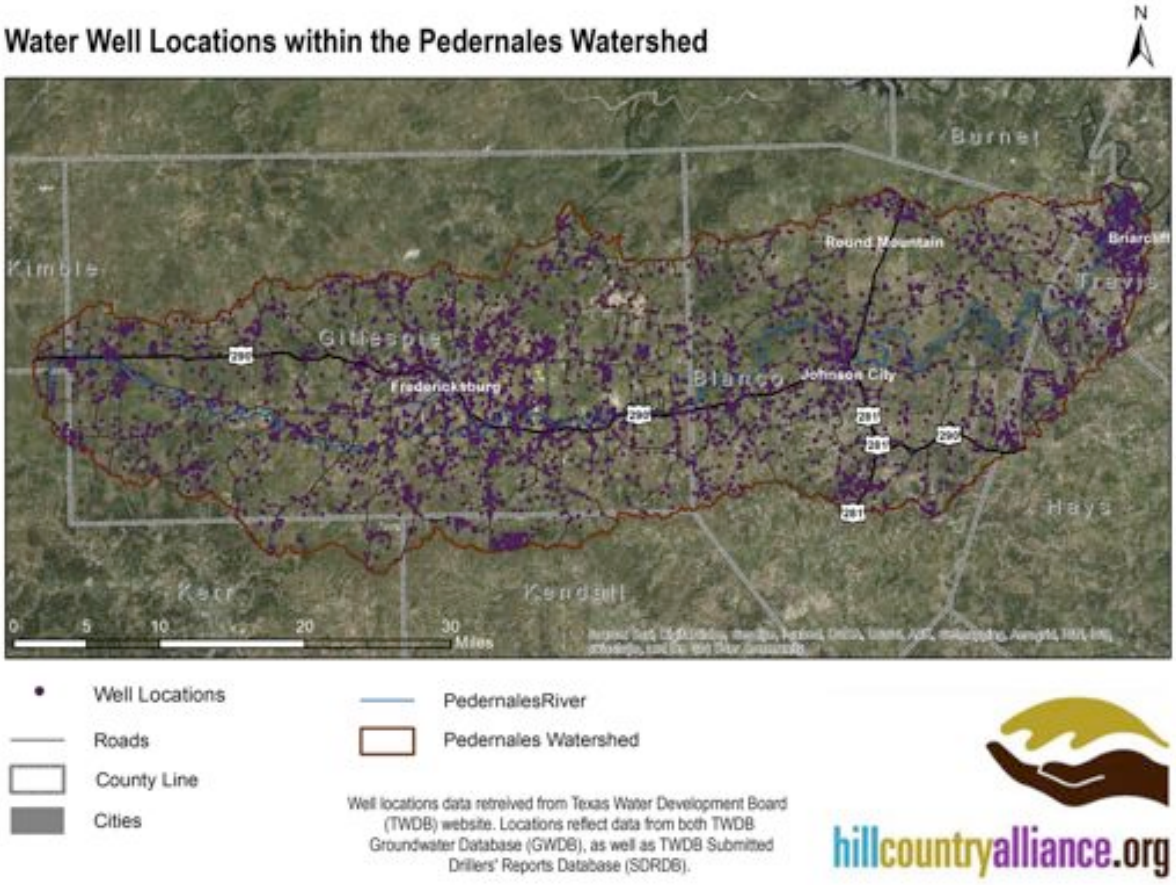
Below the Cretaceous layer is the older Paleozoic strata, which was fractured during tectonic activity 200 million years ago. In some areas, particularly in the higher western elevations of the watershed, the Cretaceous layer has been worn away to reveal the more highly fractured and irregular Paleozoic rock (Lopes and Oliver 2008). Paleozoic aquifers within the Pedernales include, from oldest to youngest, the Hickory, Mid-Cambrian, Ellenburger-San Saba, and Marble Falls aquifers (LCRA 2000).

**Figure 3:**




Within the watershed approximately 30% of the water wells in Gillespie County and 35% of the wells in Blanco County draw from the Middle Trinity aquifer. There are approximately 4,200 documented water wells within the watershed.

**Figure 4:**




The southern outcroppings of the Llano Uplift feature prominently in a small section of the Pedernales as it drops 50 feet over a 3,000 foot lateral stretch of layered limestone formations at the Pedernales Falls State Park (Meadows Center 2013). The soils of the Pedernales watershed range widely from clays to sands. Much of the soil includes gravel, cobble or stones, and is generally thin and well drained. Heavy grazing and intensive land use practices have led to erosion and loss of soil depth in some areas.

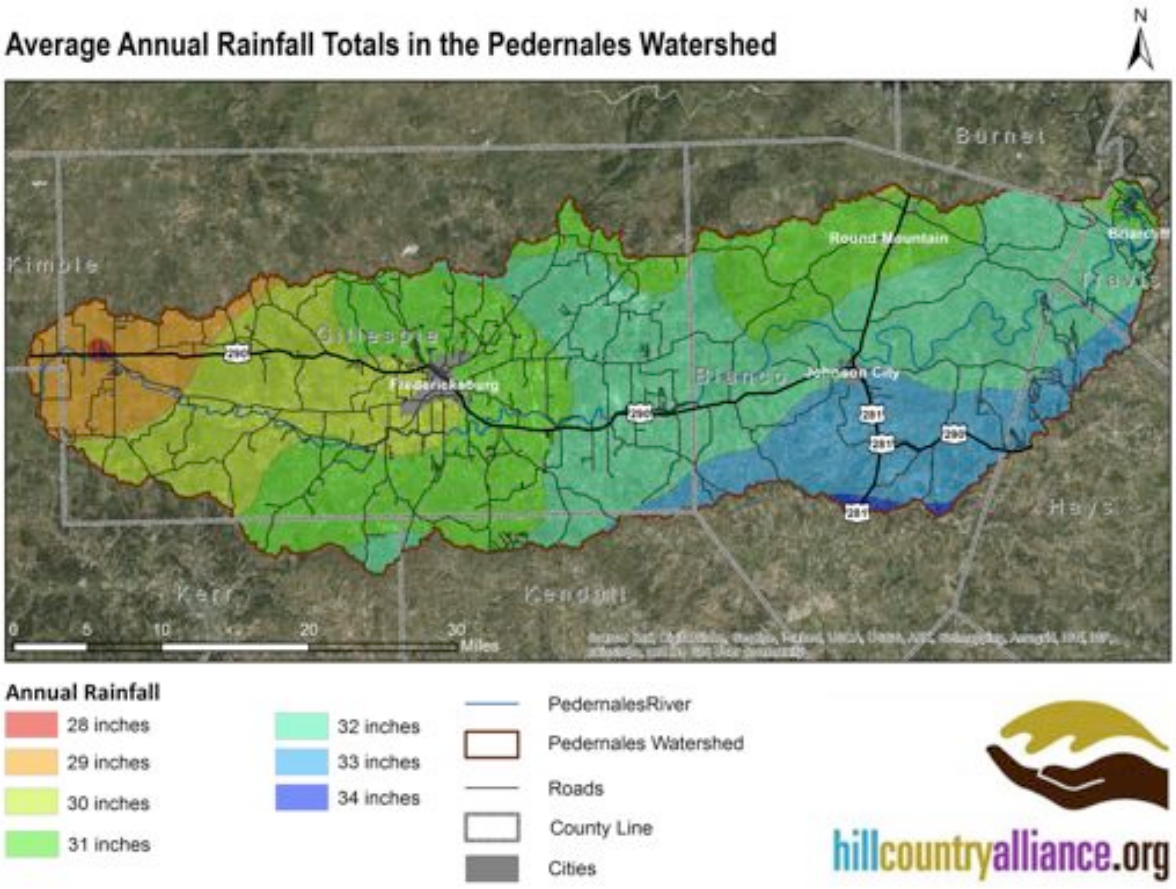
## Climate

The climate of the Pedernales River watershed is subtropical, with hot summers and dry winters (Meadows Center 2013). An in-depth analysis of precipitation patterns conducted by the Meadows Center for Water and the Environment[4] revealed that precipitation in the Pedernales watershed occurs at an extremely localized spatial scale – meaning that areas within relatively close proximity can see very different rainfall totals (Lopes and Oliver 2008). The National Climatic Data Center (NCDC) measures rainfall in Texas, though often at a course scale

[4] Formerly called the Rivers Systems Institute.

that does not allow the detection of fine spatial patterns. The Lower Colorado River Authority (LCRA) has installed an additional rainfall network to monitor their reservoir systems. Meteorological and river flow data was first collected in the Pedernales in 1939, and research suggests that there have been no major changes in climate or stream flow characteristics in the intervening years (LCRA 2000).

