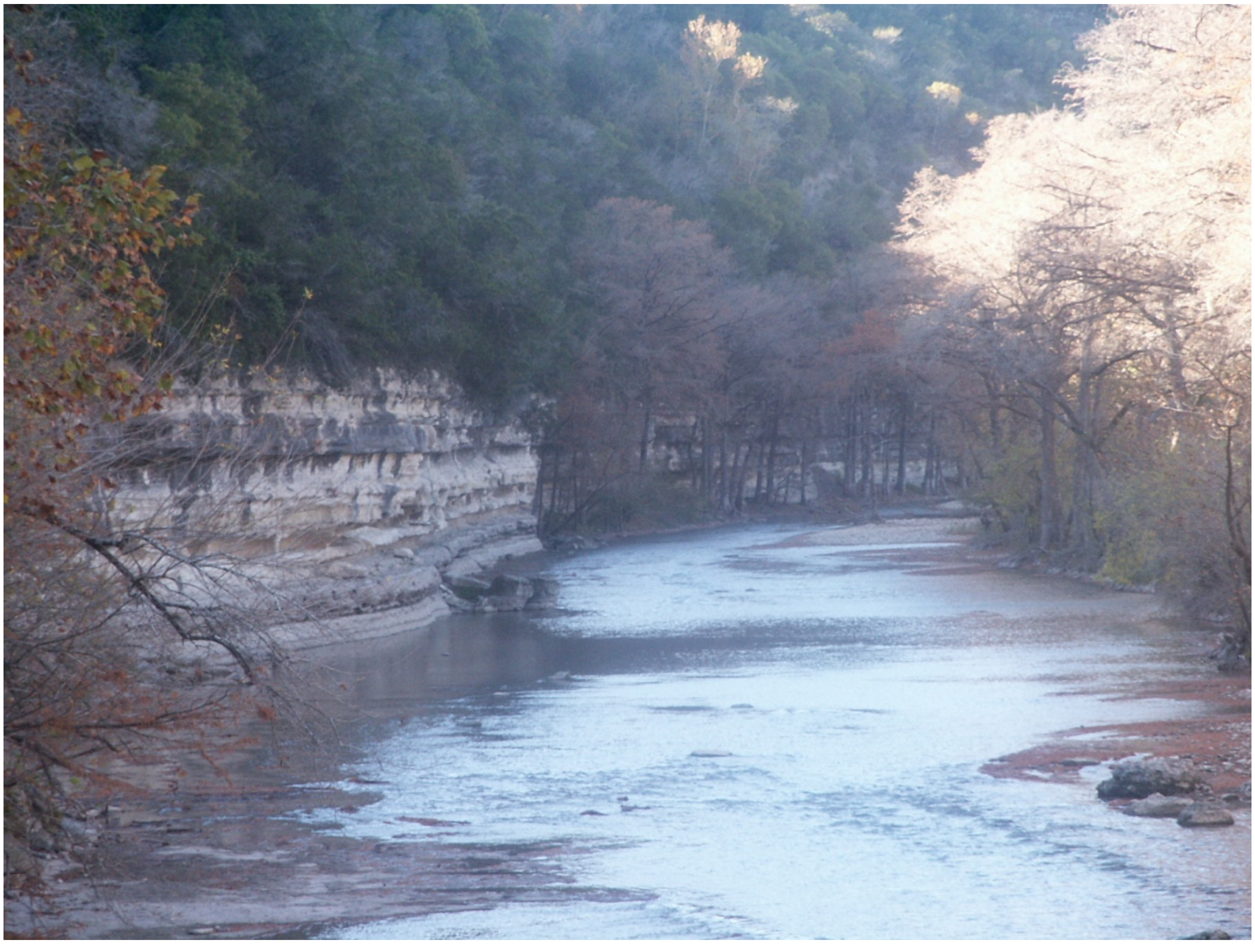

Guadalupe River. Photo courtesy of Stacy A. Bray, Texas State University-San Marcos, River Systems Institute

TEXAS STATE UNIVERSITY-SAN MARCOS

Understanding Hill Country Groundwater Resources

RIVER SYSTEMS INSTITUTE
Texas State University

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Groundwater Resources, Website, and Public Outreach Final Report

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Andrew Sansom
Executive Director

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Project Summary

The Hill Country of Central Texas is a rugged, rural landscape with near-pristine watersheds, springs, specialized and common flora and fauna, and a growing population with growing water demands. Three major aquifers support water supplies to metropolitan as well as rural populations. Due to the junction of increasing population growth which in turn places stress on natural ecosystems, reduced to no-flow status in ephemeral creeks and springs, and the threat of drought becoming a reality over the past year the Hill Country is a region threatened by difficulties in maintaining water sustainability for all inhabitants.

Managing groundwater in the Hill Country is challenged on multiple levels and different perspectives. From socio-economic concerns of population growth and difficult economic times, changing demographics, varied approaches to accessing news and civic involvement, over-drafted aquifers, unique and fragile ecosystems; and multi-level water governance through state, county, and groundwater districts, groundwater is definitely under pressure and increasingly frangible rather than resilient as a water resource. The critical, time-sensitive needs of Hill Country groundwater is the core of this project. Understanding the issues, linkages, and the benefits and worth of protecting the water systems is no small task. However, without the ongoing efforts of studies with tangible results and accessible information, it is likely that groundwater and its linked systems will continue to be deleteriously impacted in the foreseeable future.

This project targets a better understanding of groundwater issues and thus supports a sound basis for civic and stakeholder actions through the following approaches: 1) an economic study of land valuations around a unique Hill Country creek; 2) synthesis of groundwater data and related information into a website for public use; and 3) increase public and stakeholder awareness of groundwater concerns. A separate technical report communicates the economic study, methods, data, results, and recommendations for future work. The second and third items are addressed in this document through several media. Groundwater data, records, information and other materials pertinent to groundwater resources and issues in the Hill Country are summarized in this report. A new website on “Hill Country Water Resources” is under development as public education and outreach resource. State well records by country and technical publications are submitted as electronic files to provide easy to access technical information and data. A civic outreach presentation on groundwater issues and stewardship was prepared and is available on the website. Finally, a campaign for future public outreach is presented.

Through these results, collaborative efforts, and dissemination of information so as to engage and inform over time, the water resource challenges and possible solutions may be noteworthy for other water-stressed regions in Texas.

Introduction

Groundwater in the Hill Country poses varied and complex challenges that are noteworthy for other water-stressed regions in Texas. The challenges vary: socio-economic (increasing population growth partly fueled by the lure of "free" groundwater through exempt wells, demographics of multi-generational families and new residents, many of whom travel daily to work in nearby cities, the greatly varied approaches to simply reading or hearing daily news); landscape (poor, thin soils that do not provide substantial protection from non-point source pollution, over-drafted aquifers, unique and fragile ecosystems); and institutional (water governance through multiple state, county, and groundwater conservation districts or GCDs, environmental and conservation organizations addressing the many issues, a groundwater management area that is authorized but not funded, confusion and occasional turf battles between these agencies, organizations, and the stakeholders – taxpayers and permit holders). Noting these issues serves as a reminder of the critical, time-sensitive, pressing needs of the Hill Country region and how groundwater is intertwined with these and other issues. Understanding the core issues, the linkages among them, and the benefits and worth of protecting the water systems is critical. However, without the ongoing efforts of studies with tangible results, including this task, it is increasingly likely that groundwater and the linked systems could be deleteriously, perhaps permanently impacted in the foreseeable future.

This research focuses on the synthesis of the existing knowledge base, data sets, technical tools such as models, electronic outreach that continues weekly on a multitude of levels and issues. Rather than the end goal, the synthesis is the means towards disseminating the information in a manner to engage and educate over time. The challenge is to place the information in formats that reach out to the varied demographics of the Central Texas population and that are retentive over time.

Three overarching tasks and associated work efforts comprise this Component 2, undertaken to meet the project's goals and objectives. These are a synthesis of relevant groundwater, spring, and water resources data and information; an evaluation of groundwater models in the Hill Country region; and development of an informational website for the general public with regard to a broad range of groundwater data, information, and issues in the Hill Country.

Component 3 addressed the raising of public awareness concerning groundwater, is also discussed in this report. Actions taken towards messaging, evaluation of the 82nd Legislature on groundwater, and a campaign plan to target strategic actions and outreach to stakeholder groups considered likely to support sustainable water resources.

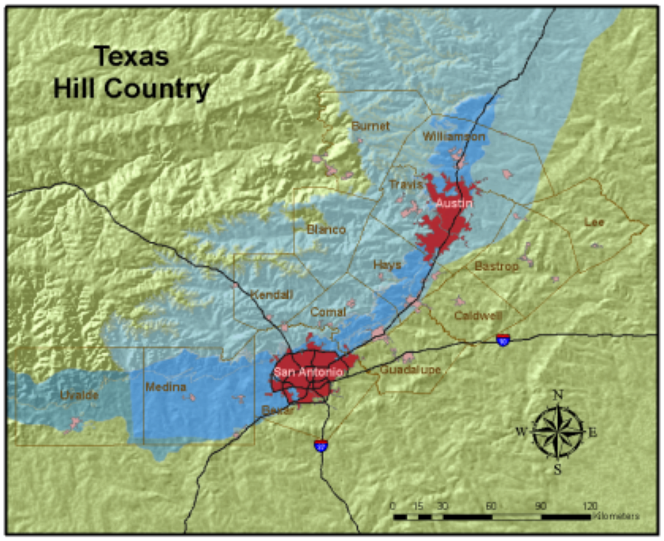


Figure 1. Elevation Map of the Texas Hill Country Overlain by Edwards (BFZ) and Trinity Aquifers (RSI)

This report presents the results of research studies and evaluation concerning groundwater and related natural resources in the Hill Country as well as an assessment of groundwater management in Texas. The public outreach component is discussed with regard to actions taken and a campaign plan for stakeholder and action-specific targets.

Methods

The methods used in this research are those appropriate to a synthesis of a large body of scientific, policy, institutional, and stakeholder-related knowledge. The tasks included literature review, analysis of relevant data and information from federal, state, and county agencies, evaluation of groundwater models, assessment of outcomes from the 82nd Legislature, and creation of materials to support public awareness of groundwater issues.

Texas Water Development Board (TWDB) records are a primary source for this project. Their extensive, groundwater- and planning-centric data sets are open source as are baseline maps, reports, publications, planning data, and well records for the state. TWDB maintains the state-funded groundwater availability models and data. Other state sources of data that have been researched for the project are those of the Texas Commission on Environmental Quality (TCEQ), Texas State Soil and Water Conservation Board, the Texas Department of Agriculture, and Texas AgriLife Extension. At the county level, well records and data of the GCDs and counties were reviewed. Also included are University publications and as pertinent, reports from University of Texas' Bureau of Economic Geology, Texas A&M's Texas Water Resources Institute, and Texas State University-San Marcos' River Systems Institute and Texas Stream Team. We have included relevant journal publications on Hill Country groundwater and consulting technical reports. Not all of these sources contain relevant data sets or publications, but all are key to establishing the knowledge base for this project.

Methods for the public outreach component comprised the development of key messages through discussions with collaborative organizations and experts regarding Hill Country groundwater. These "core" messages provided the foundation and contextual information for development of a public speaking presentation for civic groups, stakeholders, and other public entities. The presentation was designed for current and future use by different speakers. Lastly, a campaign outreach plan was developed to reach out to likely supportive stakeholder and civic groups concerning involvement in targeted actions towards sustainable water resources in the Hill Country.

Data Collection

The website is one repository of the synthesized materials, information, and data for this project. The linked network of other websites, reports, and information provides an educational base for the general public interested in different aspects and knowledge about Hill Country groundwater.

For use and analysis in this project, the TWDB well records were downloaded in two forms. The extensive spreadsheets and their codes were used in assessing two aquifers. The TWDB also makes portable document format (pdf) files available for summary tables. These TWDB well record pdf's were downloaded by county for:

- Cooperator wells and infrequent constituents in well samples
- Information about wells in TWDB records – latitude and longitude, well depth, pertinent aquifer code, well elevation, water levels over time (if available), the method of pumping and whether or not the pump is in use, and remarks
- Historic water level measurements per state well number
- Results of water quality testing per state well number including ions, cations, and other water quality parameters

Due to the length and number of summary tables, the list of counties is in Appendix A. The summary tables are submitted electronically with this report on a Universal Serial Bus (USB) storage key.

Development of Hill Country Water Resources Website

As part of this project, River Systems Institute designed and developed an informational website entitled "Hill Country Water Resources" (http://hcgw.squarespace.com/). The goal was to consolidate a wide range of disparate resources, information and data in as a single clearing house available to educators, researchers, managers, stakeholders and the community. The design includes tabs and sub-folders in an easy-to-access approach housing major components and issues facing Hill Country water resources (Table 1).

A tremendous amount of information can be found on different websites dealing with specific aquifers or groundwater issues, but such information is not always easy to locate with regard to a broad view of water resources, data, linkages to other natural resources, aquatic species, and explanations of the multi-layered groundwater management in Texas. The Hill Country Water Resources website addresses the broader range of topics while linking to other relevant, online resources and organizations throughout the web site. Thus, this web site was designed and implemented as a compilation of available information and a resource to better understand water resources in the Hill Country so that web users can readily identify the connections and build their own knowledge base.

The website currently addresses topics in the Texas Hill Country of groundwater, surface water, studies on natural resource valuations in the Cypress Creek area, and stewardship. Information about the purpose and development of the website and a list of resources and glossary terms are included.

While development of the site will continue, the initial primary focus is on groundwater – its impact on daily life, basic information about aquifers underlying the hills and valley and creeks, and how groundwater is managed in the Hill Country and throughout Texas. Table 1 notes the webpage tabs and sub-folders.

Table 1. Hill Country Water Resources Website Categories

<table>
<tr><th>Navigation Tabs</th><th>Major Folders</th><th colspan="2">Sub-Folders</th></tr>
<tr><td>Texas Hill Country</td><td colspan="3">Home, About, Glossary, Links</td></tr>
<tr><td>Groundwater</td><td colspan="3">Groundwater Basics</td></tr>
<tr><td rowspan="5"></td><td>Aquatic Species</td><td colspan="2">Deep Warm Aquifer Species
Spring Outlets Species
River Species
Karst Cave Dweller Species
Biofilms and Nutrient Cycling</td></tr>
<tr><td colspan="3">Springs</td></tr>
<tr><td rowspan="2">Groundwater Use</td><td rowspan="2">Central Texas Aquifers</td><td>Trinity Aquifer</td></tr>
<tr><td>Edwards Aquifer</td></tr>
<tr><td></td><td>Groundwater Management</td><td>How Groundwater is Managed
Groundwater Models
State Agencies
Conservation Districts</td></tr>
<tr><td rowspan="2">Surface Water</td><td colspan="3">Blanco River Watershed</td></tr>
<tr><td colspan="3">San Marcos River Watershed</td></tr>
<tr><td>Valuing Our Water Resources</td><td colspan="3"></td></tr>
<tr><td rowspan="3">Stewardship</td><td colspan="3">Water Stewardship</td></tr>
<tr><td colspan="3">Rainwater Harvesting</td></tr>
<tr><td colspan="3">Drought</td></tr>
</table>

Background and Groundwater Setting

The Texas Hill Country is a semi-arid region, with limited rainfall and a rugged landscape composed of thin soils overlying stair-step hills and low valleys characteristic of a limestone karst terrain. The area is rich in biodiversity and is home to many endemic and endangered species whose habitats and surrounding landscapes are dependent on groundwater-fed rivers and springs. The Hill Country is experiencing rapid development and population growth, which increase the demand on groundwater resources. The sections below provide information about the regions Climate and topography, demographics, etc, etc

Climate and Topography

Overall, climate in Texas can be characterized in accordance with climate divisions based on geographic locations, average monthly precipitation, and average monthly temperatures (TWDB, 2011). The upland Edwards Plateau (Climatic Division 6) is characterized as sub-tropical steppe to semi-arid brushland and savanna. This climatic region transitions in the lower portions of the Hill Country (Climatic Division 7 including the Hill Country, eastern Blackland Prairie, and south to the central coastline) to sub-tropical, sub-humid Post Oak Savanna with mixed savanna, woodlands, and prairie due to average rainfalls and temperatures and their effects on the land. Historic average precipitation is highest during April-June and September-October in both of these climatic divisions (TWDB, 2011). Annual precipitation during 1981 to 2010 averaged 30 to 35 inches per year across the region, while annual gross lake evaporation ranged from 55 to 60 inches (1971-2000). The region has also experienced extremes in weather patterns, observed over the decades as flash floods and droughts.

Since water quality in regional creeks and rivers are dependent upon flow, summer months are the most likely to have water quality impairments in regional creek including low dissolved oxygen, high algal density, and increased water temperatures.

Topography of the Edwards Plateau region of the Texas Hill Country varies from hills of predominantly karstic limestone terrain to plateaus that serve as major recharge zones to the underlying Edwards (Balcones Fault Zone, BFZ), Edwards (Plateau), and Trinity System aquifers. The hills are characterized by interbedded limestone, shale and clays. The limestone plateaus are karstic, thus the dissolved bedrock can provide many conduits for recharge from rain events. Spring-fed waterways dissect the hills and provide recharge to underlying aquifers.

Slopes are higher towards the western portion of the region, where there are many of the characteristic hills that make up the Hill Country, and slope generally decreases toward south and east. Numerous cliffs and deep valleys typify the topography of the watershed. Elevations range from about 500 feet above mean sea level in Austin to over 2,000 feet above mean sea level across the Hill Country (Barker and Ardis, 1996).

Demographics

In recent decades, the Hill Country was primarily a rural area with county seats and small towns. However, in recent years, the population is growing in both urban and rural areas. Comparing the 2010 and 2000 US Census data by county, the growth is positive (Table 2). The only county with less than 10% growth is Uvalde, a county of primarily agricultural and rural land uses. Hays, Guadalupe, Kendall, and Comal counties all have a higher percent increase in the last decade than Bexar and Travis counties with the metropolitan areas of San Antonio and Austin, respectively.

Table 2. Population Growth in Hill Country Counties (Texas State Data Center, 2011)

Hill Country County	2010 Population	2000 Population	Percent Increase
Bexar	1,714,773	1,392,931	23.1%
Blanco	10,497	8,418	24.7%
Burnet	42,750	34,147	25.2%
Caldwell	38,066	32,194	18.2%
Comal	108,472	78,021	39.0%
Guadalupe	131,533	89,023	47.8%
Hays	157,107	97,589	61.0%
Kendall	33,410	23,743	40.7%
Medina	46,006	39,304	17.1%
Travis	1,024,266	812,280	26.1%
Uvalde	26,405	25,926	1.8%
Totals	**3,333,285**	**2,633,576**	**30.6%**

Figure 2 is a chart of population projections by county through 2040. The results indicate that, should the population growth rates per county remain on trend, that highest growth will take place in counties with urban centers.

