HOW MUCH *Water* is in the GUADALUPE?

A Preliminary Data Analysis and Gap Analysis

THE MEADOWS CENTER
FOR WATER AND THE ENVIRONMENT

TEXAS STATE UNIVERSITY

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A Preliminary Data Analysis and Gap Analysis

January 2019

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LIST OF ACRONYMS

cfs: cubic feet per second
EAA: Edwards Aquifer Authority
EAHCP: Edwards Aquifer Habitat Conservation Plan
GIS: Geographical Information System
GRB: Guadalupe River Basin
GBRA: Guadalupe Blanco River Authority
MSL: Mean Sea Level
NWS: National Weather Service
RRAWFLOW: Rainfall-Response Aquifer and Watershed Flow
POR: Period of Record
SCTRPG: South Central Texas Regional Water Planning Group
TBWE: Texas Board of Water Engineers
TCEQ: Texas Commission of Environmental Quality
US EPA: United States Environmental Protection Agency
USGS: United States Geological Survey
UGRA: Upper Guadalupe River Authority
USACE: US Army Corp of Engineers

EXECUTIVE SUMMARY

The headwaters of the Guadalupe River originate in the Edwards Plateau province of central Texas and flow approximately 480 miles to San Antonio Bay in the Gulf of Mexico. The Blanco/San Marcos River system and the San Antonio River are the largest tributaries of the Guadalupe River. Surface water/groundwater interactions are dominated by the flow contribution of several major springs including the Plateau Edwards headwaters spring system, Comal Springs, San Marcos Springs, and Hueco Springs. There are unquantified gains due to shallow groundwater inflow along the river, but the major springs provide the majority of base flow to the river. There are no major documented natural losing reaches on the river, though localized losses occur.

The United States Geological Survey (USGS) maintains twenty-one stream gages on the main channel of the river as well as tributary and spring gages. Long term historic trends in flow in the main channel are difficult to assess due to the varying lengths of the period of record (POR) for many of the USGS gages. For gages with PORs over 70 years in length, such as Hunt, Spring Branch, and Victoria, discharge trends are generally flat. All gages, including major springs, with PORs since 2000 indicate decreasing discharge trends. The cause of the declines may be from increased withdrawals and/or climate change due to increasing temperatures and decreasing precipitation. Researchers have predicted continuing declines in the discharge from major springs due to climate change. In addition, population and water demand are projected to double by 2070. Additional permanent stream gages are necessary to capture discharge trends at significant points along the river.

The percentage total major spring discharge (Comal, San Marcos, and Hueco Springs) to river discharge at Victoria ranged from one percent during Hurricane Harvey in 2017 to over 190 percent during the drought of 2011. Any percentage over 100 percent represents water losses (diversions, losses to groundwater, and evapotranspiration) between the springs and Victoria. The average contribution is 62 percent of the discharge measured at Victoria. Spring flow is greater than discharge at Victoria eleven percent of the time from 2003 to 2017.

There are over 600 assigned water rights (diversions) on the Guadalupe River totaling over six million acre-feet of water per year, or over 8,700 cubic feet per second (cfs). This volume of water is significantly greater that the average of the mean daily discharge as measured at Victoria for the years 1934 to2017 of 2,113 cfs, indicating the river is oversubscribed. The actual use is likely lower than the total assigned diversions. Rights held for hydroelectric power generation are the largest class of right holders, followed by industries and agriculture. The largest number of individual water right holders occur near headwater springs in Kerr County. The largest volume of water held by water right holders occurs in Guadalupe County.

BACKGROUND AND PURPOSE

Over the past several years, the Meadows Center's "How Much Water is in the Hill Country?" research efforts have focused on developing baseline groundwater-surface water interaction and water quality data on Onion Creek, and the Blanco and Pedernales Rivers to gain a clearer understanding of the complex hydrogeology of Hill Country rivers, aquifers, and springs. The limited geographic focus in the Hill Country was by design since the groundwater/surface water interactions were largely unknown. The implications of our findings to date have helped quantify how much of the surface flows of the rivers come directly from groundwater and vice versa. These findings have direct relevance to many communities that rely on Hill Country streams and rivers as the source of their drinking water and livelihood as well as aquatic organisms living in the river.

Now that we have a better understanding of the groundwater-surface water dynamics of the Blanco, Onion and Pedernales Rivers, the Meadows Center sought to expand our research using the same methodology in the Guadalupe River Basin (GRB) from the headwaters to the tide waters. The key questions addressed in this desktop study report include:

1. What research gaps exist across transboundary lines?
2. How have Guadalupe River flow rates changed relative to recent droughts and other climactic factors?
3. What factors play a significant role in the gaining and losing reaches of the river?

This report should be considered a preliminary report as many data gaps were identified for further study in the next phase of "How Much Water is in the Guadalupe?: Headwaters to Gulf".

STUDY AREA

According to USGS' An Assessment of Streamflow Gains and Losses and Relative Contribution of Major Springs to Streamflow (2008), the study area is described as follows:

> *The headwaters of the Guadalupe River form in south¬western Kerr County. From there, the river flows easterly for about 250 river miles to Gonzales, then southeasterly for another 150 river miles to join the San Antonio River 11 river miles upstream from Guadalupe Bay, which is part of the San Antonio Bay system. The drainage area of the Guadalupe River is about 10,200 square miles including the San Antonio River watershed. The study area—the GRB upstream from the confluence of the Guadalupe and San Antonio Rivers—comprises 5,974 square miles and excludes the San Antonio River Basin. The Blanco River and San Marcos River are principal tributaries of the Guadalupe River. Two major reservoirs exist in the GRB. Canyon Lake is on the Guadalupe River in Comal County, about 12 miles northwest of New Braunfels. The reservoir impounds runoff from 1,432 square miles of drainage area and has 382,000 acre-feet of authorized conservation storage. Construction of the dam and reservoir began in 1958 and impoundment began in 1964. Coleto Creek Reservoir is on Coleto and Perdido Creeks, about 12 miles southwest of Victoria. The dam was completed in 1980 and impounds run¬off from 507 square miles of drainage area. Conservation storage for the reservoir is 35,060 acre-feet. The primary purpose of the reservoir is to provide cooling water for electric power generation.*
>
> *Major population centers of the GRB include the cities of Kerrville, New Braunfels, San Marcos, Seguin, Lockhart, Gonzales, Cuero, Luling, and Victoria, TX. Land use in the basin is predominantly rural. Elevation in the study area ranges from about 25 feet to more than 2,000 feet above sea level in the upstream parts of the GRB.*

The Guadalupe River originates within western Kerr County as three branches of the river (Johnson Creek, North Fork, and South Fork) merge west of Kerrville to form the main river course (Figure 1). From there, the river flows eastward through eastern Kerr County and beyond on its ultimate destination to the Gulf of Mexico.

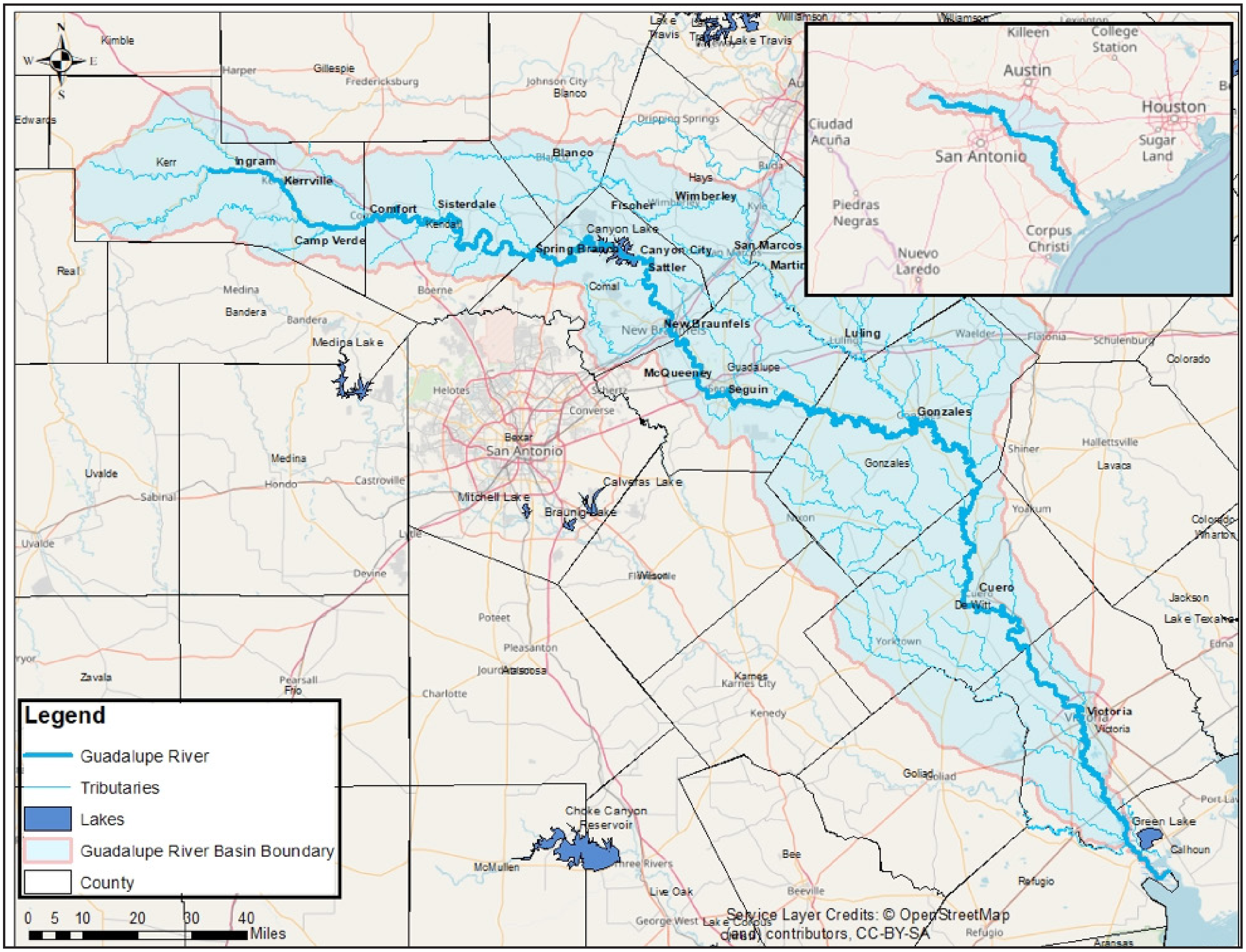

Figure 1 Guadalupe River Basin

Johnson Creek is the northernmost of the three river branches and enters the main stream at Ingram. The middle branch, or North Fork, merges with the South Fork at Hunt and, combined, they flow eastward to Ingram where they join Johnson Creek to form the main stem of the Guadalupe River (Ashworth, 2005).

Base flow in these creeks originates from various members in the Edwards Formation, such as the Fort Terrett and Segovia (Figure 2). Individual Edwards Formation beds are highly fractured and permeable, thus allowing precipitation to rapidly infiltrate downward to the groundwater table. The underlying Glen Rose limestone contains more clay, is less subject to fracturing, and therefore acts as a semi-impermeable barrier to further downward groundwater migration. Unable to migrate easily downward into the Glen Rose, much of the groundwater in the Edwards Aquifer preferentially moves laterally until it escapes its underground confinement and flows back to the land surface through springs and seeps (Ashworth, 2005) (Figure 3).

The number of springs in the headwaters area vary with precipitation. Much of the discharge measured at Comfort originates from the Edwards Formation in the headwaters area. Most springs are relatively small, but collectively, contribute significant flow to the river. The 1965 study by the USGS from the headwaters to Comfort (Kunze, 1966) states:

> *The Edwards and associated limestone contributed about 90 percent of the total 120 cfs measured at the lower limit of the investigated reach. Only a small amount, 10 percent or less, was contributed by the Glen Rose Limestone. Hydrographs for the stream-gaging stations on Johnson Creek near Ingram and on the Guadalupe River at Comfort show that discharge in the two streams was nearly constant.*

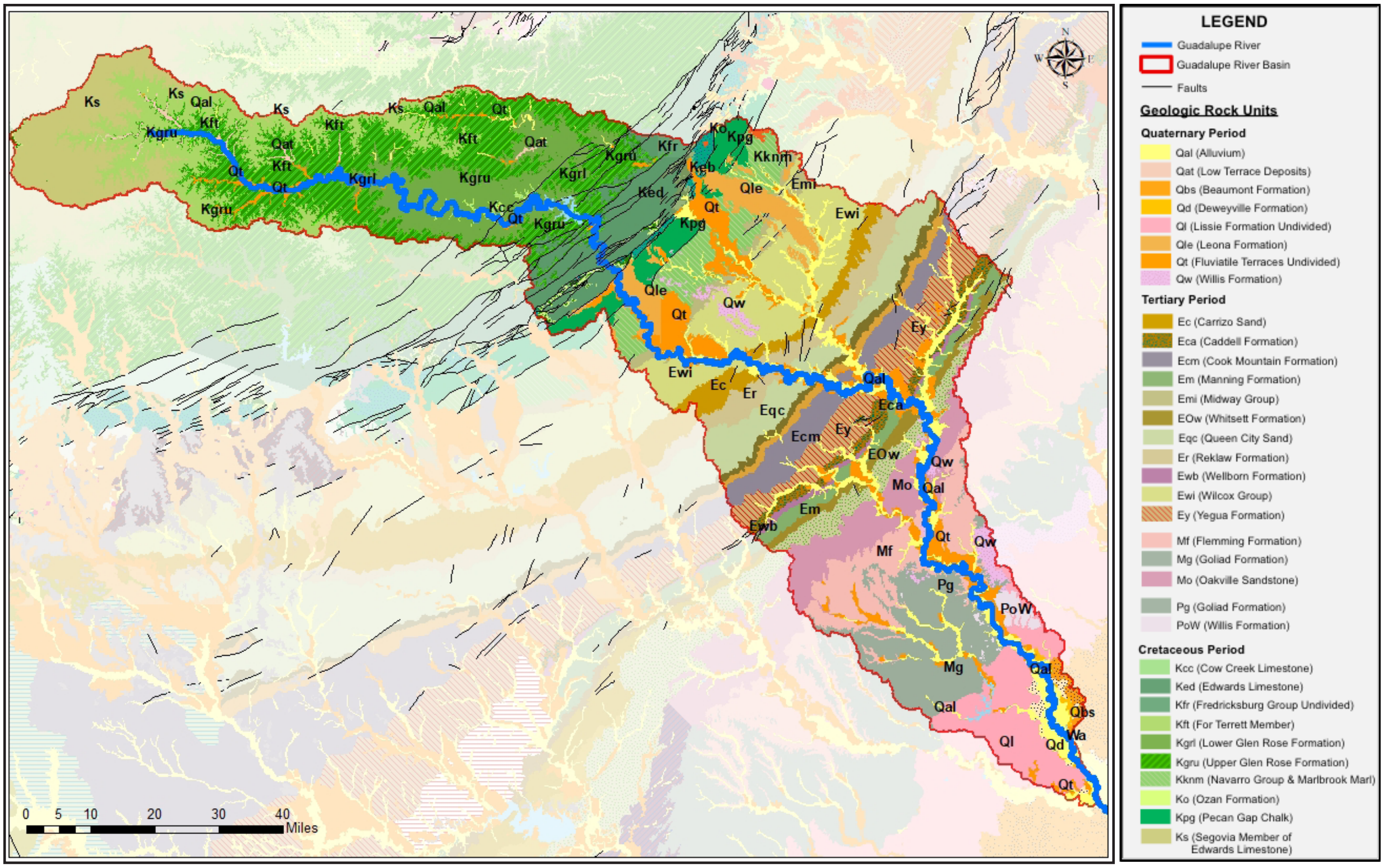

Figure 2 Geologic Map of the Guadalupe River Basin (TNRIS, 2018)