**Figure 5:**




In general, there is measurably greater rainfall in the eastern portion of the watershed than in the west (Lopes and Oliver 2008). Average annual rainfall collected from 1980-2001 shows a gradient of as much as 6 inches from the western portion of the watershed to the southeastern most section of the area.

## Water Resources

### *Water Quality*

Water quality monitoring is completed by 3 separate entities along the Pedernales River: the Texas Commission on Environmental Quality (TCEQ) (2 sites), the Colorado River Watch Network (CRWN) (14 sites) and the Lower Colorado River Authority (LCRA) (4 sites). Generally

speaking, the water quality of the Pedernales River is good (LCRA 2012). A trend analysis was completed by the LCRA at 5 water quality-monitoring stations along the Pedernales. The study looked at water temperature, dissolved oxygen, pH, nitrate/nitrite/nitrogen, total phosphorus, and chloride concentrations. Across all 5 sites, two were found to have trends of increasing phosphorus, indicating a slight decrease in overall water quality. No other trends were observed, meaning that the remaining indices seemed to point to stable water quality (LCRA 2012).

In 2013, the Meadows Center released a draft report on water quality for the Pedernales River. Stream Team citizen scientists collected water quality data including dissolved oxygen, pH, air and water temperature, and total dissolved solids. The data was collected from 14 sites along the river over the course of 5 years (from 2008-2013). The team found that total dissolved solids and pH decreased over the course of the river, although there was no pH level that fell outside of a healthy range (Meadows Center 2013).

The cities of Fredericksburg and Johnson City are the only two municipalities with permits to release treated wastewater in the watershed. Fredericksburg has a permit to discharge up to 2.5 million gallons per day of treated wastewater into Barons Creek, a tributary of the Pedernales. Johnson City has a permit for up to 0.303 million gallons per day into Town Creek (LCRA 2012). The TCEQ permits for these treatment facilities have water quality requirements relating to total suspended solids, ammonia-nitrogen, dissolved oxygen levels, and CBOD5[5].

In 2012, the Sunbelt Sand LLC applied for a permit to operate a sand and gravel facility just outside of Fredericksburg along the Pedernales River. There was a public outcry of concern about potential sedimentation and water quality issues that could result after heavy rain events, and in October of 2013 the application was withdrawn. Landowners need to apply for permits for any operation that will occur within the banks of a state-owned riverbed. The Texas Commission on Environmental Quality (TCEQ) and the Texas Parks and Wildlife Department (TPWD) handle these applications.

### *Water Quantity*

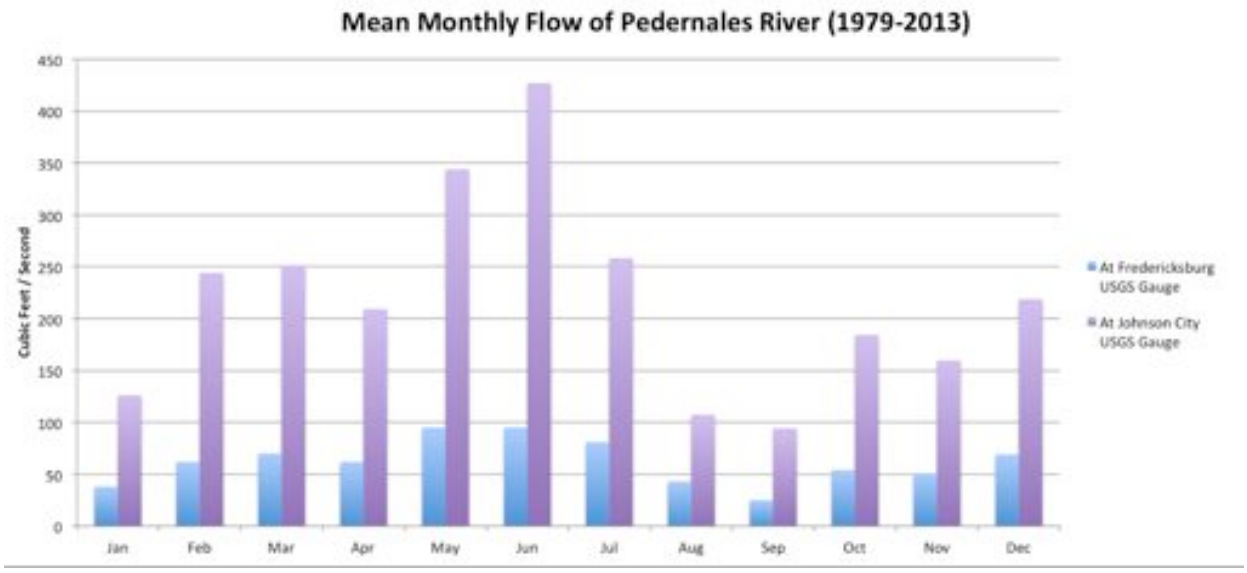
The U.S. Geological Survey (USGS) has historically maintained four flow gauges on the Pedernales River[6]. The longest regularly maintained gauge is USGS #08153500, outside of Johnson City. Data has regularly been collected there since 1939. USGS gauge #08152900 outside of Fredericksburg has also been a long-running monitoring site. Data is available dating back to 1979 (USGS 2015). USGS gauges at Spicewood and Stonewall were less frequently monitored and are not currently used.

[5] CBOD stands for carbonaceous biochemical oxygen demand, and is considered to be an indication of wastewater pollutants.

[6] The USGS has a total of more than 10 sites within the watershed- but only four have been monitored with any regularity. Two are still monitored today.

Historic data from a flow gauge located outside of Johnson City[7] shows that the highest recorded flow on the Pedernales River was 129,000 cubic feet per second (csf) on September 11, 1951. The median flow during the study period (May 1939 to June 2011) was 53 cfs. Some portions of the Pedernales do go dry during periods of extended drought (LCRA 2012).

**Figure 6:**




The Pedernales River is classified as a "gaining" stream, meaning that its flow increases downstream. Flow is largely reflective of rain conditions in the watershed, with the highest mean flow conditions coinciding with those months that see the largest quantities of rain. The flow of the river can change quickly with a severe rain event.



