**The Headwaters of the Llano**

**A CHARACTERIZATION AND COMPARISON OF THE RIVERS, SPRINGS AND WATERSHEDS OF THE NORTH AND SOUTH LLANO**



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Prepared for South Llano Watershed Alliance

in conjunction Texas Parks and Wildlife Department

by Tyson Broad

*Our mission*

The South Llano Watershed Alliance is an organization of landowners and interested stakeholders whose mission is to preserve and enhance the South Llano River and adjoining watersheds by encouraging land and water stewardship through collaboration, education, and community participation

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# Summary

The North and South Llano Rivers are 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 these rivers and their watersheds has been identified as an environmental, economic, and cultural concern. The most effective method for protecting and preserving these flows may arise from a Watershed Conservation Plan developed by local and regional stakeholders. This report attempts to facilitate the development of such a plan by providing a characterization of the North and South Llano Rivers, their springs, and their watershed.

Much of the flow of the North and South Llano Rivers is supplied from springs fed by groundwater stored in the karstic Edwards-Trinity (Plateau) aquifer. The springs of the North Llano likely originate from groundwater in Sutton County, while two areas along the watershed divide in Edwards and Real County feed the springs of the South Llano. This area supplies water not only to the South Llano River, but also to the Nueces, Frio, and Guadalupe rivers.

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 and its tributaries, 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 North Llano River has almost the same watershed area as the South Llano River, but yields about one-fourth the amount of flow and is dry 6% of the time. Despite this, the North Llano River still provides critical aquatic habitat and water supply for domestic users, livestock and wildlife. Recent fish sampling reveals the aquatic habitat of the North Llano River to be as diverse as the South Llano River.

Due to the pristine nature and relatively constant flow of the springs, the North and South Llano River are currently a healthy ecosystem, supporting 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 woody species on upland habitats have the potential to decrease the water quality and quantity of the river, as do more immediate changes such as wildfire and sand and gravel mining.

# Introduction

The Llano River of Central Texas is a vital resource to the region, providing critical flows downstream to the Colorado River and Highland Lakes, especially during times of drought. The headwaters of the Llano River are located in the watersheds of the North and South Llano Rivers, where springs issue from canyon walls along the edge of the Edwards Plateau. These springs support exceptional aquatic habitat for unique biological communities and provide constant critical flows to downstream water users.

Although the watersheds of the North and South Llano Rivers are similar in size, they exhibit different hydrologic characteristics. During periods of low flow, most of the flow down the Llano River originates from the larger springs found along the South Llano. However, springs along the upper portions of the North Llano watershed still provide critical aquatic habitat and water supply for domestic users, livestock and wildlife, even when the downstream portions of the North Llano are dry.

The protection and preservation of the flows of the North and South Llano River has been identified as an environmental, economic, and cultural concern. Local and regional stakeholders are collaborating to develop a Watershed Conservation Plan for the Headwaters of the Llano. To facilitate the development of this plan, the South Llano Watershed Alliance, in conjunction with Texas Parks and Wildlife Department have prepared this report. It characterizes and compares both the North and South Llano rivers from the upper elevations of their watersheds on the Edwards Plateau to the confluence of the two rivers at Junction. The report compiles new information for the North Llano and updates information presented in the 2008 characterization study of the South Llano Watershed, “Land of the Living Waters”. [[1]](#endnote-1)

# General Description

The headwaters for both the North and South Llano River (Figure 1) begin about 2,400 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 [[2]](#endnote-2) areas in the United States. [[3]](#endnote-3)

The North Llano River flows intermittently across the plateau for its first 31 miles; South Llano River is intermittent in its first 35 miles across the plateau. But where the rivers and their 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 South Llano river’s final 20 miles to Junction and relatively constant flow for the North Llano river’s final 27 miles. 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 North and South Llano River and surrounding area

*Area of major springs*



The North Llano River flows through Sutton and Kimble counties, while the South Llano River flows through Edwards and Kimble counties. [[4]](#endnote-4) 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 both watersheds.

Between 2000 and 2010, Kimble County experienced a 3.1% growth rate, while Edwards County has experienced a 7.4% reduction in population. The estimated population of the North and South Llano watersheds is 4,055 inhabitants, with about 63 percent of the inhabitants residing in the South Llano watershed.[[5]](#endnote-5) The majority (78%) of the population of the two watersheds resides in the cities of Junction or Rocksprings. It is estimated that about 3,015 residents in the watersheds live in Kimble County, about 985 live in Edwards County, and 55 live in Sutton County. The estimated rural population is 467 in the North Llano watershed and 434 in the South Llano watershed. 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%. [[6]](#endnote-6)

# Water Resources

Although the size of the watersheds for the North Llano (942 square miles) and the South Llano (939 square miles) are almost equal, they exhibit very different hydrologic characteristics. The mean annual flow of the North Llano River is 66 cubic feet per second (cfs), while the mean annual flow of the South Llano River is 129 cfs. [[7]](#endnote-7) The median daily flow for the North Llano River is 20 cfs, while the median daily flow for the South Llano River is 80 cfs. [[8]](#endnote-8) The principle reason for such a difference results from greater springflow in the South Llano River watershed.