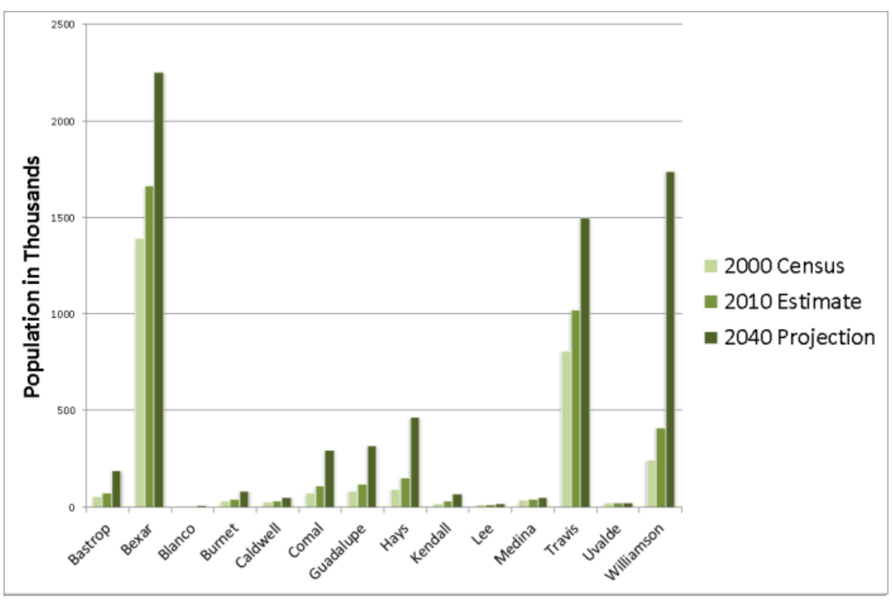


Figure 2. Population Projections, Hill Country Counties (Texas State Data Center, 2010)

Geology and Hydrogeology

The Hill Country region is predominately a karstic limestone region with thin soils (Lindgren et al., 2004). Geologic rock formations in the region are primarily Early Cretaceous-age limestone with younger Quaternary sediments found along creek beds. Upland towards the west, the rock strata are identified as basal conglomerates and limestones of the Glen Rose Formation, formed during cyclical development of shallow seas in the Cretaceous. The Glen Rose is identified with the Trinity Group aquifer system, comprised of seven formations with distinct characteristics. Hydrogeologically, the formations are recognized as the Lower, Middle, and Upper Trinity Aquifers due to variations in lithology and water production characteristics. The deepest geologic unit of these three is the Lower Trinity, estimated at 300 feet thick. It is comprised of two formations, the Sycamore/Hosston basal conglomerate and sand and the Sligo Formation, an interbedded dolomite, sandstone, siltstone, and limestone formation. A confining zone, the Hammett Shale, separates the Lower and Middle Trinity aquifers. The Middle Trinity Aquifer contains three formations, of which the Cow Creek Member and the Lower Glen Rose formations are water producing, separated by the Hensell Member, a semi-confining zone. The Upper Trinity Aquifer contains multiple strata of the Upper Glen Rose Formation. The three strata exposed at land surface within the watershed are the lower Glen Rose of the Middle Trinity Aquifer, the upper Glen Rose of the Upper Trinity Aquifer, and Quaternary sediments.

The Edwards Group overlies the younger Glen Rose and Trinity Group except where the faulted, uplifted and eroded blocks of the Edwards are found at or near land surface. The Edwards stratigraphy in the project region is comprised of Georgetown Limestone that overlies the Edwards Group, which in turn overlies Comanche Peak strata where present. The Edwards Group is capped by Del Rio Clay. However, several studies have more clearly defined the regional stratigraphy of the Edwards into depositional provinces, the Maverick Basin found in Kinney and Uvalde counties, Devils River Trend in eastern Uvalde and Medina counties, and the San Marcos Platform in Bexar County and to the northeast (Rose, 1972; Lindgren et al., 2004).

Of note are the multiple faults trending northeast-southwest throughout the region. These normal faults may have downdropped the Trinity Group as much as 1,200 feet to the southeast, juxtaposing rocks of the Edwards Group against the Trinity Group.

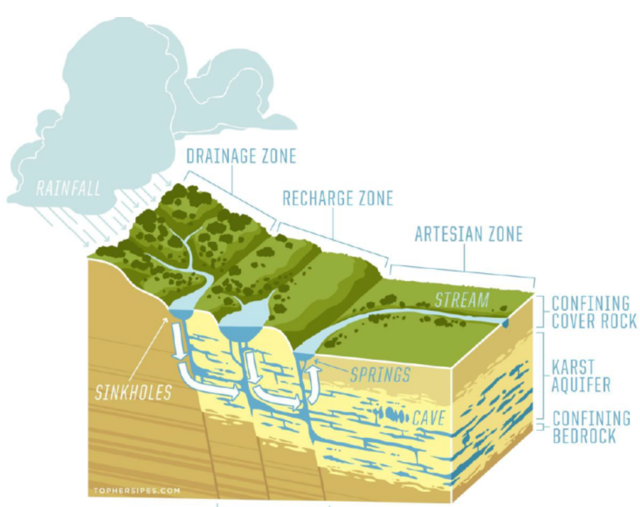


Figure 3. Diagram of Karst Terrain and Subsurface Flow (RSI)

Karst areas contain soluble rocks, such as limestone, whose structures are dominated by occasionally, but not necessarily, interconnected conduits created by dissolution (Figure 3). Water and its interaction with the rock take hundreds of thousands to millions of years to create these features. Unique characteristics of karst areas include (1) a general lack of permanent surface streams; (2) swallow holes into which surface streams sink; (3) underground channels (conduits or drains) in which rapid water flow occurs; and (4) the occurrence of large springs (Kacaroglu, 1999). Karst terrain is also susceptible to contamination as the dissolved rocks form conduits and channels for underground flow and increase the ability of water to enter into these conduits from the surface.

Springs and Surface Water-Groundwater Connectivity

Spring systems are typically found in karstic systems due to the inter-layered zones of limestone and confining rocks. Near-surface springs and seeps may flow due to recent rainfall or when shallow water-bearing zones that feed the seeps have sufficient water. Such shallow springs are prone to low or no-flows when rainfall has not provided sufficient replenishment to the groundwater. Artesian springs can flow throughout the year; they are primarily impacted by greatly lowered groundwater pressures in the deeper aquifer zones with which they are connected.

Another type of seep is the area where surface water bodies and groundwater are connected, such as fractured or faulted rock layers found in or near river and creek beds. Studies of such interconnected sites are critical to defining specific areas of gains and losses to the river or to groundwater. A 2002 project report concerning gains and losses along major rivers and the aquifers of Texas reviewed previous studies of gains and losses (Slade et al., 2002). The report noted that 126 gain-loss studies and 92 studies had been conducted in the Edwards (BFZ) and the Trinity systems, respectively. Not surprisingly, the summary tables and mapped gain-loss areas along the major rivers showed that many of the gain-loss areas are found over the Edwards and Trinity systems in the Hill Country.

While there are hundreds of springs and seeps throughout the Hill Country, three major spring systems are noteworthy due to their dependence on aquifer flows and the role that these springs play in the communities.

Jacob's Well, a Middle Trinity Aquifer artesian spring, provides the majority of flow in Cypress Creek and thence to the Blanco River. The opening of Jacob's Well in the bed of Cypress Creek occurs in the Lower Glen Rose unit of the Middle Trinity Aquifer. The nearly vertical shaft of Jacob's Well most likely follows a fracture or joint set that has been enlarged by solution activity. Approximately 70 feet below the mouth of the spring is the contact between the Lower Glen Rose and Hensell Member. There are two large caverns at the contact. At 100 feet is the contact between the Hensell and Cow Creek. The passageway becomes roughly parallel to the horizontal bedding and continues several thousand feet in a karst zone of the Cow Creek. At the current time divers have mapped in excess of 5,000 feet of passages linked to Jacob's Well. Several passages terminate in constrictions that divers cannot proceed beyond; others are still in the process of being fully explored.

The flow from Jacob's Well varies significantly with major precipitation periods and events. Artesian flow from the Cow Creek generally maintains a discharge of 3-7 cubic feet per second (cfs). During major precipitation events, peak discharge has been measured at over 60 cfs indicating a pressure surge in the Cow Creek or possibly direct recharge from the open karst features observed locally in the Lower Glen Rose. During the 2008-2009 period of drought, the flow at Jacob's Well was reduced to less than 0.7 cfs and essentially ceased to flow. Similar reductions and cessation of flow can currently be seen due to drought conditions.

The Comal Springs system is the largest in Texas. Located in Landa Park, New Braunfels, the springs feed the Comal River and are key to recreational activities for which the city is famous. Spring flows have been tied to the Edwards Aquifer Authority index well J-17 in Bexar County. When water levels in well J-17 drop below 620 feet, the flows are Comal Springs are also decreased. The springs ceased flowing in 1950's drought of record. Should the current drought continue, there are concerns that the spring system could again stop flowing.

The San Marcos spring system is second largest in the Hill Country. Archaeological surveys and cores from below the bottom of Aquarena Springs indicate humans lived around the springs at least 11,500 years ago. More than 200 spring outlets have been identified in the system. Normal flows are around 152 cubic feet per second (cfs), however, low flow during 1950's drought was recorded at 46 cfs. The springs are critical habitat for five species (Fountain Darter, Texas Blind Salamander, San Marcos Salamander, San Marcos Gambusia, and Texas Wildrice). The endangered species are discussed in more detail below.

The Aquarena Springs area is undergoing restoration activities that have been more than 10 years in planning between Texas State University-San Marcos, River Systems Institute, the City of San Marcos, U.S. Fish and Wildlife, and the U.S. Army Corps of Engineers. Goals of the project are to restore the aquatic ecosystem components as close as possible to their natural conditions, improve the riparian corridor and floodplain habitats, and support watershed functions. The Habitat Restoration Project will remove buildings that are in the 100-year flood plain such as the old restaurant, but leave the historic hotel, now housing River Systems Institute and Texas Parks and Wildlife Department staff. A new Visitor's Center is currently being built and the Center's educational programs and glass bottom boat tours will continue.

Vegetation

Vegetation on the hilltops is often sparse because of thin layers of topsoil. In the northern portion of the project area, shallow or disturbed soils support evergreen shrubs and grasses. Woodlands of juniper, oak and mesquite are interspersed along the hillsides and, towards the bottom of the slopes, more native grasses can be found. The plateau-like uplands support woody species such as Ashe Juniper (*Juniperus ashei*), Texas Oak (*Quercus buckleyi*), and Lacey Oak (*Quercus laceyi*) along with grasses. In the lower portion of the region along floodplains and streams, deciduous stands of Bald Cypress (*Taxodium distichum*), Sycamore (*Platanus occidentalis*), and Black Willow (*Salix nigra*) can be found (Riskind and Diamond 1986). Grasses commonly include Little bluestem (*Schizachyrium scoparium*), Curly mesquite (*Hilaria belangeri*), Texas wintergrass (*Stipa leucotricha*), White tridens (*Tridens muticus*), Texas cupgrass (*Eriochloa sericea*), Tall dropseed (*Sporobolus asper*), Seep muhly (*Muhlenbergia reverchonii*), Hairy grama (*Bouteloua hirsuta*), and Side oats grama (*Bouteloua curtipendula*) (Riskind and Diamond, 1986).

Aquatic Life

As noted by different authors (Longley, 1986; Fiers and Iliffe, 2000), the aquifers of Central Texas have diverse and unique ecosystems. These ecosystems are associated with groups of unique species which inhabit distinct and separate locations within the aquifers. Species that inhabit the aquifer occupy a broad range of invertebrates to fishes. Relationships in the food chain between groups of species vary from obligate predators, scavengers, filter feeders, grazers, and bacterial, algal and fungal colonies. The cooler water temperatures (21°C) within the Edwards Aquifer near the Balcones Fault Zone are home to high levels of biodiversity and have been labeled as a "gold mine... of undiscovered species" (Fiers and Iliffe, 2000). **Amphibian** habitat in the Hill Country is limited to riparian cover and immediate areas influenced by spring outflows. Population distributions, especially with salamanders, appear to be extremely limited and patchy and are dependent on constant water temperatures near spring openings. Amphibians in many ecosystems can be considered keystone species and are good indicators in bio-assessments of the health of aquatic systems (EPA, 2002). General habitat alteration and loss, due to destruction of riparian zones or inadequate spring flows from excessive pumping, has impacted populations who have restricted home ranges and limited dispersal abilities. Additionally, increased incidences of disease and malformations from introduced contaminants are common due to their vulnerable thin, moist, and highly permeable skins and unshelled eggs (EPA, 2002).

Future preservation of riverine ecosystems is dependent upon maintaining water quality and flow conditions which are optimal to its endemic **fishes**. Drastic changes from urbanization introduce factors which change fish assemblages as habitats are impacted. Traditionally, declines of southern native fishes have been primarily due to habitat degradation, as is thought to be the case in most Hill Country streams and rivers (Warren et al., 2000). Impacts from stormwater run-off and erosion increase sediment and nutrient loads. Deposition of excessive siltation alters depth and substrate characteristics on which specific riverine species depend. Soil erosion also increases nutrient loads in the form of excessive nitrogen. Contaminant loads from excessive urbanization are also of concern.

Restricted range from dam construction has also caused declines in fish numbers. The altered hydrologic regimes associated with dams and impoundments reduce connectivity between upstream and downstream river stretches important in reproduction and feeding (Porto et al., 1999). The restriction of movements of fishes results in reduced upstream biodiversity. Dams decrease periodic discharges of floods in lower river segments important in cyclical ecological periodic disturbances. Impoundments also create opportunities for dominance of species associated with lentic aquatic systems. Along with the threat of introduced species, and associated predation, competition and disease, these factors could continue to severely impact the fishes associated with the higher velocity runs and riffles of several Hill Country Rivers.

Freshwater mussels have experienced severe declines and are extremely imperiled throughout the country, and the Texas Hill Country is no exception. Populations have declined due to changes in flow rates from dam construction, increased silt deposition from excessive run-off, aquatic contaminants, and invasive species. Degraded habitats with a lack of suitable native fish hosts for larval stages inhibit reproduction, as practically all species require a fish host. As filter-feeders, mussels clean aquatic systems but also concentrate contaminants like pesticides, heavy metals, and bacteria. One threatened mollusk species, the Texas fatmucket mollusk, is found in several streams and rivers throughout the Hill Country, where habitat is limited to gravel substrates including broken bedrock and course gravel in moderately flowing water. Because the fatmucket is intolerant of impediments, dams and very slow moving water, their available habitat within the basin is limited and must be carefully managed to maintain flow and water quality (suspended solids and sediment loading), as well as substrate scouring rates.

Impacts from urbanization impose stress on the environments of stream **invertebrates and insects** (Palmer et al., 2002). Stressors of habitat loss, degradation of water quality, and river flow variability are associated with interbasin urban development. Disruption of invertebrate life cycles reduces taxonomic richness (Ebersole et al., 1997). Dysfunctional invertebrate communities impact the stability of aquatic environments (Tilman, 1999; Covich et al., 2004). Assessing the health of a river ecosystem is often monitored by assessing stream invertebrate populations and temporal comparisons of invertebrate assemblages reveal positive or negative trends to shape water management policy (Barbour et al., 1999). Several endangered and threatened insects call the Texas Hill Country home and are described in the section below.

Endangered Species

The caves, seeps, sinkholes, springs and vegetative cover in the Hill Country region provide habitat to many federally endangered species such as the Golden-cheeked warbler (*Dendroica chrysoparia*), Black-capped-vireo (*Vireo atricapilla*), San Marcos salamander (*Eurycea nana*), Texas blind salamander (*Eurycea rathbuni*), San Marcos Gambusia (*Gambusia gerogei*), Comal Springs drypoid beetle (*Stygoparnus comalensis*) and Texas wildrice (*Zizania texana*) (TPWD, 2010).

The Blanco River Springs Salamander is found only in the Blanco River flowing through Blanco, Hays and Kendall Counties. This salamander's habitat is limited to freshwater springs and has been found predominantly in Fern Bank Spring, Peavey's Springs, Boardhouse Springs, Zercher Spring, Grapevine Cave, and T Cave within the River. Several other threatened and endangered salamanders with specific habitat requirements are found only in Hill Country Rivers and their tributaries (Table 3). With such a narrow and specific range of habitat, the successful management of such organisms depends on several critical factors, including water quality and quantity parameters which can be greatly influenced by development and other human activities.

Table 3. Threatened, Endangered and Rare Amphibians (TPWD)

Common Name	Hill Country Habitat Description
Blanco blind salamander	Troglobitic; water-filled subterranean caverns; may inhabit deep levels of the Balcones aquifer to the north and east of the Blanco River
Blanco River springs salamander	Subaquatic; springs and caves in the Blanco River drainage
Cascade Caverns salamander	Endemic; subaquatic; springs and caves in Medina River, Guadalupe River, and Cibolo Creek basins within Edwards Aquifer area
Comal blind salamander	Endemic; semi-troglobitic; found in springs and waters of caves
San Marcos Salamander	Headwaters of the San Marcos River downstream to ca. ½ mile past IH-35; water over gravelly substrate characterized by dense mats of algae (*Lyng bya*) and aquatic moss (*Leptodictym riparium*), and water temperatures of 21-22 ^{o}C; diet includes amphipods, midge larve, and aquatic snails
Texas Blind Salamander	Troglobitic; water-filled subterranean caverns along a 6-mile stretch of the San Marcos Spring Fault in the vicinity of San Marcos; eats small invertebrates, including snails, copepods, amphipods, and shrimp

The endangered Warbler and Vireo require juniper-oak woodlands and are dependent on mature Ashe juniper, deciduous and broad-leaved shrubs and trees for nesting and feeding (TPWD Rare, Threatened, and Endangered Species of Texas, n.d.) (Table 4). The Zone-tailed hawk's habitat is limited to wooded canyon lands with access to wooded creeks and streams (BirdLife International, 2006). Increasing habitat and hunting range fragmentation are areas of concern in managing this species. Terns typically breed in the Northern portion of Texas, along the Oklahoma border and winter along the Texas Coast. However, in recent years, the Least Interior Tern has been identified in Central Texas, along small creeks and streams, typically with rocky and sandy terrain. Changes in water levels and land cover utilized for nesting habitats increase the tern's breeding susceptibility.

Table 4. Threatened, Endangered and Rare Birds (TPWD)

Common Name	Hill Country Habitat Description
Black-capped Vireo	Oak-juniper woodlands with distinctive patchy, two-layered aspect; shrub and tree layer with open, grassy spaces; requires foliage reaching to ground level for nesting cover; return to same territory, or one nearby, year after year; deciduous and broad-leaved shrubs and trees provide insects for feeding; species composition less important than presence of adequate broad-leaved shrubs, foliage to ground level, and required structure; nesting season March-late summer
Golden-cheeked Warbler	Juniper-oak woodlands; dependent on Ashe juniper (also known as cedar) for long fine bark strips, only available from mature trees, used in nest construction; nests are placed in various trees other than Ashe juniper; only a few mature junipers or nearby cedar brakes can provide the necessary nest material; forage for insects in broad-leaved trees and shrubs; nesting late March-early summer
Interior Least Tern	Subspecies is listed only when inland (more than 50 miles from a coastline); nests along sand and gravel bars within braided streams, rivers; also know to nest on man-made structures (inland beaches, wastewater treatment plants, gravel mines, etc); eats small fish and crustaceans, when breeding forages within a few hundred feet of colony
Mountain Plover	Breeding: nests on high plains or shortgrass prairie, on ground in shallow depression; nonbreeding: shortgrass plains and bare, dirt (plowed) fields; primarily insectivorous
Western Burrowing Owl	Open grasslands, especially prairie, plains, and savanna, sometimes in open areas such as vacant lots near human habitation or airports; nests and roosts in abandoned burrows

The Texas Parks and Wildlife lists the Guadalupe Bass as a species of concern, as its habitat and range are diminishing due primarily to impoundment and to a lesser extent by decreases in water quality (TPWD Rare, Threatened, and Endangered Species of Texas, n.d.; Tomasso and Carmichael, 1986). The fish, impacted by hybridization with smallmouth bass, is endemic to the Edwards Plateau and can be found throughout several Hill Country River Basins. Again, managing habitat and water quality in the basin are critical for the management of this species. Increasing construction of small dams and impoundments and increased development will continue pressure on the Guadalupe Bass. The rare Guadalupe darter and Headwater catfish also have narrow habitat ranges that are continuously diminishing with increasing urbanization and changing land use patterns, and are also affected by the introduction of non-native and invasive fishes. Their known habitat ranges and suitability within the basin are reported in Table 5.