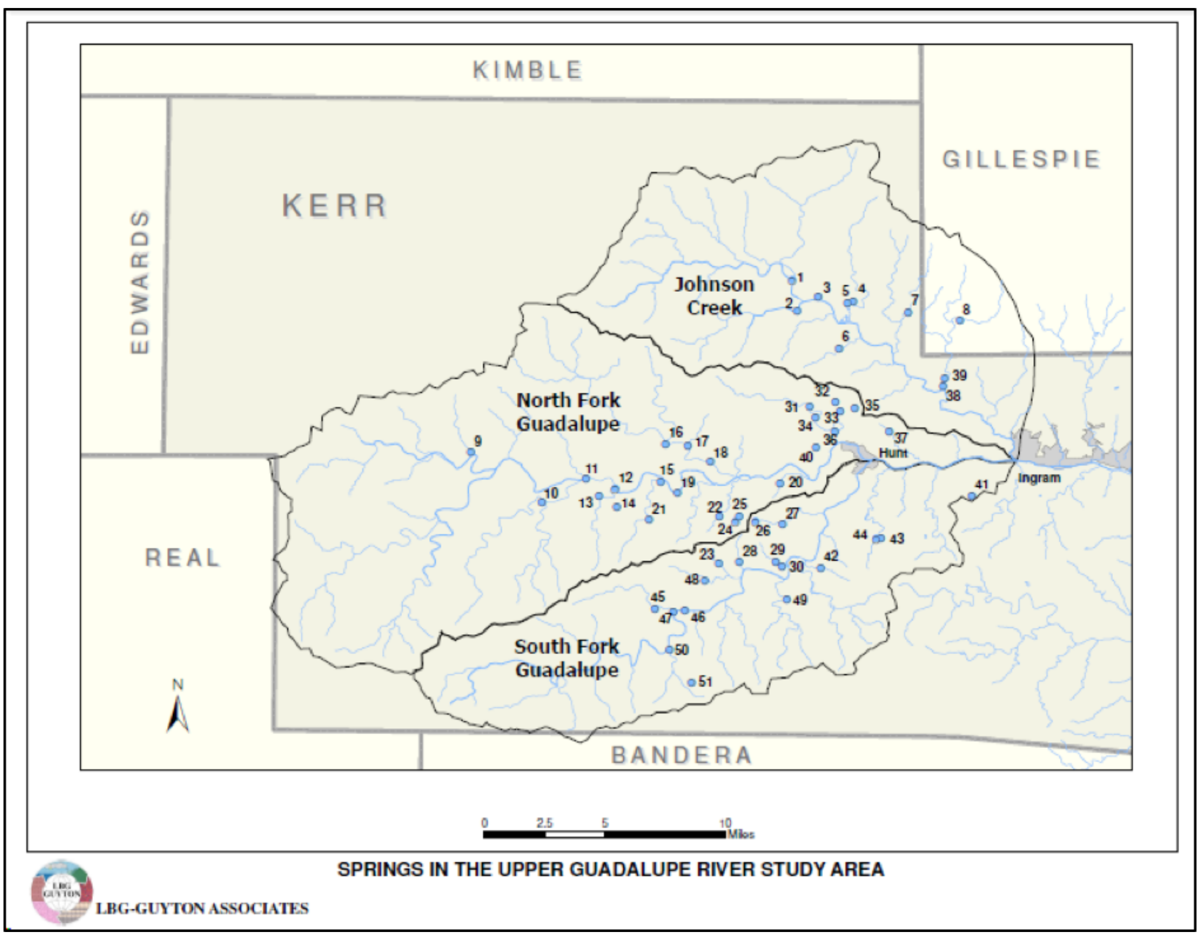

Figure 3 Springs in the Upper Guadalupe River Study Area (Ashworth, 2005)

Figure 4 Confluence of the North and South Forks at Hunt, TX (Image courtesy of UGRA website)

The river flows easterly across the lower Cretaceous Upper Glen Rose through Kerrville towards Comfort and Spring Branch, then into Canyon Lake. Canyon Lake is the largest impoundment on the Guadalupe River. It was completed in 1964 as a cooperative venture between the Guadalupe Blanco River Authority (GBRA) and US Army Corp of Engineers (USACE). The lake provides flood control and stored water supply. At maximum 'conservation pool' level of 909 feet elevation mean sea level (msl), the reservoir covers more than 8,200 surface acres and impounds 386,200 acre-feet of water to a depth of 140 feet. At maximum 'flood control pool' elevation of 943 feet msl, the reservoir impounds a total of 732,600 acre-feet of water (GBRA, 2018). Downstream from the lake, the river flows across the Edwards Limestone.

The Guadalupe River Basin includes five major springs: Comal Springs, San Marcos Springs, Hueco Springs, Pleasant Valley Springs and Jacobs Well. Comal, San Marcos, and Hueco Springs originate in the Edwards Aquifer. Comal Springs provides most of the flow in the Comal River, which joins the Guadalupe River at New Braunfels. The average discharge for Comal Springs for years 1933 – 2010 was 291 cfs (Wehmeyer, 2013). San Marcos Springs, with multiple outlets, provides most of the base flow for the San Marcos River, which joins the Guadalupe River near Gonzales. The annual average discharge for San Marcos Springs for years 1957 – 2010 was 175 cfs. (Wehmeyer, 2013). Hueco Springs occurs on the west side of the Guadalupe River about 3 miles upstream from New Braunfels. The average discharge for Hueco Springs is about 52 cfs (2004-2008) (Wehmeyer, 2013).

Pleasant Valley Springs and Jacobs Well originate from the Trinity Aquifer in the Blanco River Basin and provide the vast majority of Blanco discharge at Wimberley, TX. There is a large losing reach in the Blanco River downstream of the springs which provides recharge to the Edwards Aquifer and San Marcos Springs. From the Texas Board of Water Engineers (TBWE) (1960): *Available quality-of-water data indicate that the immediate sources of water for Comal and San Marcos Springs are different. The analyses suggest that the Blanco River might be a source of part or all of the flow of San Marcos Springs. It does not appear from that data that the flow of Comal Springs is derived from the usual flow of the Guadalupe River.* Recent dye trace studies have confirmed the connection of the Blanco River and San Marcos Springs (Johnson, 2012).

The Edwards Aquifer Recharge Zone occurs west, or upgradient of the Balcones Fault Zone. From New Braunfels, the river crosses over a series of Upper Cretaceous Formations, including the Del Rio, Buda Limestone, Austin Chalk, Pecan Gap, and Navarro. None of these formations are considered major aquifers.

Downstream of the Upper Cretaceous Formations is the Tertiary Carizo-Wilcox major aquifer followed by the Queen City, Sparta, and Yegua-Jackson minor aquifers. From roughly the Dewitt County line to the gulf, the river flows over the Gulf Coast aquifer system. Quaternary alluvium has developed in much of the river channel downstream of the Balcones Fault Zone.

Major tributaries of the Guadalupe River are the Comal River, Blanco/San Marcos/Plum Creek, Peach Creek, Sandies Creek, Coleto Creek, and the San Antonio River which connects with the Guadalupe River near the gulf where it flows into San Antonio Bay. A second major reservoir, Coleto Creek Reservoir was constructed in 1980 on Coleto and Perdido Creeks. The reservoir provides power plant cooling water and recreational opportunities.

The Calhoun Canal System is a major diversion of water from the main channel near Tivoli, TX. The diversion is operated by GBRA under permits authorized by the state of Texas. The system is a canal network for distribution to industrial, municipal, and agricultural customers in Calhoun County through a series of irrigation canals, checks, pump stations, and pipelines. A large volume of water is also delivered to agricultural users, primarily for rice irrigation, but also including row crop, pasture, aquaculture, and waterfowl operations. The operation and maintenance of approximately 75 miles of canals is required for delivery to customers. Although most of the water is delivered during the spring and summer growing season, year-round deliveries are necessary due to the variety of needs and scheduling for all customers (GBRA, 2018).

Figure 5 The mouth of the South Guadalupe River empties into San Antonio Bay (J.M. Scott, mySA.com, 2016)

The major population centers along the river include Kerrville, New Braunfels, San Marcos, Seguin, Lockhart, Gonzales, Cuero, Luling, and Victoria, TX. The basin includes portions of Kerr, Kendall, Comal, Hays, Guadalupe, Caldwell, Gonzales, De Witt, Goliad, and Victoria counties. Population is projected to increase by 22.8 percent by 2030, 46.7 percent by 2040, 68.2 percent by 2050, 96.5 percent by 2060 and 126.6 percent by 2070. Water demand for the basin is projected to increase by 20.2 percent by 2030, 38.3 percent by 2040, 57 percent by 2050, 80.2 percent by 2060 and 96.0 percent by 2070 (SCTRWP, 2016). Population and demand projections are shown on Table 1.

Guadalupe River Basin Projected Population and Water Demand

	2020	2030	2040	2050	2060	2070
Population	555,051	681,755	814,463	933,374	1,090,528	1,257,651
Water Demand (ac-ft)	194,049	238,393	268,008	305,379	349,619	380,350

Table 1 Projected Total Population and Water Demand (SCTRWP, 2016)

SCOPE OF PROJECT

To accomplish the goals of the study, the following activities took place:

1. A literature review of readily available studies and data regarding surface water/groundwater interactions in the river basin;
2. One-on-one interviews with governmental agencies;
3. Identification and inventory of historical data from USGS surface water monitoring gages throughout the basin;
4. Creation of a master database of historic surface water flow data from the USGS gages;
5. Preliminary analysis of historic flow trends;
6. Assessment of main channel gain/loss over time for the entire main channel and individual reaches;
7. Assessment of major tributary flow contribution to main channel flow;
8. Identification of major inflows and outflows;
9. Identification of data gaps and proposed plan to address existing gaps.

LITERATURE REVIEW

The following publications were key references that helped frame our understanding of the surface water/groundwater interactions of the GRB:

- Spring Flow Contribution to the Headwaters of the Guadalupe River In Western Kerr County, Texas by John Ashworth (2005) describes the geologic occurrence and location of many of the headwaters springs in the Hill County portion of the upper river basin;
- Base-Flow Studies, Upper GRB, Texas reports on gain/loss studies (flow and water quality) performed in 1965 by the U. S. Geological Survey in cooperation with the Texas Water Development Board. Study area included the reach between the headwaters and Comfort, TX;
- Streamflow Conditions in the GRB, South-Central Texas, Water Years 1987–2006 (Ockerman, 2008) included an assessment of streamflow gains and losses and relative contribution of Comal, San Marcos, and Hueco springs to streamflow;
- Channel Gain and Loss Investigations – Texas Streams was prepared by TBWE in 1960 and contains many gain/loss studies from throughout Texas from 1918 to 1958. Studies within the Guadalupe Basin includes Guadalupe River (1928, 1929 and 1955), Blanco River (1924, 1955, and 1957), and San Marcos Springs in 1955;
- A Preliminary Assessment of Streamflow Gains and Losses for Selected Stream Reaches in the Lower GRB, Texas (Wehmeyer, 2013) compares three gain/loss performed during 2010 and 2012 from Canyon Lake to Tivoli, TX;
- Surface Water/Groundwater Interaction Evaluation for 22 Texas River Basins prepared by Parsons Engineering Science, Inc. (1999) provides a summary of the geology and water interaction within the basin;
- Tens of thousands of records of daily mean discharge data from USGS stream gages were downloaded and consolidated into a single data base. This data was used to analyze surface water/groundwater interactions and historic discharge trends;
- The Historical and Projected Climate (1901–2050) and Hydrologic Response of Karst Aquifers, and Species Vulnerability in South-Central Texas and Western South Dakota report provided valuable insights into projected future changes in spring flow and aquifer levels due to temperature and precipitation trends (Stamm, 2015).


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RESOURCE MANAGEMENT/GOVERNMENT AGENCIES

The Edwards Aquifer Authority (EAA) was created by the Texas Legislature in 1993, at the behest of United States District Judge Lucius Bunton. The judge's ruling earlier that year ordered the U.S. Fish & Wildlife Service to set minimum spring flow standards for Comal and San Marcos springs, the two largest springs in the southwestern United States, to protect endangered species that relied on those springs for their survival. The Texas Legislature reacted to Bunton's decision by creating the EAA as the regulatory agency overseeing groundwater in the Edwards Aquifer. Pumping limits were written into the law designating the conservation and reclamation district, a first for Texas (EAA, 2018). The EAA initiated a multi-year Inter-Formational Flow Study in 2014 to study surface water/groundwater interactions and the relationship to inter-formational flow between the Trinity and Edwards Aquifers in the Balcones Fault Zone. The Guadalupe/Blanco Basin is one of four basins to be studied. As of this time, work has focused in other basins and work in the Guadalupe Basin is still getting underway.

The GBRA was created in 1933 by the Texas Legislature as a water conservation and reclamation district and a public corporation to provide stewardship for the water resources in its ten-county district spanning from near the headwaters of the Guadalupe and Blanco Rivers to the San Antonio Bay. GBRA provides a daily summary of the flow in the Canyon Reservoir and the river at New Braunfels and Victoria on their website (GBRA, 2018). Comal and San Marcos springs are individually accounted in the daily report with all other flow lumped as "natural baseflow" which include the net difference of all other inflows and outflows. A better understanding of the components of "natural baseflow". The quantification of groundwater inflow, diversions and inflows in the basin is necessary to develop a better understanding of the components of "natural baseflow".

Both EAA and GBRA are active partners of the Edwards Aquifer Habitat Conservation Plan (EAHCP) – a collaborative effort to provide assurance that suitable habitat for covered species will remain in the San Marcos and Comal Springs, despite lawful water use activities within the Edwards Aquifer region.

The Upper Guadalupe River Authority (UGRA) was created as a conservation and reclamation district by the Texas Legislature in 1939 to protect, develop, and manage the water quantity, quality, and sustainability in the Guadalupe watershed in Kerr County. UGRA works with USGS to monitor Guadalupe River sites downstream from known springs or spring groups.

The Texas Commission for Environmental Quality (TCEQ) South Texas Watermaster Program tracks all water rights in the Guadalupe, Blanco, and San Antonio River basins totaling an estimated 6 million acre feet of water with 60 percent sourced in the Guadalupe River. It is projected that less than half the allocated water rights are currently active. An analysis of the geographic distribution of these diversions and a correlation with climate has not been performed at this time.

HISTORICAL TRENDS

The GRB is approximately 480 miles from the headwaters at Hunt, TX to the mouth of the San Antonio Bay near Tivoli, TX. The basin has 21 USGS gaging stations on the main channel, eight major tributary gaging stations near the confluence of the tributary and the main channel, and five major spring gaging stations that influence surface water flow in the basin. Table 2 provides detailed information on each gaging station. Streamflow data was downloaded from the USGS Water Data website (USGS, 2018) and used to create stream flow discharge hydrographs. Daily mean discharge data is available in Appendix B for the POR of each gaging station. It should be noted that there is missing or incomplete streamflow information, or a short POR for some of the gaging stations, therefore not all gaging stations shown in the basin map in Figure 7 were used for this study. As a result of the Memorial Day 2015 flood on the Blanco River, additional gages have been installed on the Blanco (Figure 6). Due to the short POR of these gages, they were not used in this study.

Figure 6 Blanco River Gaging Station at Fischer Store Road

Table 2 USGS Gaging Stations for the Guadalupe River Basin

Note: The main channel gaging data from stations 6, 9, 11, 12, 14, and 19 were of limited utility due to a relatively short POR and discontinuous data.