Due to the existence of large headwater springs, 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. [[9]](#endnote-9) Figure 2 shows the median monthly discharge, or flow, (in cubic feet per second) for the period 1915-2011 and reflects the area’s normal rainfall distribution with the majority of precipitation occurring in late spring and early fall.

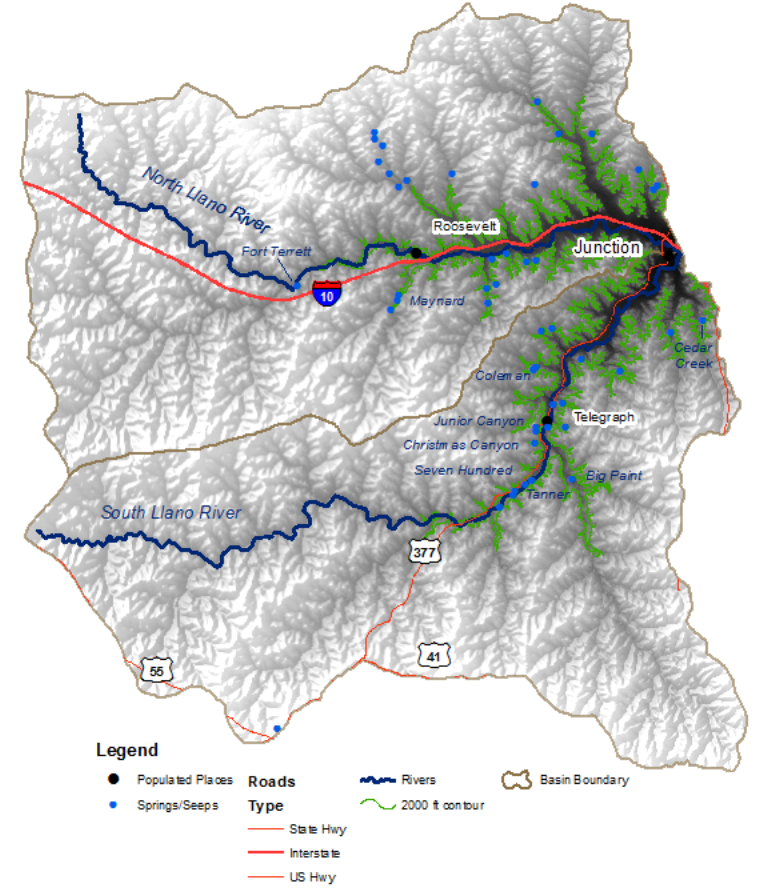
Figure 2. Median Monthly Discharge for Llano River at Junction, Texas (1915 – 1993 & 1997 – 2011) [[10]](#endnote-10)

## 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 10% of the flow to the Llano River, and is often dry.[[11]](#endnote-11) Figure 3 compares the median monthly discharge for the North Llano River at Junction to the Llano River at Junction for the period 1915 to 1977. [[12]](#endnote-12) No flow has been recorded at the North Llano River at Junction gauge several times. The longest period of zero flow occurred during the drought-of-record during the 1950s, when the North Llano ceased to flow for 246 days. By comparison, in 2011, the North Llano ceased to flow for 121 days. Over the entire period of record for this gauge (1915 to 1977 and 2001 to 2012) zero flow has been recorded six percent of the time.

Figure 3. Median Monthly Discharge for Llano River and North Llano River at Junction, Texas (1915 – 1977) [[13]](#endnote-13)

## Both the North and South Llano watersheds are subject to intense flooding. The largest recorded peak flow on the North Llano River is 102,000 cfs on September 16, 1936, while the largest recorded flood (238,100 cfs [[14]](#endnote-14)) on the South Llano occurred June 14, 1935.

## **Springs**

There are numerous springs that contribute to the flow of the North and South Llano River. The Texas Springs Database [[15]](#endnote-15) identifies 27 springs in the North Llano River watershed and 20 springs within the South Llano River watershed. More than 20 additional springs, not included in the database, are located on USGS topographic maps. While the North Llano watershed has more springs than the South Llano, it has far fewer high-flow springs. Five springs with flow greater than 0.2 cubic feet per second (100 gallons per minute) are found in the North Llano; eleven high-flow springs are found in the South Llano (Figure x). 

***North Llano Watershed***

The largest springs in the North Llano are Maynard Springs and Fort Terrett (Adams) Springs. Maynard Springs is located on Maynard Creek, south of Roosevelt in Kimble County. In 1965, when many flow springflow measurements were taken in the headwaters region of the Llano, flow at Maynard Springs was estimated to be 700 gpm (1.5 cfs). Fort Terrett Springs is located in eastern Sutton County and forms the headwaters of the North Llano River. The springs served as a water supply source for Fort Terrett, opened in 1852.

Gunnar Brune, who authored *Springs of Texas,[[16]](#endnote-16)* visited Fort Terrett Springs in 1978.

At that time, only 8 gpm leaked through two small dams designed to capture the spring flow. Given the historical significance of the spring, it is likely that the springs flowed at a greater rate previously. Brune notes the presence of bedrock mortars and middens found upstream from Fort Terrett Springs and speculates that the springs originally started about one kilometer upstream from the present spring.

