Land of the Living Waters

A CHARACTERIZATION OF THE SOUTH LLANO RIVER, ITS SPRINGS, AND ITS WATERSHED

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ENVIRONMENTAL DEFENSE FUND
finding the ways that work

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Prepared for Environmental Defense Fund
by Tyson Broad

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This report is available online at www.texaswatermatters.org/southllanoriver.htm or can by requested through Environmental Defense Fund, 44 East Avenue, suite 304, Austin, Texas 78701, (512) 478-5161.

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SUMMARY

The South Llano River is a valuable resource to Central Texas, providing recreational opportunities, habitat for unique plant and animal communities, and water supplies to local and downstream communities. The protection and preservation of the flow of the South Llano River is an environmental, economic, and cultural concern. The most effective method for protecting and preserving these flows may arise from action plans developed by local and regional stakeholders. This report attempts to facilitate potential stakeholder efforts by providing a characterization of the South Llano River, its springs, and its watershed, as well as suggesting recommendations to address identified water management issues.

The South Llano River has not ceased flowing in recorded history due to the presence of several large springs. The largest of these springs is Big Paint Spring, followed by the more famous Seven Hundred Springs. These two springs, along with numerous other springs and seeps along the South Llano River, annually provide about 80% of the flow downstream to the Llano River. During dry periods, the Llano River provides about 75% of the flows to the Highland Lakes, the major water supply for the City of Austin and other downstream water users along the Colorado River all the way to the Gulf of Mexico.

The source water for the springs of the South Llano River is groundwater stored in two areas of the karstic Edwards-Trinity (Plateau) aquifer. These areas, along the watershed divide of the South Llano, supply water not only to the South Llano River, but also to the Nueces, Frio, and Guadalupe rivers. Although not an immediate threat, large increases in pumping from the source water area for the springs has the potential to significantly reduce flows in the river, especially during severe droughts. Modeling simulations estimate that under drought conditions similar to the 1950s, pumping approximately 7,800 acre-feet annually results in groundwater level declines of 70 feet and decreases in river and spring flows of 45 percent.

Due to the pristine nature and relatively constant flow of the springs, the South Llano River is currently a healthy ecosystem that supports a variety of aquatic and terrestrial ecosystems, as well as numerous recreational opportunities. Subtle changes due to land fragmentation, loss of riparian habitat, and encroachment of juniper species on upland habitats have the potential to decrease the water quality and quantity of the river.

Because the primary threat to the South Llano River is loss of spring flow, the organizations that play the most critical role in protecting the river are the local groundwater conservation districts. These districts set rules that limit groundwater production based on well proximity and groundwater availability, but they cannot prohibit groundwater exports. These groundwater districts are currently engaged in a process to determine how much water can be pumped without significantly diminishing aquifer levels and spring flows. Lack of sufficient hydrologic data introduces some uncertainty into this process and could result in an over allocation of groundwater.

The formation of a stakeholder group could provide a cohesive voice to the region for protection and preservation of the flows of the South Llano. Such a group could also provide a forum for education, discussion, and coordination of efforts to address other identified land and water management issues that may impact the long-term viability of the resource. In addition to the lack of sufficient hydrological and ecological data, other issues include land fragmentation, the control of woody vegetation, groundwater availability, and the potential for groundwater exports and aquifer contamination.

INTRODUCTION

The South Llano River is a true gem of Central Texas. Its spring-fed flows are legendary among outdoor enthusiasts and nature lovers alike. As an ecosystem, the river and the springs that feed it support several unique plant and animal communities. As a water supply resource, the South Llano River provides constant critical flows downstream to the Llano and Colorado Rivers, especially during times of drought.

The importance of the South Llano River as a source of water results from significant springs discharging along the river. These springs, outflows from the Edwards-Trinity (Plateau) aquifer, maintain the flows in the river, even during droughts. During the drought of record in the 1950s, when most of the rivers across West and Central Texas ceased to flow, the South Llano River still continued to flow.

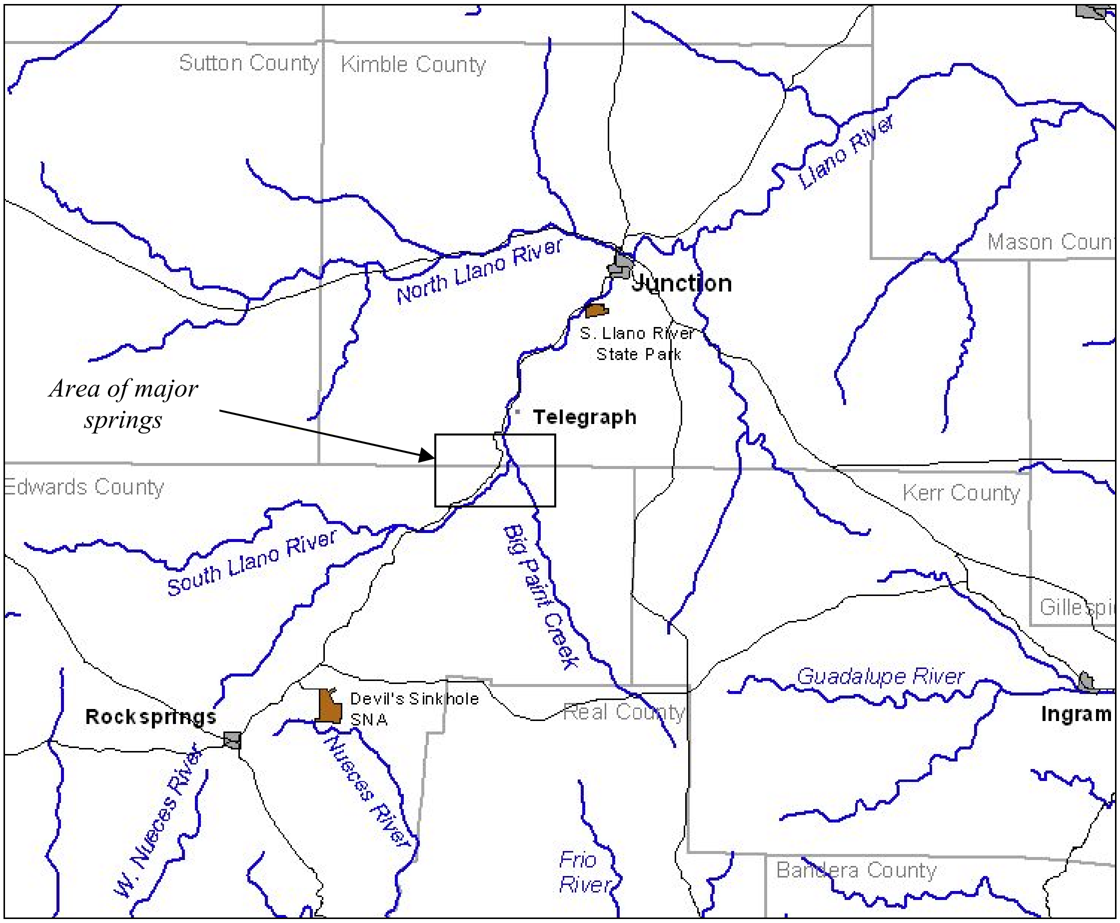
The protection and preservation of the flows of the South Llano River is an environmental, economic, and cultural concern. Effective methods for protecting these flows have the potential to result from action plans developed through collaborative efforts amongst local and regional stakeholders. To facilitate such stakeholder efforts and to provide a starting point for discussion, Environmental Defense Fund prepared this report. It characterizes the river and describes its significance to the Central Texas region. The report also examines the framework in which water management decisions in the South Llano watershed are made and discusses the current research activities in the basin. Finally, the report offers recommendations to deal with identified potential issues related to the flow of the river.