Map ID	USGS Station Gage	River Mile	Location	County	Longitude	Latitude	Drainage Area (m^2)	Period of Record	
Main Channel Gaging Stations									
1	08165500	479	Guadalupe Rv at Hunt, TX	Kerr	-99.3217	30.0699	288	1941-10-17	2018-05-14
2	08166140	469	Guadalupe Rv abv Bear Ck at Kerrville, TX	Kerr	-99.1953	30.0696	494	1978-04-27	2018-04-26
3	08166200	466	Guadalupe Rv at Kerrville, TX	Kerr	-99.1633	30.0532	510	6/12/1986	2018-05-14
4	08166250	459	Guadalupe Rv nr Center Point, TX	Kerr	-99.11	29.9877	553	2008-02-01	2018-05-14
5	08167000	439	Guadalupe Rv at Comfort, TX	Kendall	-98.8971	29.9652	839	1939-05-31	2018-04-26
6	08167200	404	Guadalupe Rv at FM 474 nr Bergheim, TX	Kendall	-98.6698	29.8935	NA	10/26/2016	2018-04-26
7	08167500	366	Guadalupe Rv nr Spring Branch, TX	Comal	-98.3836	29.8604	948	1922	2018
8	08167800	336	Guadalupe Rv at Sattler, TX	Comal	-98.1800	29.8591	1436	1960	2018
9	08167900	326	Guadalupe Rv at Third Crossing nr Sattler, TX	Comal	-98.1630	29.8036	NA	2014-09-20	2018-04-26
10	08168500	313.3	Guadalupe Rv abv Comal Rv at New Braunfels, TX	Comal	-98.1100	29.7149	1518	1927	2018

Map ID	USGS Station Gage	River Mile	Location	County	Longitude	Latitude	Drainage Area (m^2)	Period of Record	
11	08169500	311	Guadalupe Rv at New Braunfels, TX	Comal	-98.1066	29.6980	1652	1915-01-27	2018
12	08169740	285	Guadalupe Rv at Hwy 123-BR at Seguin, TX	Guadalupe	-97.9693	29.5514	NA	2016-10-14	2018-04-26
13	08169792	274	Guadalupe Rv at FM 1117 nr Seguin, TX	Guadalupe	-97.8809	29.5361	1957	2005-03-15	2018-04-26
14	08169845	224	Guadalupe Rv at CR 143 nr Gonzales, TX	Gonzalez	-97.5875	29.4876	2069	2016-07-29	2018-04-26
15	08172900	195	Guadalupe Rv at Gonzales, TX	Gonzalez	-97.4502	29.4844	3490	1996-10-01	2018-04-26
16	08174700	154	Guadalupe Rv at Hwy 183 nr Hochheim, TX	Dewitt	-97.3035	29.3144	4071	2010-01-28	2011-04-14
17	08175800	118	Guadalupe Rv at Cuero, TX	Dewitt	-97.3297	29.0905	4934	1964-01-01	2018-04-26
18	08176500	58	Guadalupe Rv at Victoria, TX	Victoria	-97.0130	28.7930	5198	1934-11-04	2018-04-26
19	08177520	31.8	Guadalupe Rv nr Bloomington, TX	Victoria	-96.9652	28.6619	5861	2011-10-01	2018-04-26
20	08188800	11.4	Guadalupe Rv nr Tivoli, TX	Refugio	-96.8847	28.5058	10128	2000-08-04	2018-04-26
21	08188810	8.4	Guadalupe Rv at SH 35 nr Tivoli, TX	Calhoun	-96.8627	28.4783	10280	2013-03-10	2018-04-26
Tributaries (river mile are at the confluence of the Guadalupe River)									
Trib 1	08165300	480	N Frk Guadalupe Rvr	Kerr	-99.3869	30.0640	169	1967-08-01	2018-04-26
Trib 2	08166000	473	Johnson Creek	Kerr	-99.2827	30.1	114	1941	2018
Trib 3	08169000	312	Comal Rvr	Comal	-98.1222	29.7064	130	1967	2018
Trib 4	08173000	200	Plum Creek @ Luling/San Marcos River	Caldwell	-97.6033	29.6994	309	1967	2018
Trib 5	08174600	168	Peach Crk	Gonzalez	-97.3163	29.4738	460	1967	2018
Trib 6	08175000	119	Sandies Creek nr Weshoff, TX	Dewitt	-97.4491	29.215	549	1939	2018
Trib 7	08177500	41	Coleto Crk	Victoria	-97.1383	28.7308	500	1939	2018
Trib 8	08188570	11.8	San Antonio Rvr nr McFaddin, TX	Refugio	-97.0426	28.5312	4,134	2005	2018
Springs									
Sprg 1	08168710	NA	Comal Spring	Comal	-98.1222	29.7058	NA	1956	2018
Sprg 2	08168000	NA	Hueco Spring	Comal	-98.1397	29.7591	NA	2002	2018
Sprg 3	08170000	NA	San Marcos Spring	Hays	-97.9338	29.8888	NA	1927	2018
Sprg 4	08170990	NA	Jacobs Well Spring nr Wimberley, TX	Hays	-98.1261	30.0344	NA	2005	2018
Sprg 5	NA	NA	Pleasant Valley Spring measured at Fischer Store Rd Bridge	Hays	-98.1277	30.035	NA	NA	NA

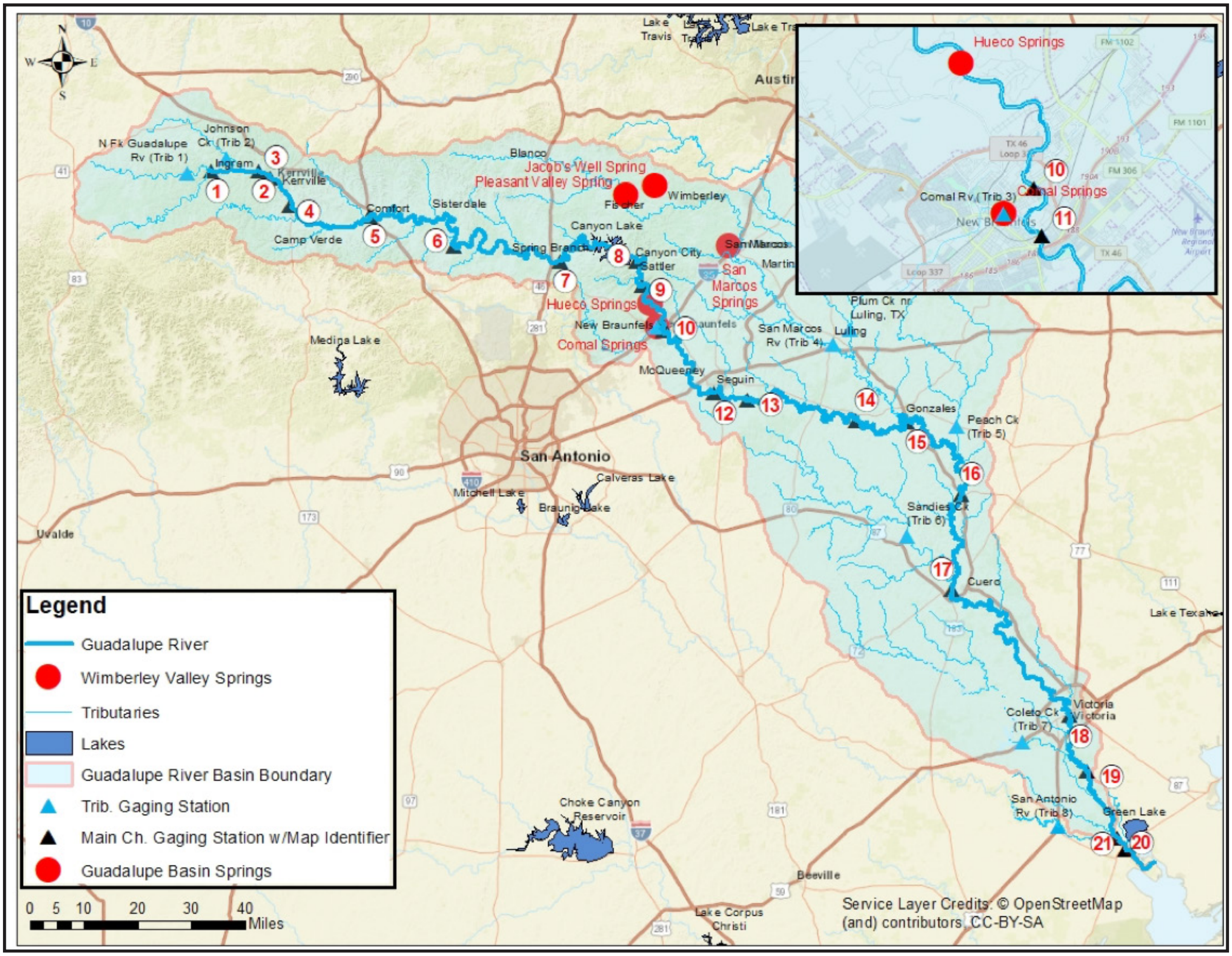


Figure 7 Guadalupe River Basin Map with Gaging Stations

Representative data from select USGS gages are presented in the following sections to describe long term (POR) and intermediate term discharge trends (2000 – 2017). The remaining gaging stations hydrographs are available in Appendix B.

Main Channel

USGS 08165500 located at Hunt, TX

The USGS gaging station at Hunt, TX is at the confluence of the North and South Forks of the Guadalupe River and representative of the headwaters springs. The drainage area is 288 square miles. Figure 8 represents the daily mean discharge data from 1965 to 2017. The trend analysis indicates that this segment of the river has a slight decreasing trend over the POR. The graph also indicates there have been many "flashy" floods over the POR. A more recent analysis from 2000 to 2017 (Figure 9) indicates that the daily mean discharge is trending down. Most notably are the summer months of 2011, 2013, and 2014 when streamflow dropped below ten cfs.

Discharge minimum, maximum, mean, and 25th percentile are presented in five-year increments as shown in Figure 10. The 25th percentile was used to represent low flows (base flow). The daily minimum is lowest between years 2010 to 2015. The daily maximum flows have been decreasing 1990 to 2017.

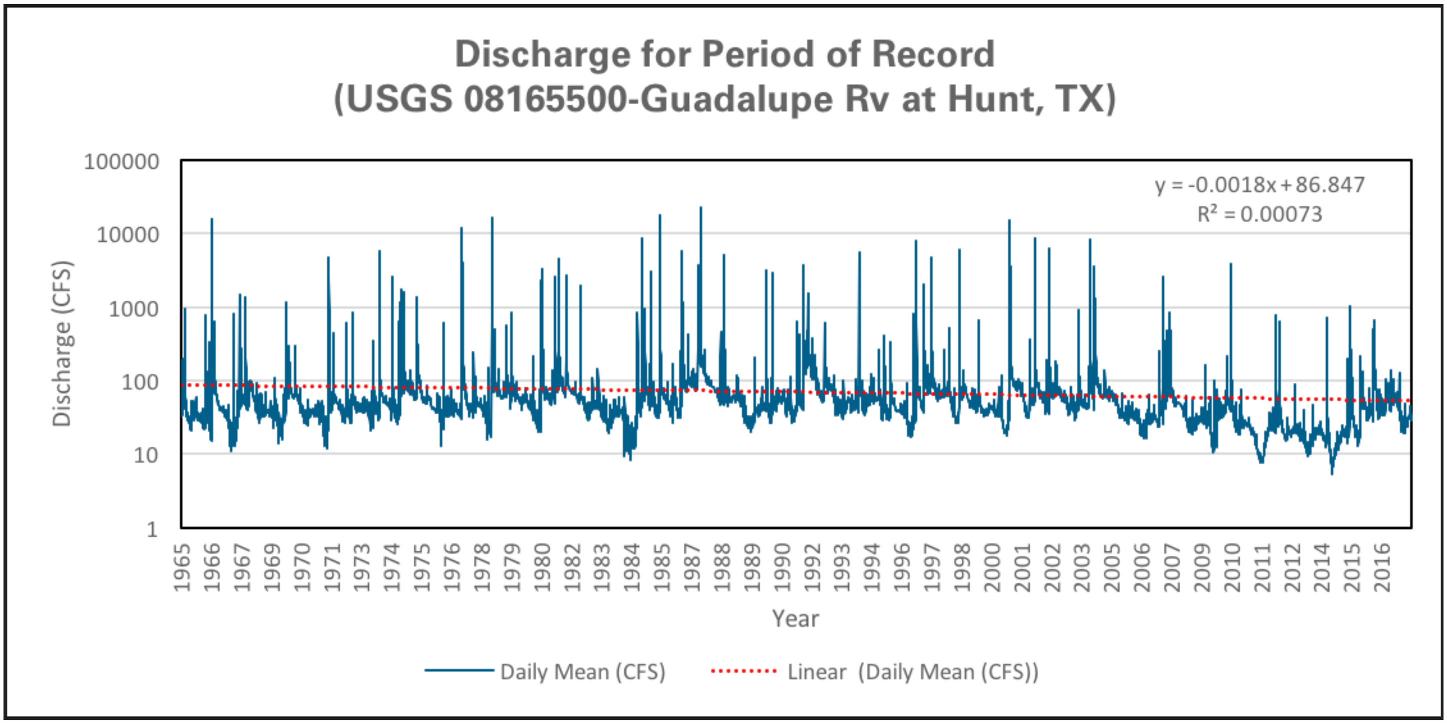


Figure 8 USGS Gaging Station 08165500 at Hunt, TX (1965-2017)

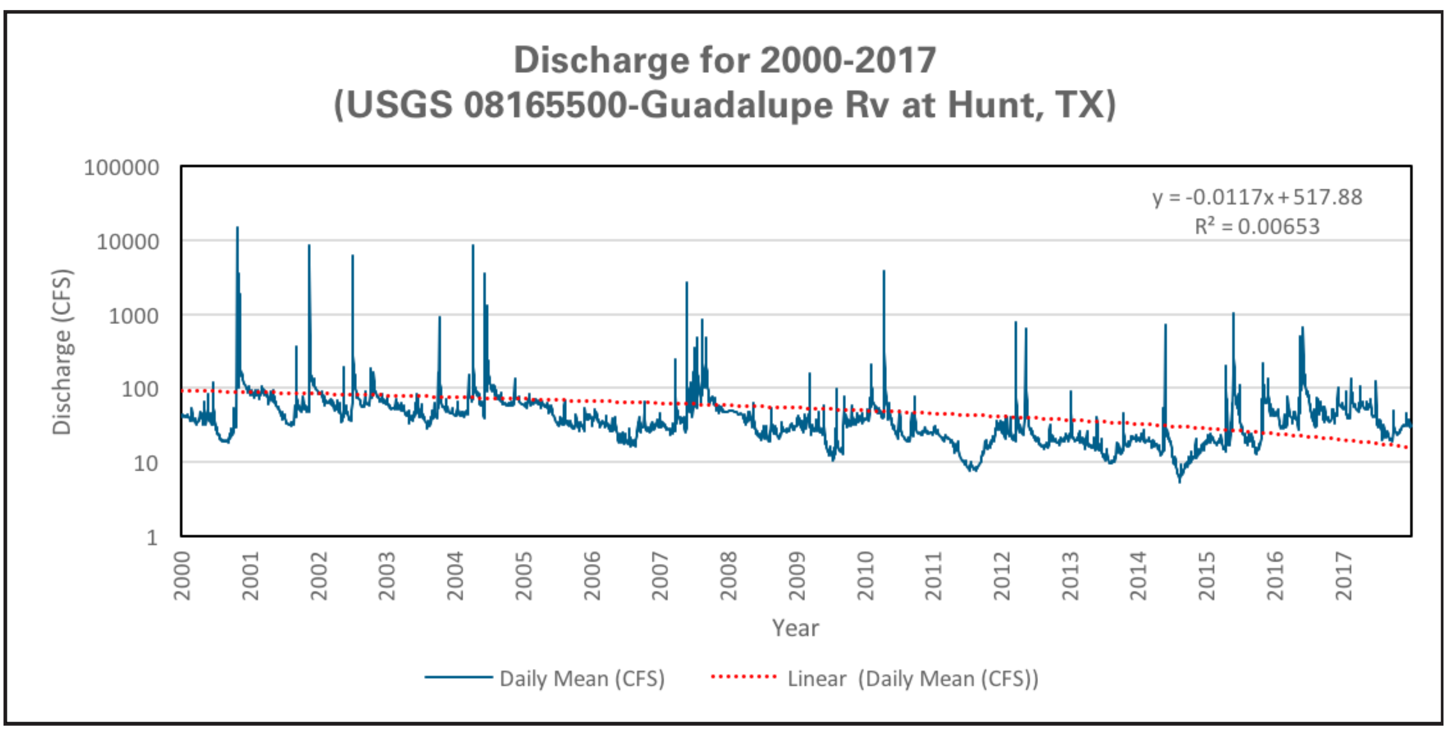


Figure 9 USGS Gaging Station 0815500 at Hunt, TX (2000-2017)

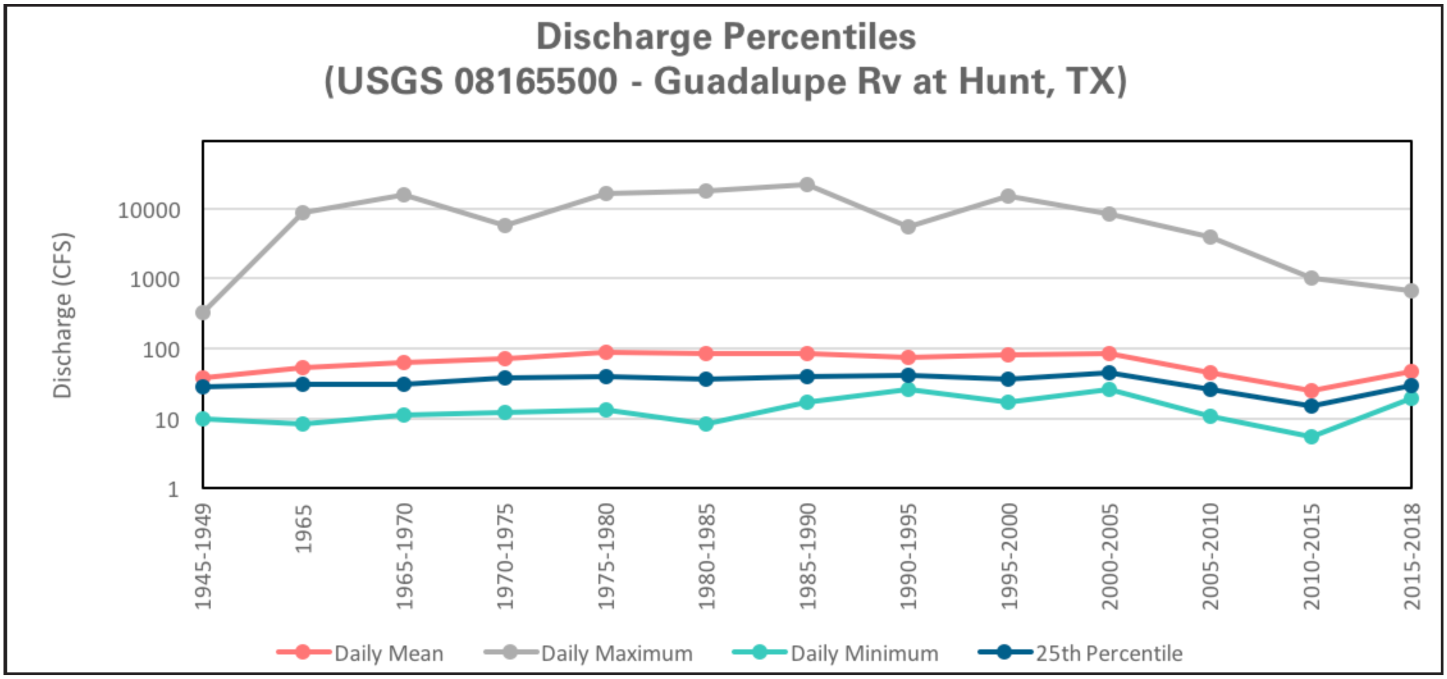


Figure 10 Discharge Minimum, Maximum, Mean, and 25th percentile for USGS Gaging Station 08165500 at Hunt, TX

USGS 08167500 located at Spring Branch, TX

The USGS gaging station at Spring Branch, TX is located at the 366-river mile marker and has a POR of 96 years. The drainage area is 948 square miles . Figure 11 represents the daily mean discharge data from 1922 to 2017. A simple linear trend analysis indicates increasing discharge over the POR. Discharge during the droughts of the 1950s, and 2000s was near or at zero. A more recent analysis from 2000 to 2017 (Figure 12) indicates that the daily mean discharge is trending down. Discharge at Hunt (Figure 8) is higher than at Spring Branch during the droughts of the 2000s. Previous studies note a natural losing reach between these two sites (Kunz, 1966). The loss of water may be from surface water diversion in Kerrville.