Downstream of Fort Terrett springs, Brune describes Adams Springs, composed of one large and many smaller springs “bursting into the north side of the river, chiefly below water line”. Stream discharge measurements taken at the upper River Road crossing of the North Llano River (below Fort Terrett and Adams Springs) by Brune and the author are shown in Table 1. 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.

**Table 1. Measured Flows in cubic feet per second and gallons per minute for North Llano River below Fort Terrett Springs and Adams Springs**

|  |  |  |
| --- | --- | --- |
| Date | **Flow (cfs)** | **Flow (gpm)** |
| **Feb 1925** | 13 | 5,700 |
| **Dec 1978** | 15 | 6,700 |
| **Apr 2011** | 6.5 | 2,900 |
| **Jun 2011** | 6.2 | 2,800 |
| **Sep 2011** | 3.0 | 1,400 |

In 1925, a gain/loss study on the North Llano between Roosevelt and the mouth of the river demonstrated that groundwater contributed 6.9 cfs to the flow of the river.[[17]](#endnote-17) During the drought of 2011, April flow in the North Llano River exhibited increasing flows below Ft. Terrett, with 10 cfs below the confluence of Maynard Creek, 12 cfs below the confluence of Copperas Creek, and 14 cfs at the USGS gauge four miles above the mouth. But from June 9 to October 7, zero flow was recorded at the gauge. However, flow from the complex of headwater springs of the North Llano (Fort Terrett and Adams), along with the flow from Maynard Spring and smaller springs along Copperas Creek, maintained some flow in the upper reaches of the North Llano River and its tributaries.

***South Llano Watershed***

Three large springs, located near the Kimble and Edwards County line contribute the majority of the flow to the South Llano 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.

Table 2 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,* [[18]](#endnote-18) 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). During the drought of 2011, spring flow was reduced to 11.7 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 2. Recorded Median and Low Flows in cubic feet per second for Seven Hundred and Tanner Springs** [[19]](#endnote-19)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **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; [[20]](#endnote-20) they are presented in Table 3. The corresponding measurements for Seven Hundred and Tanner Springs and the North Llano River are also included. [[21]](#endnote-21) 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 3. 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** **[[22]](#endnote-22)**

|  |  |  |  |
| --- | --- | --- | --- |
|  | **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. [[23]](#endnote-23) 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.

Although of less magnitude than Tanner, Seven Hundred, and Big Paint, several other springs contribute to the flow of the South Llano and its tributaries. Two springs near the South Llano River include Christmas Canyon Spring and Junior Canyon Spring that respectively had a reported flow of 5,000 gallons per minute (11 cfs) and 2,000 gpm (4 cfs) in 1966. Coleman Springs reportedly flowed at 750 gpm (1.7 cfs) into Cajac (pronounced kayak) Creek during 1966; discharge of about 1 cfs was measured on Cajac Creek by the author in May, 2011. Cedar Creek Spring on Cedar Creek reportedly flowed at 200 gpm (0.4 cfs) in 1966; the author measured 2 cfs on Cedar Creek in May of 2011.

Table 4. 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 [[24]](#endnote-24) 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.

## **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 North and South Llano watersheds. 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.

Figure 4. Cross-section of Edwards-Trinity Aquifer. (Adapted from Brune) [[25]](#endnote-25)

Subsurface drainage networks, or conduits, dominate groundwater systems that drain karst terrain. [[26]](#endnote-26) Precipitation that recharges the Edwards-Trinity (Plateau) aquifer tends to follows these conduits (Figure 4). Where rivers such as the North and South Llano carve valleys into the Edwards Plateau, these conduits are exposed, resulting in springs. These springs are usually located where the Edwards Limestone rests on top of the denser, less permeable Glen Rose Formation.

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[[27]](#endnote-27) 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 5 is a map of the potentiometric surface in the North and South Llano River area reproduced from the Kuniansky and Holligan report.

There are several areas surrounding the North and South Llano rivers and their tributaries where the elevation of the water table is over 2,000 feet above sea level. The level of the springs along the rivers is approximately 1,900 to 2,000 feet, so it can be assumed that groundwater flows ‘down gradient’ towards the springs.[[28]](#endnote-28) Kuniansky and Holligan suggest that the waters that feed the springs in the north portion of the North Llano probably originate from northeastern Sutton; springs in the south portion of the watershed likely originate from southeastern Sutton and southwestern Kimble County. In the South Llano, springs along the left bank of the river (such as Seven Hundred and Tanner) probably originate from the area to the west in 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. [[29]](#endnote-29)

Figure 5. 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

Generally, water levels in wells across the North and South Llano watersheds do not appear to fluctuate significantly. Daniel B. Stevens and Associates analyzed water levels in eleven wells in Kimble County wells from 2006 through 2008. Both 2006 and 2008 were considered dry years, while 2007 was considered a very wet year. All but two wells exhibited water level fluctuations of more than two feet during this period. Water levels in one well located in the Copperas Creek drainage fluctuated 19 feet between wet and dry years, while another well in Bear Creek fluctuated 11 feet.[[30]](#endnote-30)

Figure 6 compares water level from a recently installed (2009) monitoring well near Rocksprings with periodic measurements from Seven Hundred Springs. [[31]](#endnote-31) Declines in water levels roughly correlate with declines in spring flow. Since July of 2011, water levels in the Edwards-Trinity Aquifer have declined about two feet. During this decline, discharge at Seven Hundred Springs has fallen from 18.8 cfs in March 2010 to a low of 11.7 cfs in February 2011. Since February 2011 however, spring flows have increased slightly to about 14.3, despite a continual decline in aquifer levels. Although there is little data to compare spring flow with water levels, these might suggest that spring flow at Seven Hundred Springs is influenced some by water levels in the aquifer, but other factors may also exist.