GENERAL DESCRIPTION

The headwaters of the South Llano River (Figure 1) begin about 2,300 feet above sea level in the heart of the Edwards Plateau, a 24,000 square mile upland region. This region roughly extends from the Pecos River on the west to the Balcones Escarpment (Austin to San Antonio to Del Rio) on the east and south. Capping the Edwards Plateau is thick limestone rock that dissolved over time to form what is considered the largest continuous karst [1] areas in the United States. [2]

The South Llano River flows intermittently in its first 35 miles across the plateau. But where the river and its tributaries have carved canyons into the limestone cap, the water stored in the karst features of the plateau emerges as springs along the canyon walls. The springs, located at an elevation of approximately 1,900 feet, have historically supplied constant flow for the river's final 20 miles to Junction. At Junction, appropriately known as the "Land of Living Waters", the South Llano joins the North Llano River, becoming the Llano River for the final 100-mile journey to Lake LBJ in the chain of water-supply reservoirs known as the Highland Lakes.

Figure 1. Map of South Llano River and surrounding area



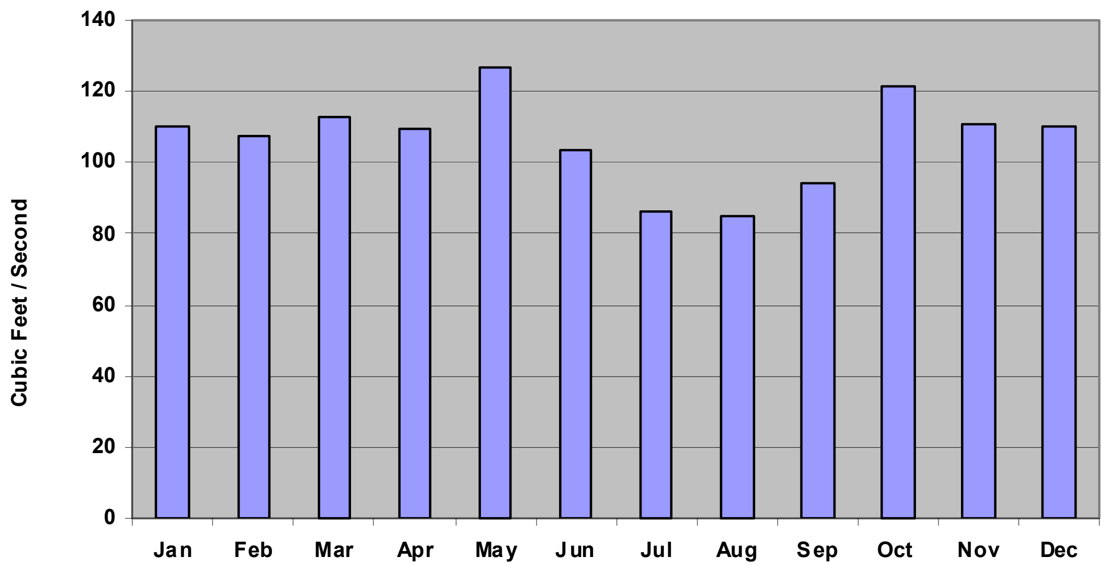
The South Llano River flows through Edwards and Kimble counties. [3] These counties can be characterized as agricultural, primarily consisting of ranches used for livestock production, and along the bottomlands, some pecan and hay production. A large source of income for these ranches is hunting leases for white tail deer and exotic species. Tourism, primarily associated with recreation along the South Llano is also an important aspect of the economy. Some natural gas production occurs in the headwaters of the river.

The current population of Kimble County is 4,570, with Junction, the county seat, accounting for about 58% of the county's population. The 1,150 inhabitants of Rocksprings, the county seat of Edwards County, also make up 58% of that county's total population (1,987). Kimble County has experienced a 2.3% growth rate since 2000, while Edwards County has experienced a 10.5% reduction in population since 2000. However, population figures alone do not provide a clear picture of the demographics in these counties. For example, of the 9,000 parcels in Kimble County, non-Kimble county residents own 55% percent, and non-Texas residents own an additional 5%. [4] Likewise, it is estimated that absentee landowners account for about 70% of the property owners in Edwards County. [5]

WATER RESOURCES

Unlike many rivers in West Texas, the South Llano River has never ceased to flow in recorded history. The US Geological Survey (USGS) has maintained a stream gauge just below the confluence of the North and South Llano Rivers since 1915. [6] Figure 2 shows the median monthly discharge, or flow, (in cubic feet per second) for the period 1915-2007 and reflects the area's normal rainfall distribution with the majority of precipitation occurring in late spring and early fall. During the summer months, when little precipitation occurs in the area, the majority of the flow at the gauge is from springs feeding the South Llano River; during low-flow periods, the North Llano River contributes less than 5% of the flow to the Llano River, and is often dry.[7]

Figure 2. Median Monthly Discharge for Llano River at Junction, Texas [8]



Springs

There are numerous springs that contribute to the flow of the South Llano River. The Texas Springs Database [9] notes 20 springs within the South Llano River watershed. An additional 19 springs, not included in the database, are located on USGS topographic maps. There are probably numerous additional springs and seeps in the watershed that have not been mapped. Three large springs, located near the Kimble and Edwards County line contribute the majority of the flow to the river: Seven Hundred Springs and Tanner Springs are located on the left (northwest) bank of the South Llano; Big Paint Springs is located on the right (east) bank of Big Paint Creek, which flows into the South Llano from the east just upstream of the community of Telegraph.

While there is a long record of discharge data for the Llano River, discharge data for the major springs of the South Llano are less abundant. Since 1959, the USGS has measured discharge from Seven Hundred Springs, two to eight times a year during extended dry periods. USGS has also made similar measurements at Tanner Springs since 1987. No regular discharge measurements are made at Big Paint Springs. Taking measurements during extended dry periods minimizes the influence of surface water runoff from precipitation and provides a conservative estimate of flow from the groundwater system.

South Llano River below Seven Hundred Springs

Table 1 shows the recorded median and low flows for Seven Hundred and Tanner Springs, along with recorded median and low flows for the South Llano River below Seven Hundred Springs. The lowest recorded flow for Seven Hundred Springs and the South Llano River occurred in 1980. Gunnar Brune, in *Springs of Texas,* [10] notes the flow of Seven Hundred Springs in 1952 and in 1956 (during the drought of the 1950's) was 11 cubic feet per second (cfs). The springs of the South Llano River above the confluence with Big Paint Creek generally provide about half of the flow (49%) to the Llano River at Junction during extended dry periods.

Table 1. Recorded Median and Low Flows in cubic feet per second for Seven Hundred and Tanner Springs [11]

	Seven Hundred	Tanner	South Llano [a]	% of Llano [b]
Median Flow	19.5	12	49.5	49
Lowest Flow (year)	8.4 (1980)	8.8 (1996)	23.5 (1980)	24 (1968)

a. The flow of the South Llano is measured above the confluence with Big Paint Creek and is the sum of both, Seven Hundred and Tanner springs, plus any additional flows from upstream springs.
b. The Percentage of Llano is the flow of the South Llano divided by the flow of the Llano River at Junction minus the flow of the North Llano River.

The other major contribution to flow in the South Llano River is from Big Paint Springs. Only three measurements have been made at these springs; [12] they are presented in Table 2. The corresponding measurements for Seven Hundred and Tanner Springs and the North Llano River are also included. [13] At the time measurements were taken at Big Paint Springs, the flow from these springs accounted for between 35 and 70 percent of the flow in the Llano River at Junction, not accounting for any water withdrawals between the springs and the Junction gauge, or water withdrawals below the North Llano River gauge. Big Paint Springs generally had between 42 and 63% more flow than Seven Hundred Springs.

Table 2. Comparison of Discharge for Big Paint Springs to Seven Hundred and Tanner Springs and the North Llano and Llano Rivers in cubic feet per second [14]

	March 1939	Sept. 1955	March 1962
Big Paint	22	18	31
Seven Hundred	15	11	22
Tanner	9		
North Llano River	18	6	23
Llano River at Junction [a]	64	31	113
Big Paint Contribution to Llano River @ Junction	47	71	34

a. This measurement does not account for any water withdrawals upstream of the gauge.