Table 5. Threatened, Endangered and Rare Fish (TPWD)

Common Name	Habitat Description
Guadalupe bass	Endemic to perennial streams of the Edward's Plateau region; introduced in Nueces River system
Guadalupe darter	Guadalupe River basin; most common over gravel or gravel and sand raceways of large streams and rivers
Headwater catfish	Originally throughout streams of the Edwards Plateau and the Rio Grande basin, currently limited to Rio Grande drainage, including Pecos River basin; springs, and sandy and rocky riffles, runs, and pools of clear creeks and small rivers.
Fountain Darter	Clear, quiet backwaters with thickly vegetated bottom and matted algae. Found only in the San Marcos and Comal rivers.
San Marcos Gambusia	Backwaters adjacent to high instream currents with unsilted river bottoms. This species was restricted to a limited portion of the San Marcos River.

Several species of threatened or endangered mollusks are found in the Hill Country. Some habitat descriptions and known locations within Central Texas are reported in Table 6, but the list is not exhaustive. Most are intolerant of dams and impoundments and require some minimum level of streamflow. As with the fatmucket, protection of these dwindling mollusks will depend upon habitat protection, flow requirements and management strategies to prevent decreases in water quality.

Table 6. Threatened, Endangered and Rare Mollusks (TPWD)

Common Name	Habitat Description
Texas fatmucket	Streams and rivers on sand, mud, and gravel substrates; intolerant of impoundment; broken bedrock and course gravel or sand in moderately flowing water; Colorado and Guadalupe River basins
Golden orb	Sand and gravel in some locations and mud at others; intolerant of impoundment in most instances; Guadalupe, San Antonio, and Nueces River basins
Smooth pimpleback	Small to moderate streams and rivers as well as moderate size reservoirs; mixed mud, sand, and fine gravel, tolerates very slow to moderate flow rates, appears not to tolerate dramatic water level fluctuations, scoured bedrock substrates, or shifting sand bottoms, lower Trinity (questionable), Brazos, and Colorado River basins
False spike mussel	Possibly extirpated in Texas; probably medium to large rivers; substrates varying from mud through mixtures of sand, gravel and cobble; one study indicated water lilies were present at the site; Rio Grande, Brazos, Colorado, and Guadalupe (historic) river basins
Texas pimpleback	Mud, gravel and sand substrates, generally in areas with slow flow rates; Colorado and Guadalupe river basins
Texas fawnsfoot	Little known; possibly rivers and larger streams, and intolerant of impoundment; flowing rice irrigation canals, possibly sand, gravel, and perhaps sandy-mud bottoms in moderate flows; Brazos and Colorado River basins

Several threatened or endangered plant species are known to reside in the Hill Country typically in areas classified as grassland or shrub. Listed in Table 7, additional varieties of threatened and endangered plants are found in sloping, rocky substrates and predominantly limestone bedrock outcrops. Canyon mock-orange, found throughout the area, requires nearby mixed evergreen-deciduous canyon woodlands to thrive, while rare granite spiderwort is found only in early successional grasslands.

The Hill Country wild mercury is located in bluestem-grama grasslands near mature Live Oak stands and is limited to moderately deep clays and clay loams. The wild mercury also is found in grassland areas with partial shade from oak-juniper woodlands in gravel based soils in steep slopes (TPWD Rare, Threatened, and Endangered Species of Texas, n.d.). Thus managing such habitats within the basin must include maintenance of available transition zones (from grassland to low canopy cover/scrub) and the prevention of erosion and scouring on steep slopes.

Texas Wildrice was historically found throughout the San Marcos River, in contiguous irrigation ditches with constant flows, and in Spring Lake at the River's headwaters, but is now limited to less than 4 miles of the upstream reach of the San Marcos River. The decline of the wildrice is attributed mainly to increased pumping and diversion of Edwards Aquifer groundwater which reduces spring outflow and river water levels, exposing islands and sandbars where wildrice grows. Damage from river dredging, damming, construction, and riparian cultivation has contributed to habitat loss, further alteration of stream flows and increased siltation, increasing the pressures on this endemic and endangered species.

Table 7. Threatened, Endangered and Rare Plants (TPWD)

Common Name	Habitat Description
Basin Bellflower	Texas endemic; among scattered vegetation on loose gravel, gravelly sand, and rock outcrops on open slopes with exposures of igneous and metamorphic rocks; may also occur on sandbars and other alluvial deposits along major rivers; flowering May-June
Big Red Sage	Texas endemic; moist to seasonally wet, steep limestone outcrops on seeps within canyons or along creek banks; occasionally on clayey to silty soils of creek banks and terraces, in partial shade to full sun; basal leaves conspicuous for much of the year; flowering June-October
Hill Country wild-mercury	Texas endemic; mostly in bluestem-grama grasslands associated with plateau live oak woodlands on shallow to moderately deep clays and clay loams over limestone on rolling uplands, also in partial shade of oak-juniper woodlands in gravelly soils on rocky limestone slopes; flowering April-May with fruit persisting until midsummer
Canyon mock-orange	Texas endemic; usually found growing from honeycomb pits on outcrops of Cretaceous limestone exposed as rimrock along mesic canyons, usually in the shade of mixed evergreen-deciduous canyon woodland; flowering April-June, fruit dehiscing September-October
Granite spiderwort	Texas endemic; mostly in fractures on outcrops of granite, gneiss, and similar igneous and metamorphic rocks, or in early successional grasslands or forb-dominated assemblages on well-drained, sandy to gravelly soils derived from same; flowering at least April-May
Texas Wildrice	Forms large clones or masses that firmly root in gravel shallows near the middle of the river in fast-flowing conditions. Requires constant year-round temperatures and is not tolerant to water quality impairments or siltation.

A wide array of snakes, lizards, frogs, toads and turtles can be found in the Hill Country, including the threatened Texas horned lizard and Cagle's map turtle. Commonly known as the "Horny toad" the Texas horned lizard was once common throughout the state. In recent years its numbers have been drastically reduced by environmental contamination, habitat loss due to land use conversion, spread of the red fire ant, and collection for the pet industry.

Historically found throughout the entire Guadalupe River Basin, Cagle's map turtle has been all but extirpated, with the few remaining populations forced southward by increasing habitat loss from reservoir construction, water diversion, decreased water quality and increased urbanization (Simpson and Rose, 2007) . The turtles' once abundant habitat consists of moderately flowing limestone bottomed channels with available pools of varying depths. This threatened turtle also has been found in slower flows, 1 to 3 meters in depth (Vermersch, 1992).

In 2005, two Texas State University Scientists in cooperation with The Nature Conservancy, surveyed the Blanco River and found a small population of Cagle's map. Although the turtles were observed in very low densities, this discovery was first grouping of Cagle's map turtles found upstream of the confluence of the San Marcos and Guadalupe rivers in several decades (Simpson and Rose, 2007). It is assumed that the population size of the turtle is limited by alternating flooding of the river, coupled with periodic drought and reduced flows in summer months.

As human activity and a potentially changing climate continue to limit Texas horned lizard, Cagle's map turtle and other reptilian habitat range, increased management and protection of suitable habitat areas within the basin will become important. Table 8 below lists habitat requirements for the Texas Horned Lizard and Cagle's Map Turtle.

Table 8. Threatened, Endangered and Rare Reptiles (TPWD)

Common Name	Habitat Description
Texas horned lizard	Open, arid and semi-arid regions with sparse vegetation, including grass, cactus, scattered brush or scrubby trees; soil may vary in texture from sandy to rocky; burrows into soil, enters rodent burrows, or hides under rock when inactive; breeds March-September
Cagle's map turtle	Endemic; Guadalupe River System; short stretches of shallow water with swift to moderate flow and gravel or cobble bottom, connected by deeper pools with a slower flow rate and a silt or mud bottom; gravel bar riffles and transition areas between riffles and pools especially important in providing insect prey items; nest on gently sloping sand banks within ca. 30 feet of water's edge

The Texas Hill Country and its karstic formations provide habitat to many rare, endangered and threatened insects. The Comal Springs dryopid have vestigial, or non-functioning eyes and very little pigment. In 1987 the beetle was first discovered and identified as a new genus and species by Barr and Spangler (1992). The Comal Springs riffle beetle is a small aquatic, surface-dwelling species, whose habitat is primarily composed of gravel substrate and shallow riffles in spring runs. These species' range and habitat likely included additional springs that are now primarily dry.

Peck's cave amphipod is a subterranean, aquatic crustacean. Also eyeless, this species is eyeless and has no pigmentation. Most known specimens have been located in crevices in rock and gravel near the largest openings of Comal Springs on the west side of Landa Park, in New Braunfels, Comal County (Arsuffi, 1993). The amphipod's underground habitat appears to be limited to aquifer openings that supply water to the springs and because of their blindness, they are easy prey and usually do survive for long outside the Aquifer.

Survival of the Peck's cave amphipod, Comal Springs riffle beetle, and Comal Springs dryopid beetle will require protection and conservation of the Edwards Aquifer and springflow at Comal, Hueco, San Marcos, and Fern Bank Springs. Due to drought and increasing water withdrawals which reduce flow and water levels, as well as potentially change water chemistry in rivers and streams throughout the Hill Country, these species' incredibly limited habitat is likely to be heavily impacted (McKinney and Watkins, 1993). Potential groundwater contamination from human sewage, leaking underground storage tanks, animal/feedlot waste, and agricultural chemicals also pose threats to these sensitive species' habitats.

In 1992, the Alamo Group of the Sierra Club, the Balcones Canyonlands Conservation Coalition, the Helotes Creek Association, the Texas Cave Management Association, and Texas Speleological Association, along with additional local groups, identified nine species of karst invertebrates known to exist only from caves in the northern and northwest parts of Bexar county and petitioned for them to be added to the List of Threatened and Endangered Wildlife. In December 2000, the insects were listed by US Fish and Wildlife Service under the Endangered Species Act. The species and their known habitat locations are listed below in Table 9.

Table 9. Karst Invertebrates

Taxonomic Designation	Habitat Description
Rhadine exilis (no common name)	
Rhadine infernalis (no common name)	Deep or dark karstic (cavelike) formations in Bexar County, Texas
Helotes mold beetle	Deep or dark karstic (cavelike) formations in Bexar County, Texas
Cokendolpher cave harvestman	Karstic (cavelike) formations in Bexar County, Texas
Robber Baron Cave spider	Karstic (cavelike) formations in Bexar County, Texas
Braken Bat Cave meshweaver	Karstic (cavelike) formations in Bexar County, Texas
Madla Cave meshweaver	Karstic (cavelike) formations in Bexar County, Texas
Government Canyon Bat Cave meshweaver	One cave in Government Canyon State Natural Area, Bexar County, Texas
Government Canyon Bat Cave spider	Two caves in Government Canyon State Natural Area, Bexar County, Texas

Synopsis of Groundwater in the Texas Hill Country

There are nine major aquifers in Texas as well as 21 minor aquifers. Three of the major aquifers provide groundwater to rivers, springs, and wells in the Hill Country region. The Edwards Aquifer is recognized as two separate aquifers that are designated the Edwards (Balcones Fault Zone; BFZ) Aquifer, found along the eastern portion of the Hill Country, and the Edwards (Plateau) Aquifer found in the higher elevations of the Edwards Plateau. The Trinity Aquifer system is composed of older strata and underlies the Edwards Group rocks of the Edwards Aquifer. The minor aquifers are the Ellenburger-San Saba, Hickory, and Marble Falls aquifers. This report summaries the characteristics and conditions of the Edwards (BFZ) and Trinity Aquifer system.

Edwards (Balcones Fault Zone) Aquifer

The Edwards Aquifer is found along the eastern edge of the Hill Country, extending into the hills in a fairly narrow zone at the surface (Figure 4).

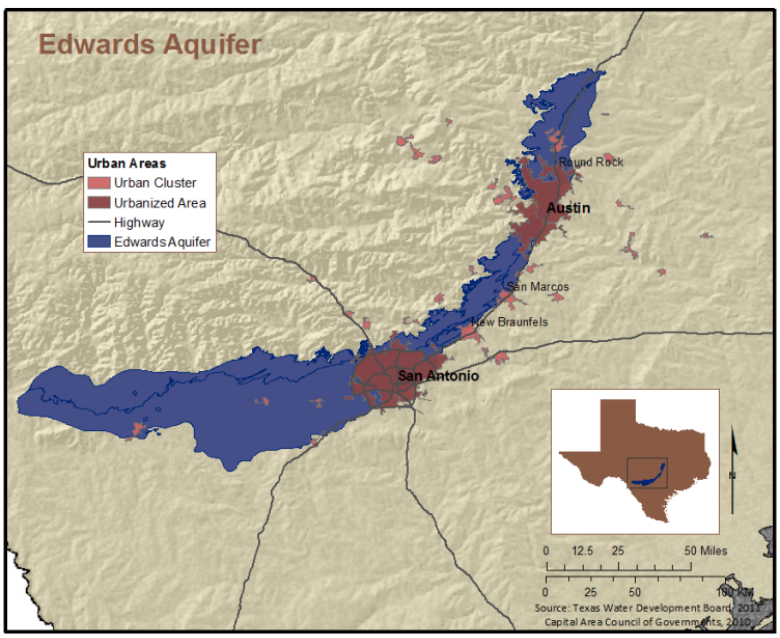
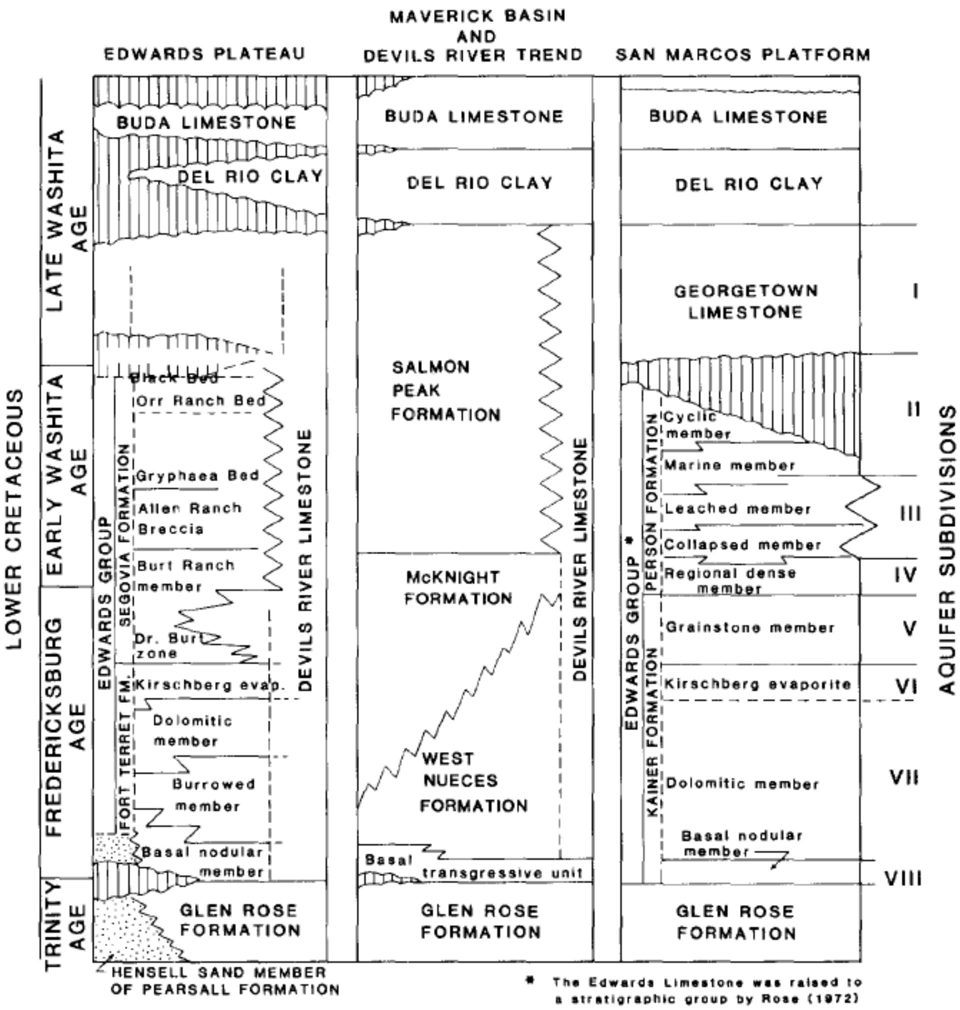


Figure 4. Edwards (BFZ) Aquifer and Urban Areas (RSI)

The Edwards Aquifer is composed of Cretaceous-age limestone formations of the Edwards Group. The rock layers are found at the surface or subsurface in the Central Texas region and comprise distinct zones of the Edwards Aquifer. Capped by the Del Rio Clay, the Georgetown Limestone, strata of the Edwards Group, and the Comanche Peak Limestone overlies the Glen Rose rock layers of the Trinity System except where faulted blocks raised the older rocks above the younger Edwards strata. To define these rocks and delineate the zones that are productive (hydrostratigraphic zones) and contain varying amounts of water, versus zones that contain little to no groundwater due to tight porosity and permeability (confining rock beds), has taken many years of study and correlation. An example of such study is in the chart below (Figure 5; from Maclay and Small 1986). Correlation between three groundwater basins of the Edwards required field studies and in-depth comparison of well cores as they became available. Such work is key to not only defining characteristics of an aquifer but also to utilizing a common framework for future studies.



Modified from Rose (1972)

Figure 5. Correlation Chart of Groundwater Basins, Edwards Aquifer (Maclay and Small, 1985; after Rose, 1972)

A simplified version of the stratigraphic column of the Edwards Aquifer and associated rock strata in the San Antonio region is shown in Figure 6.

GROUP	STRATIGRAPHIC UNIT		HYDROLOGIC UNIT
Edwards	Georgetown Limestone Edwards Group Comanche Peak (where presen	Edwards Aquifer -	Edwards Group, BFZ
Trinity	Glen Rose Limestone	Trinity Aquifer -	Upper Trinity

Figure 6. Simplified Stratigraphic Column, Edwards Aquifer (after Jones et al., 2011)

Thickness of the Edwards BFZ is estimated between 200 and 600 feet (Ashworth and Hopkins, 1995). The faults, trending northeast to southwest, are known as the Balcones Escarpment which can be seen along the Interstate 35 corridor. The escarpment is the topographic expression of uplifted and eroded fault blocks of the fault zone. The land surface of the escarpment generally separates the Hill Country to the west from the rolling prairies to the east.

The outcrop zone where rocks of the Edwards Group of the Edwards are found at the land surface, is shown in the generalized TWDB map below in dark blue (Figure 7). The outcrops denote the general recharge zone of the aquifer, replenished through rainfall or surface runoff that flow across the surface rocks and moves into the subsurface to percolate into the aquifer. The blue hatch marks indicate the Edwards rock layers that dip into the subsurface.

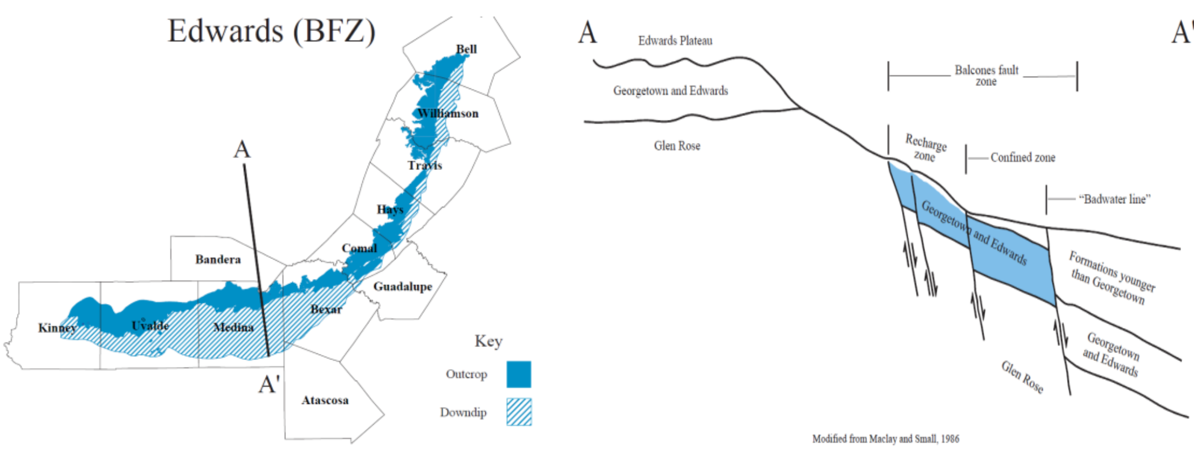


Figure 7. Map View of Outcrop and Downdip Strata and A-A' cross section of the Edwards (BFZ) Aquifer (Ashworth and Hopkins, 1995)

In Figure 7, the associated cross section on the right shows a simplified expression of the Edwards Group in blue, downdipped to the south and east. The fault blocks are downdrop to the south and east. Around the I-35 corridor, the faults significantly downdrop the Edwards below land surface, and the water chemistry changes to higher concentrations of dissolved solids.