**Figure 6. Comparison of Monitoring Well (Lazy J Ranch) 9 miles northeast of Rocksprings with Seven Hundred Springs near Telegraph**

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. [[32]](#endnote-32) Recent work by Dr. Ron Green hypothesizes that because of karstic nature of the aquifer, precipitation that falls on the North and South Llano watersheds and recharges the aquifer, rather than following the hydrologic divide and discharging to the north, may instead, follow conduits within the rock and discharge to the south in the Nueces and Frio watersheds. Such a phenomena is referred to as ‘groundwater piracy’. [[33]](#endnote-33)

Although based on sound hydrologic principles, estimates of the volume of water available in the Edwards-Trinity (Plateau) 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. [[34]](#endnote-34) 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. Recent water budget analyses for the Edwards Plateau predict that when precipitation amounts approach 70 percent of average, recharge becomes negligible.[[35]](#endnote-35)

Information on what the effect of a prolonged extreme drought would have on the flows of the North and South Llano River is also lacking. Currently, the drought of the 1950s is considered the drought of record for 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”. [[36]](#endnote-36)

## **Water Use**

In order to utilize water from the North and 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 in the North Llano watershed have been issued since 1896; the total amount of water rights issued in the basin is 1,123 acre-feet per year [[37]](#endnote-37), or less than 2 cfs. Water rights on the South Llano River have been issued since 1893, and total amount of water rights issued for the river and its tributaries is 3,665 acre-feet 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 North and South Llano are for irrigation.

In 2009, the City of Junction used about 615 acre-feet or about 204 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 3,600 acre-feet, it appears that only a fraction of this amount is currently being utilized in the North and South Llano watersheds. Through field observations during the summer of 2011, an estimated 400 to 450 acres are currently irrigated in the basin for grass, hay, and orchards. 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. Surface water irrigation was suspended in late June of 2011, when the City of Llano, a senior downstream water right holder requested a priority call on water, meaning all non-municipal rights be curtailed.

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 2009, Rocksprings pumped 200 acre-feet from wells in the Edwards-Trinity (Plateau) aquifer, or 136 gallons per person.[[38]](#endnote-38) 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, [[39]](#endnote-39) some of the City of Rocksprings wells yield greater than 500 gallons per minute. [[40]](#endnote-40) The largest use of water groundwater in Edwards and Real Counties is for livestock and native and exotic game. [[41]](#endnote-41)

One uncertainty related to the use of water resources is the use of water for hydraulic fracturing, or ‘fracking’. The North and South Llano watersheds lies within the Barnett-Woodford Shale play. To date, more than 10,000 gas natural gas wells have been drilled in Sutton, Edwards, and Kimble County. Not all of these wells are in headwater watersheds of the Llano and not all of these wells are fracked. However, the amount of water used to frack one well is often greater than one million gallons. Up until February 1st, 2012, the amount of water used to frack a well and the chemicals used in the fracking fluid did not have to be disclosed.

There are also other important considerations regarding water use in the North and South Llano watersheds. 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.[[42]](#endnote-42)

## **Water Quality**

The spring-fed waters of the North and South Llano River consistently have good water quality. There are no point sources of pollution on either river, 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 in water may result from livestock and wildlife near water or from failing septic tanks. E-Coli bacteria have been detected at the three sites where it is measured, the Llano River at Junction gauge (Site 17471), a location on the South Llano in Edwards County above the major springs (Site 16701), a location on the North Llano River 570 feet above the confluence with the South Llano River (Site 17425). [[43]](#endnote-43) Two of the 50 measurements taken at the Llano River at Junction gauge and one of the 36 measurements taken on North Llano River site detected E-Coli bacteria at levels exceeding the Environmental Protection Agency’s recommended level for moderate full body contact recreation (394 E-coli per 100 milliliters). All of these measurements were obtained following precipitation events that occurred after an extended dry period. A water body is considered impaired for E-coli only if 25 percent of the samples exceed the recommended level. None of the waterways in the North and South Llano watersheds are considered impaired.[[44]](#endnote-44)

Nitrate-nitrogen tests can also be used to test for possible pollution from livestock or septic systems. All measurements taken on the North and South Llano River record nitrate-nitrogen readings below the screening level of 1.95 mg/L. Only one measurement on the Llano River at Junction gauge has exceeded this level; this measurement was taken in 2002.[[45]](#endnote-45)

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. [[46]](#endnote-46) High dissolved oxygen (>10) has been observed at Site 16701 above the springs, where flows are usually less than 5 cubic feet per second. [[47]](#endnote-47) Elsewhere on the South Llano, DO levels suggest good aquatic habitat conditions. High dissolved oxygen is measured in about 23 percent of all measurements on the North Llano and 19 percent of all measurements on the Llano River at Junction gauge.