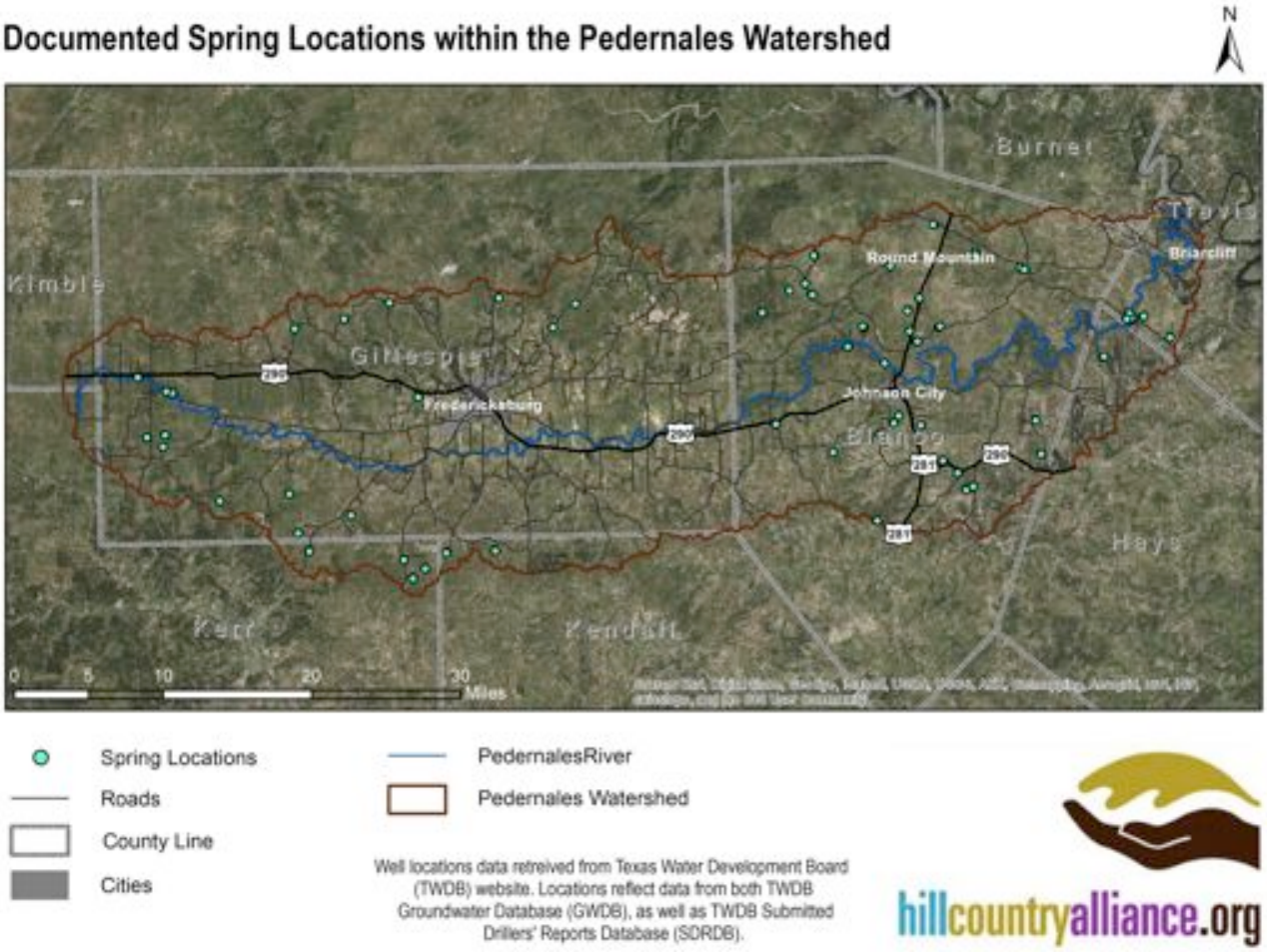
*These photos of the Pedernales during drought and flood demonstrate how drastically the flow conditions can change.*

[7] The drainage area to the gauge site is 901 square miles, roughly 2/3rds of the total watershed area. This data comes from USGS gauge #08153500.

In times of low rainfall the river is sustained by groundwater recharge. Groundwater enters the river from headwater springs originating from the Edwards and Middle Trinity aquifers. Other seeps and springs along its tributaries are the primary sources for the increase in flow downstream (LCRA 2000). Decreases in base flow are generally the result of evaporation and irrigation withdrawals. There are an estimated 1,200 springs within the Pedernales watershed, although only a small fraction of that total is mapped.

As of January 1, 2015, there were 54 active permits for surface water withdrawals from the Pedernales River, totaling just over 5,000 acre-feet of water[8] (TCEQ 2015). Johnson City maintains some surface water rights on the Pedernales River, but does not currently draw from the river. The city instead relies on groundwater drawn from the Ellenburger aquifer (Blanco-Pedernales GCD 2013). In addition to adjacent owners with pumping rights, in-stream flows in the Pedernales watershed are appropriated to downstream users including Lake Travis, the City of Austin, and the four Lower Colorado River irrigation districts (Lopes and Oliver 2008).

**Figure 7:**



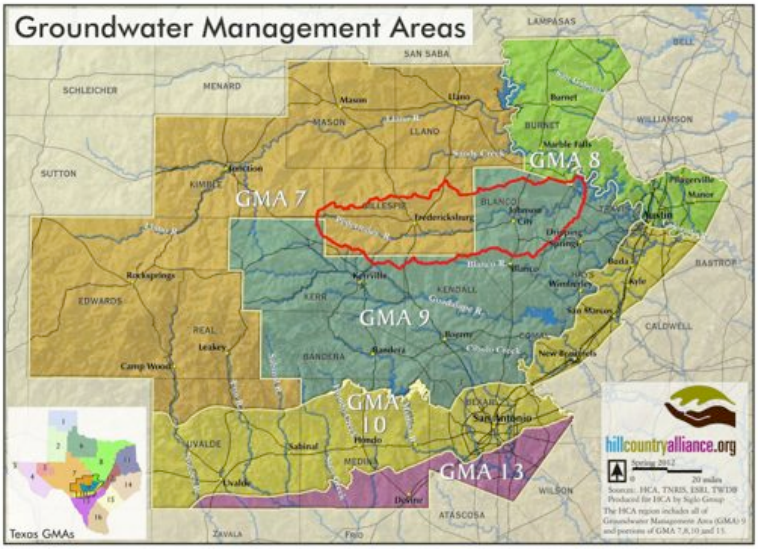

[8] One acre-foot of water is enough to cover one acre of land with one foot of water, or 325,851 gallons.

Groundwater withdrawals through wells alter the natural fluctuations of the aquifer recharge and discharge conditions—but much remains unknown on exactly how those interactions function. The Texas Water Development Board maintains a database of water level records of hundreds of water wells in Blanco and Gillespie counties. One analysis of these wells found that of wells with water level data available for 20 or more years, half of those completed in the Trinity Group aquifers had a net water level decline, with an average loss of eight feet per well. Net gains of an average of 15.9 feet were recorded in the remaining Trinity Group wells. Sixty-five percent of the wells in the Ellenburger-San Saba aquifer showed net water losses, and just over half of the wells in the Hickory aquifer showed net water level declines. The declines in the Hickory aquifer were an average of 33.7 feet (LCRA 2000).

### *Water Resource Management*

A variety of agencies and organizations play a role in managing ground and surface waters within the Pedernales. The Pedernales watershed includes portions of seven groundwater conservation districts that generally follow county lines for Blanco, Gillespie, Kendall, Kimble, Kerr, and Hays Counties.[9] The Blanco-Pedernales Groundwater Conservation District and the Hill Country Underground Water Conservation District have jurisdiction over Blanco and Gillespie Counties, respectively. By statute, wells used solely for domestic or livestock purposes on tracts that are more than 10 acres and that are capable of producing no more than 10,000 to 25,000 gallons of water per day (depending on enabling statue) are exempt from permitting by groundwater districts. Many of the wells within the Pedernales are therefore exempt from permitting.

Because groundwater conservation districts (GCDs) in this region tend to follow county lines, rather than watershed or aquifer lines, in 2005 the Legislature set up a process through which groundwater districts could work together to conduct joint planning to maintain shared aquifers. The resulting Groundwater Management Areas (GMAs) established groups of GCDs that more closely follow aquifer boundaries. Unfortunately, the Pedernales watershed is divided between two GMAs- GMA 9 and GMA 7, so management of its aquifer resources is still somewhat disjointed. The GMAs are



The Pedernales watershed falls in two GMAs- GMA 9 and GMA 7.

[9] The Hays Trinity GCD in Hays County does not cover the entire county.

tasked with establishing Desired Future Conditions (DFCs) for the aquifers. The DFC establishes the parameters within which the aquifer will be managed over the next 50 years.

In 2010, GMA 9 adopted desired future conditions that would allow for a region-wide water-level decline of an additional 30 feet through year 2060, as averaged over the entire management area. This could have serious implications for spring flow and river recharge in the region. In GMA 7, the groundwater conservation districts agreed to a desired future condition with a 0-7-foot drawdown on the aquifers within their jurisdiction over the next 50 years. These groundwater management areas are preparing to enter another phase of planning in 2015, and will have to revisit their desired future conditions. The DFC planning process provides an excellent opportunity for groundwater conservation districts and the general public to voice their concerns and ensure the sustainable management of their groundwater resources.

In addition to the GMA planning process, there are also Regional Water Planning Groups (RWPGs) that guide the formation of a statewide water plan every 5 years. This regional water planning process was initiated in 1997, and there are 16 RWPGs. The majority of the Pedernales watershed falls into region K, the Lower Colorado RWPG. The RWPGs are currently working on updates to their regional plans, which will ultimately inform the 2017 update to the State Water Plan. Meetings of the regional planning groups are open to the public.