An updated TWDB cross section details the key regions of the Edwards that are important to understanding water movement through the aquifer (Figure 8). The upland area of the Edwards Plateau is known as the catchment or drainage area. This area of outcropping Edwards strata allows rainfall and surface runoff to percolate into the subsurface aquifer system. Where uplifted Glen Rose rocks are present at the land surface, rainfall and runoff water infiltrate into the Trinity system. The recharge zone occurs where the Edwards strata are exposed in the lower reaches of the Hill Country. As shown in the cross section, this area is highly faulted, further supporting rapid flows of water into the aquifer. The "confined zone" capped by strata overlying the Edwards Group is under artesian pressure; wells in this region tend to be highly productive and yield groundwater of high drinking quality. San Antonio relies almost exclusively on this source for its public water system. Once the Edwards strata are downdropped east of the "bad water line," the groundwater is more saline than fresh.

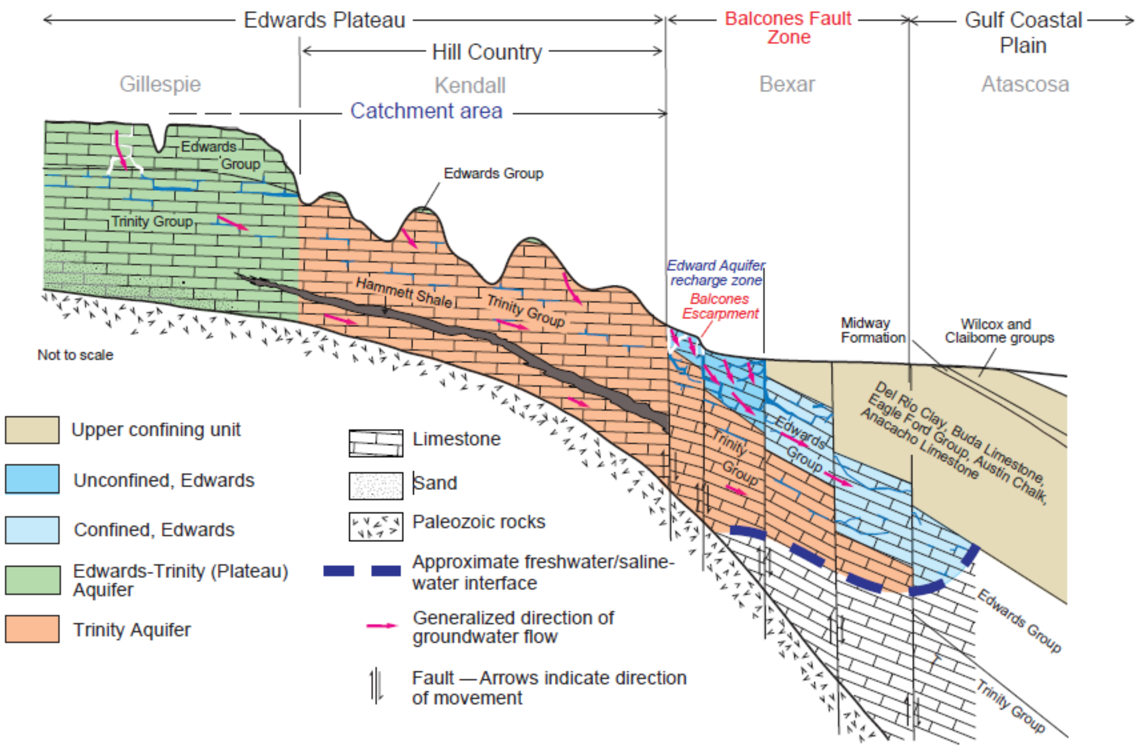


Figure 8. Generalized Cross section of the Edwards (BFZ) Aquifer (George et al., 2011)

Other characteristics of the Edwards (BFZ) Aquifer include the following points (from George et al., 2011; Lindgren et al., 2004; USGS, 1996):

- At least 8 hydrostratigraphic or water-bearing zones have been defined in the Edwards, some more permeable than others.

- The rock strata have been leached and re-crystallized, resulting in increased pore spaces and high interconnectability in some, but not all, of the rock layers. Thus, groundwater movement and flow rates are highly varied.
- Groundwater flow is generally downdip to the southeast along the northwestern region, but is influenced by faulting and moves towards the east and northeast in the central area of the aquifer.
- Hydraulic conductivities vary greatly from less than 20 feet per day (ft/d) to over 7,000 ft/d.
- According to TWDB Report 345 concerning the Edwards BFZ, well yields are considered moderate to large, up to 24,000 gallons per minute in a 30-inch diameter well drilled in Bexar County.
- The freshwater zone to the west of the escarpment requires very little to no treatment for drinking water purposes, while groundwater to the east in the "bad water line" contains higher concentrations of dissolved solids. These trace minerals are due to the presence of pyrite and gypsum in the rocks.

Information about Edwards BFZ Wells and Data

A great amount of data and information are available for the aquifers of Texas, however it can be difficult to access all such data. This section provides overview information about the Edwards in graphs, maps and charts. The primary groundwater data source is the Texas Water Development Board's well records database that can be downloaded or accessed through the Water Information Integration & Dissemination (WIID) System. This data system is public and can be downloaded at any time, however the system is updated on a regular basis.

Wells completed in the Edwards Aquifer are found across the region, but particularly along the more productive areas of major fault zones. Over 10,000 wells have been recorded in the Edwards; to date in 2011, at least 210 wells have been installed. Figure 9 demonstrates that the majority of wells are installed in the artesian zone, the productive area along the fault zone. A land surface expression of such a fault zone in the Hill Country can be seen in Figure 9. Trending generally northeast-southwest along the curve of the Balcones Fault zone, wells are clustered along fault zones in the central portions of Medina, Bexar, Hays, and Travis counties.

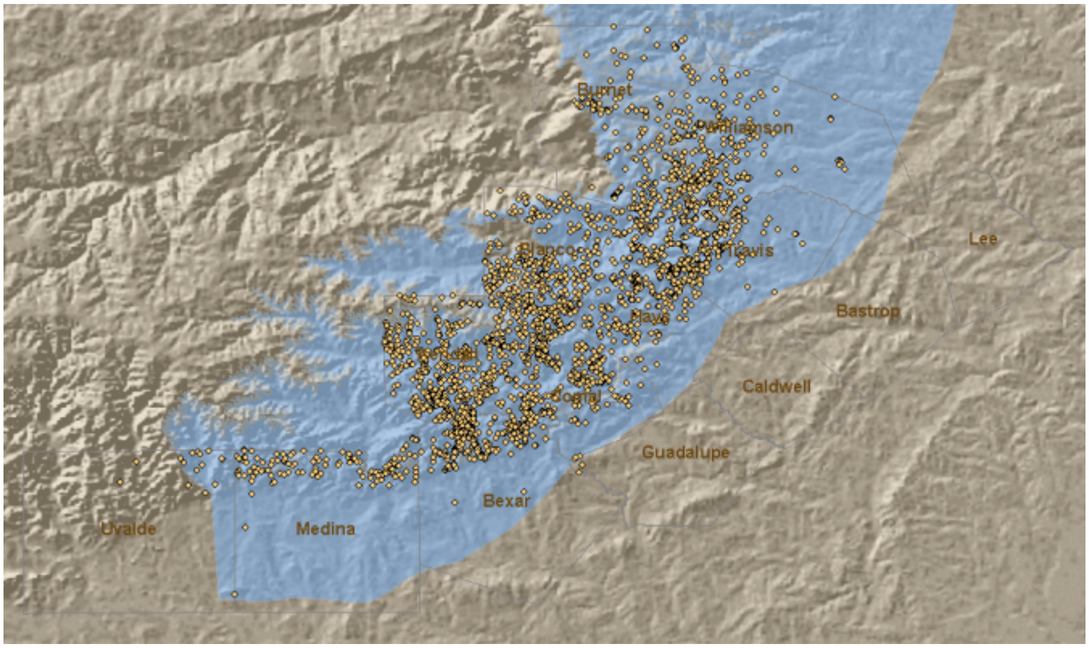


Figure 9. Edwards (BFZ) Aquifer Well Locations (from TWDB Database, 2011)

Water levels within the Trinity vary greatly. Table 10 summarizes well information from Edwards and Trinity database records. The summary data highlight the differences in aquifer productivity via number of wells, whereas water quality records indicate that about one half of the wells have been tested for water quality parameters (ion and cation, calcium, bicarbonate, etc.). Water level measurements exist for many of the wells, but depending on well access, are collected through different techniques as noted by the water level code on the right. Well records are displayed by county in Table 11.

Table 10. Well Record Summary, Trinity and Edwards Aquifers (TWDB Database, 2011)

Aquifer	Wells	Water Quality		Water Level	
Trinity	1759	N	897	C	9
		Y	856	D	38
		(blank)	6	H	68
				L	5
				M	1103
				N	506
				P	4
				R	10
				U	10
				(blank)	6
Edwards	3169	N	1293	C	47
		Y	1293	D	76
		(blank)	4	H	242
				L	21
				M	1526
				N	1140
				P	1
				R	0
				U	110
				(blank)	6

Table 11. Well Record Summary by County, Edwards Aquifer (TWDB Database, 2011)

County	Wells	Water Quality		Water Level	
Bexar	1092	N	644	C	3
		Y	447	D	7
		(blank)	1	H	25
				L	2
				M	485
				N	526
				U	43
				(blank)	1
Caldwell	5	N	2	M	2
		Y	3	N	3
		(blank)	0		
Comal	230	N	115	C	8
		Y	115	D	28
		(blank)	0	H	54
				L	2
				M	56
				N	78
				U	4
Guadalupe	52	N	30	H	1
		Y	22	M	34
		(blank)	0	N	14
				M	U
Hays	295	N	135	C	7
		Y	159	D	19
		(blank)	1	H	21
				L	6
				M	137
				N	75
				U	28
				(blank)	2
Medina	610	N	451	C	11
		Y	158	D	4
		(blank)	1	H	67
				L	3
				M	359
				N	159
				U	6
				(blank)	1
Travis	446	N	167	C	7
		Y	279	D	1
		(blank)	0	H	46
				L	4
				M	248
				N	122
				P	1
				U	17
Uvalde	439	N	328	C	11
		Y	110	D	17
		(blank)	1	H	28
				L	4
				M	205
				N	163
				U	9
				(blank)	2

The impact of well records and locations are more pronounced when considered in light of population growth. Figure 10 represents population growth over the Edwards BFZ Aquifer in 2004. Compared to the percent growth anticipated over the next 50 years as discussed in the above section **Demographics**, very few areas may be expected to remain rural and dependent solely on groundwater wells for water supplies.

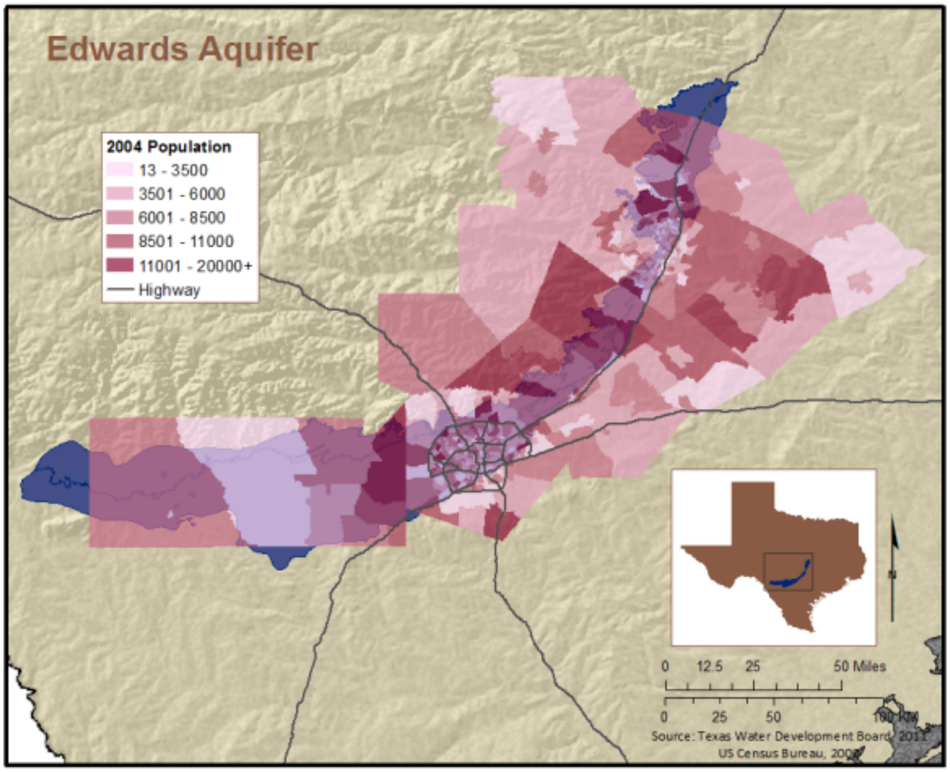


Figure 10. 2004 Population Ranges overlying Edwards BFZ) Aquifer (Texas State Data Center, 2011)

Primary uses for the Edwards Aquifer might be anticipated to be for irrigated agriculture. However, the four top uses charted in Figure 11 show that by number of wells, domestic wells are only slightly the highest in number. The well numbers are fairly split among domestic, unused, public supply, and irrigation. By volume, the greatest use is spring discharge, followed by municipal uses, irrigation, industry, and domestic applications (EAA, 2011).

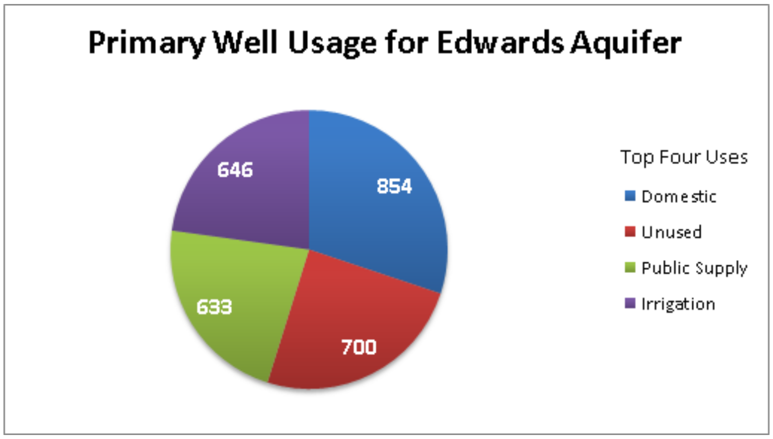


Figure 11. Primary Well Usage, Edwards Aquifer (TWDB Database, 2011)

Trinity System

The Trinity aquifer is composed of Early Cretaceous formations of the Trinity Group of rocks. The rock layers are found at the surface or subsurface "through the central part of the state in all or parts of 55 counties, from the Red River in North Texas to the Hill Country of South-Central Texas" (Ashworth and Hopkins, 1995). Trinity Group deposits also occur in the Panhandle and Edwards Plateau where they are included as part of the Edwards-Trinity (High Plains and Plateau) aquifers. However, the rock layers are not necessarily connected south of the Colorado River.

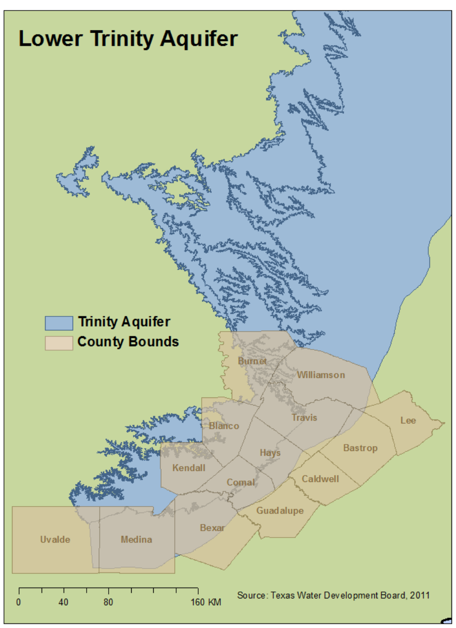


Figure 12. Trinity Aquifer in the Hill Country

In the subsurface, the Trinity consists of layers of limestone, calcareous sands and silts, and conglomerates. These layers were deposited around 145 million years ago when shallow seas covered areas of what is now Texas and the southwestern US. The Llano uplift was higher in elevation and provided much of the land-based sands, silts, and conglomerates found in the Trinity rock layers (Barker and Ardis, 1996).

As noted in the section above concerning the Edwards, outcropping rocks of the Trinity are found in the upland region of the Hill Country (Figure 12). A stratigraphic column of the Trinity Group and associated aquifer system are shown in Figures 13 and 14.

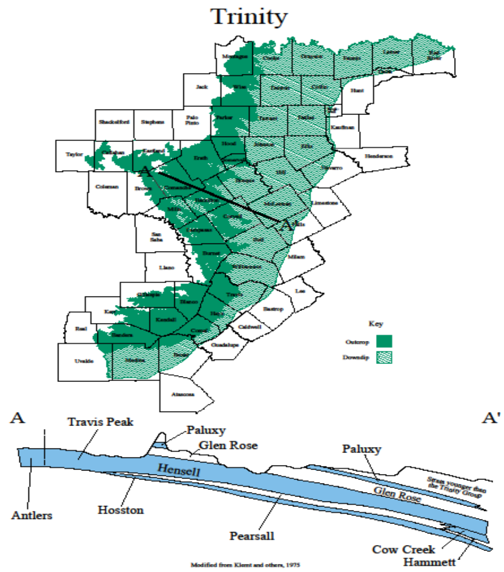


Figure 13. Outcrops and Downdipped Strata, Trinity Aquifer (Ashworth and Hopkins, 1995)

GROUP	STRATIGRAPHIC UNIT			HYDROLOGIC UNIT
Edwards	Segovia Formation			Edwards Group
	Fort Terrett Formation			
Trinity	Glen Rose Limestone	Upper Member	Trinity Aquifer System	Upper Trinity
		Lower Member		Middle Trinity
	Hensell Sand/Bexar Shale			
	Cow Creek Limestone			
	Hammett Shale			confining unit
	Sligo Formation			Lower Trinity
	Sycamore Sand/Hosston Formation			

Figure 14. Stratigraphic Column, Trinity Aquifer System (Jones et al., 2011)

While the stratigraphic column denotes general relationships between the strata of the Trinity rocks, almost all rock strata vary in how deep they are found below the ground surface and how thick they are at any given location. Studies of the aquifer have indicated that the Hosston Formation at the base of the Trinity Group is up to 900 feet thick, while the Sligo is around 250 feet thick. The Hammett Shale, a rock unit that is known as a "confining" unit through which little groundwater moves, is about 130 feet. The overlying Glen Rose formation has been shown to be up to 1,500 feet thick.

The cross sections in Figure 15 generalize the Trinity Aquifer system in the subsurface (Jones et al., 2011) and are based on previous studies (Ashworth, 1983; Mace et al., 2000). The sections are drawn from north (or A on the left side of the top column) to south (A' at the right side of the bottom column) across the Hill Country, and the vertical scale on the left shows the elevation of the rock strata in feet above sea level. The horizontal scale of one inch = 6 miles, while exaggerated in comparison to the vertical scale, allows visualization of the layers at depth. A map insert into the top section shows the general location of the cross section, and the legend noting the names of the rock formations per color band. Well cores are noted by vertical lines with a TWDB classification number at the top, and major fault zones are the vertical lines with small up and down arrows to either side, showing relative movement of the fault blocks.