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 wells sampled in the North Llano watershed, nine have, or have had, nitrate levels in excess of the recommended drinking water standards of 10 milligrams per liter. Four such wells are located in the South Llano watershed. [[48]](#endnote-48)

# Habitats

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

## **Aquatic**

The North and South Llano River provides some unique aquatic habitat for a variety of species. One of the most notable species is the Guadalupe Bass, the Texas state fish and a Species of Concern, meaning that the species is at potential risk due to its hybridization with other bass species. Until recently, the South Llano River was believed to be the only major watershed containing a genetically pure population of Guadalupe Bass. However, recent sampling has revealed that about 3 percent of the population has hybridized with non-native smallmouth bass and largemouth bass; [[49]](#endnote-49) sampling of 22 Guadalupe Bass on the North Llano River revealed no hybridization. [[50]](#endnote-50) In an effort to ameliorate the effects of this hybridization and to restore degraded habitat for Guadalupe Bass, the Texas Parks and Wildlife Department along with other institutions and organizations (including the South Llano Watershed Alliance), began the Guadalupe Bass Initiative.[[51]](#endnote-51)

Bi-annual fish samples were taken by the LCRA at South Llano River State Park between 2002 and 2008. In addition ongoing sampling efforts associated with the Guadalupe Bass Initiative are being conducted at two sites on the South Llano and one site on the North Llano. These samples have identified Guadalupe Bass (*Micropterus treculii*), along with Texas Shiners (*Notropis amabilis*) and Greenthroat Darters (*Etheostoma lepidum*). Texas Shiners and Greenthroat Darters are considered Indicator Species, meaning they are a good indicator of ecosystem health.[[52]](#endnote-52) In these samples, Guadalupe Bass account for about 0.5 percent of the relative abundance in the North Llano and 1.5 percent in the South Llano. The relative abundance of Texas Shiner in the North Llano is 36 percent and 12 percent in the South Llano. The relative abundance for Greenthroat Darters is 2 percent for the North Llano and 0.5 percent for the South Llano.[[53]](#endnote-53)

The waterways of the North and South Llano watershed currently provide, or historically have provided, habitat for four species of freshwater mussels recently listed as candidates for the endangered species list. The Texas Fatmucket (Lampsilis bracteata) has been recently found in the watersheds of the headwater watersheds of the Llano. Historically, these two watersheds have been within the historical range for Texas Fawnsfoot (*Truncilla macrodon*), Smooth Pimpleback (*Quadrula houstonensis*), and Texas Pimpleback (*Quadrula petrina*). [[54]](#endnote-54)

The springs of the North and 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 North and South Llano River, 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.[[55]](#endnote-55)

## **Terrestrial**

The North and South Llano River are also principal components 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. [[56]](#endnote-56) 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. [[57]](#endnote-57) The Endangered Tobusch Fishhook Cactus is found in these watersheds.

The endangered Golden-cheeked Warbler and Black-capped Vireo are found in the North and South Llano watersheds. It is believed that dense stands of old growth juniper in the canyons provide nesting habitat for a significant portion of the Warbler population. Vireo populations prefer more open habitat with less juniper cover and more shrubby deciduous cover. The riparian corridor along the river also provides critical wildlife habitat for Rio Grande Turkey and White-tailed deer.

## **Riparian**

Much of the riparian habitat along the lower portions of the watersheds consists of stands of mature native pecans. These pecans bottomlands provide wildlife habitat, bank stability, and enhance aquatic habitat. A 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. [[58]](#endnote-58)

There are several aggressive exotic species that grow along riparian areas of the North and South Llano waterways. These species, including *Arundo donax*, also known as giant reed or Carrizo cane, Chinaberry (*Mezlia azedarach*), and elephant ear (*Colocasia esculenta*) have the ability to utilize large amounts of water and monopolize native riparian vegetation.

# Land Use

Land use changes have occurred across most of the terrestrial habitats of the North and South Llano Watersheds during the last one and a half centuries. Crop and hay production by early settlers along fertile bottomlands, as well as livestock grazing in the bottomlands and uplands, has greatly influenced the current landscape across the Edwards Plateau. In some areas, historical overgrazing and the resulting loss of soil, along with the suppression of fire, have changed the Edwards Plateau from grassland savannah to juniper woodlands. [[59]](#endnote-59)

An exception to this land-use change may be found in the mesic canyon sides. These canyons may have been less impacted by grazing and fire suppression as inaccessibility reduced grazing pressure and the steep slopes limited the ability of fire to become a dominant ecological process. **[[60]](#endnote-60)**

As discussed below, the encroachment of woody vegetation may have had significant impacts on the hydrology of the spring-fed canyon systems 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. In addition, recent events have placed additional strain on aquatic, terrestrial, and riparian resources.