Surface water within the Pedernales River is governed by the Texas Commission on Environmental Quality and is fully allocated to downstream users. The Lower Colorado River Authority (LCRA) has water management authority in Blanco County (which is part of its original statutory district), but its authority stops at the Blanco-Gillespie line. The LCRA does take an active interest in water quantity and quality in the Pedernales. The LCRA is the largest holder of downstream water rights in the Colorado River basin. Upstream rights with a priority date later than the LCRA rights must not withdraw water if there is not enough water to meet downstream users' needs (Broad 2010).

## Species and Ecology

The Pedernales River has been designated as an ecologically significant stream segment by the Texas Parks and Wildlife Department, and features a variety of aquatic and terrestrial habitats that support a unique array of species. Aquatic fauna of conservation interest include endemic species such as Pedernales River springs salamander (*Eurycea sp 6*) and Guadalupe bass (*Micropterus treculii*) (TNC 2007, TWPD 2012). Guadalupe bass is endemic to Central Texas and is listed as a species of greatest conservation need because of issues including hybridization with non-native smallmouth bass, hydrologic flow alternation, and habitat degradation. Native, genetically pure populations of Guadalupe bass exist in only four western tributaries of the Colorado River[10] drainage and in the upper portions of the San Antonio River drainage (Perkin et al. 2010).

[10] The San Saba River, Pedernales River, Llano River and Gorman Creek in the Colorado drainage and the Medina River in the upper San Antonio drainage maintain genetically pure populations of Guadalupe Bass.

Historically, much of the uplands in the Pedernales watershed contained extensive savannahs interspersed with stands of juniper and oak. Stands of Ashe juniper (*Juniperus ashei*) primarily existed on steep slopes, in shallow soils, on sites where naturally occurring fires could not reach. Grassy expanses were more likely on deeper soils in the flat areas of the watershed where fire could spread unchecked (LCRA 2000). The disappearance of large herds of grazing bison, and the removal of wildfires from the watershed that accompanied the more permanent settlements of 19$^{th}$ and 20$^{th}$ centuries contributed to the encroachment of woody species into areas that were traditionally savannahs.

Riparian forests include species such as cedar elm, bur oak, sycamore, and bald cypress, while upland areas more commonly support Ashe juniper, Texas persimmon and mountain laurel. Native grasses including little bluestem, indiangrass, and sideoats grama mix with non-native King Ranch bluestem. The watershed also includes rocky canyon forests with Ashe juniper, Texas oak, Texas ash, and cedar elm (TNC 2007).

Two of the most widely known avian species in the Edwards Plateau are the endangered Black-capped vireo and Golden-cheeked warbler, both of which can be found in the Pedernales watershed. These species rely on the presence of old growth cedar breaks for nesting habitat and cover, which has implications for proposed widespread removal of brush. Public agencies including TPWD, NRCS and AgriLife Extension advocate avoiding brush control in areas that could include endangered species habitat.

In the Texas Conservation Action Plan, the Texas Parks and Wildlife Department (TPWD) created a list of Priority Habitats for conservation action throughout the state of Texas. Within the Edwards Plateau ecoregion, riverine and riparian ecosystems including the Pedernales River are listed as conservation priorities (TPWD 2012).

## Land Uses

The 2008 Meadows Center for Water and the Environment watershed study (Lopes and Oliver 2008) included a land cover change analysis that used aerial photography to classify the entire Pedernales watershed into land cover types. Two datasets were used, one with land cover data from 1996 and a second with data from 2004. The comparison showed relatively little overall change in land cover over the 8-year study period.

The Texas Parks and Wildlife Department (TPWD) has undertaken an intensive ecological systems classification for the entire state of Texas. Phase 1 of the project included classification of the Edwards Plateau, which includes the Pedernales watershed. TPWD's classification shows that 33,000 acres of the watershed- more than 4% of the total area – is considered to be riparian. A further 41,484 acres, or 5%, are considered to be floodplain. TPWD's classification shows just over 1% of the watershed to be urban, and nearly 15% of the roughly 820,000-acre watershed includes some density of Ashe juniper (TPWD 2008).

*Farmland*

Farming is an important economic driver for the Pedernales River watershed counties. Looking more specifically at Gillespie and Blanco counties, which make up the bulk of the watershed, farmland occupies 92% of the total two-county area. In Blanco County 395,667 acres are in farms and in Gillespie County 652,940 acres are in farms. The majority of farm acreage is used for forage for livestock—hay, silage, and greenchop.

**Figure 8. Land in farms by agriculture type, 2002 & 2007** (table adapted from TNC 2007)

| | Blanco County | | Gillespie County | |
|---|---|---|---|---|
| **Type of Agriculture** | **Acres 2002** | **Acres 2007** | **Acres 2002** | **Acres 2007** |
| Crops | 62,781 | 43,597 | 112,311 | 90,426 |
| Orchards | 299 | 318 | 2,079 | 1,642 |
| Pasture | 293,090 | 305,375 | 452,053 | 465,285 |

*Source: US Department of Agriculture, 2007*

*Rangeland*

The majority of lands in the Pedernales watershed (more than 70% as of 2004) are classified as pasture or rangeland (Lopes and Oliver 2008). Ranching continues to be an important economic activity in the watershed, as does hunting- though there is less accurate data on income and acreage relating to hunting leases. Monitoring the impacts of grazing on ecosystem health is important, particularly during times of drought when overgrazing can dramatically reduce biodiversity of plant species and leave exposed soil vulnerable to erosion.

**Figure 9. Livestock inventories, 2002 & 2007** (table adapted from TNC 2007)

| | Blanco County Inventory | | Gillespie County Inventory | |
|---|---|---|---|---|
| **Livestock** | **2002** | **2007** | **2002** | **2007** |
| Cattle | 20,432 | 20,694 | 44,212 | 53,702 |
| All Goats | 12,015 | 827 | 33,409 | 29,694 |
| Sheep | 5,953 | 4,016 | 43,988 | 49,238 |
| Hogs | 242 | 175 | 4,898 | 1,381 |
| Poultry | 1,339 | 2,354 | 3,745 | 2,900 |

*Source: US Department of Agriculture, 2007*

*Conserved Lands*

The Pedernales watershed includes a number of parks and protected areas[11] that are preserved in varying degrees of natural state. Parks makeup roughly 8,800 acres (LCRA 2012) and constitutes roughly 1% of the total land area of the watershed. These parks provide public access points to some of the recreational activities the watershed has to offer: hiking, bird watching, mountain biking, swimming, kayaking, trail riding and simply enjoying the diverse flora and fauna of the region. Private lands can be conserved through conservation easements

[11] Parks in the watershed include: LBJ National Historic Park, Westcave Preserve, Hamilton Pool Nature Preserve, Milton Reimers Ranch Park, Pedernales Falls State Park and several city parks (TNC 2008).

and deed restrictions, preserving open spaces in perpetuity. The Hill Country Land Trust, the Nature Conservancy and the Texas Land Conservancy are all active in the Pedernales watershed. In total, 28,079 acres are conserved- roughly 3.4% of the watershed.

## Demographics

The two largest municipalities located within the watershed are Johnson City and Fredericksburg. As of 2012, the population of Johnson City was 1,716, while that of Fredericksburg was 10,715 (US Census Bureau, 2013). These cities rely on groundwater and pump from the Cretaceous and Paleozoic aquifers. Fredericksburg relies on the Hickory, Ellenburger-San Saba, and Middle Trinity aquifers. Johnson City relies primarily on the Ellenburger-San Saba aquifer (LCRA 2000).

Population density in the 2010 census was 23.5 per square mile in Gillespie County and 14.8 per square mile in Blanco, compared to a statewide 98.1 per square mile. The unemployment rate was 5.5% in Blanco County and 4.2% in Gillespie (Texas Association of Counties 2013).

As more people move to the Texas Hill Country, the nature of landholdings and landowners are shifting. Historic, large-scale ranching and farming operations are in some places now mixed with smaller parcels of recreational ranches and home sites. Land fragmentation and changing ownership patterns have the potential to drastically impact wildlife movement and habitat health. In Blanco and Gillespie counties the number of acres in small farms increased dramatically between 1997 and 2007. Gillespie County saw a 46% increase in acres held in tracts of 100 acres or smaller in that 10 year period, while Blanco County saw 54% increase over the same time period. This proliferation of small parcels generally indicates growth in the number of landowners who do not make a living off their land. This can provided needed rest from grazing and farming pressures, but can also raise land value and have implications on the spread of brush species.