In 1918, and again in 1925, a gain-loss study was done on the South Llano River to understand the contributions of various tributaries to the river. [15] Table 3 shows these contributions to the river. The 1918 study showed that 62% of the flow in the South Llano came from Big Paint Creek; the 1925 study showed that the contribution from Big Paint was 50%. It should be noted that from below the confluence of Big Paint Creek and the South Llano River to the confluence with the North Llano River, the South Llano River gained an additional 2.3 cfs in 1918 and an additional 3.5 cfs in 1925. It is presumed that these additional flows came from other springs discharging to the river.

Table 3. Measurements in cubic feet per second from Gain-Loss Studies on South Llano River

	April 1918	February 1925
Big Paint Creek	23.1	36.5
South Llano above Big Paint Creek	11.7	32.6
South Llano above North Llano River	37.1	72.6

a. The flow presented for the South Llano River is the flow of the River above the confluence with the North Llano, plus the addition of upstream water withdrawals.

These various measurements and gain-loss studies demonstrate, but do not specifically quantify, the contribution that spring flow makes to the flow of the South Llano River. However, a 1989 US Geological Survey [16] study estimates that baseflow (that part of streamflow that is not direct surface runoff) accounted for approximately 81% of all flow passing the Llano River gauge at Junction between 1974 and 1977. While the North Llano River does contribute some baseflow to the gauge, the majority of the flow comes from the South Llano River.

Confluence of North (foreground) and South Llano (background) River, June 2008

Source of the Springs

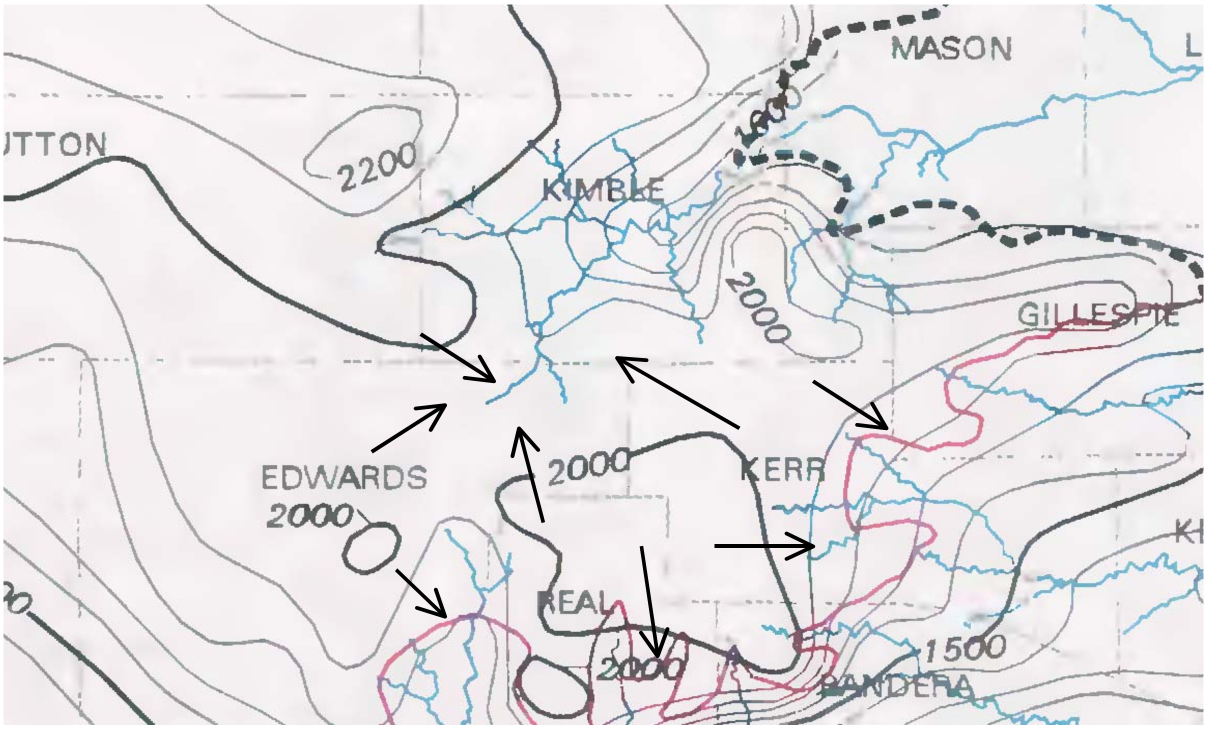
The Edwards limestone, which makes up the Edwards Plateau, is a karst terrain characterized by the presence of caves, sinkholes and subsurface drainage networks. On average, approximately 22-24 inches of precipitation falls annually within the South Llano River watershed. As most of the watershed consists of thin soils atop limestone bedrock, the majority of this precipitation runs off quickly. However, some of this precipitation finds its way through sinkholes, caves, rock fractures, and root zones to enter the Edwards-Trinity (Plateau) aquifer.

Subsurface drainage networks, or conduits, dominate groundwater systems that drain karst terrain. [17] Precipitation that recharges the Edwards-Trinity (Plateau) aquifer tends to follows these conduits. Where rivers such as the South Llano carve valleys into the Edwards Plateau, these conduits are exposed, resulting in springs.

Little is known about the exact origin of the water that feeds these springs. However, some information can be inferred from topography and existing hydrogeological studies. Kuniansky and Holligan[18] note that the potentiometric surface (the elevation of the top of the water table) and the flow of groundwater tends to follow the topography in the Edwards Plateau region. Figure 3 is a map of the potentiometric surface in the South Llano River area reproduced from the Kuniansky and Holligan report.

There are several areas surrounding the South Llano River and its tributaries where the elevation of the water table is over 2,000 feet above sea level. The level of the springs along the South Llano is approximately 1,900 feet, so it can be assumed that groundwater flows ‘down gradient’ towards the springs.[19] Kuniansky and Holligan suggest that the waters that feed the springs along the left bank of the river (such as Seven Hundred and Tanner) probably originate from the area to the west in

Figure 3. Historical potentiometric surface of the Edwards-Trinity aquifer system for the South Llano River watershed, 1915-69. (From Kuniansky and Holligan, 1993) Arrows added to depict probable direction of groundwater flow



southwestern Kimble, southeastern Sutton, and northern Edwards counties. Waters that feed the springs on the east side of the river and along Big Paint Creek probably originate from eastern Edwards, northern Real, and western Kerr counties. This water, located beneath the divide between the South Llano River (to the north), the Nueces, West Nueces, and Frio Rivers (to the south), and Guadalupe River (to the east), is most likely the source of spring flow for all of these river systems. [20]

Without detailed potentiometric surface mapping and tracer testing, however, it is very difficult to accurately depict actual groundwater basins with any certainty. There are many examples where groundwater basin boundaries are not coincident with topographic watershed boundaries. The volume of water that discharges from the springs does indicate that the groundwater basins are sizable and probably incorporate hundreds of square miles. [21]

Water Use

In order to utilize water from the South Llano River, its tributaries, or any other river in the state, a water right is required from the Texas Commission on Environmental Quality (TCEQ) or its predecessor agencies. Water rights on the South Llano River have been issued since 1893; the total amount of water rights issued for the river and its tributaries is 3,665 acre-feet [22] per year or about 5 cfs. The largest water right holder is the City of Junction with a right to withdraw 1,000 acre-feet per year or 1.4 cfs. With the exception of about 100 acre-feet per year for mining purposes, the rest of the water rights on the South Llano are for irrigation.