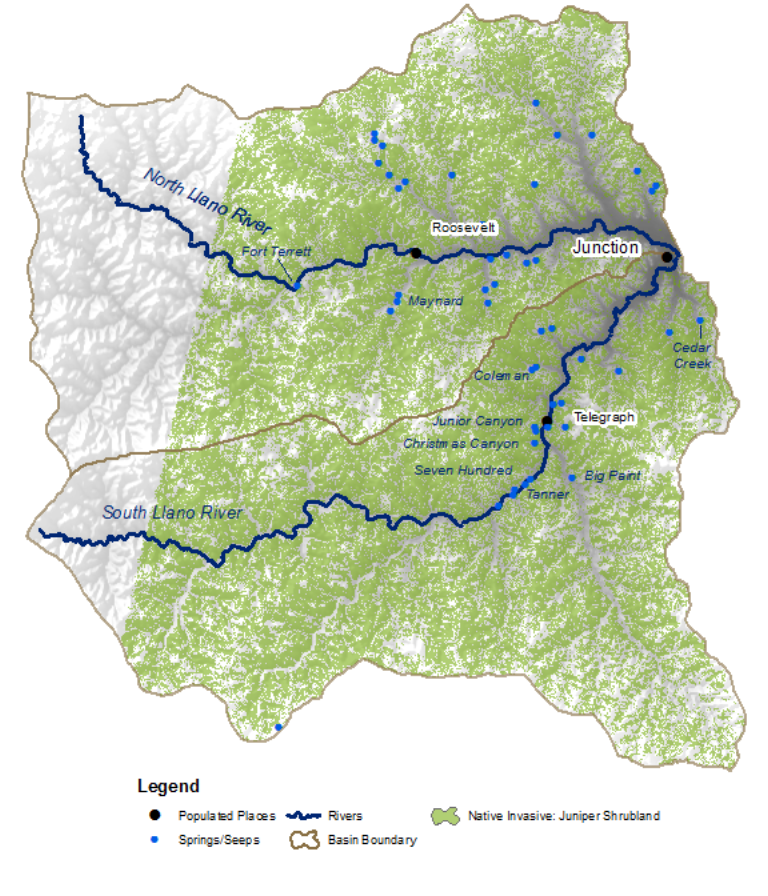
## Juniper woodlands along watershed divide between North and South Llano River

## **Land Stewardship and Brush Management**

Land stewardship utilizes a variety of management practices to balance, preserve and enhance natural ecological systems. Such practices include prescribed 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 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 a tree. [[61]](#endnote-61) Under grassland cover, precipitation is slowed by grasses and infiltrates into the soils and eventually the underlying water table. With the loss of soil and grasses and an increase in woody species, especially juniper, more precipitation is kept from reaching the ground. What does reach the ground runs off more quickly, rather than infiltrating down to the water table.

Ashe juniper is the primary brush species found in the North and South Llano watersheds. It is estimated that about 60 percent of the basin in covered…



Ashe juniper is the primary brush species found in the North and South Llano watersheds. 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. There is much debate in the scientific community as to whether removal of juniper increases water supply on a large scale. However, there is scientific confidence that increased spring flow and/or groundwater recharge (up to 1.5 inches per year) will result, at least in the near term, from converting Ashe juniper woodlands to grasslands in small catchments with sufficient soil to support grassland development 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 eight acres of land may result in an increased yield of one acre-foot. 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. In karst regions, this can result in slightly increased volumes of baseflow. [[62]](#endnote-62)

Control of Ashe juniper should not be undertaken without serious consideration of the resulting effects. There is little to no benefit to be gained from removing Ashe juniper from moderate to steep slopes or from areas with little to no soil cover. The former is subject to severe erosion during intense rainfall events and the latter will not support the development of continuous grass cover. Indeed, in cases with little to no existing soil cover Ashe juniper actually serves to re-create the lost soil layer through leaf fall and trapping of sediment and organic debris. In addition, mature Ashe junipers serve as the exclusive nesting material of the endangered golden-cheeked warbler.[[63]](#endnote-63)

As with Fort Terrett Springs mentioned earlier, Paint Rock Springs and their 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). [[64]](#endnote-64) 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. This trend is driven by the influx of new absentee landowners. As with many areas of the Texas Hill Country, people purchase rural land seeking a weekend retreat to escape urban crowds and reconnect with the land through hunting, fishing, or small-scale agriculture. [[65]](#endnote-65) 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 into smaller tracts also increases 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, managed grazing, and controlled burning. [[66]](#endnote-66)

The impacts of fragmentation in Edwards, Kimble, and Sutton counties are shown in Table 5. Between 1997 and 2007, the total amount of acres in Edwards County in ranches greater than 2,000 acres decreased 19 percent from over one million acres to 864,000 acres. The amount of acreage in this category declined 33 percent in Kimble County but only 5 percent in Sutton County. Land values in these counties increased by as much as fourfold (Kimble County) during this period.

**Table 5. Changes in Ranching Acreage and Land Values for Edwards and Kimble Counties** [[67]](#endnote-67)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | ***Acres in Ranches > 2,000 acres (1,000 acres)*** | | ***Ag. Land Value ($/acre)*** | |
|  | **1997** | **2007** | **1997** | **2007** |
| **Edwards County** | 1,069 | 864 | $253 | $579 |
| **Kimble County** | 580 | 384 | $408 | $1,642 |
| **Sutton County** | 877 | 832 | $200 | $663 |

**Wildfire and Drought**

Although the average annual flow for the Llano River in Junction during the 2011 was 60.7 cfs, the lowest flow since the drought of the 1950s, this dry period actually began in 2008. [[68]](#endnote-68) On April 26th, 2011, in the middle of this dry period, lightning caused a fire in the South Llano watershed approximately 13 miles southwest of Junction. By the time the fire was extinguished in the middle of May, an estimated 10,000 acres of upland and riparian habitat had been destroyed, along with numerous structures.