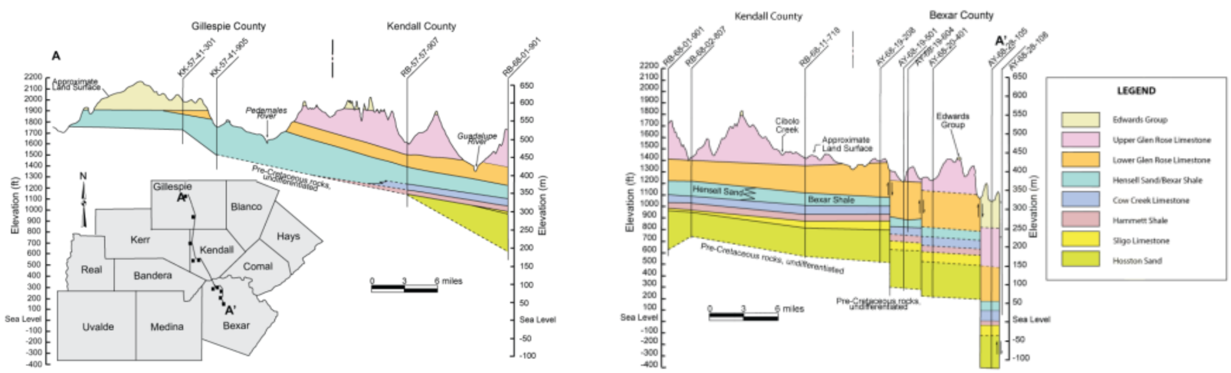


Figure 15. Cross-sections of the Trinity Aquifer System (Jones et al., 2011)

How groundwater flows through this system of layered rocks containing different rock matrices (chalky sands, limestones of varied depositional character, and other layers), found at different depths below the ground, and flows through a major fault system is of great interest. Geologists and hydrogeologists with years of experience in the Hill Country aquifers addressed this question through a recent compilation of data, studies, and interpretations. The "Hydrogeologic Atlas of the Hill Country Aquifer, Blanco, Hays and Travis Counties, central Texas" compiles data, well records, geologic maps, groundwater flow cross sections, and water chemistry via plates and pertinent reports per topic (HTGCD et al., 2010).

Trinity System Wells and Data

Wells in the Trinity are found across the county, but particularly along the more productive areas of major fault zones. A land surface expression of such a fault zone in the Hill Country can be seen in the map below (Figure 16). Trending generally north-south, a linear clustering of wells along a fault zone is found in the central portions of Travis and Hays counties. Estimates of over 6000 wells have been used in preparing groundwater models.

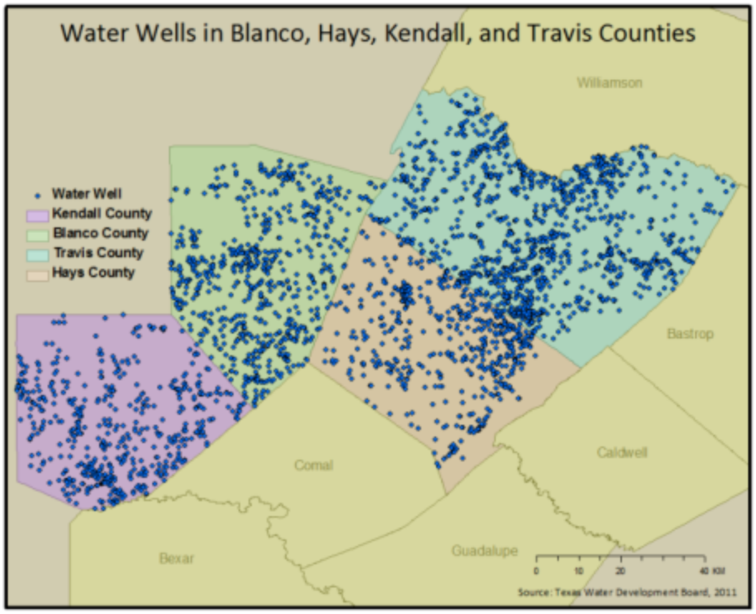


Figure 16. Well Locations by County, Trinity Aquifer (TWDB Database, 2011)

Wells in Texas are identified through the TWDB statewide monitoring program. Each well that is logged and recorded is given a specific number, based on the state well grid. Table 12 provides a summary of well information per county overlying the Hill Country portion of the Trinity aquifer system.

Table 12. Well Record Summary by County, Trinity Aquifer (TWDB Database, 2011)

County	Wells	Water Quality		Water Level	
Bexar	351	N	234	C	1
		Y	114	D	0
		(blank)	3	H	10
				L	3
				M	224
				N	105
				R	2
				U	5
				(blank)	1
Burnet	126	N	86	D	4
		Y	40	H	12
		(blank)	0	L	12
				M	65
				N	30
				(blank)	3
Comal	319	N	188	C	2
		Y	129	D	1
		(blank)	2	H	14
				M	202
				N	91
				R	3
				U	4
				(blank)	2
Hays	323	N	177	C	0
		Y	145	D	37
		(blank)	1	H	12
				L	1
				M	196
				N	67
				P	4
				R	3
				U	1
				(blank)	2
Medina	135	N	90	C	0
		Y	45	H	8
		(blank)	0	L	0
				M	90
				N	37
				(blank)	0

Table 12 continued					
County	**Wells**	**Water Quality**		**Water Level**	
Travis	607	N	200	C	6
		Y	407	D	0
		(blank)	0	H	24
				L	1
				M	382
				N	191
				R	2
				(blank)	1
Williamson	230	N	50	C	5
		Y	180	D	0
		(blank)	0	H	21
				M	154
				N	49
				R	1

Water levels within the Trinity vary greatly. A summary chart of wells in Hays County dated March 2010 shows this variation.

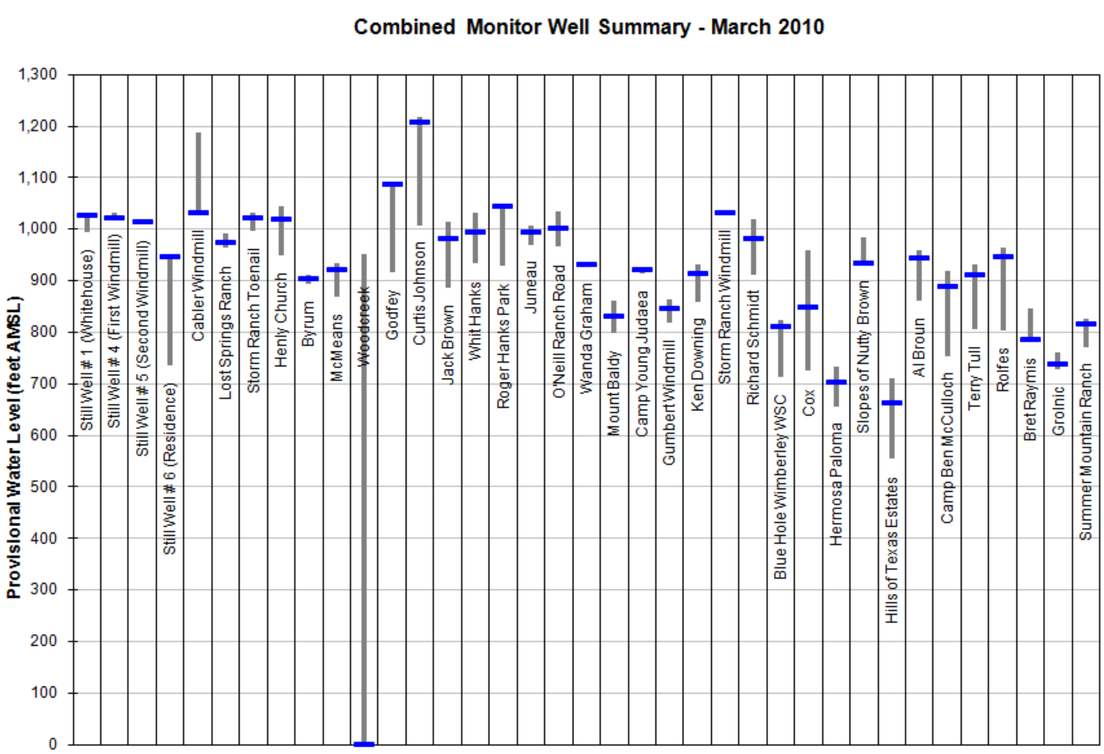


Figure 17. March 2010 Water Levels, Hays County (TWDB, 2011)

Well data are also meaningful when connected to population centers and population growth corridors and to waste sites in the same region. The following three maps identify a) urban centers overlying the Trinity, b) population ranges, and c) waste sites over the Trinity (Figures 18-20).

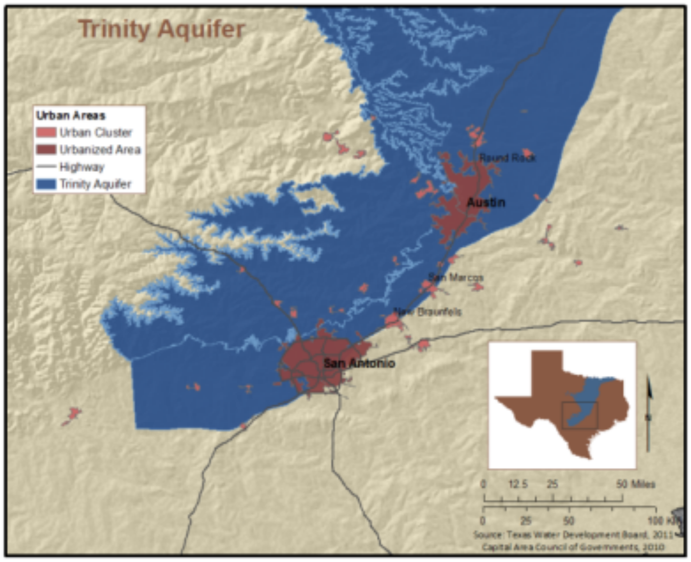


Figure 18. Urban Areas Overlying the Trinity Aquifer

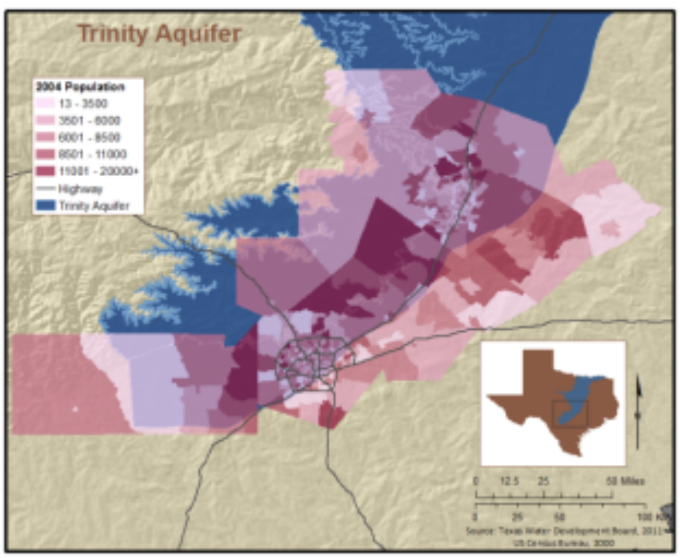


Figure 19. 2004 Population Ranges Overlying the Trinity (Texas State Data Center, 2011)

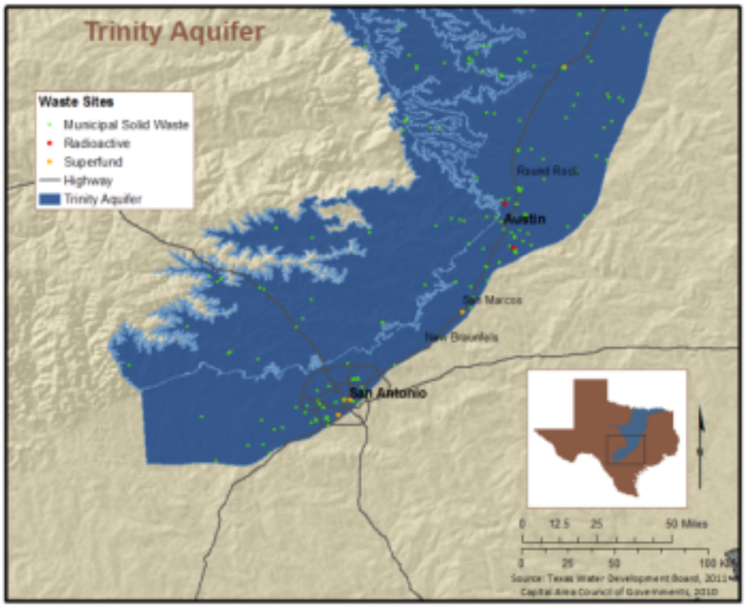


Figure 20. Waste Sites Overlying the Trinity (TWDB Database, 2011)

Water uses are different across Texas, as are the dominant well categories. In the Hill Country Trinity region, which is predominated by rural landowners, ranches and small cities, domestic use is the top category, followed by public supply wells (Figure 21).

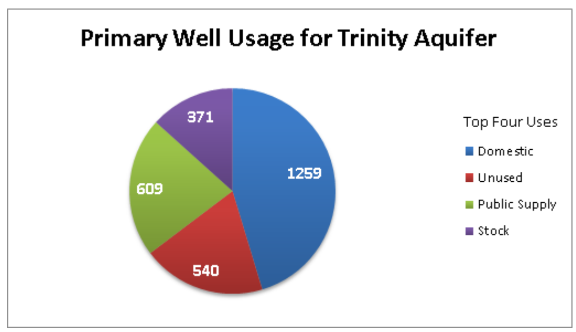


Figure 21. Primary Well Usage, Trinity Aquifer (TWDB Database, 2011)

Groundwater Models and the Hill Country Portion of the Trinity System

The TWDB groundwater availability model (GAM) program is the state's primary approach to understanding and defining "available" groundwater. The term "availability" refers to the fact that while deeper volumes of groundwater may be present in deeper zones of an aquifer, such groundwater may not economically feasible to withdraw nor may the water quality be necessarily desirable. The GAM program has its base in the many groundwater models developed over the past few decades in Texas for aquifers or portions of aquifers. While the GAMs are developed to better characterize and understand the aquifers of Texas, other models such as water quality or recharge distribution models also play a key role in building balanced groundwater models that reflect and utilize known aquifer characteristics and movement of groundwater so as to accurately simulate the aquifer, past, present, and future. The models in the TWDB GAM program are used to address current and future estimates of available groundwater. To better appreciate the current discussions of managing the Hill Country portion of the Trinity Aquifer, it is important to understand what information, data, and modeling on which such decisions are based. Therefore, this discussion gives an overview of the TWDB GAM for the Trinity Aquifer in the Hill Country (Mace et al., 2000) and its subsequent updates and model runs.

Key Model Features and Inputs

The 2000 Trinity GAM model boundaries were defined by 1) the area of interest to be modeled, that is, the Hill Country region of the Trinity Aquifer, and 2) sufficient area to include outcrops of the Trinity, the downdipped region where most of the water wells are installed, and land features such as springs and major river basins. An important distinction is that while the Trinity aquifer system is much larger, stretching into northeastern Texas, only the Hill Country portion of the Trinity Aquifer system was modeled for this GAM (Mace et al., 2000). Key features and inputs of the model include:

- The rock strata are composed of karstic limestone, calcareous sands, and shales. Such rock layers are associated with horizontal and vertical water flow through dissolution features, faults, and fractures.
- Average yields in the Middle Trinity Aquifer are about 250 times less than those of the Edwards Balcones Fault Zone (BFZ) Aquifer.
- The aquifer's water levels and therefore pumping yields may fluctuate within a wide range in response to rainfall, drought, and pumping.

The numerical model was developed using MODFLOW, a finite difference model coded by US Geological Survey and used in many model areas around the world (McDonald and Harbaugh, 1983). For the 2000 Trinity GAM, a grid of 3 layers (the Upper and Middle Trinity Aquifers and the Edwards-Plateau Group) and 1-mile by 1-mile cells was established in the model area for a total of 9,262 active cells plus boundary cells (Mace et al., 2000). As far as possible, the model's numeric and grid structure approximated the rock types, layers, their changes in thickness and depth below ground, and related features.

The model was calibrated to known water levels over time, particularly for 1975 conditions when the data indicated that the aquifer was near steady state, i.e., natural, low pumping conditions. The calibrated model indicated that about 64,000 acre-feet per year flows from the Upper and Middle Trinity zones to the Edwards (BFZ) Aquifer.

Historic water levels recorded in wells across the model area were input to the model grids. Wells are often installed to different levels in the aquifers.

Hydraulic conductivity (K) values used for the model relied on previous studies:

- 10 ft/day (Hammond, 1984)
- 10 ft/day (Barker and Ardis, 1996)

- Range of 0.0001 – 0.003 ft/day in the Hammett and Upper Glen Rose (Guyton and Associates, 1993)

Due to the range of factors that affect hydraulic conductivities throughout the model area, the K values were input from kriged, statisical distributions for each of the Trinity aquifers (upper, middle, and lower aquifers).

Storativity, the volume of water that can be taken from the saturated zone of the aquifer, is measured in units of foot per foot and thus is dimensionless. Values considered for the model ranged from 3 x 10^{-5} to 10^{-3}. Values input into the model were from test locations.

Estimates of recharge can be difficult, and there are multiple methods for such estimates (Table 13). For the 2000 Trinity GAM, the following estimates of recharge as a percent of rainfall were considered.

Table 13. Recharge Values Considered for the Trinity GAM (from Mace et al., 2000)

Source	Recharge Value (% of rainfall)
Muller and Price (1979)	1.5%
Ashworth (1983)	4 %
Kuniansky (1989)	11 %
Kuniansky and Holligan (1994)	7 %
Bluntzer (1992, calculated)	6.7 %
Bluntzer (1992, estimated)	5 %
GAM analysis	6.6 %
Trinity GAM model (2000)	4 %

Model control points were also a key feature in the GAM. The study identified data points (wells, outcrops, groundwater-surface water interactions in river beds, etc.) across the study area. One such set of model control points were the stratigraphic lower elevations for the Edwards, the Lower Trinity, and the Middle Trinity.

Groundwater pumping by county in acre-feet per year was estimated for the 2000 GAM (Figure 22). As the discussion below notes, the pumping estimates have been a point of continuing refinement for subsequent model runs. Historic values were established for the years 1975-1997; values were projected for subsequent years.