In 2005, the City of Junction used about 615 acre-feet or about 208 gallons per person per day. Since 1964, the highest recorded use by the City is 963 acre-feet during 1993. This equates to 310 gallons per person per day. While permitted irrigation rights total more than 2,500 acre-feet, it appears that only a fraction of this amount is currently being utilized in the South Llano watershed. Through field observations during the summer of 2008, it is estimated that between 125 to 150 acres are currently irrigated in the basin. Water is also withdrawn for domestic and livestock use. These uses generally do not require a water right and the total use is relatively small.

Because much of the flow from the South Llano River comes from spring flow, the use of the groundwater that feeds these springs is an important consideration. The largest groundwater user in the basin is the City of Rocksprings, located on the watershed divide of the South Llano. In 2005, Rocksprings pumped 237 acre-feet from wells in the Edwards-Trinity (Plateau) aquifer, or 162 gallons per person. During 1996, the City pumped nearly 300 acre-feet. While most wells in the area that draw from the Edwards-Trinity (Plateau) aquifer generally yield less than 30 gallons per minute, [23] some of the City of Rocksprings wells yield greater than 500 gallons per minute. [24]

There are also other important considerations regarding water use in the South Llano watershed. As previously mentioned, the flows of the South Llano maintain much of the flows to the mainstem of the Llano River. Several downstream irrigators rely on adequate flows from the river, as does the City of Llano, which relies solely on the Llano River for its water supply. The Llano River also supplies water to the Highland Lakes, a critical supply not only for downstream municipalities and irrigators, but also for aquatic species that rely on adequate flows within the river and into Matagorda Bay. On average, the Llano River provides about 27 percent of the flow into these reservoirs. However, during periods of drought, such as the summer of 2006, the Llano River contributes approximately 75 percent of the inflow to the reservoirs.[25]

Water Quality

The spring-fed waters of the South Llano River consistently have good water quality. There are no point sources of pollution on the South Llano such as industrial outfalls or wastewater discharge facilities. There is some potential, however, for non-point sources of pollution from agricultural runoff or septic systems. Both the TCEQ and the Lower Colorado River Authority (LCRA) maintain monitoring programs on the river. E-Coli bacteria have been detected at the two sites where it is measured, the Llano River at Junction gauge (Site 17471) and at a location on the South Llano in Edwards County above the major springs (Site 16701). [26] Two measurements, both taken at the Llano River at Junction gauge, detected E-Coli bacteria at levels exceeding the Environmental Protection Agency's recommended level for moderate full body contact recreation (298 E-coli per 100 milliliters). These measurements, 7,300 and 390 E-coli per 100 milliliters (ml), were obtained following precipitation events that occurred after an extended dry period. The other 23 measurements at this site were below 90 E-coli/100 ml. It is uncertain if the majority of the E-coli bacteria detected at this site comes from the North or South Llano River.

Dissolved oxygen (DO) is also a measure of health of the river. Exceedingly high or low levels of DO may suggest the presence of algae blooms, possibly caused by an increase in nutrients reaching the river. [27] High dissolved oxygen (>10) has been observed at Site 16701 above the springs, where flows are usually less than 5 cubic feet per second. [28] Elsewhere on the South Llano, DO levels suggest good aquatic habitat conditions.

Groundwater wells located in the study area tend to have hard water as a result of the limestone. A few wells in the area also have elevated levels of nitrates, possibly resulting from poor well location and construction, agricultural runoff or inadequate septic systems. Of the 29 wells sampled in the South Llano River watershed, seven have, or have had, nitrate levels in excess of the recommended drinking water standards of 10 milligrams per liter. [29]

HABITATS

In addition to being an important water resource, the South Llano River and its watershed provide important and unique aquatic and terrestrial habitats. These habitats play a crucial role in the biological diversity and recreational opportunities of the area.

Aquatic


Guadalupe Bass

The South Llano River provides some unique aquatic habitat. It is the only major watershed containing a genetically pure population of Guadalupe Bass, the Texas state fish. The springs of the South Llano also provide habitat for insects that are an important component of aquatic diversity and an indicator of stream health. During their larval stages, some species of caddis fly require dead and dying plant material for food as well as for the construction of casings used for protection and respiration. Because the streams of the Edwards Plateau are subject to flash floods, much of this material is often removed. Spring areas of the South Llano, because they tend to be located above the main river channel, are less likely to be impacted by these floods, thus providing stable habitat for this important group of insects.[30]

Bi-annual fish samples are taken by the LCRA at South Llano River State Park. These samples have identified Guadalupe Bass, along with Texas Shiners and Greenthroat Darters. The Guadalupe Bass, a highly regarded game fish, is also a Species of Concern, meaning that the species is at potential risk due to its hybridization with other bass species. Texas Shiners and Greenthroat Darters are considered Indicator Species, meaning they are a good indicator of ecosystem health.[31]

Terrestrial

The South Llano River is also a principal component of unique biological communities and ecological systems found in the Edwards Plateau region: Lacey-oak-Ashe juniper woodland, Southern Great Plains canyon forests, Edwards Plateau shaded cliff and rock outcrops, and Southern Great Plains streambed herbaceous vegetation. [32] These unique areas provide habitat for native hardwoods such as Spanish oak, Escarpment Black Cherry, and Texas Mountain laurel, as well as a variety of moss found only in Edwards County. [33] The Endangered Tobusch Fishhook Cactus is found in the South Llano River watershed, as are the Golden-Cheeked Warbler and Black-Capped Vireo. The riparian corridor along the river also provides critical wildlife habitat for Rio Grande Turkey and White-tailed deer.

LAND USE

There have been historic vegetation and land use changes in the South Llano River basin over the past one hundred years. The lands of the South Llano River watershed have been used for ranching for many years. In some areas, historical overgrazing and the resulting loss of soil, along with the suppression of fire, have changed the Edwards Plateau and the South Llano River basin from grassland savannah to juniper woodlands. As discussed below, such encroachment of woody vegetation may have had significant impacts on the hydrology of the South Llano River as well as other spring-fed rivers in the Edwards Plateau. Currently, there are efforts to reverse this impact through land stewardship and brush control. At the same time however, the transformation of large agricultural land holdings to smaller ranchettes is fragmenting the landscape, complicating large-scale land management efforts and resulting in potential impacts to wildlife habitat and water resources.

Juniper woodlands along watershed divide between North and South Llano River

Land Stewardship and Brush Management

Land stewardship utilizes a variety of management practices to balance, preserve and enhance natural ecological systems. Such practices include controlled burns to enhance grasslands, game management to decrease over-browsing and enhance wildlife populations, and creation of upland water sources to reduce pressure on riparian habitats. One land stewardship technique that is widely used across the Edwards Plateau is brush control.

The control, clearing, and sculpting of brush species, especially Ashe juniper, is a popular technique used to increase spring flows and improve livestock grazing and wildlife habitat. Some studies have shown that because juniper is evergreen and has a high leaf area, the canopy and litter of a juniper tree can intercept as much as 40% of the precipitation falling on the tree.[34] Under grassland cover, the precipitation that falls on the watershed is slowed by the grasses and infiltrates into the soils and eventually the underlying water table. With the loss of soil and grasses, and the increase in woody species, especially juniper, more precipitation is kept from reaching the ground, and what does, runs off more quickly, rather than recharging the groundwater.