Discharge minimum, maximum, mean, and 25th percentile are represented in five-year increments as shown in Figure 13. The daily minimum is lowest between during the 1950s drought and more recently between 2010 and 2015. This is consistent with historical streamflow discharge graphs upstream gaging stations. The decreasing trend in maximum daily discharge observed at the Hunt gage is present but not as pronounced at Spring Branch.

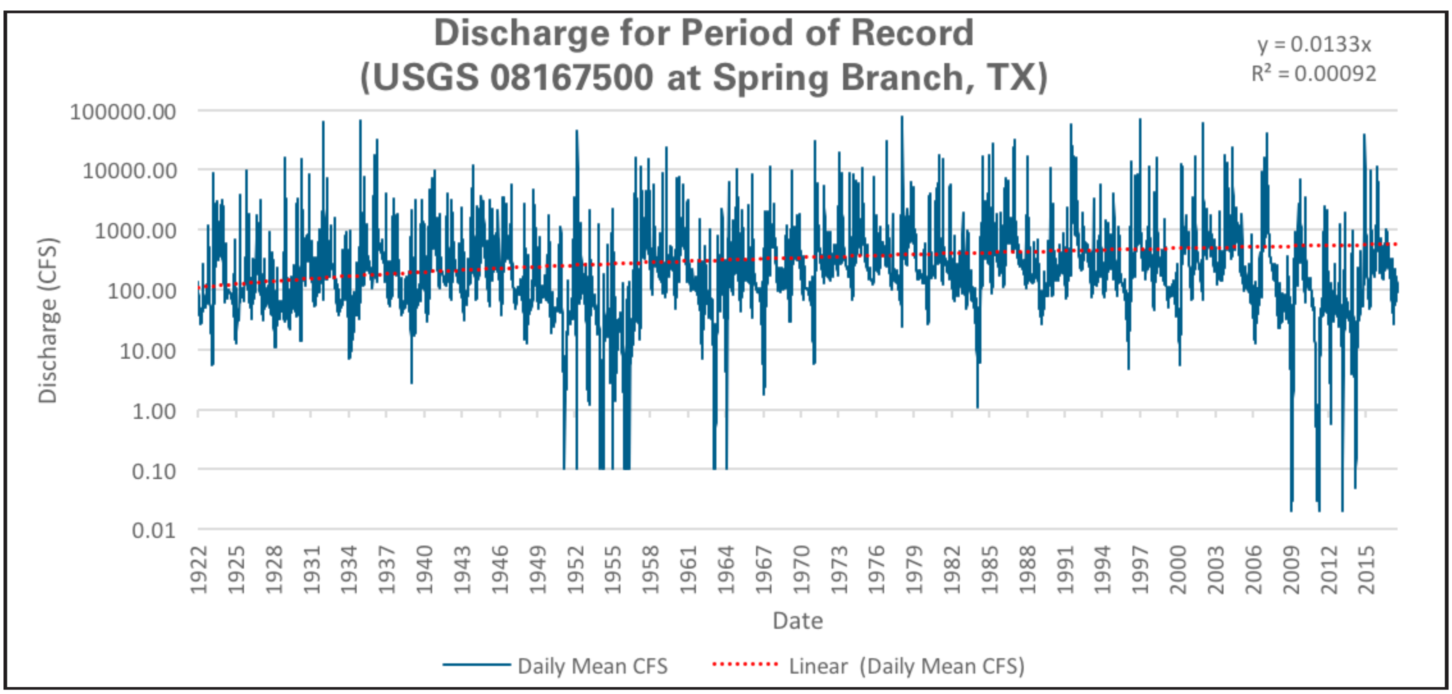


Figure 11 USGS Gaging Station 08167500 at Spring Branch, TX (1922 – 2017)

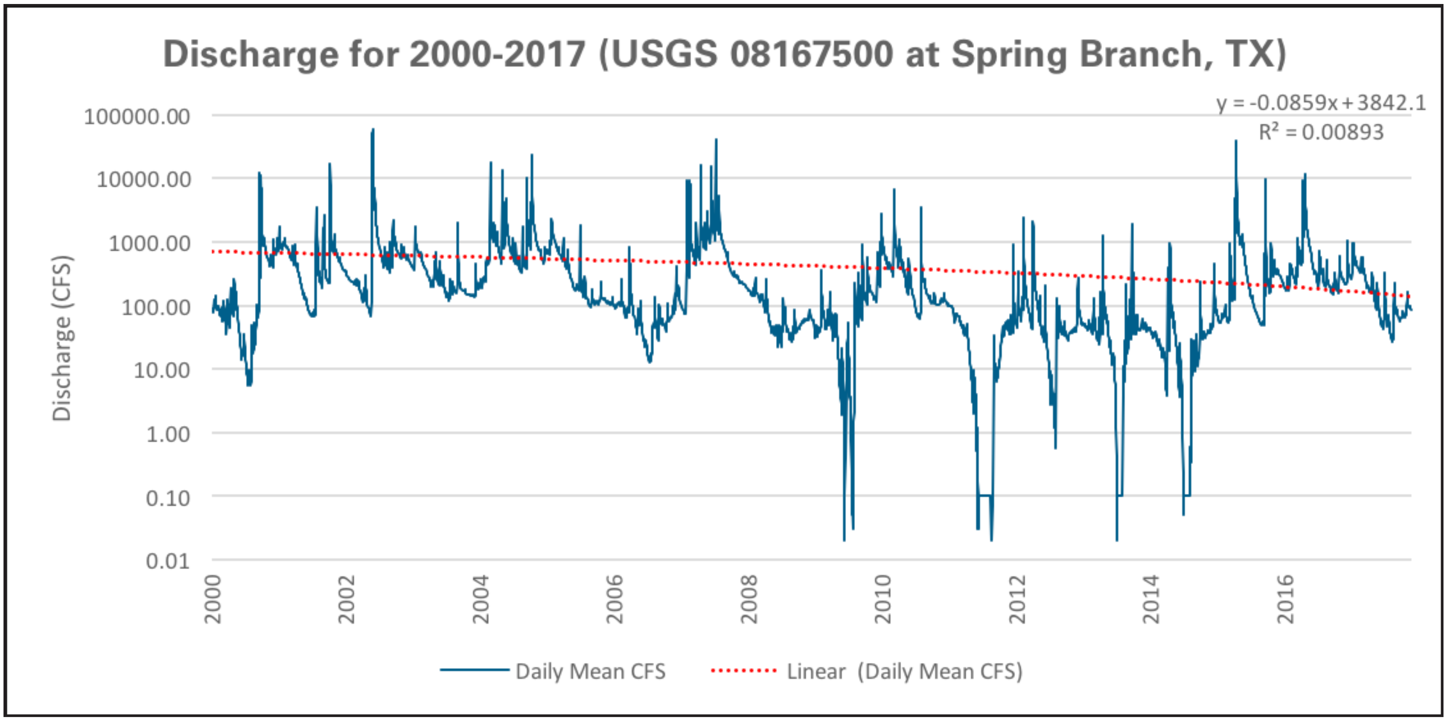


Figure 12 USGS Gaging Station 08167500 at Spring Branch, TX (2000 – 2017)

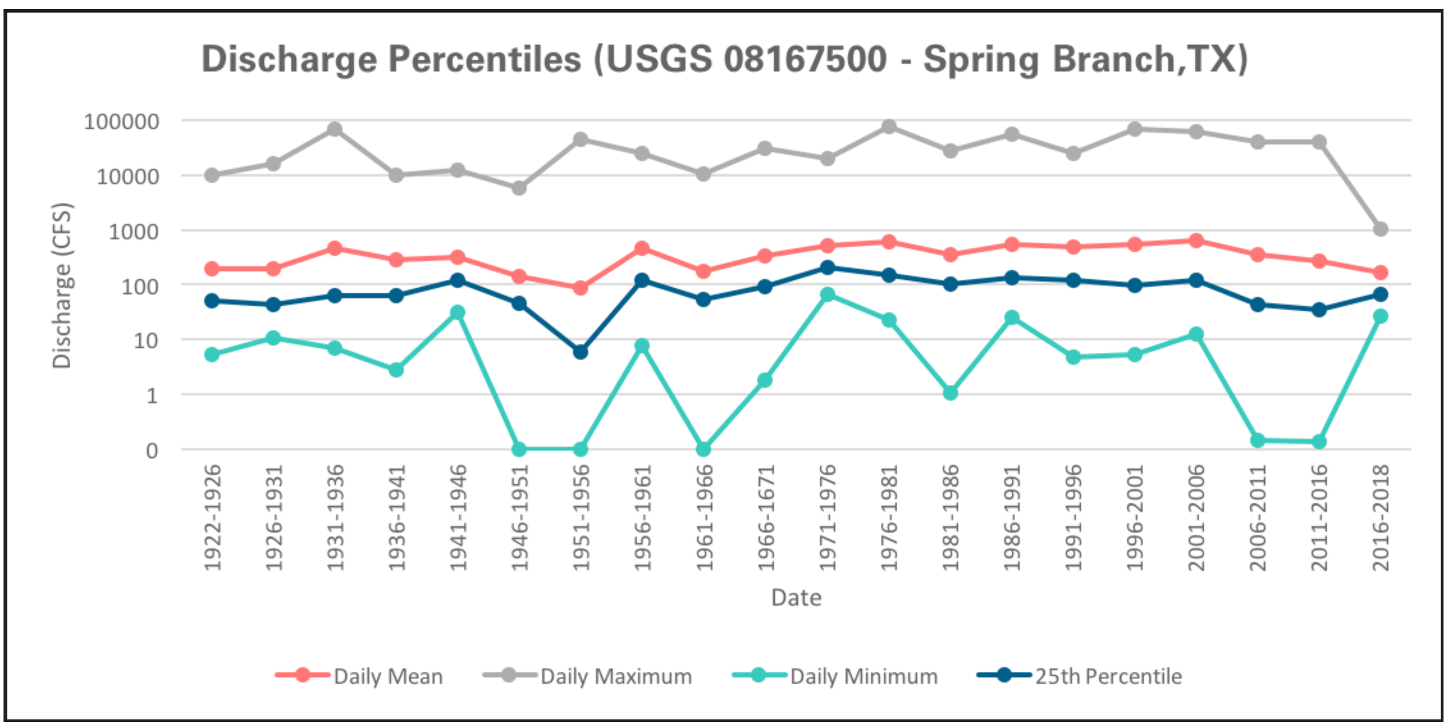


Figure 13 Discharge Minimum, Maximum, Mean, and 25th percentile for USGS Gaging Station 08167500 at Spring Branch, TX

USGS 08176500 located at Victoria, TX

The USGS gaging station at Victoria, TX is at the 58-river mile marker and has a POR of 84 years. The drainage area is 5,198 square miles. Figure 14 represents the daily mean discharge data from 1934 to 2017. The trend analysis indicates that this segment of the river is generally increasing over time. A more recent analysis from 2000 to 2017 (Figure 15) indicates that the daily mean discharge is trending down similar to the other locations.

Discharge minimum, maximum, mean, and 25th percentile are represented in five-year increments as shown in Figure 16. The lowest daily minimum streamflow is during the 1950s drought.

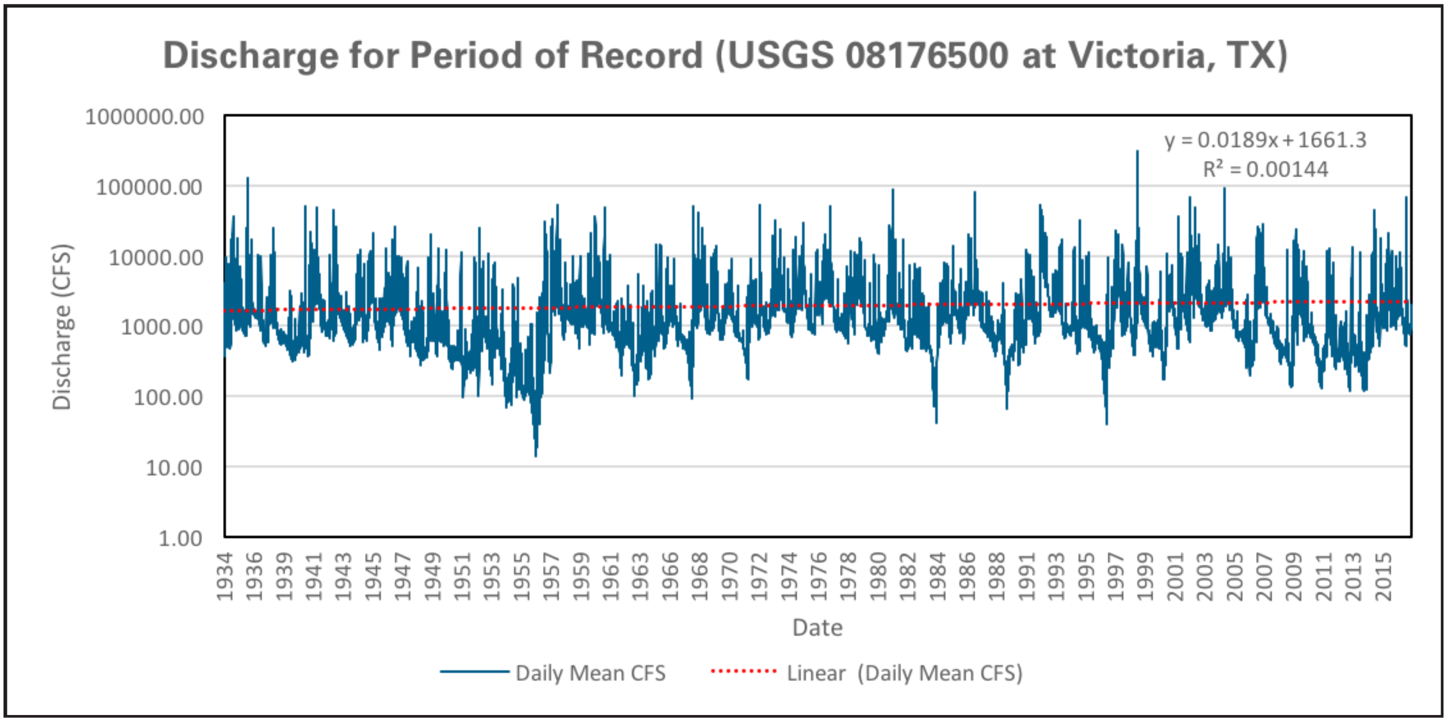


Figure 14 USGS Gaging Station 08176500 at Victoria, TX (1934 – 2017)