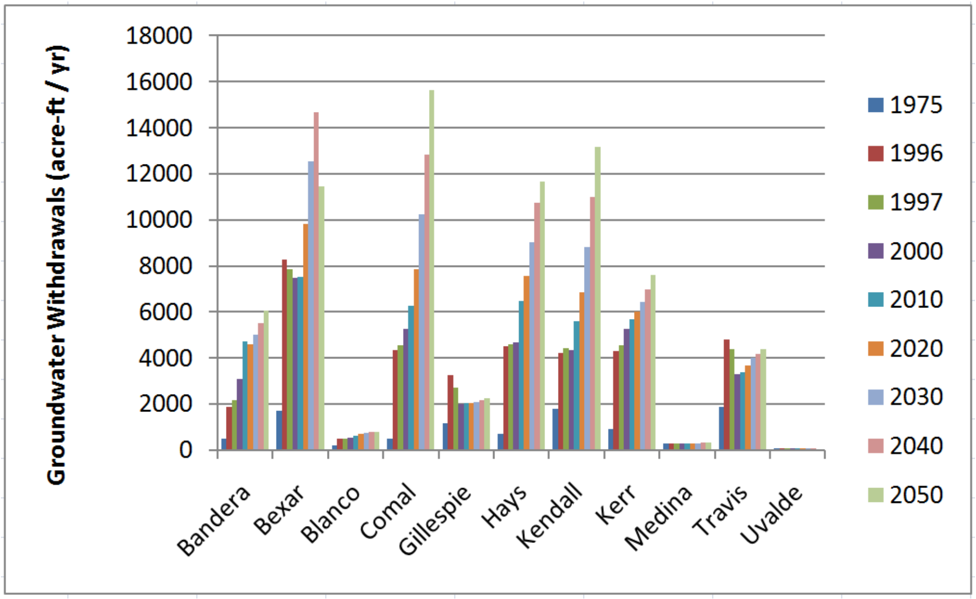


Figure 22. Historic and Projected Groundwater Withdrawal Estimates by County, 2000 GAM (from Mace et al., 2000)

Model Projections, Results and Assumptions

Having been tested for calibration, or "steady state" using historic groundwater pumping and water levels in the aquifer, the GAM was then used to test scenarios of future pumping. As shown in Figure 23 below, future pumping levels from 2010 to 2050 were estimated to increase based on population growth projections and increased groundwater withdrawals from the aquifer. The GAM results indicated that areas of the Hill Country Middle Trinity Aquifer could "go dry" in areas of heaviest pumping under drought-of-record (the 1950's drought) conditions. The following two maps are shown at small scale to emphasis the projected changes in aquifer water levels (Figure 23, a-b).

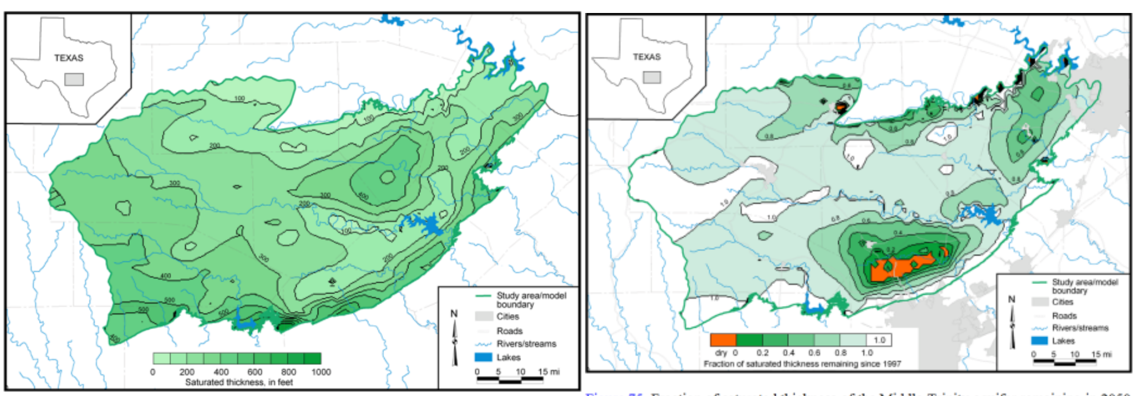


Figure 70. Simulated saturated thickness of the Middle Trinity aquifer in 1997.

Figure 75. Fraction of saturated thickness of the Middle Trinity aquifer remaining in 2050 with a drought-of-record compared to the saturated thickness in 1997.

Figure 23. (a) Simulated Saturated Thickness of the Middle Trinity, 1997. (b) Simulated Saturated Thickness of the Middle Trinity, 2050 (Mace et al., 2000)

These results indicated to the TWDB and stakeholders of the Trinity Aquifer that portions of the aquifer could dry in 50 years. To summarize from the 2000 Trinity GAM report (Mace et al., 2000):

- In 2010, the aquifer might experience 100-foot declines in water levels.
- Under the 2000 pumping levels, a large part of the aquifer could be depleted by 2030.
- In 2040, 100-foot drawdown of the aquifer may occur in the Dripping Springs area.
- By 2100, 50 to 100-foot declines may occur in the Hays, Blanco, southeastern Kerr, and eastern Bandera counties.
- Major rivers in the region might continue to flow seasonally even with increased pumping levels and drought-of-record (1950's) conditions.

To place the model and above results in context, several assumptions and limits helped to define the model. The model utilized data from the Upper and Middle Trinity Aquifers and the Edwards Group in the Hill Country Plateau; the Lower Trinity Aquifer was not included in this model. A key assumption used to prepare the model inputs was "no-flow" between the Middle and Lower Trinity aquifers. The model grid of 1x1-mile cells supported the overall model, but may not be sufficiently detailed to address smaller-scale features and pumping scenarios. Data for hydraulic properties such as conductivity, transmissivity, storativity, thickness of hydrostratigraphic layers, etc., were based on available information and in some areas of the model boundaries, limited data. Recharge was assumed to be linear with precipitation, however, the model authors recognized that this is not necessarily linear due to local factors such as soil thickness and ground slope.

As the above discussions, summaries, and table indicate, groundwater modeling is a needed tool for understanding groundwater over time. Various modeling scenarios help to predict what impacts of drought and pumping changes may bring to the aquifer. However, models can only provide information related to specific decisions, and are only one component necessary for successfully managing aquifers. Managing aquifers and groundwater are discussed below.

Managing Aquifers and Groundwater

Texas has based its groundwater management in sound, hydrogeologic identification of aquifer locations and characteristics. Throughout the years, many geologic, geophysical, and hydrogeologic studies of rock formations and the associated aquifers have contributed to in-depth understanding of the aquifers in Texas. TWDB has not only studied but also provided summary information, data, and maps (George et al., 2011; Ashworth and Hopkins, 1995). Of the nine major and 21 minor aquifers, three major and three minor aquifers are located beneath the Hill Country.

These aquifers span many counties and most of the major aquifers are transboundary between Texas and other states or Mexico. All have distinct characteristics and features, water chemistry, flow regimes, and water uses. Groundwater is managed under various policies and approaches in most US states, and Texas is no exception. Managing groundwater in Texas predominantly occurs at the local and county level through groundwater conservation districts. Some of the primary approaches to groundwater management are:

- Landowner well management under "rule of capture"
- Groundwater conservation districts (GCDs) and special districts such as the Edwards Aquifer Authority
- Groundwater management areas (GMAs)
- Priority groundwater management areas (PGMAs)
- Statewide water planning through Regional Water Planning (RWP)

As Figure 24 indicates, groundwater management in Texas involves more than one agency and one level of planning and decision-making. A brief overview of each management approach follows.

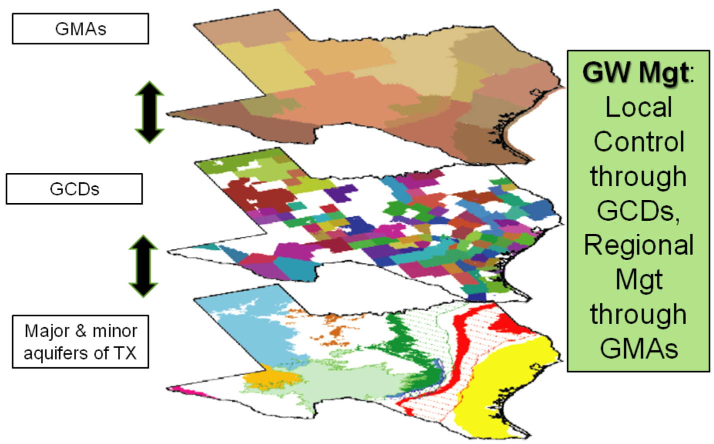


Figure 24. Levels of Groundwater Management in Texas

Landowner well management through "rule of capture" and exempt wells: Since the 1904 court case *Houston & Texas Central Railway Co. v. East* (98 Tex. 146, 81 S.W. 279), the rule of capture, also known as the "law of the biggest pump," has been part of the Texas groundwater management landscape. Generations of landowners installed wells on their land with the right to pump an indeterminate of groundwater. Subsequent case law established exceptions to the rule of capture – pumping cannot intentionally injure a neighbor, is not intentionally pumped so as to waste groundwater, and cannot cause land subsidence.

Exempt wells are those by law that do not fall into regulated categories of wells. In Texas, exempt wells are generally installed for domestic and livestock use and pump less than 25,000 gallons per day (gpd). Other US western states have similar rules for exempt wells. As these wells have not historically been part of a state's water management program, the total number and pumping capacities can only be estimated. Their impacts on groundwater management of an entire aquifer are also difficult to quantify.

Groundwater conservation districts (GCDs): Texas has stated that these districts are the State's preferred method of groundwater management, thus supporting local control of groundwater at the district and county level. These districts have been in existence for decades; the High Plains Underground Water Conservation District No. 1 was created in 1951. Currently there are 97 GCDs and 3 special districts (the Edwards Aquifer Authority, the Harris-Galveston Subsidence District, and the Fort Bend Subsidence District). Each GCD has its own enabling legislation and may have slightly different rules and approaches to managing groundwater in that district. In general the GCDs are authorized under Texas Water Code Title 2, Chapter 36.

Groundwater management areas (GMAs): To provide for the "…conservation, preservation, protection, recharging, and prevention of water of groundwater," the Texas Legislature authorized the creation in 2001. The Texas Water Development Board created sixteen GMAs in 2002. The areas of the GMAs are roughly those of the state's major aquifer modeling areas, with modified boundaries to adjust for GCDs within each groundwater management area. The GMAs do not serve as oversight for the GCDs within their boundaries. Rather the individual districts utilize groundwater availability models within the GMAs to establish current aquifer conditions and future projections, called "desired future conditions" or DFCs. GMA 8 and GMA 9 are located in the Texas Hill Country.

An important part of managing the aquifers through local control is the evaluation and determination of Desired Future Conditions (DFCs). Such DFCs are adopted by a 2/3 vote of all the districts in a GMA. In the last few years, many districts and GMAs have been reviewing and revising their groundwater models to determine the best DFCs per GMA. In the Hill Country GMA 9, the most recent DFC of allowing an average 30-foot drawdown in the Trinity aquifer has come under much dispute by different organizations. Such disagreements can be brought to TWDB and TCEQ which have processes for appealing DFCs.

Priority groundwater management areas (PGMAs): PGMAs were authorized by the Texas Legislature to deal areas that may have experienced, or are likely to experience, significant groundwater problems such as water shortfalls, land subsidence due to groundwater pumping, or contaminated groundwater. The PGMA management is overseen by TCEQ, TWDB, and Texas Parks and Wildlife Department (TPWD). Currently there are eight PGMAs. Of interest to central Texas is the PGMA designation for portions of Hays, Comal, and Travis counties.

Statewide water management through Regional Water Planning: Texas has an active statewide planning process. Sixteen Regional Water Planning Groups (RWPGs) were established and reflect regional water uses (for example, the Panhandle's reliance on the Ogallala Aquifer as well as Lake Meredith and the Canadian and Red Rivers), portions of river basins and their communities (an example is the Lower Colorado River Basin). These RWPGs have provided input to the State Water Plan through planning cycles. The data and information about water use, including groundwater, are incorporated into the State Water Plan 2012 (Draft) (TWDB, 2011).

Key findings of the most recent cycle of statewide planning and analysis of water resources are:

- The state's population is expected to grow by 82 % over the next 50 years, from 25.4 million to 46.3 million.
- Water demands may increase only around 22%. While agricultural uses over the next 50 years are expected to decrease, municipal water demands are increasing.
- Texas water supplies are currently from surface water (reservoirs and rivers), groundwater, and reuse of water.
- Available groundwater, particularly in the Ogallala Aquifer, is expected to decrease by about 30%.
- In times of drought, Texas does not have enough water for all demands, including support of riparian, riverine, and spring-fed ecosystems. Strategies to address this gap are water conservation measures, new reservoirs, new wells, increased water reuse, and desalination.
- Implementing additional water supply strategies will not be free. The Draft 2012 State Water Plan estimates that capital costs for the strategies are $53 billion.

Managing Groundwater in the Hill Country: GMA 9

GMA 9 is the area designated for the Hill Country portion of the Trinity Aquifer system (Lower, Middle, and Upper Trinity Aquifers). As shown below, there are nine partial or complete GCDs as well as the Edwards Aquifer Authority that are part of GMA 9. The map also shows the parts of Travis and Comal counties that have no GCD.

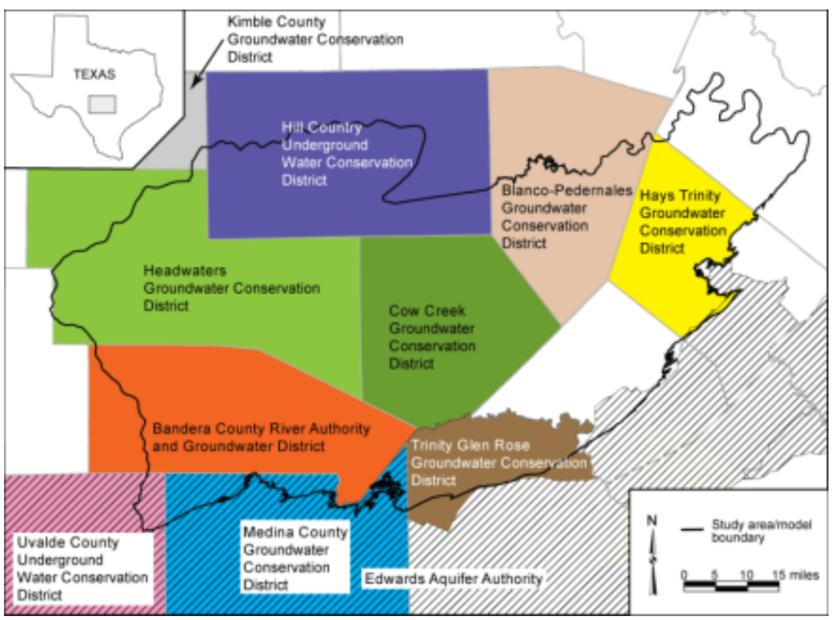


Figure 25. Groundwater Conservation Districts, GMA 9 (Jones et al., 2011)

Aquifer management takes place at the level of groundwater management through individual well owners, GCDs which are often county-bounded districts, and at the aquifer level, or portions of an aquifer that reflect changes over geographic distances and changes in land use and land cover. For example, the Trinity Aquifer extends from north-central Texas southwest through the Hill Country. As the aquifer flows and characteristics change in the subsurface, the TWDB designated management within two GMAs. GMA 8 manages two major aquifers, the Edwards Balcones Fault Zone (BFZ) and the northern Trinity, as well as seven minor aquifers.

GMA 9 manages three major aquifers, the Edwards (BFZ), the Edwards-Trinity (Plateau), and the Hill Country portion of the Trinity. Three minor aquifers are also in the GMA 9 jurisdiction. As well, statewide Regional Water Planning covers 16 areas that focus on major river basins. GCD and GMA data and information about the major and minor aquifers, their models, known and projected uses of groundwater, and groundwater demands and modeled available supply, are provided during each 5-year cycle of planning.

Desired Future Conditions (DFCs)

A key part of managing aquifers in Texas is underway. Each aquifer, or portion of an aquifer, has undergone several rounds of groundwater modeling. Various model scenarios that test assumptions about recharge, current and future pumping, water levels under drought conditions, etc., have been run and continue to be evaluated. The information gained through these critical models is used by member GCDs within a GMA to assess how to best manage each aquifer. GCDs come together through the oversight of the GMA as a whole to discuss aquifer conditions, issues, and future groundwater demands and supplies. The GCD members therefore must agree on how the aquifer is managed at the GMA level.

The Desired Future Conditions (DFCs) are "the desired, quantified conditions of groundwater resources such as water levels, water quality, spring flows, or volumes) at a specified time or times in the future or in perpetuity" (TWDB, 2008). As such, DFCs are intended to support management approaches for future aquifer conditions.

Once the member GCDs in a GMA adopts a set of DFCs, a decision process begins. Should an entity in a GCD disagree with the "reasonableness" of one or more of the adopted DFCs, a petition may be filed with the GCD within 11 months of the DFC adoption date to appeal the DFC. Should the GCD not resolve the DFC petition's issues within 30 days, the petition will be submitted to TWDB. A series of reviews and hearings will then commence, including technical evaluation of submitted evidence that the DFC is reasonable or not reasonable.

The DFC process has been underway for the past few years, and in 2009-2011, reports on the DFC model runs and results have been available on the various GMA websites and in technical reports. Some of these decisions are also undergoing petitions to appeal the reasonableness of a DFC. In GMA 9, two petitions are currently undergoing public hearings on the GMA9-adopted reasonableness of allowing an average 30-foot drawdown of the Hill Country portion of the Trinity Aquifer over a 50-year timeline (see TWDB GMA 9 Home page under "Petitions" for a downloadable pdf of the two petitions).

The TWDB has continued to update the Trinity GAM; Tables 14 and 15 summarize work to date.

Table 14. Overview of Trinity GAM Modeling Results, 2000-2008

Date	Trinity GAM & Model Run	Purpose	Key Points	Results / Comments
2000	Trinity GAM – TWDB Report 353	Model current & future aquifer conditions under pumping scenarios		
July 2007	Run 7-18	Address discharges to springs and rivers; address water budget and GAM projections	19 springs added, based on available discharge measurements	Model projections similar to 2000 Trinity GAM with some differences in modeling mid-1990 water budgets
July 2008	GR08-15, -20	Assess model scenarios of average 35-foot and 15-foot aquifer decline s	Update pumpage data, assess average 35-ft drawdown in Middle Trinity Aquifer, GMA 9	35-foot drawdown scenario: decline in 4 counties and Upper Trinity; spring and base flows decreased in 3 counties. 15-foot drawdown scenario: 2008 pumping levels resulted in average 13-foot drawdown across GMA 9
August 2008	GR08-30	Run Trinity GAM with average recharge, specific pumping levels per county	Specify annual baseline pumping over 60 years to assess declines per county	Model results indicated 10-80 % reduced baseflow; water level declines in Bexar, Blanco, Travis, western Kerr. Potentially 45,000 acre-feet of water could be annually pumped.
December 2008	GR08-70	60-year predictive results for 3 scenarios	Use 25% and 50% additional pumpage over 2008 rates; compare to steady-state, no pumping, average recharge rates	Using 25% increase showed increase of 12,500 acre-feet per year; 50% increase showed 25,000 acre-feet per year

Table 15. Overview of Trinity GAM Modeling Results, 2010-2011

Date	Trinity GAM & Model Run	Purpose	Key Points	Results / Comments
Sept 2010	Runs 09-011, 09-012, 09-24	Assess effects of drought, average recharge, pumping,	1 – show effects of drought	WL dec ~ 33 ft, baseflow red to 98,000 AFY, flow across BFZ reduced to 66,000 AFY due to drought
			Evaluation of model runs & results	Under drought: reduced water levels and decreased flow to surface water and across BFZ. Average recharge conditions: after period of increased pumping, return to previous conditions.
Sept 2010	10-005	Assess 7 pumping scenarios	Each scenario ran 387 50-year simulations, based on tree-ring precipitation estimates (1537 – 1972)	Results used to asses pumping vs. drawdown, spring and base flow, outflow across BFZ. Results evaluated as minimum, average, maximum.
			Scenario 6 – 100,000 AFY withdrawal	1.5 x 2008 pumping (92,000 AFY): average drawdown = 29 ft after 50 years with a range of 6-33 ft. Spring & base flow reduced by 14,000 AFY.
Jan 2011	10-005 Supplement	Assess 7 pumping scenarios	Assess simulations of Sept 2010 runs	Results used to consider water budgets per county and prepare contour maps
			4 – 60,000 AFY (2008 conditions)	Average drawdown = 14.5 ft; 3-ft water rise in some areas
			5 – 80,000 AFY	Average drawdown = 0 to 54 ft
			6 – 100,000 AFY	1.5 x 2008 pumping (92,000 AFY), average drawdown = 0 to 74 ft

The most recent work was conducted in January 2011. Based on GAM runs conducted and reported in January 2011, the following maps demonstrate two scenarios for the Hill Country portion of the Trinity Aquifer. In Figure 26, aquifer water levels in the Trinity Aquifer under 2008 conditions are simulated for GMA 9. Average water level drawdowns are shown in the concentrated blue potentiometric contours.