**Figure 10: Changes to Agricultural Land Acreage and Value in Two Pedernales Counties**

| | **Acres in ranches < 100 acres** **(in thousands of acres)** | | **Agricultural Land Value** **($ per acre)** | |
|---|---|---|---|---|
| | 1997 | 2007 | 1997 | 2007 |
| Blanco County | 9,170 | 14,192 | $1,286 | $7,530 |
| Gillespie County | 23,195 | 33,959 | $1,150 | $4,957 |

*(Texas Land Trends 2007)*

In the same 10-year period mentioned above, agricultural land values in Blanco County rose by 486%, from $1,286 to $7,530 per acre. In Gillespie County the increase was 331%. This explosive growth in land prices puts pressure on traditional farming and ranching operations. Higher land values result in smaller parcels and greater fragmentation. Owners of these properties are more likely to own their land as a hobby, and are less likely to have a goal of making a living from the land. Subdividing can put stress on water resources, lead to additional septic systems and potential for contamination of ground and surface water, and can also lead to increased brush cover unless actively managed.

## Brush Control

The density of Ashe juniper has increased in Central Texas over the past 200 years. Ashe juniper now covers 6.7 million acres of the Edwards Plateau (Owens et al. 2006). The scale-like leaf structure and large leaf area of juniper trees are well designed for capturing and storing rainwater. Many see the removal of Ashe juniper as a way to increase the amount of rainwater that enters the ground and surface water systems.

One analysis of Ashe juniper's impacts on the ability of rainwater to reach the ground in Texas Hill Country found that very small amounts of rainwater (<2.5mm) were entirely captured in the canopy and evaporated into the atmosphere. The study, which involved rainfall and rainwater interception measurements across 10 sites for 5 years, found that roughly 60% of the rainfall reached the soil beneath the trees, while 40% was intercepted either in the trees' canopy or leaf litter (Owens et al. 2006). Lighter storms with lower precipitation totals were more likely to result in interception, while heavier rainfall events saw upwards of 80% of rain reaching the soil beneath the trees. Over the course of the 3-year study, the annual precipitation immediately beneath the trees studied was reduced from 600 to 360mm per year in the western sites and from 900 to 540mm per year at the eastern sites (Owens et al. 2006).

While selective brush control may be one way to increase overall water yield in a system, it is important to remember that Ashe juniper play an important ecological role in the Texas Hill Country and is native to the Edwards Plateau ecoregion. Some research indicates that upland brush management will only benefit areas that receive at least 18 inches of rain per year (Ball and Taylor 2003). In arid areas where soils are extremely dry, rainfall that reaches the ground is often evaporated before plants can use it or it can recharge the aquifer. Brush management is often costly and when done improperly can increase erosion, decrease natural habitat for wildlife, and have long-term negative impacts on the land (Ball and Taylor 2003). Changes in water yield as a result of brush control are intimately connected to soil typology and health, as well as the underlying geology. Brush control, when done properly, can be used to improve habitat diversity and resilience.

*Photo credit: Rose Epps*

## Research Needs

Monitoring the long-term health of the Pedernales watershed will require robust baseline documentation with which to compare future changes. While some important information has already been collected, there are ample opportunities for enhancing our existing understanding of the watershed, its flora and fauna, and how human development in the watershed may be shaping the future health of the entire system.

**Hydrological Data**

The hydrologic conditions that govern the Pedernales are still not completely understood. Connectivity between surface water and underlying groundwater resources exists, but it is unclear where the important recharge features are within the basin, how the hydrology changes over the 106-mile course of the river, where important seeps and springs exist and how the watershed is connected to the wider Colorado Basin and Edwards Plateau region. The most recent gain loss study of the Pedernales was completed in 1962. Much has changed in the prevailing 50 years. It is time to revisit that study, as well as existing well information and geologic records, to better understand how the watershed collects, retains and sheds water.

The Meadows Center for Water and the Environment plans to undertake a watershed-level study to understand the hydrological forces at work in the basin. The U.S. Geologic Service (USGS) has expressed interest in re-creating portions of the 1962 study in order to create data for comparison on how the watershed has changed. The LCRA has a desire to better understand inflows into the Highland Lakes system, and will be a partner in those efforts. The data generated by a watershed-wide study would be invaluable in understanding the dynamic conditions of the river and its connection to the land.

***Tributary Health***

It is thought that a great deal of the main stem flow of the Pedernales comes from its tributaries. More data is needed on the health of these systems. There has been no concerted effort to study the ecological health of the ephemeral and perennial streams that feed the main stem river. Invasive species, erosion, and declines in water quality that happen on the tributaries of the Pedernales will ultimately impact downstream river health. By targeting these areas for conservation and stewardship we can the health of the wider system.

***Spring Flow***

According to the LCRA, there are roughly 1,272 springs within the Pedernales River watershed (LCRA 2012). Roughly ¾ of these springs are located at the eastern edge of the basin in Travis County. Efforts have been made to map the locations of these springs but are not released to the general public in the interest of the privacy of landowners. A 1981 study of the springs of Blanco County identified 12 spring sites in the Pedernales watershed, ranging in size from an intermittent trickle to 2,220 gallons per minute (LCRA 2000). Groundwater withdrawals throughout the watershed will impact the aquifers' ability to sustain spring flow into the future. Only by establishing Desired Future Conditions (DFCs) that recognize and protect future spring flow can we ensure the river's connection with its underground aquifers. Generally speaking,

there is a lack of data on the number of springs, the quantity of water entering the system through springs, and baseline water quality of water originating from springs.

**Ecological Data**

In addition to the hydrological data needed to form a robust baseline picture of the health of the Pedernales, having a picture of the health and resilience of the river's plant and animal communities is critical to prioritize conservation and stewardship efforts.

***Invasive Species Mapping***

In order to establish a strategic plan for controlling the spread of invasive plant species, we must first understand their existing range within the watershed. *Arundo donax* (Giant cane) is one species of particular concern within the watershed. An initial ground survey of the upper portions of the Pedernales revealed that the plant is most prevalent in the tributaries of the Pedernales in and around Fredericksburg, but does not extend beyond that point on the main stem river. Barons Creek and Town Creek in the city of Fredericksburg are both choked with *Arundo*, and are likely experiencing hydrologic impacts of the infestation. Mapping the extent of *Arundo* and other invasive plant species in these tributaries and throughout the watershed should be a priority.

***Land Management Challenges: Information Sharing***

The majority of landowners are interested in seeing the overall health and resilience of their land improve during their tenure as the steward of that property. At the same time, the land management challenges faced by landowners in the Hill Country are incredibly site-specific – no two ranches are the same, and the goals and priorities of each landowner will inform the methods and tools that are most effective for their property. There is a need for increased information sharing, monitoring and research on the land management tools most commonly used in the Hill Country. Programs that include public funding or reimbursement for stewardship should include resources to track the successes and failures of those activities. We need a better understanding of the impacts of drought on these ecosystems and the tools available to recover plant communities after fire, drought or overgrazing. Our state and federal agencies should be keenly curious in seeking empirical and anecdotal evidence to support their efforts.

***Ecosystem Services Analysis***

The Pedernales River provides numerous environmental resources that provide a direct economic benefit to the area. These benefits can be quantified in terms of market products, non-market services and added value. An analysis of the economic contributions of the Pedernales in terms of water quality, water supply, farm products, wildlife habitat, increased property values, carbon storage and sequestration, and revenues generated from tourism and recreation would be useful in making the case for the river's long term conservation and protection.