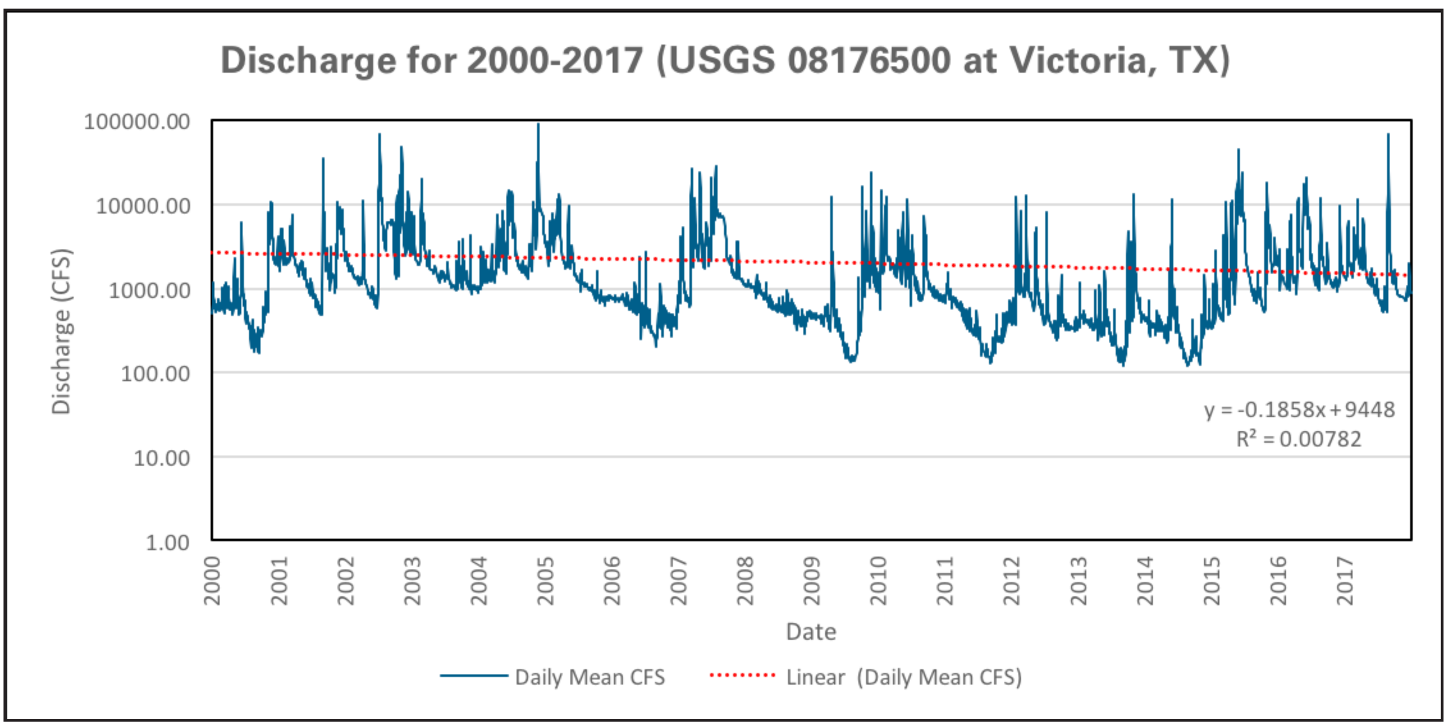


Figure 15 USGS Gaging Station 08176500 at Victoria, TX (2000 – 2017)

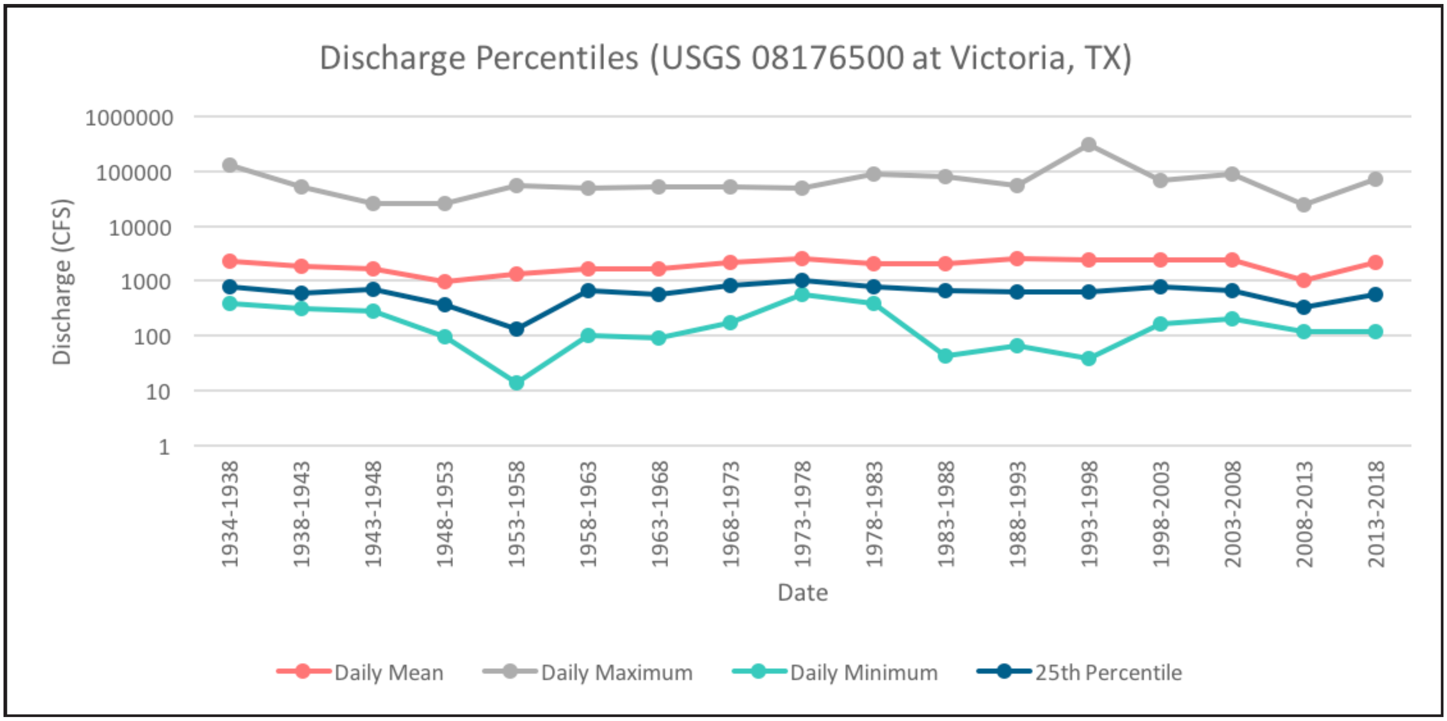


Figure 16 Discharge Minimum, Maximum, Mean, and 25th percentile for USGS Gaging Station 08176500 at Victoria, TX

Trends of Major Springs

Major Spring Flow Contributions

The contribution of major Edwards Aquifer springs to total river discharge is significant. Table 3 is a summary of average daily discharge for Comal Springs, San Marcos Springs, and Hueco Springs for 2003 – April, 2018. This time period was chosen based on the short POR for Hueco Springs and is reflective of the climatic conditions of the last 15 years in the basin. The headwater springs upstream of Ingram contribute spring flow to the river, but only a few of the springs are monitored. The USGS gage at Ingram (USGS #08166140) could be used as a surrogate for all of the headwaters springs, but the gage also measures storm flow in the headwaters watershed. Future studies are intended to parse out the base flow component of discharge and storm flow for the main channel gages. Pleasant Valley Spring and Jacob's Well (both Trinity Aquifer springs) are part of the Blanco River which contribute, in part, to San Marcos Springs (Johnson, 2012).

Table 3 Average Spring Discharge of Major Edwards Aquifer Springs (2003-2018)

Spring	Average Mean Daily Discharge (cfs)
Comal Springs	293
San Marcos Springs	186
Hueco Springs	46
Total	525

The average daily mean discharge for the three major springs is 525 cfs. A comparison of daily discharge measurements for the combined major spring discharge and the USGS gage at Victoria, TX is shown on Figure 17. The analysis only went back as far as the shortest POR, which is Hueco Springs. The comparison with Victoria versus Tivoli (a little further downstream) was made in that the Tivoli gage is downstream of the confluence with the San Antonio River. In general, the graphs trend together, reflecting the effect of precipitation in the basin. Occasional large, short term increases in discharge are noted at Victoria, likely related to heavy rainfall from the Gulf of Mexico on the lower reaches of the basin. Figure 18 is a simple illustration of the contribution of the major Edwards Aquifer springs to river discharge at Victoria. The percentage total spring discharge to river discharge ranged from one percent during Hurricane Harvey in 2017 to over 190 percent during the drought of 2011. Any percentage over 100 percent represents water losses (withdrawals and evaporation) between the springs and Victoria. The average contribution is 62 percent. Spring flow is greater than discharge at Victoria 11 percent of the time from 2003 to April 2018.

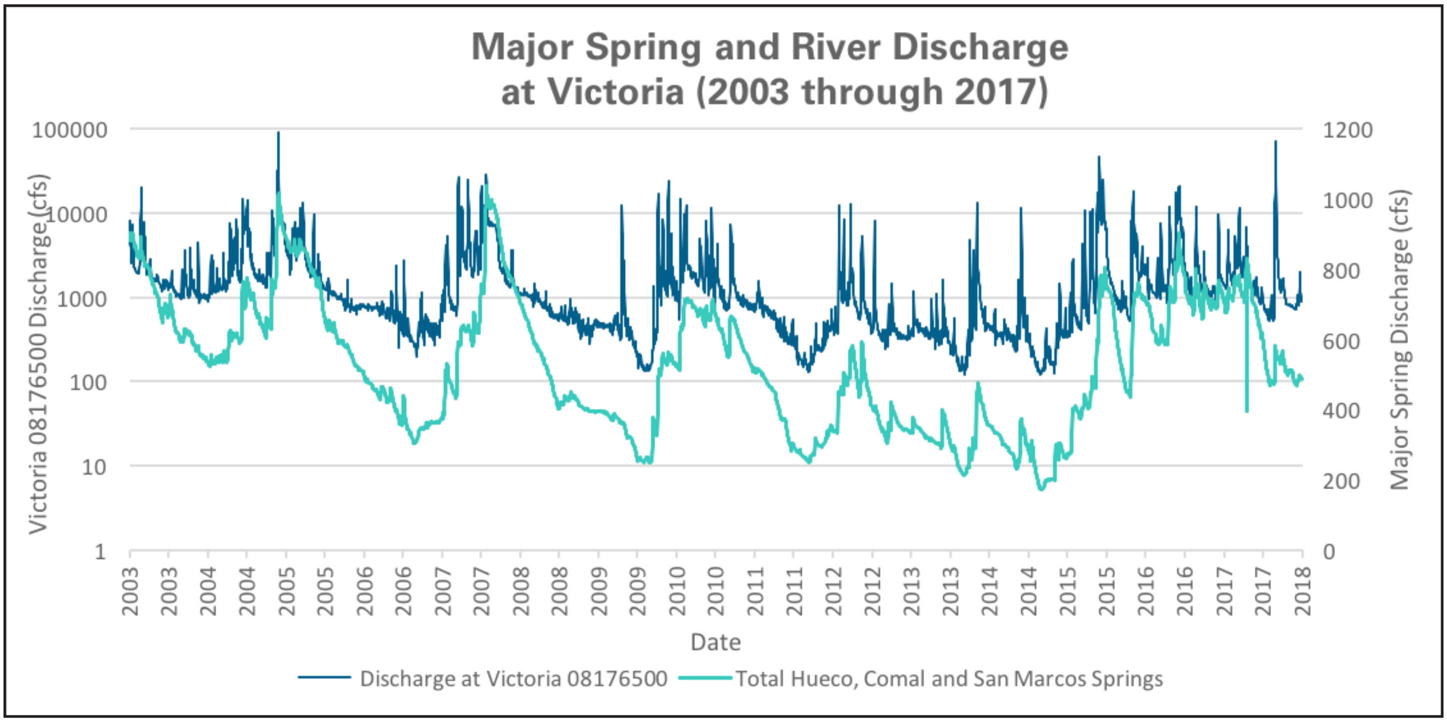


Figure 17 Major Spring and River Discharge at Victoria, TX

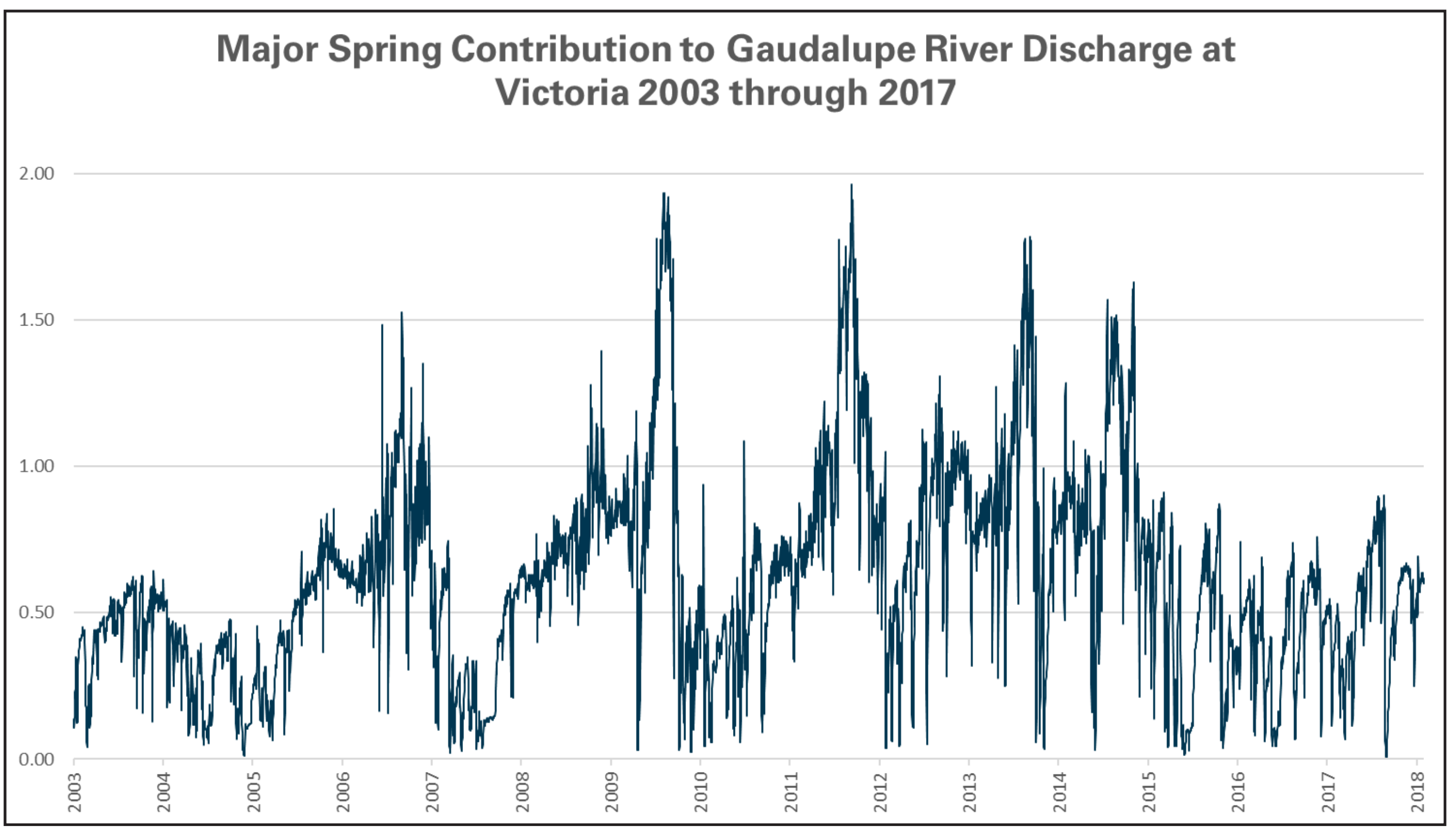


Figure 18 Percentage Major Spring Contribution to Guadalupe River Discharge at Victoria, TX (2003 through 2017)

Historic Discharge Trends of Major Springs

USGS Gaging Station 08170000 San Marcos Springs

The San Marcos Springs are the source of the San Marcos River and a major contributor to streamflow in the GRB. Figure 19 represents the daily mean discharge data from 1956 to 2017. The trend analysis indicates that the San Marcos River is generally increasing over the POR although a more recent analysis from 2000 to 2017 (Figure 20) indicates that the daily mean discharge is trending down.