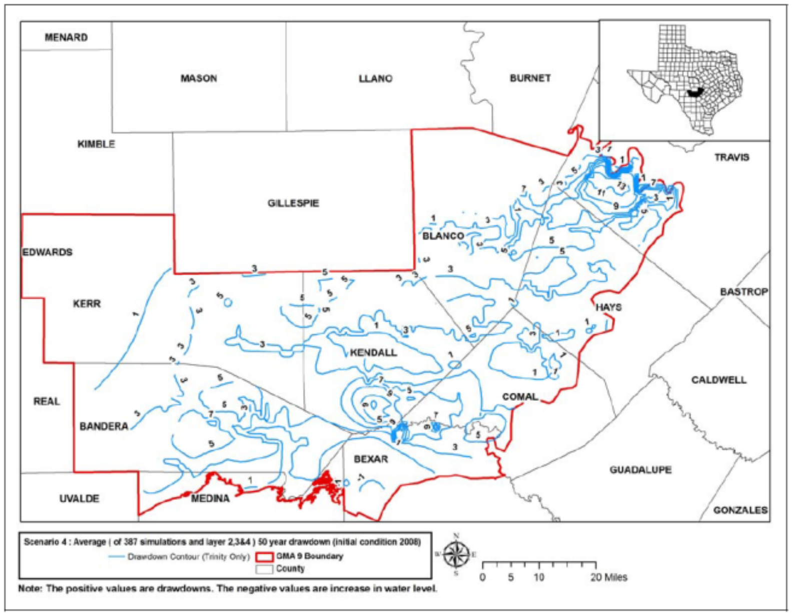


Figure 26. Simulated Water Levels, 2008 Conditions, Trinity GAM (TWDB 2011, Figure 13)

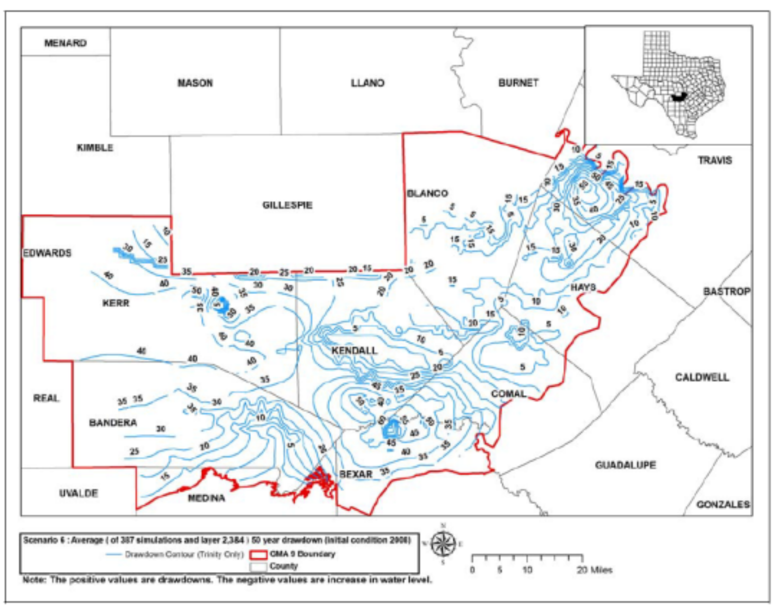


Figure 27. Simulated Water Levels, Scenario 5 Using 1.5 Times 2008 Conditions, Trinity GAM (TWDB, 2011, Figure 14)

In each of these scenarios, drawdowns are projected to be deepest in the areas of highest pumping such as southwestern Travis County and northwestern Bexar County. Drawdown may also be fairly steep in the updip areas of the aquifer where the water-bearing rock layers thin in Kerr County.

In summary, management of aquifers in Texas is not only a multi-layered, bottom up process, it is also evolving. Updates to data, the model design, and inputs for the Trinity Aquifer system GAM clearly demonstrate that the science is growing along with available information. The DFC process and petitions for GMA 9 are actions based on the science that nonetheless require discussion and the evolution of policies for future groundwater management. The current drought conditions underscore the necessity of discussions and decisions among the stakeholder groups with support throughout the process from the state. It is unlikely that the need for continued educational outreach and informed citizen groups will lessen in the future.

Groundwater and Water Resource Challenges

Water resources in the Hill Country have been long known to be an integral part of living in a rural landscape with poor soils for farming and ephemeral creeks that may not fill a rancher's tank every season for livestock. Other challenges include an increasing population, changes in traditional water supplies through groundwater withdrawals, and impacts on natural resources such as springs and ecosystems. Increasing population growth in the Hill Country towns and new developments has come with increased demands on the water and wastewater systems. Groundwater modeling of the Trinity system has shown that drawdown of the aquifer compared to historic water levels is occurring. The traditional approach of having a groundwater well on every parcel of land is now questioned in some circles. The town of Dripping Springs has surface water pipelines supplied by the Lower Colorado River Authority rather than be completely dependent upon groundwater.

The current drought is undoubtedly adding stress on the water resources in the Hill Country. The Edwards Aquifer Authority, responsible for management and conservation of the San Antonio segment of the Edwards Aquifer, is under a State II Critical Period as defined by the Critical Period Management Plan (EAA, 2011). This plan supports the management of the aquifer and permitted wells such that decreases in the aquifer and spring levels are slowed. During critical periods, all permitted users must submit groundwater withdrawals on a monthly basis. Should aquifer levels continue to decline, so does the allowance of permitted groundwater pumping. Similarly, the Hays Trinity Groundwater Conservation District drought management has declared the region's status as Stage Critical for the Trinity Aquifer system (HTGCD, 2011). In accordance with their Drought Management Plan, the District is requiring that permit holders reduce pumping in their wells by 30% and that exempt well owners with domestic and livestock uses are requested to reduce by 30%.

As the Hill Country communities look to their future and manage the present, these challenges may only increase. Technical reports such as this one are intended to provide information for stakeholders and decision-makers, but the actions that will guide the community ultimately rest with the community. The following sections of this report therefore provide summaries of information pertinent to better defining the issues facing groundwater decisions in the region.

Raising Awareness of Hill Country Groundwater Issues

Component 3 of this project addressed the need to raise public awareness concerning groundwater. Actions taken towards messaging, evaluation of the 82nd Legislature on groundwater, and a campaign plan to target strategic actions and outreach to stakeholder groups considered likely to support sustainable water resources were included. These actions resulted in development of key messages, a civic outreach presentation, and planning for strategic public actions in the near future. The “core” messages provided the foundation and contextual information for development of a public speaking presentation for civic groups, stakeholders, and other public entities. The goal of the presentation is consistent messaging, not only about raising awareness of groundwater concerns but also water stewardship and actions that can be taken to better support sustainable groundwater resources.

As a partner of the River Systems Institute, Laura Raun Public Relations (LRPR) worked with relevant Hill Country organizations staff and board members to develop and implement a public outreach campaign to educate audiences about the groundwater issues. Tactics included message development, public relation discussions and collaboration-building with the relevant Hill Country organizations working with these issues, development of an overview presentation intended for a variety of audiences, and preparation of a public outreach campaign specific to the Hill Country region and its water concerns.

Key Messages and Presentation for Civic Groups

Key messages were developed to date through discussions with groundwater legal experts and representatives of Wimberley Valley Watershed Association and the Hill Country Alliance, as well as knowledge of current issues in the 82nd Legislature. The importance of developing these messages was emphasized in teleconferences with these organizations. Every teleconference returned to the question of how well the various representatives and experts felt that the correct messages were getting out to the general public. Two sets of key messages were developed.

The first list of key messages grew from teleconferences and discussions with the representatives and experts in Hill Country groundwater concerning different perspectives (Table 16). The purpose is to ensure consistent messages across various audiences; provide meaningful information about the district and the Edwards and Trinity aquifers; and explain how groundwater users can change their behavior to protect the resource.

Table 16. Messages for Public Outreach about Texas Hill Country Groundwater (Laura Raun Public Relations, 2011)

1. Hill Country aquifers are declining due to population growth demand and susceptibility to drought.
2. The Edwards and Trinity aquifers will continue to decline as the Hill Country's population doubles over the next 50 years, unless alternative water supplies are developed and used.
3. Groundwater in the Hill Country is a shared resource that is a critical source of drinking water.
4. Groundwater in the Hill Country must be managed sustainably if there is to be enough for growth and prosperity in the region.
5. Groundwater and surface water should be managed jointly to ensure sound policy.
6. Groundwater can be taken from one owner by another owner under the Rule of Capture.
7. The groundwater permitting process was mandated by the Legislature to protect property owners and ensure groundwater supplies are fairly allocated.
8. Groundwater in the Hill Country is best managed through locally-controlled groundwater conservation districts.
9. Groundwater conservation districts protect property rights by balancing the groundwater ownership interests of one individual with the interests of all other groundwater owners.
10. Groundwater conservation districts allocate available groundwater; they do not control or direct growth.
11. The Texas Commission of Environmental Quality will create one or more groundwater conservation districts in Hays, Travis and Comal counties by mid-2011 if local residents don't voluntarily create one.
12. Sound stewardship of the land is one of the best ways to conserve and protect groundwater.

The second set, shown in the text box on the right, evolved during an April 2011 teleconference with the afore-noted organizations concerning public outreach and groundwater. The need is for memorable yet quickly noted key issues that can be remembered and used in a consistent manner as members of the organizations reach out to residents at local meetings. Together, the key messages offer common themes to act as the core of future outreach efforts and as a shared communications resource.

Key Messages about Hill Country Groundwater (LRPR, 2011)

- Hill Country aquifers are declining.
- Groundwater in the Hill Country is a shared resource.
- Groundwater conservation districts protect property rights.
- Groundwater planning ensures that the resource is shared equitably.
- Groundwater is a renewable, but finite resource.

A major challenge is formulating a common message or platform that unifies different organizations and stakeholders with similar goals. Such a common message can be used to rally the general public to take positive action about an issue. To address this challenge, RSI and LRPR developed a presentation that explains groundwater resources, aquifer protection and institutions in a straightforward and engaging way and that can be used for a wide range of audiences. The presentation makes use of graphics, maps, charts, and video clips. The presentation also addresses water conservation and stewardship through highlighting positive actions that can be taken by any household. The presentation handouts are shown in Appendix B. The presentation can be accessed on the Hill Country Water Resources website under "Water Stewardship" and on the thumbdrive of electronic documentation submitted with this report.

Public Outreach Campaign Plan

The final action of the "Raising Awareness" component of this project was development of a campaign plan to address public outreach in the Hill Country region. Based on years of public relations experience in Texas water concerns, LRPR developed a campaign that targets groundwater, "a resource under pressure" (Appendix C). LRPR and RSI identified primary concerns throughout the project as well as primary stressors on groundwater resources through the development of the civic presentation; these provide the basis of the campaign plan. The overarching campaign goal is to "build toward a consensus on water conservation and protection in the Hill Country." Towards this end, the plan uses a situational analysis of strengths, threats, opportunities and weaknesses to hone the campaign components. These include use of key messages to address specific audiences, further development of pertinent channels of communications including the appropriate utilization of social media, and measuring the results of the campaign. The outreach actions should support concerted strategies and actions towards sustainable water resources in the Hill Country.

Conclusions

The state of groundwater in the Hill Country region of central Texas is changing at a rapid pace. Changes to the aquifers' surface and subsurface system are occurring naturally through external stressors of drought that is taking a toll on water levels in the aquifer, the well owners that depend on minimum water levels or risk dry wells, on springs and river flows that are connected with the aquifer system, and on ecosystems and species that are endemic to the springs and unique watersheds of the region. Issues for the Trinity Aquifer system, regardless of location at the land surface, include these concerns:

- Rainfall and runoff carrying various chemicals can easily enter different water-bearing layers of the Trinity aquifer system.
- The localized nature of the recharge zones means that when there is no rainfall, little water enters the Trinity system. The longer between rainfall events as is occurring during the 2011 drought, the lower the aquifer levels are.
- When the aquifer levels decrease below the zones that provide water to creeks and springs, those natural features will dry up, affecting water supplies to humans and the environment.
- Well pumping in the Trinity also affects water levels. From the TWDB summary of the Trinity system (Ashworth and Hopkins, 1995), water levels in the Trinity around the Fort Worth-Dallas region have previously dropped as much as 550 feet.

- Additionally, water levels in the Hensell and Hosston formations around Waco have declined up to 400 feet.

Considering the last two points, it is noteworthy that these decreases were observed over 15 years ago. As the Hill Country prepares for its future, actions and decisions should include the high likelihood of a growing population, declining aquifer levels and springs, and probable impacts to river watersheds and ecosystems. The local and regional economy will continue to be a part of decisions through context of policies and outcome of funding for specific, agreed-upon actions towards groundwater management.

A recent interview[1] included discussions of California water policy and the future of water. One question targeted water policy:

> *"If you could change one thing about California water policy, what would it be?"*

The response:

> *"Education about California water. By that I mean, many of the legislators and the regulators have only been involved with California water issues for a relatively short time, especially given the history of California water… you are looking at over 100 years of history; a history that has directly influenced the current status and choices before us."*

This response is explicit about the need for greater education and public outreach and is as true for any US region as for the referenced state. Texas continues to grow best through involving education at every step. The heart of the Hill Country Water Resources website, the RSI/LRPR civic presentation for use by any organization desiring to address civic audiences about Hill Country groundwater issues and actions, and the LRPR public outreach campaign plan all address different approaches to educate and inform. Education is an essential component to any changes and improvements in public policy concerning not only groundwater but all water-linked resources and uses.

In providing a synthesis of key information, data, and materials, this report supports the educational outreach. The development of the "Hill Country Water Resources" website furthers that goal and hopefully will support a network of information and future discussions.

Recommendations

Based on the work conducted in this project, and in light of the larger issues surrounding water resources of the Hill Country region, RSI recommends that informational outreach continue through the Mitchell Water Program. To support that outreach, recommended actions are targeted towards specific goals. Actions to consider:

[1] *BC Water News* and Brett Farver, P.E., Director of the State and Federal Contractors Water Agency, October 2011.

- **Economic concerns in a "down" economy**: Increase community awareness of and access to information related to the economic ties between the Hill Country, its citizens, businesses and water resources. This may accomplished through 1) additional economic analyses to better understand and quantify the economic contribution of Cypress Creek to the tourism-based economy in Wimberley, and 2) compilation of methodologies, economic research outcomes, recommendations and relevant resources into an Economic Assessment Library and Resource Guide. The Guide can be used by any entity or organization to assess economic relationships in the Hill Country in a format that will facilitate expansion to other areas in the Hill Country.
- **Expansion of the Hill Country Water Resources website** to address drought impacts, add data and information about other watersheds in the region, thereby tying groundwater, surface water, and natural resources together in an accessible, informational format. Non-traditional water management approaches such as rainwater harvesting that can be used by people throughout the region is another key to expanding the usefulness of the website.
- Address landowner and well owner concerns about well permits and rules through a **GIS-based well rules "toolbox."** Many of the GCDs have slightly to very different approaches to well permits and regulations. An easy-to-use GIS tool that provides a quick look-up of rules and applications per GCD and GMA would be useful to current land owners and potential well installations.
- Develop **Atlas of regional watersheds**, such as the Blanco, Comal and San Marcos, to highlight the unique water and natural resources of this little-known Hill Country treasure. As the population increases in the affected watersheds, more information in a photojournalistic and educational format is anticipated to support stakeholder-based discussions and decisions about regional watersheds.
- Utilize a **public relations strategic approach** with stakeholder groups through identification of primary organizations that may join or increase support for public actions that sustain groundwater and water resources, conduct presentations and similar outreach efforts within civic groups, and develop a social media program to assess the results of public outreach.

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Appendix A. List of TWDB Well Records by County

TWDB well records that were downloaded for this project include the following counties and files. The well records are electronically submitted as pdf files on a USB drive. The following files are submitted for each listed county:

- Cooperator Infrequent Constituent Report
- Infrequent Constituent Report
- Record of Wells
- Water Level Publication Report
- Water Quality Publication Report

As well, the TWDB Code Lookup Tables are submitted with the files.

List of Counties with TWDB Records Submitted Electronically

Bastrop

Bexar

Blanco

Burnet

Caldwell

Comal

Guadalupe

Hays

Kendall

Lee

Medina

Travis

Uvalde

Williamson

Appendix B. LRPR/RSI Groundwater Outreach Presentation

The following are the handout pages from the Civic Outreach Presentation developed by Laura Raun Public Relations (LRPR) and River Systems Institute, Texas State University-San Marcos. This presentation is also electronically submitted on a USB drive.

Groundwater in the Texas Hill Country:

A Resource Under Pressure

RIVER SYSTEMS INSTITUTE
Laura Raun Public Relations

LRPR

PRESENTER | SEPTEMBER 1, 2011

Aquifers are the Lifeblood of the Hill Country

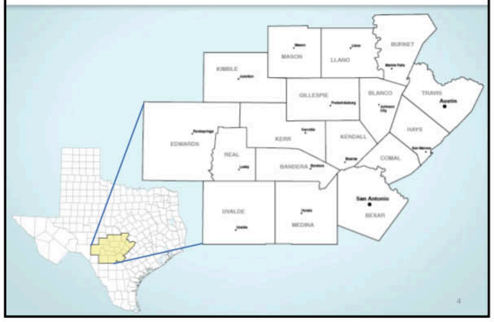
- Groundwater makes it possible to live in harsh terrain that lacks major rivers
- Groundwater and surface water (rivers and lakes) are closely linked in Hill Country
- Demands on our water resources are exceeding supply

Development Poses Risks for the Aquifers

Hill Country Landowner

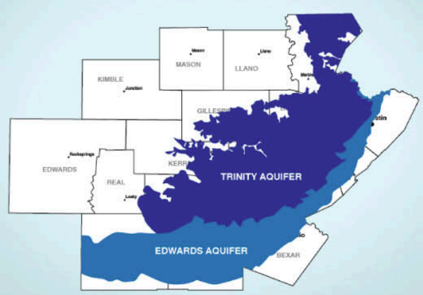
Courtesy of TPWD

The Texas Hill Country

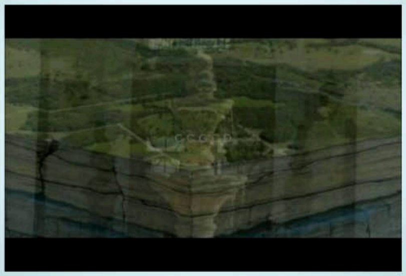


Edwards Aquifer

Trinity and Edwards Aquifer

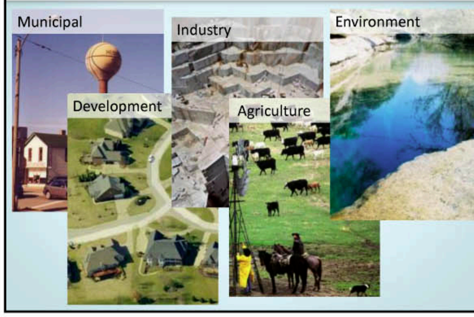


How Aquifers Work

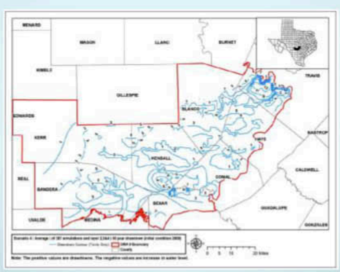


Courtesy of Cow Creek GCD 7

Competing for Groundwater

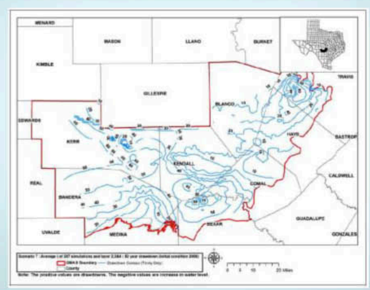


Trinity Aquifer: 2008 Pumping and Modeled Water Levels



9

Trinity Aquifer: Modeled Water Levels at 2x 2008 Pumping



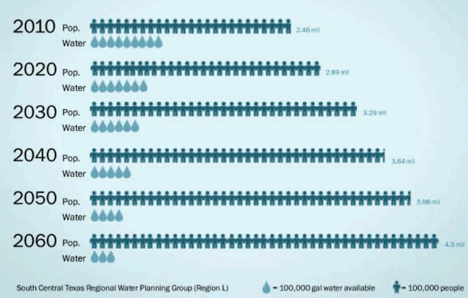
10

Pressures on Groundwater

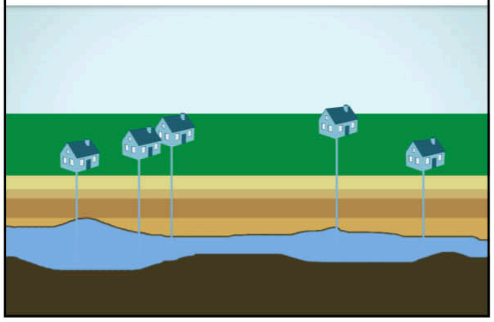
- Rapid Population Growth
- Climate Extremes
- Hydrogeology
- Market Forces