Ashe Juniper is the primary brush species found in the South Llano River watershed. There have been a number of field studies done in Texas in recent years to monitor the effectiveness of using brush clearing to augment water supplies. While there has been much debate in the scientific community as to whether removal of juniper increases water supply on a large scale, there is scientific confidence that increased spring flow and/or groundwater recharge (up to 1.5 inches per year) will result from converting Ashe juniper woodlands to grasslands in small catchments and in areas where drainage is rapid and deep, such as the karst systems associated with the Edwards Plateau. At this small catchment scale, it is estimated that clearing brush from 8 acres of land may result in an increased yield of 1 ac-ft. However, on a larger scale, it is still uncertain if similar increases would occur, though recent research has indicated that reduced grazing pressure in combination with brush control can increase herbaceous cover and result in increased soil infiltration capacity, which in karst regions, can result in slightly increased volumes of baseflow. [35]

Paint Rock Springs and its upland landscape may provide anecdotal evidence of how the changing landscape from grasslands to juniper cover can impact water resources. Gunnar Brune, in *Springs of Texas*, describes Paint Rock Springs (just east of the Highway 377 crossing of the South Llano River above Telegraph) as “much larger” when they formed the headwaters of the South Llano River and were the midway stop on the Fort Clark to Fort McKavett road from 1852 to 1883. Today, however, less than 5 gallons per minute flows from the spring and the headwaters of the South Llano are located two and half miles downstream at Llano Springs (below the rest area on highway 377). [36] As only minor groundwater pumping occurs above Paint Rock Springs, the decline in spring flow is most likely the result of changes in the upland landscape from grassland savanna to juniper woodlands.

Fragmentation

There is a growing trend in Texas whereby large-scale land holdings are being sold and subdivided (fragmented) into smaller parcels, or ranchettes. In part this trend is driven by the influx of new absentee landowners, whose primary residence is outside the area. As with many areas of the Texas Hill Country, people have purchased rural land seeking a weekend retreat to escape urban crowds and reconnect with the land through hunting, fishing, or small-scale agriculture. [37] For many, these smaller parcels are, or will become, a place of retirement. Because these new landowners have outside sources of income, they generally do not need to make a living off of the land. This has the potential to take pressure off of grasslands that are usually stressed during times of drought. On the other hand, these changes also result in a marked increase in land values and increased pressure on water resources and wildlife habitat.

As new owners purchase lands for scenic and recreational value, rather than productive value, land prices escalate. Such escalation places pressure on traditional rural agricultural economies, as producers are able to make more money from the sale of land than from production from the land, resulting in less land being utilized for agriculture. The subdividing of large ranches in smaller tracts also places more pressure on wildlife habitat and water resources, as more homes, roads, fences, and more wells and septic systems are introduced to the landscape. It also complicates the efficient implementation of land stewardship practices such as brush control, rotational grazing, and controlled burning. [38]

The impacts of fragmentation in Edwards and Kimble counties are shown in Table 4. Between 1997 and 2002, the average ranch size in Edwards County decreased 20% from 3,507 acres to 2,789 acres and the amount of land in ranching declined by 13%. From 1992 to 2007, land values more than doubled from $215/acre to $579/acre. In Kimble County, the average ranch size decreased by 18% and the total amount of land in ranching declined by 25%. Land values in Kimble County increased more than fourfold during this period.

Table 4. Changes in Ranching Acreage and Land Values for Edwards and Kimble Counties [39]

	Avg. Ranch Size (acres)		*Ag. Land (million acres)*		*Ag. Land Value ($/acre)*	
	1997	**2002**	**1997**	**2002**	**1992**	**2007**
Edwards County	3,507	2,789	1.12	0.97	$215	$579
Kimble County	1,414	1,166	0.81	0.62	$405	$1,642

These countywide figures can generally be applied to the South Llano River watershed, though more of the fragmentation in Kimble County has occurred outside of the basin. Because of historic land use patterns along the river, there has probably been less recent fragmentation of lands than in other parts of the county. Prior to the construction of the Highland Lakes, the South Llano was one of the few water bodies used during the summer for recreation. As such, tourist camps were constructed in the 1930s along the west bank of the river between Junction and the springs. These camps tended to be on smaller tracts of land; many of the cabins that were part of these camps, still exist today, though on slightly smaller tracts of land, [40] The scenic nature of the springs themselves also created coveted tracts of land that have changed some in ownership, but little in tract size over the years. The portion of the South Llano River basin above the springs continues to be held in larger tracts, though there has been some minor fragmentation. From field and aerial reconnaissance, the author of this report estimates that there are between 150 and 175 homes in the South Llano River watershed above Junction.

WATER MANAGEMENT

There are several water and related resource agencies and organizations that play a role in issues related to the South Llano River. At the local level, groundwater conservation districts in Kimble, Edwards, and Sutton counties manage the groundwater resources of their respective counties. These three districts, along with other groundwater districts in the Edwards Plateau region, participate in a state-mandated Groundwater Management Area joint planning program. A regional water planning process also provides an opportunity for strategies for meeting regional water needs to be developed through local stakeholder involvement. At the federal level, the Natural Resources Conservation Service, an agency within the U.S. Department of Agriculture, works with local and state soil and water conservation boards to coordinate land stewardship efforts in the area. Educational programs and activities related to water are provided by governmental, volunteer, and commercial organizations.

Groundwater Conservation Districts

Groundwater districts are the preferred method for managing groundwater in the State. [41] There are three groundwater districts that encompass the three South Llano River counties: the Real-Edwards Conservation and Reclamation District (CRD), the Kimble County Groundwater Conservation District (GCD), and the Sutton County Underground Water Conservation District (UWCD). All three of these Districts have rules and management plans that govern the groundwater resources in the counties. [42] State law does not allow groundwater conservation districts to require or issue permits for wells on tracts larger than 10 acres, which are used for domestic use and livestock watering and produce less than 25,000 gallons per day. [43] Most of the wells in all three districts are exempt from permitting.

For those wells that do require a permit, several considerations apply. All three of the districts have a 'drilled to density' provision in their rules that prohibit too many wells or too much pumping from occurring within a one-square mile area or section (640 acres). These are outlined below in Table 5. Kimble County allows four wells per square mile but has no total production limits; however, the maximum production from wells in the GCD is about 20 gallons per minute. [44] Sutton County allows eight wells per section, but limits total production from all wells in the section to 640 gallons per minute. The Real-Edwards District restricts production to no more than 10 gallons per minute per contiguous acre, with a maximum production per acre in a section of 2 acre-feet. With spacing and total production requirements, this limits production to about 3,200 gallons per minute, or 1,280 acre-feet per year.

Table 5. Groundwater Production Limits for Groundwater Districts

District	***Groundwater Production Limits Per Section [45]***	
	(gallons/minute)	***(acre-feet/year)***
Real-Edwards CRD	~3,200	1,280
Sutton County UWCD	640	1,032
Kimble County GCD	none	none

When issuing a permit, groundwater districts must consider the amount of groundwater that is available. Much of the determination of availability is based on estimated aquifer recharge. The Kimble County GCD will not issue a permit if issuing the permit could result in total withdrawal permits exceeding the recharge to the Edwards-Trinity aquifer within the boundaries of the district. However, this total does not include pumping from exempt wells; it also does not consider that if permitted withdrawals are equal to recharge, there is no water remaining for spring flows.

By law, districts cannot impose more restrictive production limits on groundwater exports outside the boundaries of a district, [46] but they can require an export permit. Kimble and Real-Edwards Districts require such a permit. In the granting of an export permit, both districts require for consideration, the total groundwater availability in the district, any impacts to nearby well owners, the projected effect on aquifer conditions, the indirect costs and social impacts associated with the transfer, and other considerations related to the public welfare and management of natural resources in the District. The Real-Edwards District, in the transfer permit application process, also requires a mitigation plan to offset the adverse social, economic or hydrologic impacts within the District.

Groundwater Management Area Joint-Planning Process

The amount of water actually available in each aquifer and groundwater district is not definitively quantified. To complicate matters, groundwater district boundaries are often based on county boundaries, resulting in several sets of rules and management plans for one aquifer. In an effort to better coordinate the determination of availability, the state initiated a process in 2005 that requires groundwater districts within a designated Groundwater Management Area (GMA) to meet on a regular basis, share management plans, and participate in joint planning for the various aquifers within the GMA boundaries. It also requires that each of the groundwater management areas adopt "desired future conditions" for each aquifer within the GMA. All three groundwater districts in the South Llano River basin are in Groundwater Management Area 7 (GMA-7), which coordinates efforts for the Edwards-Trinity (Plateau) aquifer.