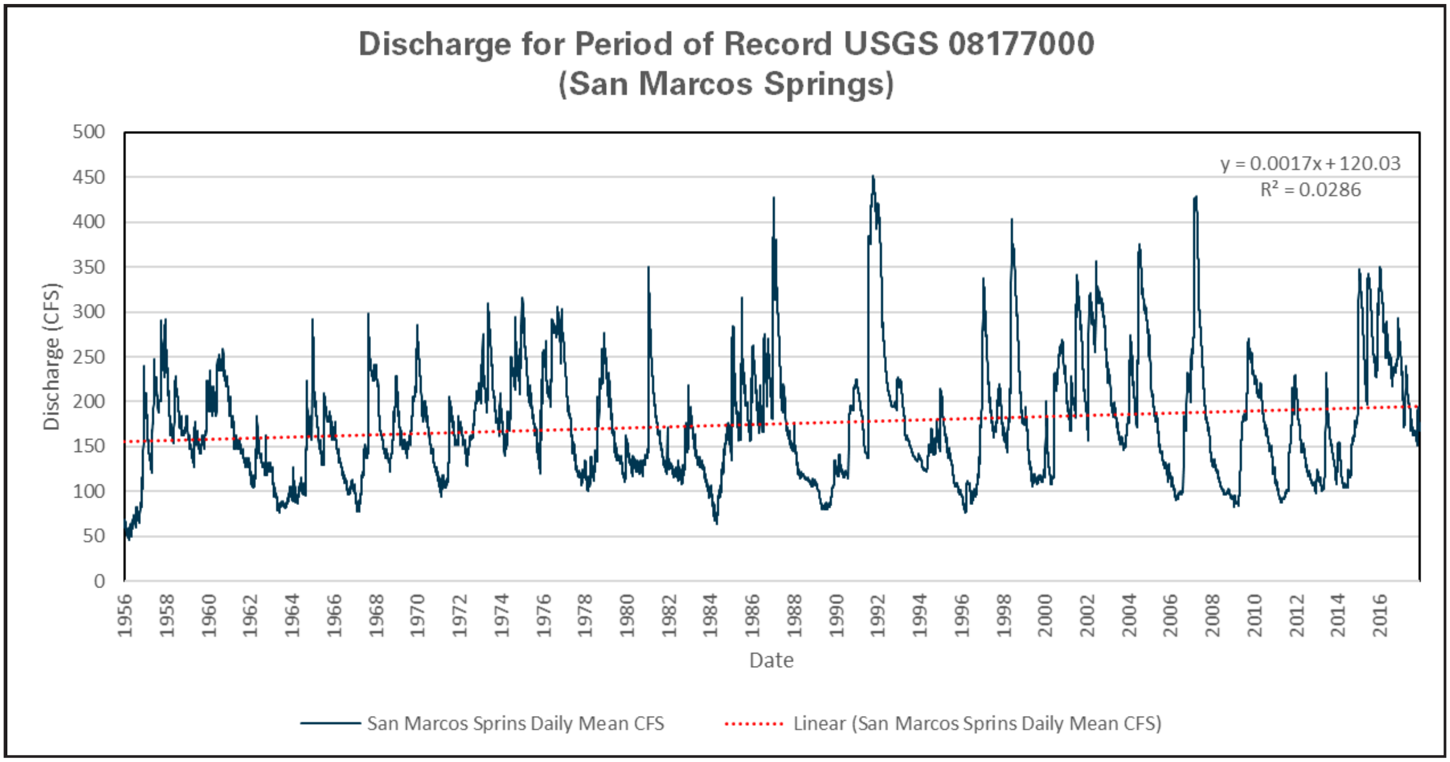


Figure 19 USGS Gaging Station 08170000 San Marcos Springs (1956 – 2017)

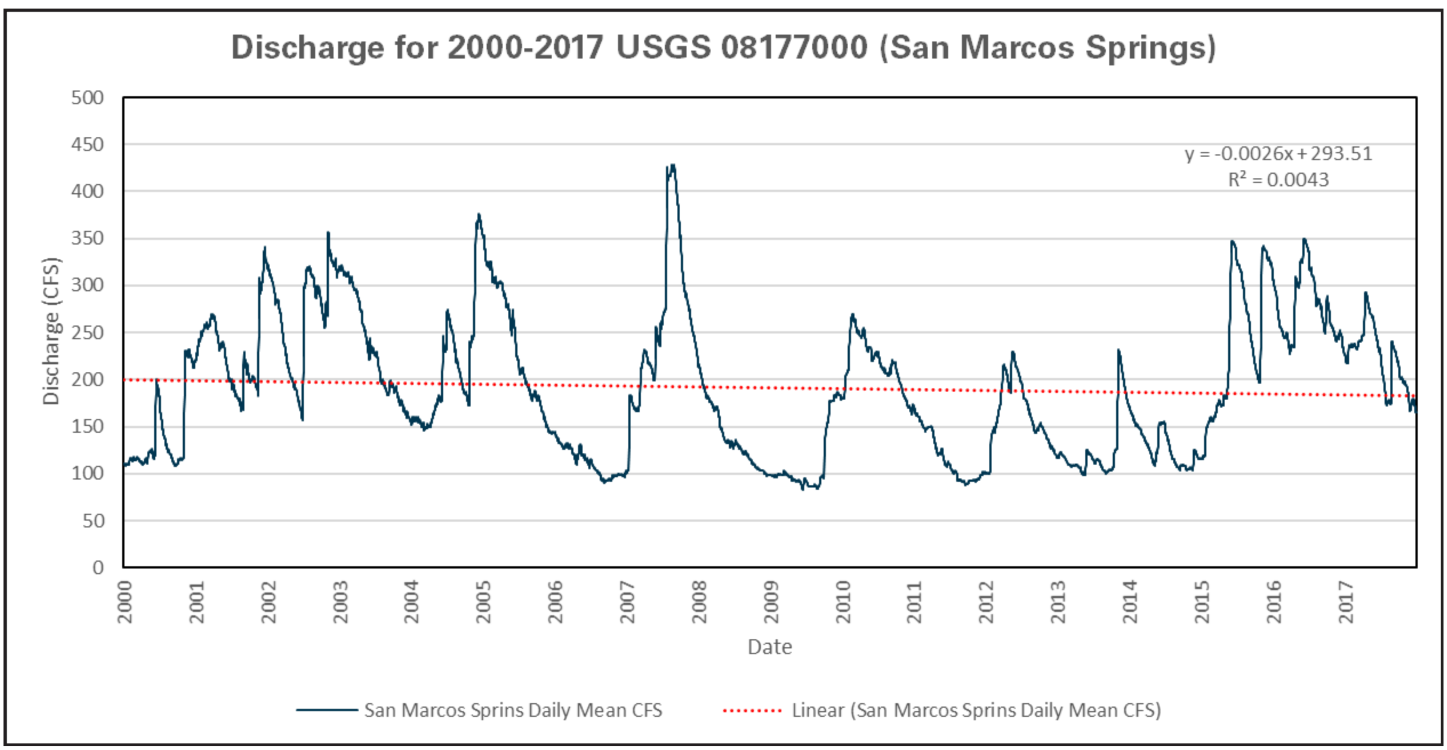


Figure 20 USGS Gaging Station 08170000 San Marcos Springs (2000 – 2017)

USGS Gaging Station 08168710 Comal Springs

Comal Springs located in New Braunfels, TX is the source of the Comal River and a major contributor to streamflow in the GRB. Figure 21 represents the daily mean discharge data from 1927 to 2017. The trend analysis indicates that the discharge from Comal Springs is consistent over the POR. A more recent analysis from 2000 to 2017 (Figure 22) indicates that the daily mean discharge is slightly trending down, most notably in the period of 2007 and 2014.

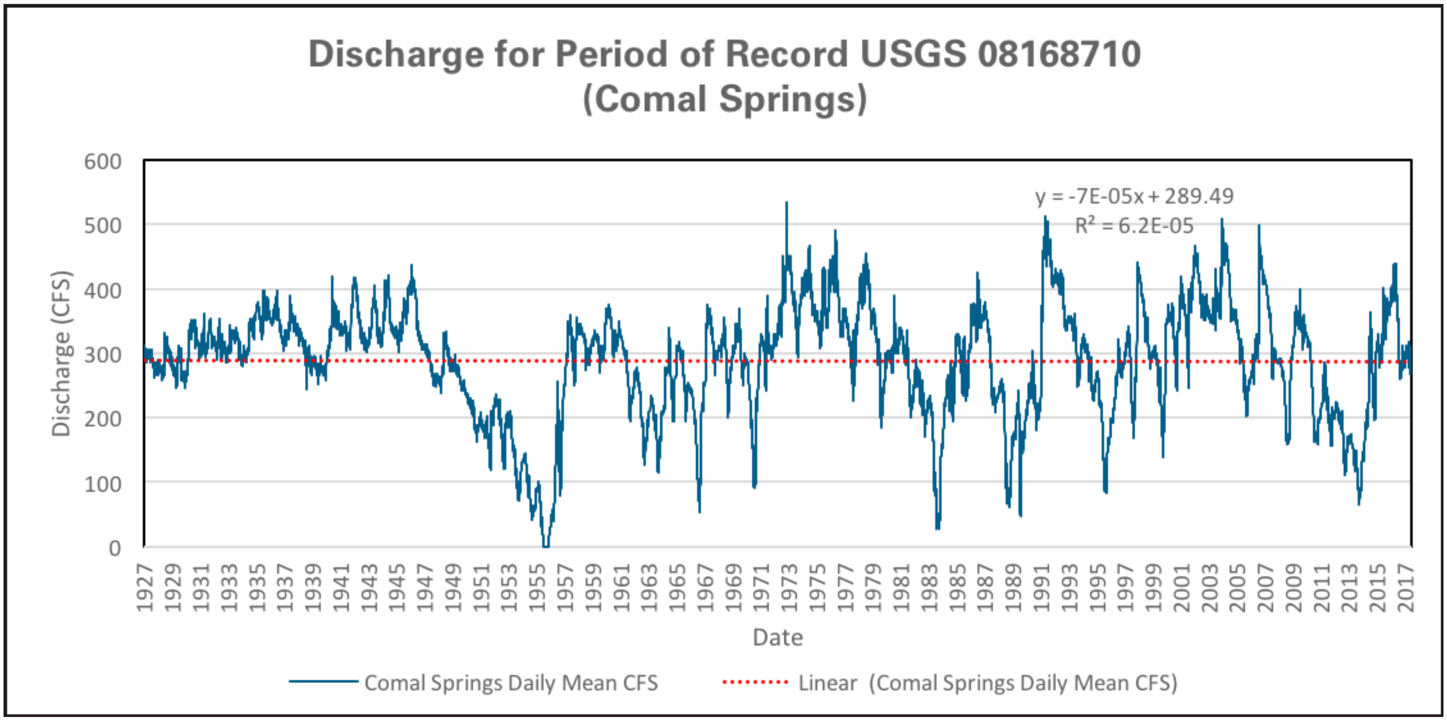


Figure 21 USGS Gaging Station 08168710 at Comal Springs (1927 – 2017)

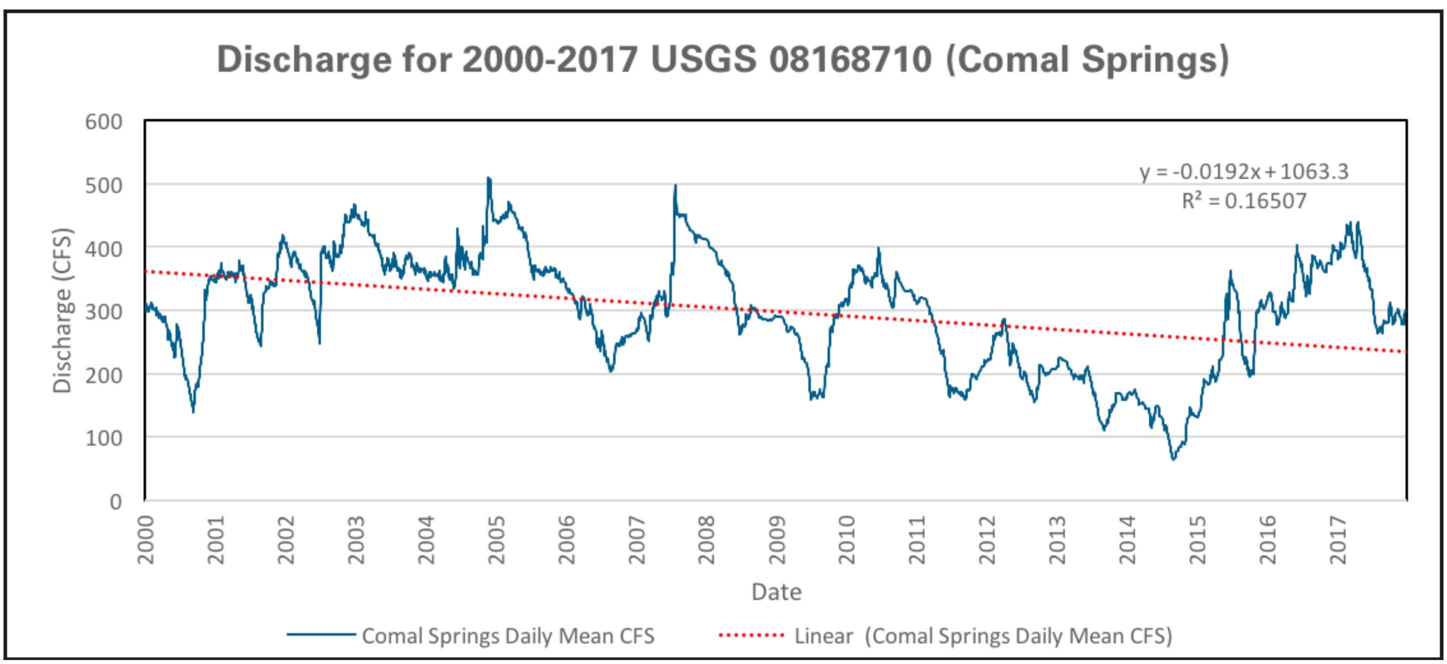


Figure 22 USGS Gaging Station 08168710 at Comal Springs (2000 – 2017)

USGS Gaging Station 08168000 Hueco Springs

Hueco, or Huaco, Springs located near New Braunfels, TX is on the Guadalupe River. Figure 23 represents the daily mean discharge data from 2003 to 2017. The spring has a relatively short POR and the trend analysis indicates that the spring is generally losing flow. The graph indicates that the highs and lows are extreme and indicate that the spring is extremely sensitive to climatic cycles. The gage indicates that there are several years between 2011 and 2015 that the spring was not contributing significant flow to the Guadalupe River.

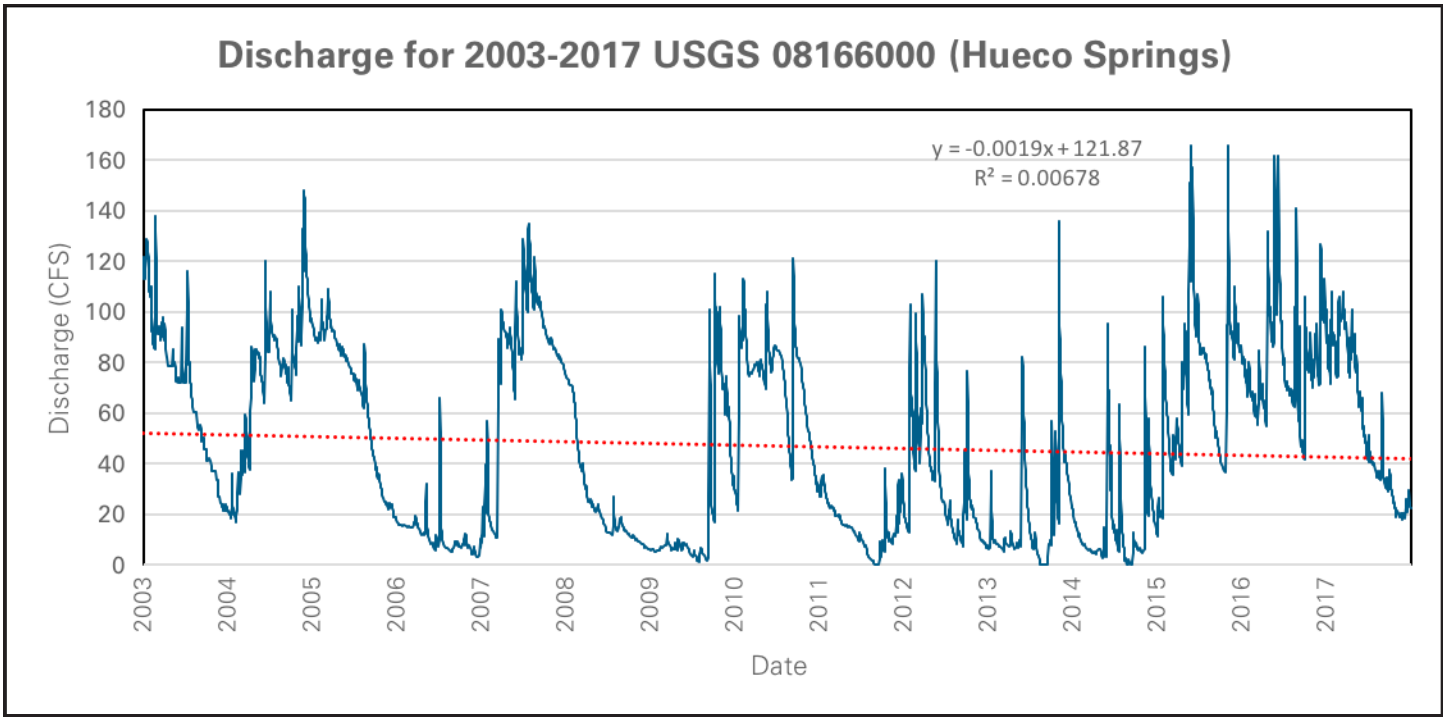


Figure 23 USGS Gaging Station 08168000 at Hueco Springs (2003 – 2017)

Potential Climate Trends of Major Springs

Climate change in the form of increasing temperature and decreasing precipitation may be a factor in the observed reduced spring flows at the major Edwards Aquifer springs feeding the Guadalupe River. Stamm, et al (2014) evaluated the Edwards Aquifer for hydrologic response to projected climate change through 2050. The Madison Aquifer in the Black Hills of western South Dakota was also evaluated. The Edwards Aquifer evaluation included Barton Springs, the Bexar County Index Well completed in the Edwards Aquifer, and Comal Springs. San Marcos Springs were not specifically evaluated but will likely react similar to the other Edwards sites. Data from the weather station in Boerne, TX were used.