Fire is a valuable land management tool when used in a prescribed setting and can dramatically increase the health of a landscape. The ecosystem of the Edwards Plateau evolved with fire. However, fires of this magnitude have the potential to cause dramatic increases in sediment in the rivers.



**Sand and Gravel Extraction**

Since the mid-1980s, sand and gravel has been extracted from the North Llano River about one mile above the confluence with the South Llano. TPWD oversees the extraction of such materials from navigable waterways through the issuance of permits. Although the permit for this operation was retired in 2004, the impacts of these extraction activities are still visible. Most notably, the mining activity within the channel apparently caused the channel downstream to migrate approximately 700 feet to the south.

# Water Management

There are a number of agencies and organizations that play a role in the natural resource issues of the headwater watersheds of the Llano. At the local level, groundwater conservation districts manage the groundwater resources of their respective counties. These districts participate in a state-mandated Groundwater Management Area joint planning program. A regional water planning process also provides an opportunity for local stakeholders and the community to develop strategies for meeting regional water needs. 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.

## **Groundwater Conservation Districts**

Groundwater districts are the preferred method for managing groundwater in the State. [[69]](#endnote-69) There are three groundwater districts that encompass the three North and 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. [[70]](#endnote-70) 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. [[71]](#endnote-71) 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 and production limits can be applied if nearby wells are impacted. [[72]](#endnote-72) 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 6. Groundwater Production Limits for Groundwater Districts**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **District** |  | ***Groundwater Production Limits Per Section [[73]](#endnote-73)*** | | | |
|  |  |  | ***(gallons/minute)*** | ***(acre-feet/year)*** |  |
| **Real-Edwards CRD** | |  | ~3,200 | 1,280 |  |
| **Sutton County UWCD** | |  | 640 | 1,032 |  |
| **Kimble County GCD** | |  | none | none |  |

By law, districts cannot impose more restrictive production limits on groundwater exports outside the boundaries of a district, [[74]](#endnote-74) 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**

Until recently, the amount of water actually available for withdrawal in each aquifer and groundwater district was not definitively quantified. 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 North and South Llano watersheds 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 (TWDB) determines the physical volume of groundwater available from the aquifer. GMA-7 adopted a desired aquifer condition allowing for an average drawdown of seven feet for the Edwards-Trinity (Plateau) aquifer through the year 2060. The Modeled Available Groundwater for three groundwater districts based on this DFC is shown in Table 4. While the average drawdown for the entire aquifer is seven feet, drawdown in individual counties may be greater or less.

Table 7. Groundwater Availability and Drawdown 2010-2060 [[75]](#endnote-75)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | ***Modeled Available GW***  ***(acre-feet)*** | | ***Average Drawdown***  ***(feet)*** | |
|  | **2010** | **2060** | **2010** | **2060** |
| Edwards County | 3,002 | 5,659 | 0 | 2 |
| Kimble County | 847 | 1,400 | 1 | 1 |
| Sutton County | 3,794 | 6,450 | 2 | 6 |

The drawdown predicted in Table 7 is based on output scenarios from a groundwater model. This model assumes that recharge for each scenario is equal to the average annual recharge. As previously mentioned, actual recharge may approach zero when precipitation amounts are 70 percent of average. [[76]](#endnote-76) Thus the amount of drawdown, or drop in the water table, is likely to be greater during periods of drought.

## **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 2011. 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. [[77]](#endnote-77)

Many regions of the state are experiencing water shortages and looking outside their immediate area for water sources. However, the 2011 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 North or South Llano River, [[78]](#endnote-78) [[79]](#endnote-79) nor did other regions look to the North or 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, “These discharges from springs are thus the primary source of continuous flow to the rivers downstream and, therefore, their protection is warranted”.[[80]](#endnote-80)

## **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 North and 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 North and South Llano watersheds. 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 North and 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 North or South Llano River.

## **National Resource Conservation Service (NRCS)**

In the North and South watersheds, the Natural Resource Conservation Service (NRCS) works with local Soil and Water Conservation Districts to assist local landowners with the conservation, maintenance, and improvement of natural resources. [[81]](#endnote-81) Much of the current effort to improve natural resources is through the Environmental Quality Incentives Program (EQIP). Agricultural producers who participate in the program are eligible for a 75 percent reimbursement from NRCS for up to $300,000. 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 $50,000 in matching funding to complete projects that improve habitat, including brush management. Other NRCS programs designed to promote land stewardship include the Conservation Reserve Program and the Conservation Stewardship Program.

## **Texas Parks and Wildlife Department (TPWD)**

The Texas Parks and Wildlife Department, through land management and cooperative programming, are actively involved in stewardship efforts in the North and South Llano watersheds. TPWD manages the South Llano River State Park, over 2,700 acres of riparian and upland habitat along the South Llano River, for recreation, nature study and wildlife habitat improvement and protection.