## Threats to Watershed Health

In its 2007 conservation action plan, The Nature Conservancy identified 5 primary threats to the health of Pedernales Basin ecosystems: residential and commercial development, overabundant wild ungulates, unsustainable groundwater and surface water withdrawal, exotic plants and aquatic wildlife, and ecologically incompatible land and livestock management. In addition, TPWD has identified numerous threats to ecosystem health in its 2012 Texas Conservation Action Plan. The extensive list of threats identified by TPWD range from land fragmentation and infrastructure construction to fire suppression and a lack of planning regulations in unincorporated areas. Understanding the nature of these myriad threats and the gaps in our baseline understanding of the health of the river will be critical to prioritizing efforts in the future

### *Invasive Plant Species*

While some baseline climate and water quality data exist for the river, little is known about the ecological health of the system. The encroachment of invasive species such as giant cane (*Arundo donax*) and elephant ear (*Colocasia esculenta*) could impact the river's natural hydrology and crowd out native plants. Populations of these invasive species have been well documented on other Central Texas rivers, but a survey of the Pedernales has not been done.


*Invasive Arundo donax as seen here in Barons Creek in Fredericksburg threatens to drastically alter stream flow and water availability.*

Non-native grasses are also perceived to be problematic in the area. Bermudagrass, a common feature in pastures with deep soils and urban areas, as well as King Ranch bluestem are thought to be very common in the Pedernales, but eradication and control efforts are for the most part economically infeasible (TNC 2007). Other invasive species including chinaberry (*Melia azedarachI*), Japanese privet (*Ligustrum japonicum*) and Christ's thorn (*Paliurus spina-christi*) have been identified within the watershed and could pose additional challenges.

### *Invasive & Overabundant Animal Species*

In addition, overabundant wild ungulates, including feral hogs, white-tailed deer, axis deer, and blackbuck antelope have profound impacts on riparian areas. The recommended density of white tail the Hill Country is one deer per 10-12 acres. In some areas of the Hill Country those rates are closer to one deer per every 3.5 acres (Armstrong and Young 2002). While TPWD suggest white-tailed populations are at 1 per 10-12 acres, rates of exotic ungulates, livestock and other grazers should be considered when determining the carrying capacity of the habitat.

More information is needed regarding the river's aquatic species. While it is widely perceived that smallmouth bass have not significantly impacted the native Guadalupe bass populations in the river, regular monitoring should be a priority. Little is known about the habitat preferences and distributions of the Pedernales River spring salamander and the Eurycea troglodytes species complex. In addition, the habitat preferences and life history traits of a number of aquatic species need to be studied in order to understand how changes in the watershed are impacting populations and their ability to survive.

***Population Growth and Development***

Population growth models for the two counties that contain the bulk of the Pedernales watershed area, Gillespie and Blanco counties, show significant growth over the next 50 years. Blanco County's population is predicted to double by the year 2060, while the population of Gillespie County is predicted to grow by 33% (TWDB 2014). Increasing sprawl from Austin and the I-35 will likely result in more significant population increases for the western portions of Hays and Travis Counties. This growth will lead to increasing demand on the groundwater supply in the basin, and could impact the flow of the Pedernales.

The majority of the watershed falls in unincorporated areas, and counties in Texas have little authority to direct development in any organized way. Fragmentation may result in the loss or degradation of wildlife habitat. Development of rural lands and the associated increases in impervious surfaces will likely result in increased sediment loading to the tributaries of the Pedernales and the river itself. More study of the nature of this growth is needed to understand the potential implications for the health of the river. The demographic changes associated with this growth could have implications for the stewardship of the land.

**Figure 11. Total groundwater pumping 1940-2004 from the Hill Country Underground Water Conservation District in Gillespie County**

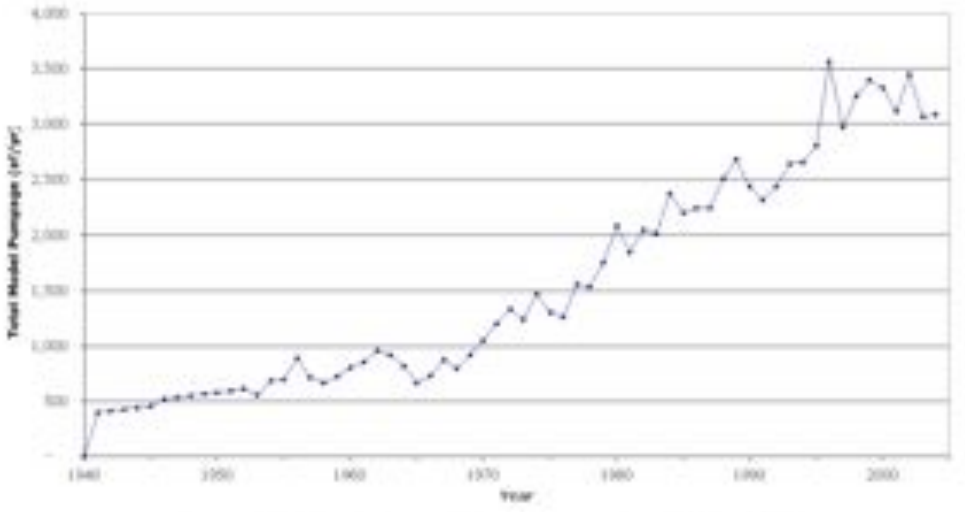


Figure 4.15 Total groundwater pumping 1940 – 2004

*(LBG-Guyton Associates 2007).*

### *Increasing Groundwater Demand*

With the predicted population growth within the watershed, demand for groundwater will rise. Improving our understanding of the complex workings of the aquifer system will inform responsible groundwater management. Determining the environmental and societal base flow needs for the river will also help to ensure that aquatic and terrestrial ecosystems are protected. As groundwater resources are increasingly accessed for a growing population, challenges could arise when springs stop flowing and the connection between the groundwater and the river becomes more intermittent.

**CURRENT AND FUTURE WATER DEMAND IN GILLESPIE AND BLANCO COUNTIES**

| | Annual Water Demand (acre-feet) | | | | | | |
|---|---|---|---|---|---|---|---|
| Water Demand Category | 1990 | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 |
| **Blanco County** | | | | | | | |
| Municipal (Excluding City of Blanco) | 677 | 985 | 1,130 | 1,285 | 1,424 | 1,482 | 1,493 |
| Irrigation | 483 | 458 | 435 | 413 | 392 | 362 | 353 |
| Livestock | 553 | 670 | 670 | 670 | 670 | 670 | 670 |
| Mining | - | 13 | 9 | 5 | 1 | - | - |
| Manufacturing | - | - | - | - | - | - | - |
| Total | 1,713 | 2,126 | 2,244 | 2,373 | 2,487 | 2,514 | 2,516 |
| **Gillespie County** | | | | | | | |
| Municipal | 3,154 | 4,130 | 4,259 | 4,487 | 4,675 | 5,268 | 5,768 |
| Irrigation | 2,000 | 1,184 | 1,169 | 1,154 | 1,139 | 1,124 | 1,110 |
| Livestock | 1,056 | 1,294 | 1,294 | 1,294 | 1,294 | 1,294 | 1,294 |
| Mining | 14 | 5 | 3 | 1 | - | - | - |
| Manufacturing | 451 | 502 | 556 | 608 | 657 | 727 | 795 |
| Total | 6,675 | 7,115 | 7,281 | 7,544 | 7,765 | 8,413 | 8,967 |
| **Total** | | | | | | | |
| Municipal | 3,831 | 5,115 | 5,389 | 5,772 | 6,099 | 6,750 | 7,261 |
| Irrigation | 2,483 | 1,642 | 1,604 | 1,567 | 1,531 | 1,486 | 1,463 |
| Livestock | 1,609 | 1,964 | 1,964 | 1,964 | 1,964 | 1,964 | 1,964 |
| Mining | 14 | 18 | 12 | 6 | 1 | - | - |
| Manufacturing | 451 | 502 | 556 | 608 | 657 | 727 | 795 |
| Grand Total | 8,388 | 9,241 | 9,525 | 9,917 | 10,252 | 10,927 | 11,483 |

Municipal category includes residential and commercial use
Source: Texas Water Development Board

*Photo Credit: Steve Stokan*

## Watershed Resources

Perhaps the greatest opportunities for protecting the long-term health of the watershed lie in the organizations, agencies, businesses, and individuals working for sustainable land management and conservation. By collaborating and sharing resources across groups we can easily achieve improved outreach and education results. This is in no way an exhaustive list, but a brief summary of some of those organizations that are active in the Pedernales watershed.