Flora and fauna that live in or rely upon springflow from Edwards Aquifer sites were evaluated using an index that evaluates vulnerability to climate change by assessing the exposure of a species to climate, the sensitivity of the species, and the ability of the species to cope with climate change.

From the summary of the report: *The hydrologic response to projected climate at spring and well sites was based on the Rainfall-Response Aquifer and Watershed Flow (RRAWFLOW) model. The RRAW¬FLOW model uses observed or projected climate data (air temperature and precipitation) to simulate a hydrologic response. The model simulates two processes in series: the process of precipitation becoming recharge, and the transition of recharge into a hydrologic response. Projected (2011–2050) annual springflow simulated by the RRAWFLOW model had a significant downward trend for Edwards Aquifer sites and no trend for Madison aquifer sites. Drought equivalent to the 1950s was not projected by the RRAWFLOW model for springflow at Comal Springs (Edwards aquifer site), but a general downward trend in projected springflow might reflect effects of associated projected increases in air temperature at this and other Edwards aquifer sites. Simulated annual mean water-table level of the Bexar County Index Well fell below that observed in the 1950s (192.7 meters in 1956) for simulation years 2046 and 2047.*

Sixteen species associated with springs and groundwater were assessed in the Balcones Escarpment region. The Barton Springs salamander

(Eurycea sosorum) was scored as highly vulnerable with moderate confidence. Nine species—three salamanders, a fountain darter (Etheostoma fonticola), three insects, and two amphipods—were scored as moderately vulnerable. The remaining six species—four vascular plants, the Barton cavesnail (Stygopyrgus bartonensis), and a cave shrimp—were scored as not vulnerable/presumed stable.

Historic Floods

Canyon Lake

Though declines in river discharge have been noted over the last 18 years, major floods have and will continue to occur in the GRB. Canyon Lake, the largest reservoir on the river, has been very effective in its role of flood control as illustrated during the 1987 Guadalupe River Flood. During the night of July 16-17, 1987, a large area of 5-10 inches of rain fell in the upper headwaters of the GRB. As much as 11.50 inches of rain occurred nine miles west of Hunt, TX. This resulted in a massive flood wave that traveled down the Guadalupe River through Ingram, Kerrville, and eventually Comfort, TX during morning hours of the 17th (NWS, 2018). The observed rainfall during the rain event is shown on Figure 24.

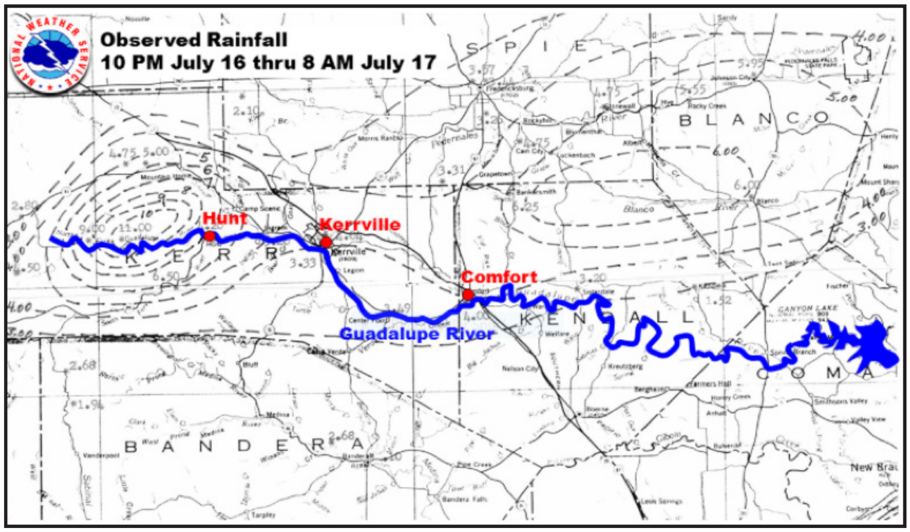


Figure 24 Observed Rainfall July 16 – 17, 1987 near Hunt, TX (NWS, 2018)

Figure 25 is a series of hydrographs constructed from USGS stream gages from Hunt to Sattler. The Sattler gage is downstream of the Canyon Lake discharge point. From NWS (2018): The Guadalupe River at Comfort rose 29 feet that morning and crested at 31.50 feet, the ninth highest crest in recorded history. Upstream at Kerrville and Hunt, the river crested at its second highest crest on record and higher than the famous 1978 flood. At the peak of the flood, the Guadalupe River was estimated to be two-thirds of a mile from its normal bank near Comfort, Texas. As evident from the Sattler gage down stream of Canyon Lake, the flood waters were contained in the lake, preventing a large, downstream flood event in New Braunfels and further downstream.

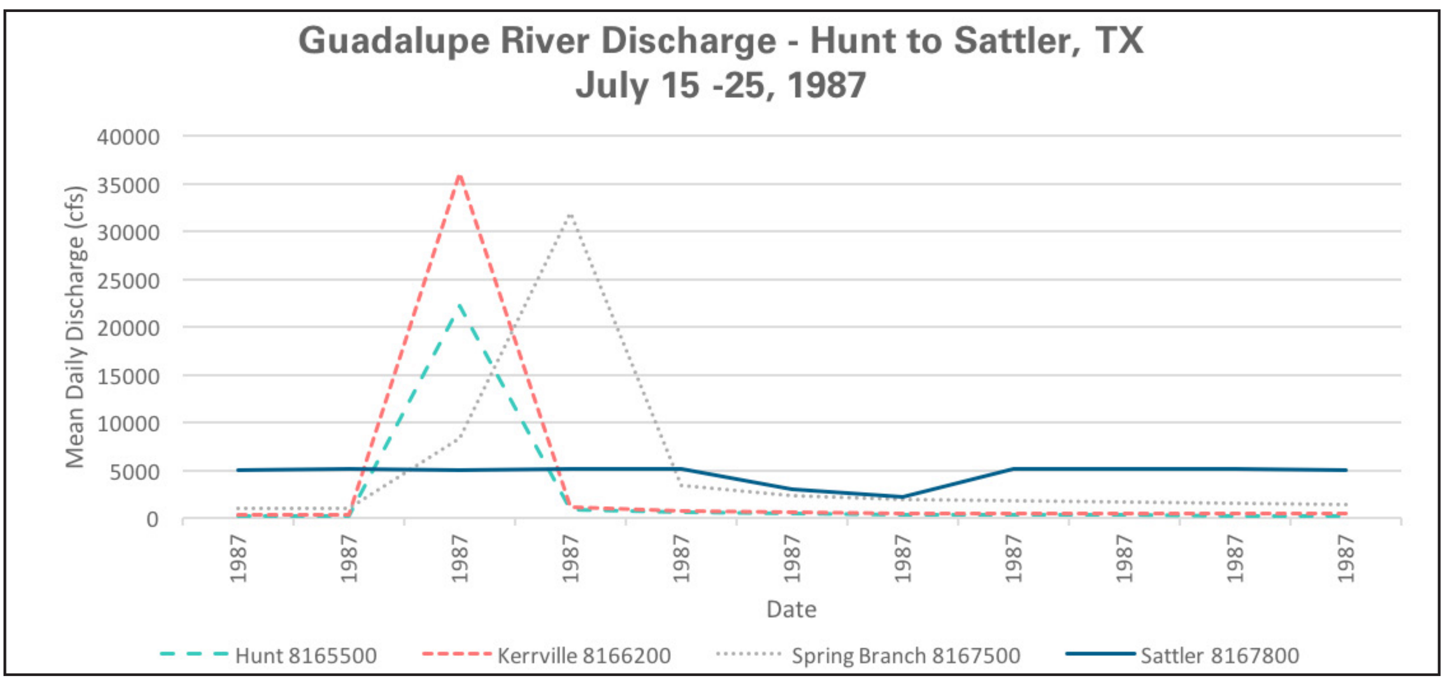


Figure 25 Hydrographs of Guadalupe River Discharge - Hunt to Sattler, TX from July 15 -25, 1987

Figure 26 Flood of 1987 - the worst flood on the Guadalupe since 1932 (J.M. Scott, My SA.com)

Though Canyon Lake has been very effective in its role of flood protection, the Canyon Lake Flood of 2002 overwhelmed the lake, causing water to flood over its spillway. Initial flooding started on the Upper Guadalupe River near Spring Branch. The observed rainfall during the rain event is shown on Figure 27. As shown on Figure 28, the Spring Branch gage rose quickly, followed by Sattler and New Braunfels. Due to already occurring downstream precipitation, water releases were not increased at Canyon Lake. Note the increasing discharge at Cuero and Victoria days prior to the flood wave from the upper Guadalupe River reached those areas due to additional precipitation further down stream. Just under 1-1/2 times the amount of water stored in the lake (at normal level) went over the spillway during the flood event. There was no significant increase in discharge at Tivoli, near the Gulf of Mexico. An account of the event can be found at http://canoeman.com/canoe/docs/flood2002.html.

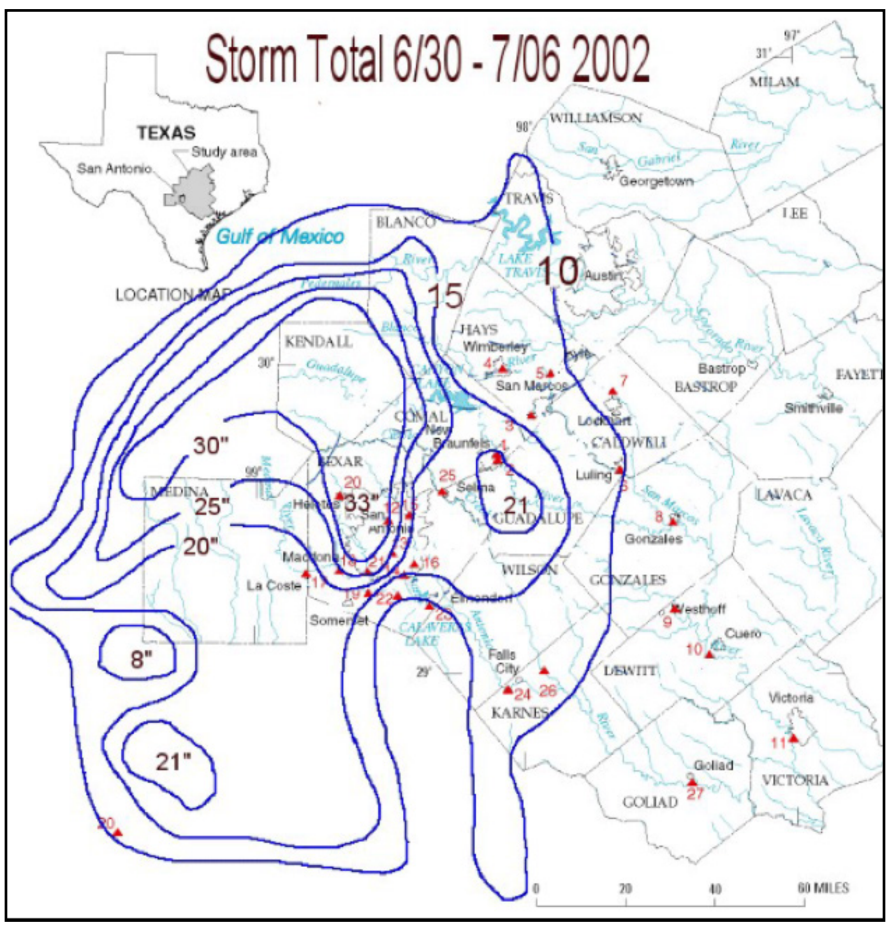


Figure 27 Observed Rainfall June 30 – July 6, 2002 (Comal County Engineers Office, 2018)

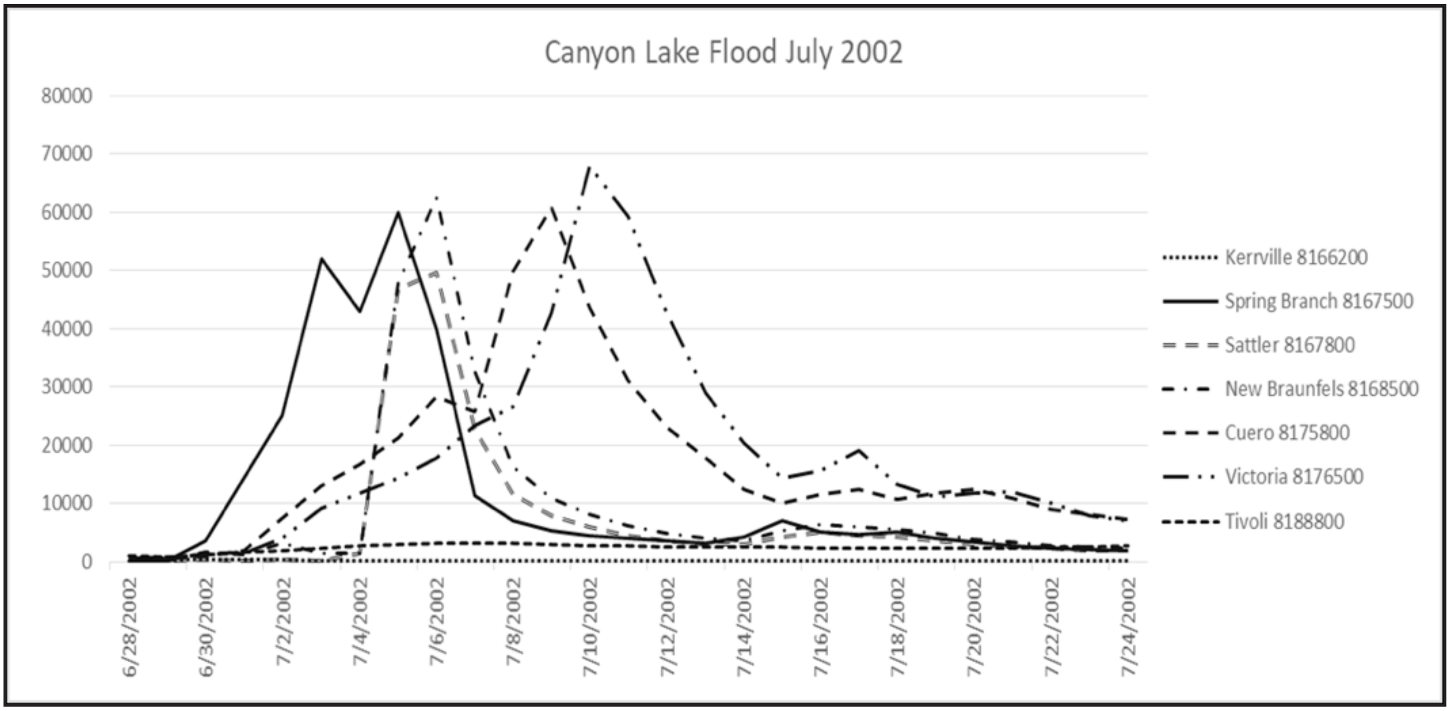


Figure 28 Hydrographs of Guadalupe River Discharge – Spring Branch to Tivoli, TX from June 28 – July 24, 2002

Figure 29 Canyon Lake Spillway – June 2002 (Comal County Engineers Office, 2018)

GAIN/LOSS

The USGS Fact Sheet 2008-5165 (USGS, 2018) reports that the GRB streamflow is affected by several factors including spring flow, rain-fall runoff processes, point source discharges, withdrawals for water supply, reservoir operations, evapotranspiration, gains, and losses to aquifer recharge.