As part of the process of adopting a desired future condition (DFC) for an aquifer, the GMA member districts determine their goal for the condition of the aquifer 50 years into the future. A goal can be a particular groundwater level, level of water quality, volume of spring flows, etc. Based on this DFC, the Texas Water Development Board determines the volume of groundwater available from the aquifer. The groundwater districts in the GMA-7 area that lie within the South Llano River watershed, in order to protect spring flows, are moving toward adopting a desired aquifer condition where there is no net depletion of the aquifer over the next 50 years; they are working with TWDB to develop a methodology for modeling the sustainability of spring flows. [47] Some of the initial modeling efforts for GMA-7 predict how aquifer levels and spring flows may react to certain scenarios, and demonstrate the importance of setting good desired future conditions.

As previously mentioned, the top of the water table along the watershed divide of the South Llano River is about 2,000 feet above sea level; the springs of the South Llano River are at about 1,900 feet (see Figure 3). This water underlying the divide, feeds not only the springs of the South Llano, but also, the springs of the Nueces, West Nueces, Frio, and Guadalupe Rivers. In one theoretical groundwater modeling scenario, pumping in Edwards County is increased eightfold (to 7,793 acre-feet per year) over current levels of pumping. This increase results in a projected decrease in water levels along the divide of about 25 feet. [48] However, when this level of pumping is coupled with a drought similar to the one that occurred in the 1950s (simulated by a 25% reduction in recharge over a seven year period), water levels are projected to decline more than 70 feet. [49] This drought scenario also predicts that flows to rivers and springs in Edwards County would be reduced by 40-45% and by about 20-25% in Kimble County.

Regional Water Planning

In 1997, the state began a locally driven regional water planning process. As part of this process, the state was divided into sixteen planning regions and representatives from all the water user groups within a particular region were charged with developing a regional water plan that provides for the fifty-year water needs of their region. The resulting water plans evaluate water needs for various categories such as domestic, industrial, irrigation, and livestock based on projections developed by the TWDB. The regional plans are modified every five years, with the most recent round of planning completed in 2006. At the end of each five-year cycle, the state compiles the regional water plans and prepares a State Water Plan. Two regional planning groups cover the South Llano River: Region F (which includes Kimble and Sutton Counties) and the Region J (Plateau), which includes Edwards and Real Counties. [50]

Many regions of the state are experiencing water shortages and looking outside their immediate area for water sources. However, the 2006 plans for both Region F and Region J (Plateau) did not identify any water shortages that required additional water supplies that would significantly impact the South Llano River, [51] [52] nor did other regions look to the South Llano for additional water supplies. Both the Region F and Region J planning groups specifically noted the potential impact that increased aquifer withdrawals could have on spring flow and baseflow to the rivers. The Region J (Plateau) plan comments, "Protection of these spring flows is important to the continued flow of many of the rivers in the region".[53]

Lower Colorado River Authority (LCRA)

The LCRA does not have any direct water management authority in the area. Such authority only applies to the Authority's original statutory district, which stops at the Llano-Mason County line. However, the Authority is involved directly and indirectly in water management activities on the South Llano River.

The LCRA does not hold any water rights in the river, but collects streamflow, water quality, and aquatic habitat information in the South Llano. However, as they are the largest holder of downstream water rights in the Colorado River basin, they do have an effect on water distribution from the South Llano. Upstream water rights with a priority date later than the LCRA rights, must not withdraw water if there is not enough water available to meet the downstream LCRA demands. Consequently, there is little or no additional water available for additional surface water rights in the South Llano River.

National Resource Conservation Service (NRCS)

In Kimble and Edwards County, the NRCS works with the Upper Llanos Soil and Water Conservation District to assist local landowners with the conservation, maintenance, and improvement of natural resources. Much of the current effort to improve natural resources is through brush management. In 2006, in an effort to increase water quantity, the North and South Llano watersheds were designated 'resource concern areas' whereby brush control projects in these watersheds could receive specific funding for cost share programs. Depending on the method used, clearing juniper can cost between $135 and $250 per acre. Agricultural producers who participate in the program are eligible for a fifty percent reimbursement from NRCS for up to $400,000. Lands that are in wildlife habitat plans are not eligible for these funds, but may participate in the Wildlife Habitat Incentive Program that provides up to $25,000 in matching funding to complete projects that improve habitat, including brush management.

Texas Parks and Wildlife Department (TPWD)

Texas Parks and Wildlife Department, through the South Llano River State Park and Walter Buck Wildlife Management Area, manage over 2,700 acres of riparian and upland habitat along the South Llano River for recreation, nature study and wildlife habitat improvement and protection. In addition, TPWD operates the Private Lands and Habitat Program to provide assistance to land owners interested in the conservation and development of wildlife habitats. TPWD also awards Lone Star Land Steward Awards in recognition of landowner accomplishments in habitat management and wildlife conservation. Recently, the Llano Springs Ranch, at the headwaters of the South Llano River was awarded the Leopold Conservation Award for their land stewardship efforts. [54]

South Llano River in South Llano River State Park

Additional Organizations

In addition to the water management entities mentioned above, there are several other organizations that promote water resources education and or activities as a component of their programs. At the state level, Texas Tech University Llano River Field Station at Junction offers 3-week college courses in freshwater ecology, mammalogy, and herpetology as well classes in aquatic biology, ecology, and stream flow velocity for K-12 students in the Outdoor School. Texas AgriLife Extension (formerly, Texas Agricultural Extension Service) provides landowner information on successful land stewardship practices developed through university research. AgriLife Extension also works with the Texas Soil and Water Conservation Board to promote the Texas Watershed Steward Program that engages local stakeholder participation in the planning and implementation of water resource management and protection programs in selected watersheds. [55] The Nature Conservancy of Texas has implemented the Western Rivers Project in the Sabinal, Frio and Nueces rivers. This project provides assistance to landowners and develops voluntary public and private partnerships to conserve terrestrial and aquatic resources in the Edwards Plateau. [56]

At the local level, a program coordinated through Texas Parks and Wildlife and Texas AgriLife Extension is the Master Naturalist Program that educates volunteers to provide education, outreach, and service for beneficial management of natural resources within the local community; the Western Edwards Plateau Chapter of this program recently sponsored a Land Stewardship Workshop. The Edwards Plateau Prescribed Burning Association helps provide the education and resources necessary to use fire as effective range management tool. The Kimble County Historical Society, in cooperation with the local landowner, sponsors an annual tour of the Seven Hundred Springs. Native American Seed Company, a commercial enterprise located near Junction, promotes and sells native grasses and plants as an important component of land stewardship.

ONGOING RESEARCH

Helen Besse, an independent researcher, is currently conducting spring surveys in the 71 counties not included in Gunnar Brune's *Springs of Texas, Volume I*. In Volume I, Brune describes the physical characteristics of springs, the archeology and history of spring's use, the ecological setting of springs, and the local use and lore surrounding springs in 183 out of 254 Texas Counties. Mr. Brune passed away before completing Volume II. Many of the counties in the Hill Country, including Kimble, are among the remaining counties. In an effort to publish Volume II, Ms. Besse is currently compiling flow and water quality data for springs in these counties.

Chad Norris, with Texas Parks and Wildlife Department, is compiling an Assessment of Biological and Hydrologic Conditions in Selected Texas Springs. The study measures spring flow and collects biological data at springs to provide baseline data or to document major changes that may have occurred since springs were visited by Gunnar Brune 20-30 years ago during the *Springs of Texas* compilation. Several springs in the South Llano River watershed are included in the Assessment.

Tim Bonner, Biology Professor at Texas State University, is attaching radio telemeters to twelve Guadalupe Bass in the South Llano River to track their behavior and better understand habitat requirements for the species. Dr. Bonner is doing a similar study in the Pedernales River.