***Hill Country Alliance (HCA)***

HCA is a regional non-profit whose mission is "to bring together an ever-expanding alliance of groups throughout a multi-county region of Central Texas with the long-term objective of preserving open spaces, water supply, water quality, and the unique character of the Texas Hill Country."

HCA includes resources and expertise working in all Hill Country watersheds, and has acted as convener for Pedernales-related groups in the past. The HCA-led Pedernales Team is comprised of stakeholders from across the watershed who are business owners, local government employees, nonprofit representatives and landowners. HCA hosts educational events, creates educational materials, facilitates discussion, research and stewardship of our Hill Country natural and cultural resources. The Pedernales Basin program is the largest program of the organization and drives much of our work.

***Groundwater Conservation Districts***

The Pedernales Basin includes portions of seven groundwater conservation districts that generally follow county lines for Blanco, Burnet, Gillespie, Kendall, Kimble, Kerr, and Hays Counties.[12] Blanco-Pedernales Groundwater Conservation District and the Hill Country Underground Water Conservation District have jurisdiction over Blanco and Gillespie Counties, respectively. These districts are responsible for managing the majority of the area's groundwater, and will be critical in ensuring that groundwater is used in a sustainable way. The

[12] The Hays Trinity GCD in Hays County does not cover the entire county.

GCDs also have requirements for public outreach and education, and might be good partners for those efforts.

***The Meadows Center for Water and the Environment***

The Meadows Center is based out of Texas State University and has a program entitled "Pedernales River Project." The purpose of the project is to study the current structure and function of the Pedernales River for the development of a conservation plan for the basin. By compiling data on the current status of the watershed, the program will enable future research that will shed light on the impact of land use change in the watershed over time. Since the program's establishment in 2007, a great deal of data collection has been completed. The 2008 Integrated Assessment and 2013 Watershed Data Report are cited in this literature review. Aside from Director Andrew Sansom, Dr. Lopes, Dr. Bonner, Dr. Greoger and Dr. Curran are listed as co-principal investigators on the project.

Phase I of the Pedernales River Project involves collecting hydro-geomorphic data to understand current and historic river conditions. Parameters including land use and land cover, precipitation, water use and physical geography will be studied along with hydrology to understand causal relationships. In Phase II of the project, modeling will be used to predict the impact of future development and land use change (Lopes and Oliver, 2008). The Texas Stream Team, with the support of the Meadows Center, has collected extensive water quality data on the River.

***Soil and Water Conservation Districts (Pedernales, Gillespie) and USDA NRCS***

These agencies serve as an additional source of information and resources at the county level. Gillespie County Soil and Water Conservation District, for example, offers brush-clearing assistance through the NRCS Environmental Quality Incentives Program (EQIP). Also assist landowners in preparing conservation plans, developing prescribed burning plans, planning for pond construction and erosion control. Local Soil and Water Conservation Districts also have access to the statewide resources offered by the Texas State Soil and Water Conservation Board (TSSWCB).

***Texas A&M AgriLife Extension Service***

Offices are funded and operated by the Texas A&M University. Various AgriLife specialists provide a wide range of public services and information related to farming, ranching, gardening and land management. AgriLife hosts a variety of educational events for landowners throughout the year and are available to make site-specific stewardship recommendations.

***Texas Commission on Environmental Quality (TCEQ)***

The TCEQ is responsible for establishing surface water quality standards in Texas. In addition, TCEQ holds the public permits for surface water withdrawals from the Pedernales, and wastewater and stormwater discharge permitting. TCEQ periodically updates its surface water quality standards. Public involvement in this process is an important component to those updates, and engagement by local stakeholders will be important in the future.

***Texas Master Naturalist Program***
The Master Naturalist Program is a statewide volunteer program coordinated by TPWD and AgriLife Extension. They have a strong presence in the Texas Hill Country and within the Pedernales through the Hays County, Hill Country and Highland Lakes chapters. Volunteers working with the Master Naturalist program provide education, outreach and service for the beneficial management of natural resources.

***Texas Parks and Wildlife Department (TPWD)***
The TPWD has extensive knowledge, expertise and resources to offer in the Basin. Technical guidance is available from wildlife biologists assigned by county. TPWD staffers commonly assist with game counts, wildlife and land management strategies and in providing assistance in writing wildlife management plans for 1-d-1 open space applications. TPWD staffers are also hard at work on restoration initiatives and in conducting research.

The Landowner Incentive Program (LIP) is one TPWD program that provides funding for sustainable land management practices. TPWD has received some funding from the Texas Guadalupe Bass Restoration Initiative through the National Fish and Wildlife Foundation (NFWF) US Native Black Bass Keystone Initiative for watershed improvements in the Pedernales. Through the Guadalupe Bass initiative, TPWD has supported efforts in other watersheds within the Hill Country to support educational programming, fund restoration and stewardship projects on private lands, and restock native Guadalupe Bass.

TPWD also runs the Pedernales Falls State Park, as well as the LBJ Ranch State Park within the watershed. These parks provide outdoor opportunities for the general public to engage with the natural resources of the watershed.

***Texas State Soil and Water Conservation Board***
Beginning in September of 2002, the TSSWCB established a brush control program to remove brush in the Pedernales Basin with the goal of increasing flow to Lake Travis. The Pedernales River program has been allocated more than $4.4 million for this cost-share program. The TSSWCB has a goal of treating 140,000 acres of brush in the watershed. In 2012 the program's name was changed from Brush Control Program to Water Supply Enhancement Program, and the statewide annual funding dropped from roughly $4.5 million per year to $2.1 million per year (TSSWCB 2012). As of 2010, just over 70,000 acres had been treated (TSSWCB 2010).

The TSSWCB also runs the Water Quality Management Plan Program, designed to assist large farm or ranch owners to manage their property in a way that protects water quality. They also work with TCEQ to implement Watershed Protection Plans.

## Unique to the Pedernales:

***Hill Country Land Trust (HCLT)***
The HCLT is a regional land trust that is very connected to local leaders and landowners in the Pedernales Basin. Formed in 1998, HCLT has the mission of conserving and protecting the

agricultural lands, wildlife habitat, and watersheds of the Texas Hill Country for present and future generations. HCLT is responsible for the monitoring and enforcement of 17 easements in Texas Hill Country, totaling 4,850 acres. The Pedernales River basin is one of HCLT's priority conservation areas.

***Hill Country Science Mill***

Opening in early 2015 in Johnson City, the Science Mill will be a place for middle and high school students from around the region to come for a hands-on learning experience in the STEM fields- science, technology, engineering and math. The Mill's focus will be on careers in STEM and will inspire students to pursue science-related degrees. The Science Mill will feature an exhibit sponsored by the Hill Country Alliance that takes students inside an aquifer using state of the art video capabilities. The exhibit will demonstrate why the sustainable management of our groundwater resources is so important.

***Lower Colorado River Authority (LCRA)***

The LCRA is responsible for maintaining the health of the lower Colorado River and the Highland Lakes system, and as such has a vested interest in the environmental sustainability and resilience of the Pedernales River, one of the Colorado's most important tributaries.

The LCRA initiated its Creekside Conservation Program in 1990, with a goal of reducing sedimentation in the Highland Lakes. The program advances the use of best management practices to improve riparian health. LCRA partners with the Natural Resources Conservation Service, soil and water conservation districts and willing landowners within the watershed. As of 2012 48 landowners had participated in the program with more than 33,000 management acres complete in the Pedernales Basin. More than 71,000 feet of cross fence were installed over the first 22 years, and 3,900 brush management acres were completed (LCRA 2012).

The LCRA is also an important resource for scientific data collection along the Pedernales. The LCRA monitors water quality, quantity, rainfall and weather conditions as well as biological information along the river. It also manages several parks and nature areas, including the Pedernales River Nature Park in Johnson City.

***Pedernales Wildlife Management Co-op Program***

The co-op started more than 10 years ago by Harris Greenwood, who was interested in combatting the negative impacts of land fragmentation on wildlife habitat. The group holds annual meetings, with different speakers invited to present on wildlife management issues pertinent to the area. A planning committee meets more regularly. The two primary goals of the group are to increase residents' information about wildlife in the area, and to get neighbors together to meet each other. The group has grown from an initial meeting of 20 neighbors to an event that regularly exceeds 100 attendees.