TPWD is also involved in cooperative efforts, such as the Guadalupe Bass Restoration Initiative. Partnering with the South Llano Watershed Alliance, TPWD is working to protect Guadalupe bass populations and their habitat by developing networks of willing landowners interested in implementing coordinated landscape conservation actions at watershed-scales. Such conservation actions promote functional riparian and stream systems, and emphasize the conservation of native fish communities and supporting habitats. [[82]](#endnote-82) The development of this characterization report and the creation of a stakeholder-driver Watershed Conservation Plan are a portion of this initiative.

# Notes and References

1. “Land of the living waters: a characterization of the South Llano River, its springs, and its watershed”. Environmental Defense Fund, 2008. [↑](#endnote-ref-1)
2. Karst areas include features such as caves, sinkholes, and subsurface drainage networks, or conduits. [↑](#endnote-ref-2)
3. 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: <http://www.twdb.state.tx.us/publications/reports/GroundWaterReports/GWReports/R60AEPC/Ch02.pdf>. [↑](#endnote-ref-3)
4. A portion of the watershed of the North Llano also occurs in Menard and Edwards County. A portion of the watershed of the South Llano also occurs in Sutton and Real County. [↑](#endnote-ref-4)
5. Estimate based on Block Data from U.S. Census Bureau, accessed January 11, 2012; where Block Data are located in both watersheds, watershed assignments were based on imagery from Google Earth. [↑](#endnote-ref-5)
6. Judge Delbert Roberts, Former County Judge, Kimble County, personal communication, June 19, 2008. [↑](#endnote-ref-6)
7. Calculated as the difference between annual flow of Llano River at Junction less the annual flow of North Llano at Junction. [↑](#endnote-ref-7)
8. Calculated as the difference between daily median flow of Llano River at Junction less the daily median flow of North Llano at Junction. [↑](#endnote-ref-8)
9. The lowest recorded discharge for this gauge is 3.7 cubic feet per second on August 17, 1956. [↑](#endnote-ref-9)
10. *See* U.S. Geological Survey, National Water Information System (NWISWeb) data, accessed June 16, 2008, available at <http://waterdata.usgs.gov/nwis/dv/?site_no=08150000&amp;referred_module=sw>. [↑](#endnote-ref-10)
11. 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. [↑](#endnote-ref-11)
12. Longest continuous period of record for both the North Llano at Junction and Llano River at Junction is 1915 to 1977. The North Llano gauge was discontinued in 1977; it was re-established in 2001. [↑](#endnote-ref-12)
13. *See* U.S. Geological Survey, National Water Information System (NWISWeb) data, accessed June 16, 2008, available at <http://waterdata.usgs.gov/nwis/dv/?site_no=08150000&amp;referred_module=sw>. [↑](#endnote-ref-13)
14. The peak discharge measurement for the South Llano is calculated by subtracting the peak discharge measurement for the North Llano River at Junction from the peak discharge measurement for the Llano River at Junction. [↑](#endnote-ref-14)
15. 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:

    <http://pubs.er.usgs.gov/usgspubs/ofr/ofr03315>. [↑](#endnote-ref-15)
16. Gunnar Brune, *Springs of Texas*, volume 1. Fort Worth, Tex., Branch-Smith, Inc., 1981. [↑](#endnote-ref-16)
17. 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: <http://pubs.er.usgs.gov/usgspubs/ofr/ofr0268>. [↑](#endnote-ref-17)
18. Gunnar Brune, *Springs of Texas*, volume 1. Fort Worth, Tex., Branch-Smith, Inc., 1981. [↑](#endnote-ref-18)
19. Heitmuller and Reece, US Geological Survey Open-File Report 03-315, 2003. [↑](#endnote-ref-19)
20. Ibid. [↑](#endnote-ref-20)
21. 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. [↑](#endnote-ref-21)
22. Heitmuller and Reece, US Geological Survey Open-File Report 03-315, 2003. [↑](#endnote-ref-22)
23. 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: <http://pubs.er.usgs.gov/usgspubs/ofr/ofr0268>. [↑](#endnote-ref-23)
24. E.L. Kuniansky, “Precipitation, streamflow, and baseflow, in West-Central Texas, December 1974 through March 1977”. U.S. Geological Survey Water-Resources Investigations Report 89-4208, 1989, available at: <http://pubs.er.usgs.gov/usgspubs/wri/wri884218>. [↑](#endnote-ref-24)
25. Gunnar Brune, *Springs of Texas*, volume 1. Forth Worth, Tex., Branch-Smith, Inc., 1981. [↑](#endnote-ref-25)
26. Geary Schindel, Chief Technical Officer, Edwards Aquifer Authority, written communication, August 5, 2008. [↑](#endnote-ref-26)
27. 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 <http://pubs.er.usgs.gov/usgspubs/wri/wri934039>. [↑](#endnote-ref-27)
28. 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: <http://www.twdb.state.tx.us/publications/reports/GroundWaterReports/GWReports/Individual%20Report%20htm%20files/Report%20235.htm>. [↑](#endnote-ref-28)
29. *See* plate 3 in Kuniansky and Holligan, 1993. [↑](#endnote-ref-29)
30. Daniel B. Stevens and Associates, Inc, “Geodatabase Deliverable for Kimble County”, April 29, 2009. [↑](#endnote-ref-30)
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32. Geary Schindel, written communication, August 5, 2008. [↑](#endnote-ref-32)
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