Daniel B. Stevens and Associates are preparing a three-dimensional visual model of the hydrogeology of Sutton County. As part of this project for the Sutton County UWCD, they will also calculate groundwater availability and estimate recharge.

Texas Parks and Wildlife Department is cooperating in a study of the relationship between rainfall and water level of a subterranean lake located at the bottom of the Devil's Sinkhole in the State Natural Area near Rocksprings. This lake, which is probably a 'surface' representation of the water table, contains a small shrimp-like creature found only in the Sinkhole, the Devil's Sinkhole amphipod. [57]

IDENTIFIED WATER RESOURCE ISSUES

During this characterization of the South Llano River, a number of issues were identified that are essential components for addressing the long-term viability of the resource. In order to facilitate the initial development of potential action plans by local and regional stakeholders, some recommendations for addressing these issues are suggested.

Basic Data Needs

Hydrological Data

Although based on sound hydrologic principles, estimates of the volume of water available in the Edwards-Trinity (Plateau) aquifer, along with the movement of water within the aquifer, are rough estimates at best. Some of the basic components of the hydrological budget, which are integral to the ability to determine water availability within aquifers, are lacking. The TWDB currently estimates recharge in the basin between one and two percent of mean annual precipitation. [58] Because these recharge estimates are applied over large areas, any errors associated with the estimate can have a significant impact on estimates of water availability.

Information on what the effect of a prolonged extreme drought would have on the flows of the South Llano River is also lacking. Currently, the drought of the 1950s is considered the drought of record for the South Llano River and the Edwards Plateau. Evidence from a report by Dr. Malcolm Cleaveland on tree ring data has shown that droughts during the 1100s and 1200s, while not as severe in terms of drought intensity, were more severe from the standpoint that the region was in drought conditions for approximately 40-50 years. Dr. Cleaveland notes, "since the world appears to be heading into a period of elevated temperatures…the possibility of experiencing drought similar to the 1100s and 1200s cannot be dismissed lightly". [59]

Ecological Data

Information pertaining to sensitive ecological areas in the watershed should be enhanced. While some baseline aquatic information has been established for one location on the South Llano, other locations and springs have no information by which to monitor changes associated with aquatic habitat.

Recommendations

The following recommendations are suggested to address the identified basic data needs:

1. Further research into the volume of water that annually recharges the aquifer; including, the identification of important recharge areas and key recharge features such as sinkholes, streambed fractures, and caves.
2. Further research into quantifying the volume, location, and timing of the water that discharges from the aquifer through springs, seeps, and base flows to the river;
3. Assess recharge and discharge variability due to changes in precipitation in the region.
4. Build an ecological data inventory of the area to include information on some of the more sensitive aquatic habitat areas within the watershed

Land Management Issues

Riparian Habitat

Much of the riparian habitat along the lower portions of the South Llano consists of stands of mature native pecans. These pecans bottomlands provide wildlife habitat, bank stability, and enhance aquatic habitat. A recent study of pecan bottoms in several areas of the Edwards Plateau found that because of intensified browsing from increased deer populations, very few younger pecan trees or other woody plants are growing under the mature pecans. [60] As the mature pecan trees die, there will be fewer trees in the riparian zone to replace them.

Fragmentation

The division of large tracts into smaller 'ranchettes' is a primary concern of many residents in the area. Such subdividing places stress on water resources, wildlife habitat, and rural infrastructure, and decreases the efficiency of resource management efforts such as brush management, rotational grazing and controlled burning.

Land Stewardship

Land stewardship is practiced throughout much of the South Llano River watershed. Currently, matching funds for brush management on lands in agricultural production are available through NRCS. However, there is no mechanism to ensure on-going funding and coordination for these and other land stewardship efforts. At the same time, there is continued scientific debate about the benefits of brush control and watershed yield on a large-scale basis.

Recommendations

The following recommendations are suggested to address the some of the identified land management issues:

1. Explore the effectiveness of wildlife management plans to curtail wildlife overgrazing in the area;
2. Conduct a more detailed analysis of the effects of current fragmentation and foster discussions among local stakeholders about how to prevent further fragmentation or reduce its impacts.
3. Explore additional mechanisms for funding and coordinating land stewardship efforts in the basin.
4. Further research quantifying spring flows following brush removal in large catchment areas underlain by karst, such as the South Llano River watershed.

Water Management Issues

Use of Spring Flow

In Texas, the regulation of use of water from springs is governed by the location where the spring water is captured. If spring flow is utilized before entering a watercourse, it is classified as groundwater. Once in a watercourse, it is considered waters of the state and requires a water rights permit from the Texas Commission on Environmental Quality. [61] The Texas Administrative Code defines a watercourse as "a definite channel of a stream in which water flows within a defined bed and banks..." [62] Because many of the springs discharge in close proximity to the banks of the South Llano River, the classification of their waters as surface or groundwater may be unclear and regulatory jurisdiction over their use uncertain.

Water Exports

Although there are currently no known plans to export groundwater from the South Llano River basin, there is no certainty that such plans will not develop. And while groundwater districts can restrict production from permitted wells, it is illegal for them to place more stringent production limits on groundwater exports than on in-district use. Rules for the Real-Edwards County CRD, where most of the groundwater that feeds the springs is located, allow permitted groundwater withdrawals of up to

1,280 acre-feet per section of land. The Real-Edwards County CRD is in the process of reviewing and revising their rules. [63]

Groundwater Availability

Due to insufficient available hydrological information, the estimates of how much groundwater may be available from the Edwards-Trinity (Plateau) aquifer have some degree of uncertainty. Local groundwater districts grant permits for water withdrawals up to the currently estimated amount of available groundwater. Despite a district's authority to do so, once a permit is issued, it may prove contentious to reduce the permitted amount if later studies determine that there is less available groundwater than previously believed.

Aquifer Contamination

The very porous nature of Edwards Limestone makes the aquifer that feeds the springs of the South Llano very susceptible to contamination. As the number of gas wells in production increases, [64] and the number of wells and septic systems in the watershed increases, the possibility of such contamination also increases.

Recommendations

The following recommendations are suggested to address the identified water management issues:

1. Provide education and local stakeholder support in the efforts of the Real-Edwards County CRD to adopt pumping restrictions that protect spring flows and base flows to the South Llano River.
2. Provide education and foster local stakeholder involvement in the Groundwater Management Area process that leads to the development of desired future conditions that include the preservation of aquifer outflows to the South Llano River.
3. Provide continued support of local groundwater districts and their efforts to provide for the protection of the groundwater resources within their jurisdiction.

Community Involvement and Downstream Education

Cohesive Voice

It appears that the residents of the South Llano River basin, as well as the community at large, are interested in natural resource issues. Yet, as stakeholders, they lack a cohesive voice in the protection of spring flows and associated flows of the river. Without this voice and its presence in the arena of groundwater and surface water management decisions, the river remains unprotected from potential threats.

Geographical Benefits

The flows of the South Llano River provide benefits to water users and the environment all the way to Matagorda Bay and the Gulf of Mexico. These downstream beneficiaries are often not aware of the significant contribution that the South Llano provides to these supplies and the efforts necessary to protect these supplies.

Recommendations

The formation of a regional stakeholder interest group can be beneficial in providing a forum for natural resource management education, discussions, and lending a cohesive voice to the local community. Numerous water or water-related interest groups exist in Texas, which are formed through a variety of organizational frameworks. The following list provides a sampling of these frameworks and organizations:

1. Numerous non-profit organizations operate across the state with the goal of providing education and outreach, advocacy, and protection of a particular natural resource such as a spring, river, or watershed. These organizations are supported locally through volunteer and in some case grant funded efforts. The San Marcos River Foundation provides a good example of an organization created to protect the flow, natural beauty, and purity of the San Marcos River through an interest-generating endowment fund established in 1985. [65] Locally, the Llano River Association is in the process of organizing members interested in protecting the quality and appearance of the river. [66]

2. The Texas Parks and Wildlife Department facilitates the formation of Wildlife Management Associations and Co-ops across the state. [67]These associations consist of a group of interested landowners, wildlife enthusiasts, hunters, and other interested parties who have organized to cooperatively manage their wildlife and its habitat. The association members operate under a non-binding agreement to cooperate on issues such as land stewardship, habitat improvement, and wildlife and game management. Over 150 Wildlife Management Associations and Wildlife Co-ops currently operate across the state; one example, the Bandera Canyonlands Alliance, is a Wildlife Management Co-op composed of northwest Bandera County landowners. This Alliance, formed in 2007, has a coordinating board, hosts regular meetings, and is quickly becoming an effective participant in both water and land management issues in their part of the Hill Country.