11

Population Growth vs Water Availability



Depleting Our Resource



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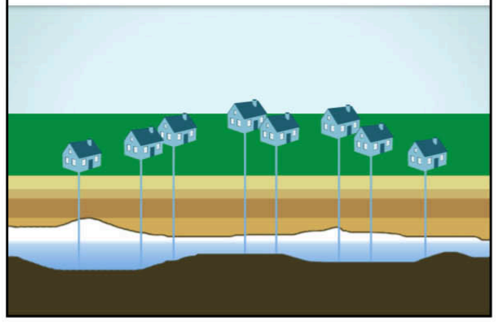
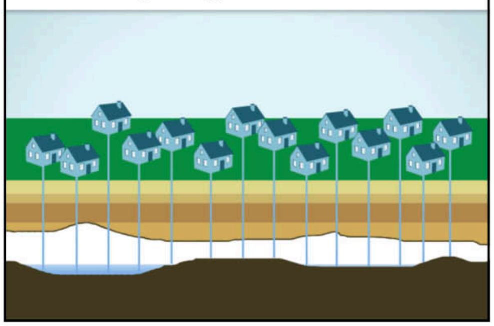
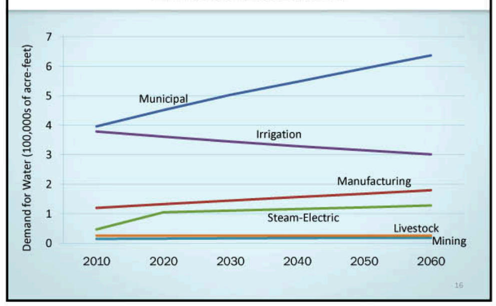


Depleting Our Resource



Water Demands are Growing Across the Board

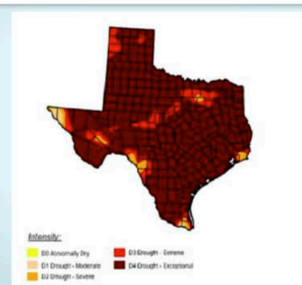


Pressures on Groundwater

- Rapid Population Growth
- Climate Extremes
- Hydrogeology
- Market Forces

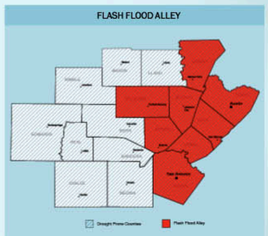
Drought in Texas

Sept. 20, 2011



Climate Extremes Stress Groundwater

1. Extreme droughts end in extreme rain
2. Heavy rain runs off without recharging aquifers
3. Hill Country topography channels runoff into flash floods
4. Frequent flash flooding has branded the Hill Country as "Flash Flood Alley"



Pressures on Groundwater

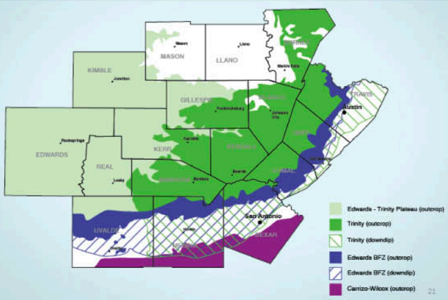
Rapid Population Growth

Climate Extremes

Hydrogeology

Market Forces

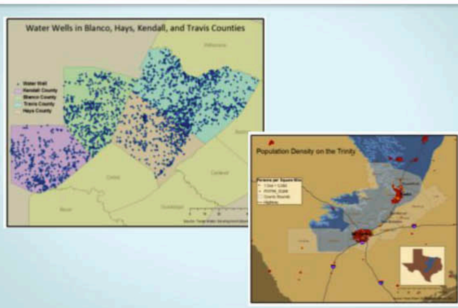
Hydrogeology



A Reliable But Vulnerable Resource

- Aquifers in the Hill Country are connected
- Faulted and fractured limestone with confining layers
- Porosity and permeability vary, determining groundwater flow
- Not all productive zones are similar
- Groundwater flow is affected by pumping and connections along faults and fractures

More Wells Than You Might Expect



Pressures on Groundwater

Rapid Population Growth

Climate Extremes

Hydrogeology

Market Forces

Landowners are Responding to Market Pressures

Landowner

Courtesy of TPWD 25

Industry Responds to Market Forces

- Service Industries drawn to Hill Country
- Industry creates jobs

26

A Healthy Economy requires Development


Construction Site Foreman

Courtesy of TPWD 27

Competition Requires Regulation

- Groundwater Management Modifies the Rule of Capture
- Rule of Capture allows landowners to pump all of the groundwater they want, even if it drains the neighbor's

28

Groundwater Management is Seen as Essential by Some Residents

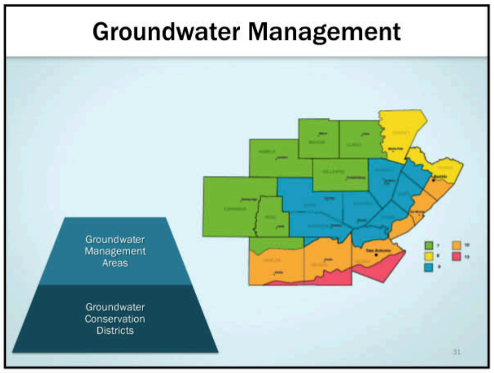

Water Planning Advocate

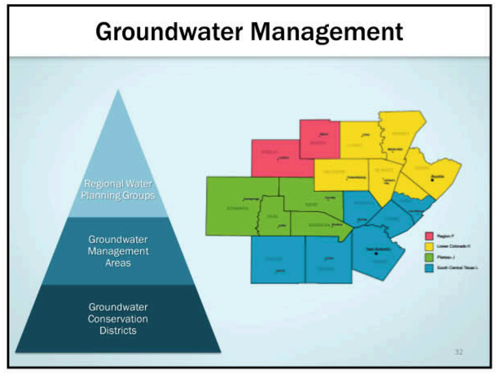
Courtesy of TPWD 29

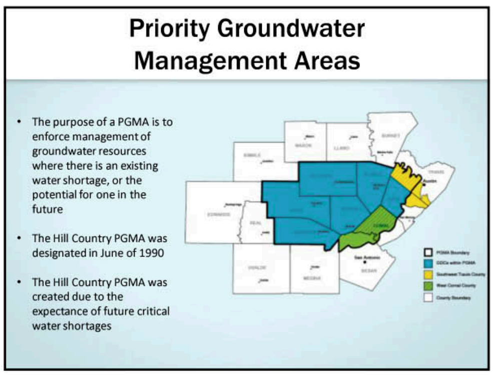
Groundwater Management

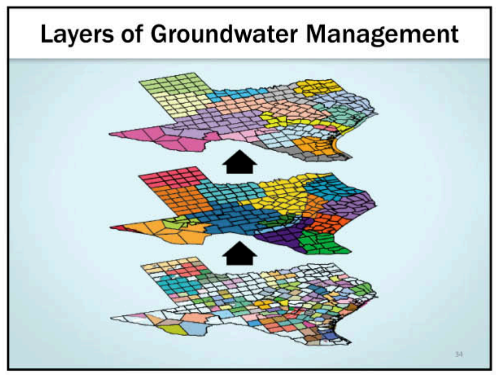
Groundwater Conservation Districts

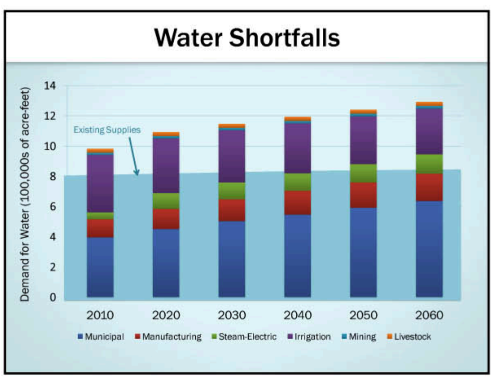
30

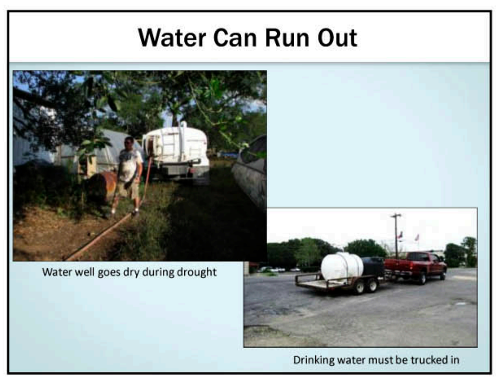

Groundwater Management
Groundwater Management Areas
Groundwater Conservation Districts


Groundwater Management
Regional Water Planning Groups
Groundwater Management Areas
Groundwater Conservation Districts


Priority Groundwater Management Areas
• The purpose of a PGMA is to enforce management of groundwater resources where there is an existing water shortage, or the potential for one in the future
• The Hill Country PGMA was designated in June of 1990
• The Hill Country PGMA was created due to the expectance of future critical water shortages


Layers of Groundwater Management


Water Shortfalls
Demand for Water (100,000s of acre-feet)
0
2
4
6
8
10
12
14
Existing Supplies
2010
2020
2030
2040
2050
2060
Municipal
Manufacturing
Steam-Electric
Irrigation
Mining
Livestock


Water Can Run Out
Water well goes dry during drought
Drinking water must be trucked in

When Your Well Goes Dry…

Haul in water

- $56 for 2,800 gallons

Deepen your well

- about $27 per foot

What You Can Do Indoors

Use a low flow, water efficient, toilet

- 13,000 gallons = more than **$100 per year**

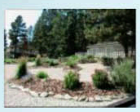
Wash clothes with a water efficient washer

- 6,000 gallons = **$120 per year**, with decreased annual water usage up to 40%

Purchase a water efficient showerhead

- 6 gallons per person per day = **$25 per person per year**

What You Can Do Outdoors



Compared to traditional lawns, water-conserving landscapes required:

- 75% as much labor
- 61% as much fertilizer
- 20% as much pesticides
- 44% as much fuel

Benefits of low water use landscapes

- An average of 54% less water
- Conserving up to 209 gallons per day
  - Adding up **to $200+ per year** in savings
- Save 22,500 gallons of water = more than $85 per year

What You Can Do Outdoors

Harvesting Rainwater

- 50,000 gallons = more than **$150 per year**

Audit your irrigation system

- 7,200 gallons = over **$25 per year**

Acknowledgements

- Texas Parks & Wildlife
- Cow Creek Groundwater Conservation District
- Texas Commission on Environmental Quality
- City of Austin
- Texas Water Development Board
- Sustainable Sources

Questions?

RIVER SYSTEMS INSTITUTE

Laura Raun Public Relations

LRPR

Appendix C. LRPR Public Outreach Campaign

LRPR
LAURA RAUN PUBLIC RELATIONS
SIMPLICITY WORKS

Public Outreach Campaign: *Hill Country Groundwater - a Resource Under Pressure*

Oct. 11, 2011PU

Groundwater in the Hill Country is a scarce resource that is under growing pressure. Pressures are coming from several sources:

- Intensifying competition for water
- Growing population
- Increasing extremes in climate

With current drought conditions and demand for water, it is critical that residents of the Hill Country understand groundwater issues and change their behavior accordingly.

This campaign plan is designed to be implemented by RSI, with assistance from LRPR as desired. LRPR has identified tasks where its expertise and experience can add value and build on work done during the 2010-2011 Mitchell Grant.

Campaign Objective

The objective of this campaign is twofold:

1. To inform and educate residents of the Hill Country about:

    - Declines in aquifer level sand spring flows
    - Implications for groundwater management
    - More efficient use of water

2. To carry out targeted outreach

Campaign Goal

The goal of this campaign is to build toward a consensus on water conservation and protection in the Hill Country; change audiences' behavior; foster sounder policies related to groundwater.

<u>Situational Analysis (SWOT)</u>

- Strengths
    - Skilled team of researchers, advocates and communicators (LRPR)
    - Existing communications tools ("A resource under pressure" PowerPoint, key messages, website)
    - RSI/TSU resources
- Weaknesses
    - Lack of public awareness
    - Fragmentation of existing RSI communications tools
    - Limited resources/budget
    - Different messages from various advocacy groups

- Opportunities
    - Drought, which focuses public attention on critical nature of water
    - Build on messages and tools developed during the 2010-2011 Mitchell Grant
        - "A resource under pressure" PowerPoint
        - "Hill Country Groundwater" beta site
        - Other RSI initiatives and research
    - Inform the greater TX Hill Country public
    - Reach out to secondary audience (students, alumnae, teachers, church members, non-profits)
    - Ally with interested groups in Hill Country, where common ground exists
    - Gather volunteers to help with effort
    - Develop social media strategy

- Threats
    - Lack of interested citizens
    - Weak economy
    - Polarized politics paralyze development of sound groundwater policies
    - Excessive competition for groundwater favors expedient decisions over more considered ones
    - Economic/political imperatives encourage depletion of aquifer over sustainable management
    - Sufficient funding is lacking to "buy" mind share among audiences
    - Water messages from other entities dilute or muddy the message (ex: Texas Water Resources Institute)

<u>Campaign Components</u>

1) Refine/adapt key messages developed during 2010-2011 Mitchell Grant

Refine/adapt key messages to achieve the following:

- Coordination across communications tools (website, PowerPoint, social media, media relations, etc.)
- Implementation in new channels, such as social media
- Tie-in to water conservation and drought awareness
- More precise targeting of audiences
- Development of policy options

2) Identify Target Audience

Identify target audiences with greater precision, after campaign objectives and goals are agreed.

The target audience for "A resource under pressure" PowerPoint was the widest possible one, in the absence of a comprehensive campaign with unifying message.

A more clearly defined campaign will enable more specific targeting of audiences.

Here is a list of targeted audiences, in alphabetical order:

- Churches and synagogues
- Civic groups
- Environmental advocates (Hill Country Alliance, Wimberley Valley Watershed Association)
- Gardening clubs
- Landscaping companies
- Non-profit organizations
- Ranchers/farmers
- Real estate professionals
- Residents in areas of drought
- Students, staff and alumnae of Texas State University
    - Associations
    - Clubs
- Well owners

3) Develop channels of communication

Develop appropriate communications channels. An outreach campaign requires a range of communications materials that reinforce each other.

a. PowerPoint presentation
    - Adapt presentation to specific audiences
    - Present PPT to audiences
    - Train other presenters

b. Website – update Hill Country website to accommodate new materials that are developed (i.e., social media; news releases)

c. Media relations
   - News Releases– draft news release (including video news releases)
   - Opinion pieces – draft opinion pieces to be submitted to news media outlets, including *"In the Flow"*

d. Public meetings/events
   - Plan and hold meetings and/or events to engage public in behavioral changes to promote sustainable management of groundwater
   - Tie into existing RSI initiatives

e. Social media

Strategy: Use online social media sites to interact with other organizations and the target audience to convey the need for water conservation and water policy.
Tactic: Use Twitter and Facebook to gain followers. A growing number of organizations participate in online discussion through these social media. Interactions among water entities, governments, and residents can create a greater awareness of water issues.

Goal: Become a trusted source of water information in the Texas Hill Country area and create two-way educational communication between target audiences.

Initial Research on Facebook

- Texas Agricultural Land Trust is aggressively using Facebook

Initial Research on Twitter

- Well owners
  - No results for the hash tag **#welldrill**, **#drill** used as slang, no information about well owners on Facebook
- Gardening clubs
  - There is a Facebook page with 2,389,402 "likes"
  - **#gardening** on Twitter receives a lot of results related to gardening tips
- Real Estate
  - 128,618 people "like" on FB
  - **#TXrealestate** had no results, whereas **#realestate** had too many from all over the U.S.
- Residents in areas of drought
  - **#TXdrought** more relevant to the overall drought occurring in TX
  - **#drought** is used as slang

- **Examples of how other organizations are using Twitter**
  - **@TxWRI** - Uses Twitter extensively

- News stories
- Updates on drought conditions in TX
- Alerts the public about upcoming stakeholder meetings
- Includes information about legislation on water issues
- Training courses

- **@TexasFarmBureau**
  - Updates on drought conditions in TX
  - Interacts with water legislation (#eminentdomain)
  - Reports farming news/issues
  - News videos
- **@Texasgov**
  - About TX Legislation
  - Includes water news - drought conditions, water rationing, water shortages, etc.
  - Press Releases
- **@MySAWS**
  - Covers water news mainly around San Antonio, but covers TX and national level as well
  - Encourages followers to tweet water questions and they will tweet back with answers

- Potential Twitter accounts that RSI can follow
  - **@EPAgov**
  - **@EPAowow** (Environmental Protection Agency's Office of Welands, Oceans, and Watersheds)
  - **@EPAwatersense** (WaterSense helps people save water with a label for water-efficient products, new homes and services)
  - **@EPAsmartgrowth** (Environmentally-sensitive development strategies)
  - **@Colin_McDonald_** (San Antonio Express-News' environment and water reporter)
  - **@H2OWonk** (a water guy in Austin,TX)
  - **@TexasFarmBureau**
  - **@USGS** (official U.S. Geological Survey)
  - **@americanrivers**
  - **@KeepTXBeautiful**
  - **@WaterStJournal** (news stories about water)
  - **@MySAWS** (San Antonio Water System)
  - **@txextension** (AgriLife Extension)

- Twitter Content
  - Cover news stories both locally, state-wide and nationally
    - Legislation on water
    - Grants & funds
    - Droughts

  - Floods
  - Fire Warnings
- Activities at RSI should direct traffic to RSI's website
  - Courses
  - Stakeholder meetings
  - Conferences
  - Newsletters
  - Park Activities
  - Educational Tours
  - Diving for Science

4) Measure results of campaign

Develop measurement tools to quantify/qualify the impact of campaign and refine messages/materials accordingly.

Methods of measuring campaign success will depend on its goals and objectives. One suggestion is to do a before-and-after survey given at the initial and final stakeholder meeting will be a means to compare awareness of water supply and the drought, and show if the audience has learned anything from this campaign.

Measurement results can be incorporated into communications materials to refine them as the campaign progresses.

a. Qualitative

- Online measurement will include observing responses to posts and topics and discussions.
- Social Media (retweets, trends, replies, etc.)
  - Did Twitter followers re-tweet our messages?
  - Did Twitter followers reply to the content we were posting?
- Media hits resulting from campaign initiatives
  - Newspaper articles
  - Bloggers
  - Website content
- Before and after surveys of stakeholders at initial and final meeting

b. Quantitative

- Impressions - before and after
  - How many impressions did website get before/after? Was there an increase during the campaign?
- Twitter
  - Number of tweets, re-tweets, followers, use of our and TX water related hash tags, impressions, clicks on link (bitly)
- Facebook

    - “Likes” can be counted
- Before and after awareness “quiz” at stakeholder meetings
    - Are members more educated about water issues than they were initially?