***Pedernales, Doss, Harper Wildlife Management Associations***

These are groups of private citizens that have joined together to manage their land for the benefit of wildlife. They are recognized and supported by the TPWD and hold regular meetings.

More information on these and other Wildlife Management Associations can be found at http://tpwd.texas.gov/landwater/land/associations/

***Pedernales Neighbors Gathering***

Landowners up and down the Pedernales meet bi-annually for social and educational gathering. Two watershed landowners lead the group: J. David Bamberger and Pam Reese. The Pedernales neighbors gathering is an excellent example of regular community meetings that routinely recruit more than 100 participants. Speakers are invited to provide short presentations about important ecological and policy-related issues facing the basin.

***Texas Land Conservancy (TLC)***

In 2013, the Texas Land Conservancy announced its Land for Water initiative. Using Geographic Information Systems (GIS), TLC identified six key watersheds with irreplaceable natural resources that face imminent threats including land fragmentation and development. The six priority areas are the Lower Brazos, Lower Trinity, Neches, Llano, Pedernales and Medina Rivers—an area of more than 27 million acres (Gaskill, 2013). The identification of these priority areas will guide the Conservancy's outreach efforts going forward, and TLC will have an increased focus on the Pedernales River basin.

***Travis County Parks- Milton Reimers Ranch and Hamilton Pool***

On the eastern edge of the Watershed are two Hill Country parks that afford educational opportunities and outdoor recreation for visitors from around the state and around the country. Hamilton Pool, in particular, is a well-known attraction that draws large crowds of visitors. These Travis County Parks provide a critical connection for urban residents of Austin to be exposed the importance of the land and water resources of the Hill Country.

***Westcave Outdoor Discovery Center***

A 75-acre preserve located just outside of Austin, Westcave Outdoor Discovery Center (Formerly Westcave Preserve) is committed to inspiring people to develop a lifelong practice of enjoying and protecting nature. Westcave hosted 8,000 school children for educational programing in 2012. The Lower Pedernales Stewardship Roundtable convenes regularly to explore topics in conservation along the Pedernales.

**Reference List**


Armstrong W.E., and Young E.L. 2002. White-tailed deer management in the Texas Hill Country. Texas Parks and Wildlife Report W7000-828. Smith School Road, Austin, Texas.

Ashworth, John and Flores, Robert. 1991. Delineation Criteria for the Major and Minor Aquifer Maps of Texas. Texas Water Development Board LP-212. Austin, Texas.

Ball, Laura and Taylor, Melinda. 2003. Brush Management: Myths and Facts. *Environmental Defense Fund*. Accessed from www.environmentaldefense.org

Birnbaum, J.S., Winemiller, K.O., Shen, L., Munster, C.L., Wilcox, B.P., and Wilkins, R.N. 2007. Associations of watershed vegetation and environmental variables with fish and crayfish assemblages in headwater streams of the Pedernales River, Texas. *River Research and Applications* 23:979-996.

Blanco-Pedernales Groundwater Conservation District (GCD). 2013. Groundwater Management Plan. Accessed from www.blancocountygroundwater.org

Bowles, D. E. and Arsuffi, T. L. 1993. Karst aquatic ecosystems of the Edwards Plateau region of central Texas, USA: A consideration of their importance, threats to their existence, and efforts for their conservation. Aquatic Conserv: Mar. Freshw. Ecosyst., 3: 317–329.

Broad, Tyson. 2010. The Unknown River of Central Texas: A characterization of the James River, its springs and its watershed. Environmental Defense Fund. Austin, TX.

Gaskill, Melissa. 2013. Texas Land Conservancy's new Land for Water initiative aims to protect key watersheds. *Culturemap Austin.* Accessed from http://austin.culturemap.com/news/innovation/07-24-13-texas-land-conservancy-announces-land-for-water-initiative/

Kreuter, Urs P., Tays, Mark R., and Conner, J. Richard. 2004. Landowner willingness to participate in a Texas brush reduction program. *Journal of Range Management* 57 (3): 230-237.

LBG-Guyton Associates. 2007. Report on the Groundwater Availability Model for the Ellenburger Aquifer in Southeast Gillespie County, Texas. Austin, Texas.

Leffler, John J. 2010. Farmers, Ranchers, the Land and the Falls: A History of the Pedernales Falls Area, 1850-1970. *Texas Parks and Wildlife Department.* Accessed from http://www.tpwd.state.tx.us/

Lopes, Vicente L. and Oliver, Leonard L. 2008. Integrated Assessment of the Pedernales Watershed: Year 1 Final Report. *River Systems Institute*. Texas State University, San Marcos. [13]

LCRA (Lower Colorado River Authority). 2000. Pedernales River Watershed Brush Control Assessment and Feasibility Study. Accessed from http://www.tsswcb.texas.gov/files/docs/brush/feasibilitystudies/FS_LCRA_2000.pdf

LCRA (Lower Colorado River Authority). 2012. Pedernales River Watershed poster. Accessed from http://maps.lcra.org/default.aspx?MapType=Watershed%20Posters

Meadows Center for Water and the Environment. 2013. Pedernales River Watershed Data Report: Draft. Texas State University.

Olenick, Keith L., Kreuter, Urs P., and Conner, J. Richard. 2005. Texas landowner perceptions regarding ecosystem services and cost-sharing land management programs. *Ecological Economics* 53:247-260.

Owens, M. Keith, Lyons, Robert K., and Alejandro, Chris L. 2006. Rainfall partitioning within semiarid juniper communities: effects of event size and canopy cover. *Hydrological Processes* 20: 3179-3189.

Perkin, Joshuah S., Shattuck, Zachary R., Bean, Preston T., and Bonner, Timothy H. 2010. Movement and Microhabitat Associations of Guadalupe Bass in Two Texas Rivers. *North American Journal of Fisheries Management* 30:33-46.

Smyrl, Vivian Elizabeth. 2013. Pedernales River. *Handbook of Texas Online.* Published by the Texas State Historical Association. Accessed from http://www.tshaonline.org/handbook/online/articles/rnp03

Texas Association of Counties. 2013. Texas County Profiles. Accessed from http://www.txcip.org/tac/census/CountyProfiles.php

Texas Land Trends. 2007. Texas A&M Institute of Renewable Resources. Accessed from http://texaslandtrends.org/2007/10yrtrends.aspx

TCEQ (Texas Commission on Environmental Quality). 2015. Water Rights Database. Accessed from https://www.tceq.texas.gov/permitting/water_rights/wr_databases.html

TNC (The Nature Conservancy). 2007. Conservation Plan for the Pedernales River Watershed.

TNC (The Nature Conservancy). 2008. Pedernales River Project: community-based conservation of a Texas Hill Country treasure. Accessed from nature.org/texas.

[13] The River Systems Institute is now the Meadows Center for Water and the Environment.

TPWD (Texas Parks and Wildlife Department). 2008. Texas Ecological Systems Classification Project: Phase 1. Accessed from https://tpwd.texas.gov/landwater/land/maps/gis/tescp/index.phtml

TPWD (Texas Parks and Wildlife Department). 2012. Texas Conservation Action Plan 2012 – 2016: Edwards Plateau Handbook. Editor, Wendy Connally, Texas Conservation Action Plan Coordinator. Austin, Texas.

TSSWCB (Texas State Soil and Water Conservation Board). 2012. Water Supply Enhancement Program 2012 Annual Report. Accessed from http://www.tsswcb.texas.gov/reports#wsep

TSSWCB (Texas State Soil and Water Conservation Board). 2010. Brush Control Program 2010 Annual Report. Accessed from http://www.tsswcb.texas.gov/reports#wsep

TWDB (Texas Water Development Board). 2014. 2016 Regional Water Plan Population and Water Demand Projections. Accessed from http://www.twdb.state.tx.us/waterplanning/data/projections/2017/popproj.asp

United States Census Bureau. 2012. American Factfinder. Accessed from http://factfinder2.census.gov/faces/nav/jsf/pages/index.xhtml

United States Department of Agriculture. 2007. Census of Agriculture. Accessed from http://www.agcensus.usda.gov/Publications/2007/Full_Report/Volume_1,_Chapter_2_County_Level/Texas/

Weniger, D. 1984. The explorers' Texas: the land and waters. Eakin Publications, Inc. Austin, Texas.