NOTES

[1] Karst areas include features such as caves, sinkholes, and subsurface drainage networks, or conduits.
[2] Roberto Anaya, Conceptual Model for the Edwards-Trinity (Plateau) Aquifer System, Texas. In: *Aquifers of the Edwards Plateau* (eds. Robert E. Mace, Edward S. Angle, and William F. Mullican, III). Texas Water Development Board Report 360, February 2004, available at: www.twdb.state.tx.us/publications/reports/GroundWaterReports/GWReports/R60AEPC/Ch02.pdf.
[3] A portion of the headwaters of the South Llano also occurs in Sutton County.
[4] Judge Delbert Roberts, County Judge, Kimble County, personal communication, June 19, 2008.
[5] Lee Sweeten, General Manager, Real-Edwards Conservation and Reclamation District, personal communication, July 3, 2008.
[6] The lowest recorded discharge for this gauge is 3.7 cubic feet per second on August 17, 1956.
[7] US Geological Survey has operated a stream gauge on the North Llano River above Junction, from 1915 to 1977, and from 2001 to the present.
[8] *See* U.S. Geological Survey, National Water Information System (NWISWeb) data, accessed June 16, 2008, available at waterdata.usgs.gov/nwis/dv/?site_no=08150000&referred_module=sw.
[9] Franklin T. Heitmuller and Brian D. Reece, "Database of historically documented springs and spring flow measurements in Texas." US Geological Survey Open-File Report 03-315, 2003, available at: pubs.er.usgs.gov/usgspubs/ofr/ofr03315.
[10] Gunnar Brune, *Springs of Texas*, volume 1. Fort Worth, Tex., Branch-Smith, Inc., 1981.
[11] Heitmuller and Reece, US Geological Survey Open-File Report 03-315, 2003.
[12] Ibid.
[13] It should be noted that the measurements presented in Table 2 were not always obtained on the same day. As these measurements are presumed to have been taken during dry periods, daily fluctuations are assumed to be minimal.
[14] Heitmuller and Reece, US Geological Survey Open-File Report 03-315, 2003.
[15] Raymond M. Slade, Jr, J. Taylor Bentley, and Dana Michaud, "Results of streamflow gain-loss studies in Texas, with emphasis on gains and losses to major and minor aquifers, Texas, 2000". U.S. Geological Survey Open-File Report 2002-68, 2002, available at: pubs.er.usgs.gov/usgspubs/ofr/ofr0268.
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[17] Geary Schindel, Chief Technical Officer, Edwards Aquifer Authority, written communication, August 5, 2008.
[18] Eve L. Kuniansky and Kelly Q. Holligan, "Simulations of flow in the Edwards-Trinity aquifer system and contiguous hydraulically connected units, west-central Texas". US Geological Survey Water-Resources Investigations Report 93-4039, 1993, available at pubs.er.usgs.gov/usgspubs/wri/wri934039.
[19] Loyd E. Walker, 1979. "Occurrence, availability, and chemical quality of ground water in the Edwards plateau region of Texas". Texas Department of Water Resources, Report 235, available at: www.twdb.state.tx.us/publications/reports/GroundWaterReports/GWReports/Individual%20Report%20htm%20files/Report%20235.htm.
[20] *See* plate 3 in Kuniansky and Holligan, 1993.
[21] Geary Schindel,written communication, August 5, 2008.
[22] An acre-foot is 325,851 gallons and represents the amount of water necessary to cover one acre of land with one foot of water.
[23] *See* Texas Water Development Board, Record of wells by county, Edwards, available at www.twdb.state.tx.us/publications/reports/GroundwaterReports/GWDatabaseReports/Database Reports/Edwards/Record of Wells.pdf.
[24] Lee Sweeten, written communication, August 18, 2008.

[25] *See* U.S. Geological Survey, National Water Information System (NWISWeb) data, accessed January 14, 2008. Available at waterdata.usgs.gov/nwis/dv/?site_no=08151500&referred_module=sw.
[26]*See* Lower Colorado River Authority, Water Quality Site Index, accessed July 11, 2008, available at waterquality.lcra.org/sitelist.asp.
[27] Texas Commission on Environmental Quality, 2005, *A guide to freshwater ecology*, GI-034, revised 8/05, available at www.tceq.state.tx.us/comm_exec/forms_pubs/pubs/gi/gi-034.html.
[28] *See* Lower Colorado River Authority, Water Quality Site Index.
[29] *See* Texas Water Development Board, Ground Water Data System, accessed August 2, 2008, available at www.twdb.state.tx.us/publications/reports/GroundwaterReports/GWDatabaseReports/Gwdata.
[30] Dr. Tom Arsuffi, Aquatic Ecologist and Director, Field Research Station, Texas Tech University Llano River Field Station, personal communication, April 19, 2008.
[31] Robert J. Edwards, Gary P. Garrett, and Nathan L. Allen, "Aquifer-dependent fishes of the Edwards Plateau region", *in Aquifers of the Edwards Plateau*, Texas Water Development Board Report 360, 2004.
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[39] Brent Stevener, Systems Analyst, Institute of Renewable Natural Resources, Texas A&M University, written communication, August 15, 2008. Data derived from U.S. Census of Agriculture and Texas Comptroller of Public Accounts.
[40] Frederica Wyatt, Chairman, Kimble County Historical Commission, personal communication, July 9th, 2008.
[41] Texas Water Code, Chapter 36.001.
[42] The information in this section is obtained from the District Rules for each respective District unless otherwise noted.
[43] Texas Water Code § 36.117.
[44] Jerry Kirby, Manager, Kimble County Groundwater Conservation District, personal communication, May 27, 2008.
[45] One section is 640 acres or one square mile.
[46] Texas Water Code § 36.122(c).
[47] Caroline Runge, Manager, Menard County Underground Water District and Secretary, GMA-7, personal communication, July 16, 2008.
[48] *See* Texas Water Development Board, GAM Run 07-03, June 13, 2007, available at www.twdb.state.tx.us/gam/GAMruns/GR07-03.pdf.
[49] *See* Texas Water Development Board, GAM Run 07-32, December 11, 2007, available at www.twdb.state.tx.us/gam/GAMruns/GR07-32.pdf.
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[57] Russell A. Graves, 2008, When the earth opens, in *Texas Parks and Wildlife Magazine*, January 2008, available at www.tpwmagazine.com/archive/2008/jan/ed_5/
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[63] Lee Sweeten, written communication, August 16, 2008.
[64] Texas Railroad Commission Gas Well Counts show production wells in Sutton County (5,394) have nearly doubled over the last 8 years. See www.rrc.state.tx.us/divisions/og/statistics/wells/wellcount/index.html.
[65] See www.sanmarcosriver.org.
[66] See llanoriverassociation.org.
[67] See towma.org.

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Cover photo: Seven Hundred Springs, Jennifer Walker, Lone Star Chapter Sierra Club
South Llano River below Seven Hundred Springs, Jennifer Walker
Confluence of North Llano and South Llano River, author
Guadalupe Bass, Josh Perkins, Department of Biology, Texas State University
Juniper woodland along watershed divide between North and South Llano River, author
South Llano River in South Llano River State Park, author