The GRB creates several challenges in determining detailed gaining and losing reaches. The basin stretches from the Edwards Plateau to the San Antonio Bay, with varying climatic conditions. A rain event in one part of the basin can take weeks to work through the basin which makes it difficult to determine consistent base flow conditions. While the basin is currently relatively well-populated with stream gages compared to other Texas rivers, there are still insufficient data for detailed analysis. To supplement the gages with manual readings across the basin requires a large amount of manpower. The USGS performed several gain/loss studies in the lower reaches of the basin in 2010 – 2011 (Wehmeyer, 2013) USGS and GBRA (USGS, 2018) have been cooperatively using relatively new geophysical methods to determine gain/loss over short reaches of the river. This approach would require a large effort to implement over the entire basin. Detailed anthropogenic water inflow and outflow data is also needed.

Though detailed gain/loss studies are difficult and have rarely been performed on a basin wide basis, there are some generalizations that can be made. The river is generally a gaining river from headwaters to the gulf. As previously discussed, there are several major springs that contribute a significant amount of water to the basin. Wehmeyer (2013) performed three major gain/loss studies which indicated there are losing and gaining reaches during some surveys, but they are not consistently measured in the various studies. These findings are consistent with those found in PECI (1999). There appear to be gains in the river from diffuse groundwater discharge from shallow aquifers with shallow groundwater tables. This portion of base flow has not been quantified for the basin and is a data gap for future analysis. Quantification of diffuse base flow from shallow aquifers may provide insight into changes in aquifer levels in the basin.

Daily mean discharge values from 2000-mid 2018 (n=6757) from two reaches of the river indicate there are intervals of apparent gains and losses. The discharge data for the reach from Bear Creek above Kerrville (081661400) to Spring Branch (08167500) indicates that there is less discharge at Spring Branch than at Bear Creek 19 percent of the time. Similarly, the reach between Gonzales (08173900) and Victoria (08176500) indicates that 38 percent of the time there is more water flowing at Gonzales than downstream at Victoria. These apparent losses may in part be due to surface water/groundwater interactions, but factors such as uneven distribution of precipitation, diversions, inflows, and evapotranspiration play a large role. Detailed field studies during low, or base flow, conditions would be necessary to separate effects.

The gain/loss graph in Figure 30 depicts typical stream flows recorded at gaging stations from the headwaters to the mouth of the river under relative low flow conditions. The headwaters form in Kerr County near Hunt, TX. The river maintains a consistent discharge under 100 cfs until reaching river mile 313 near New Braunfels, TX. Spring flow contributions from Hueco and Comal Springs increase streamflow at the gaging station near Seguin, TX. The Blanco River and San Marcos River are major tributaries of the Guadalupe River. These rivers receive streamflow from the Pleasant Valley and Jacob's Well Springs in Wimberley and the San Marcos Springs. The Blanco River and San Marcos River merge downstream of San Marcos and contribute significant streamflow to the Guadalupe River near Victoria, TX. Coleto Creek and San Antonio River provide the greatest streamflow contribution at the Tivoli, TX gaging station at river mile 11.

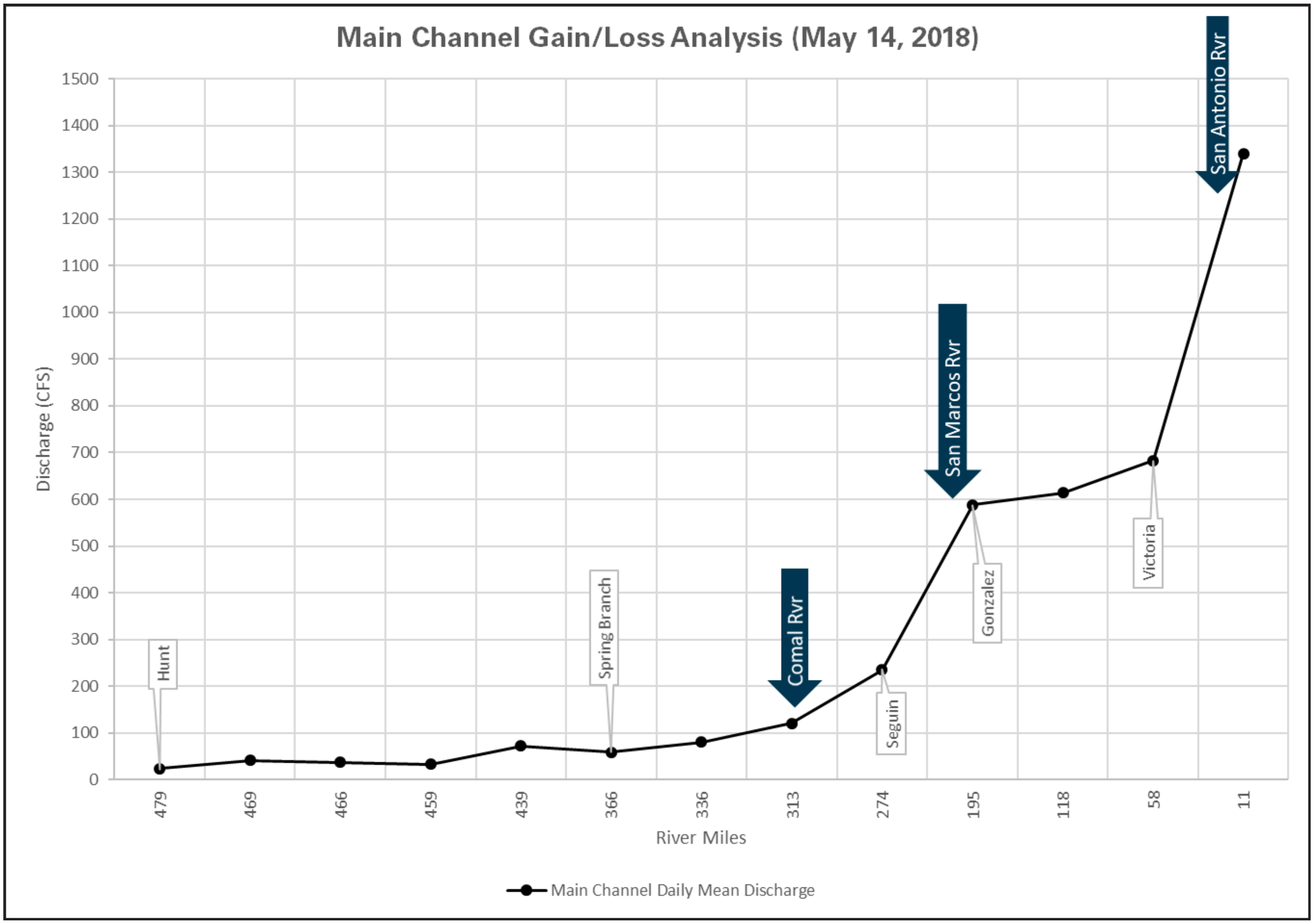


Figure 30 Gain/Loss Study of the Guadalupe River Basin on May 14, 2018

Gain/loss studies similar to the one shown in Figure 31 below show a significant dip in streamflow after Cuero, TX and then a significant spike in streamflow after Victoria, TX. Major contributions and reductions of streamflow near Victoria occur over various study dates and require additional investigation to determine the cause. It is recommended to conduct gain/loss studies during low flow events in order to improve accuracy. The role of diversions of surface water in this area should be investigated.

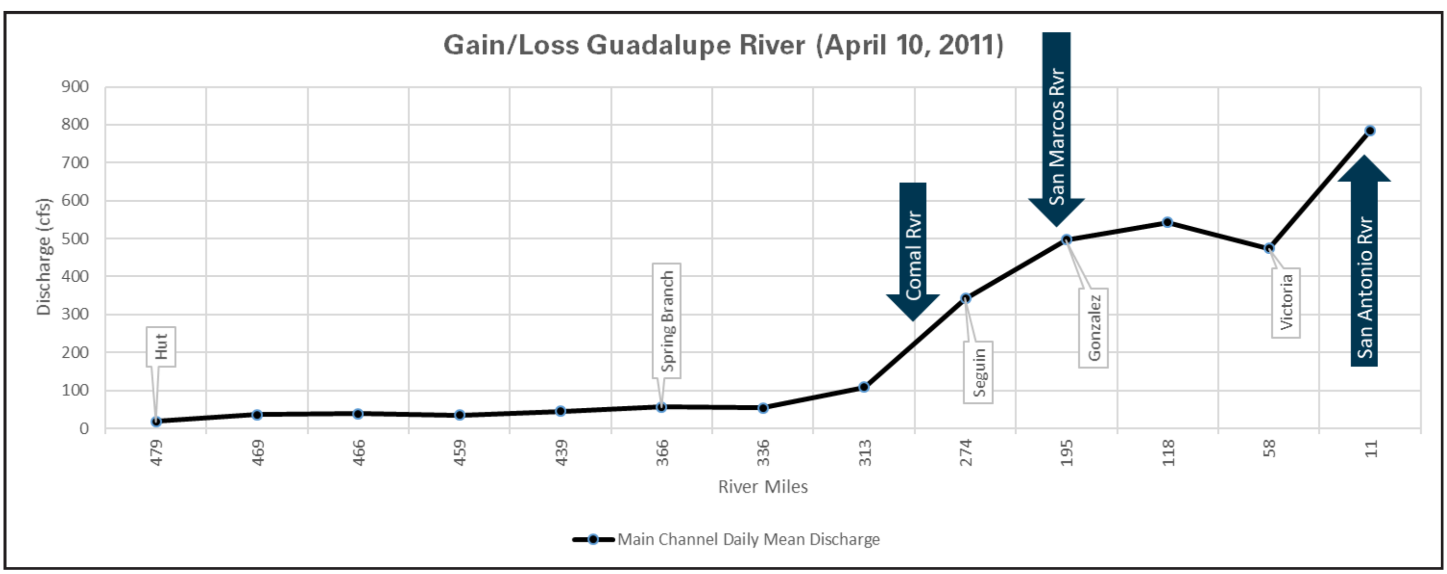
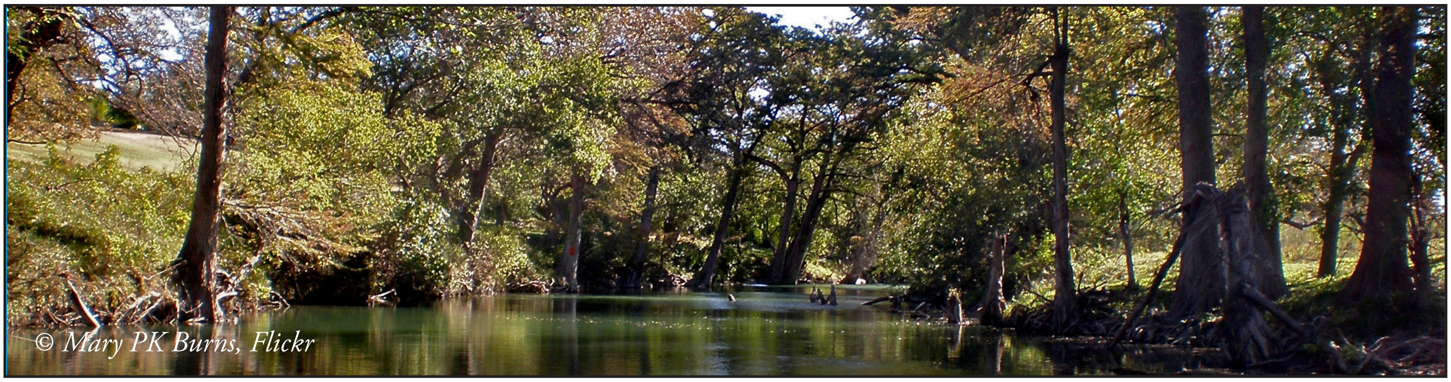


Figure 31 Gain/Loss Study of the Guadalupe River Basin on April 10, 2011



Major Inflows and Outflows

There are numerous permitted inflows and outflows to the river that have the potential to influence the quantity of flow in the river. Inflows are typically discharges from either municipal or industrial wastewater treatment plants. Inflows are typically regulated and permitted by the TCEQ and the United States Environmental Protection Agency (US EPA).

Outflows consist primarily of withdrawals for public water supply systems. Outflow also consist of diverted water for individual water rights, including the domestic and livestock exempted withdrawals.

The USGS performed three gain/loss studies in 2010 and 2011 (Wehmeyer, 2013) on the lower Guadalupe River from Canyon Lake to the gulf. The studies were conducted in March 2010, April 2011 and August 2011. Forty-one permitted inflows were identified from TCEQ and US EPA. Twenty-six outflow sites were identified. Total monthly average values for inflows and outflows for each of the three studies are shown on Table 4 along with the total flow at the most downstream USGS gage at Tivoli, TX (08188800).

Table 4 Permitted Inflows and Outflows – Gain/Loss Studies on the Lower Guadalupe River, Canyon Lake to Tivoli (2010 and 2011) (Wehmeyer, 2013)

Study Date	Inflow (cfs)	Outflow (cfs)	Inflow – Outflow (cfs)	Streamflow at Tivoli (cfs)
March 2010	27.7	14.2	13.4	1843
April 2011	27.2	1.7	25.5	523
August 2011	23.6	0.4	23.2	184

During these three studies, inflows were fairly constant and greatly exceeded outflows indicating a gaining of flow in the river. The net inflows accounted for between less than one percent to 12 percent of the total flow at Tivoli.

One source of inflow may indicate an anthropogenic surface water/groundwater interaction. Municipalities and/or industries that extract groundwater and then discharge effluent into the river may be acting as a groundwater to surface water diversion. Quantification of these groundwater-to-surfacewater diversions is a data gap in our understanding of the river system.

This analysis is very preliminary in nature as several other factors need to be considered to assess the net impact of inflows and outflows to the river now and into the future. The study did not account for the upper reaches of the river upstream of Canyon Lake and the potential impacts from cities, such as Kerrville. From an inflow perspective, the total allowable discharge amounts are significantly higher than current, actual flows. A preliminary review of the TCEQ data indicates there is approximately 360 cfs of wastewater discharge currently permitted (TCEQ, 2018).

Outflows may be significantly underestimated in that individual water rights are not accounted. There are numerous water rights owners that either do not use, or potentially do not report, withdrawals of water. Also, under the Texas Water Code Sec. 11.142., a person may construct on the person's own property a dam or reservoir with normal storage of not more than 200 acre-feet of water for domestic and livestock purposes without obtaining a permit. In addition, a person may construct on the person's property a dam or reservoir with normal storage of not more than 200 acre-feet of water for fish and wildlife purposes without obtaining a permit if the property on which the dam or reservoir will be constructed is qualified open-space land. These exempt uses are not required to be reported.

Surface water rights in the State of Texas are regulated by TCEQ. Water rights are prioritized by the date of the right, with the older rights having the highest priority. TCEQ maintains an active water rights database and can be found at https://www.tceq.texas.gov/permitting/water_rights/wr-permitting/wrwud. The TCEQ database indicated there are slightly over 600 assigned water rights in the GRB, totaling 6,366,792 acre-feet/year or 8786 cfs. This volume of water is significantly greater that the average of the mean daily discharge as measured at Victoria for the years 1934 to 2017 of 2,113 cfs.

The timing of outflows from the river can be critical to the river's health. Most domestic and livestock withdrawals will occur during the dry season or during drought when river flows are naturally reduced. A complete accounting of actual and potential inflows and outflows, particularly during times of drought, is a major data gap to understanding the river flow system.

Figure 32 illustrates a breakdown of active water rights by usage type. The majority of the rights (82 percent) are classified as hydroelectric which is not a major consumptive use. Industry and agriculture are the next two largest classifications at nine percent and six percent, respectively. As shown on Figure 33, the largest number of acre-feet is in Guadalupe and Gonzales Counties. The largest rights owners in these counties are the City of Gonzales and GBRA.

The counties with the most water rights owners are Kerr and Kendall (Figure 34) with 40 percent of the number of owners in Kerr County. With less than one percent of the acre-footage of water rights, most of the water rights in Kerr County are quite small in volume. It was beyond the scope of the current study to research actual historic outflows under authorized water right. Data was not available during this study to determine potential and actual water rights diversions by river segment.

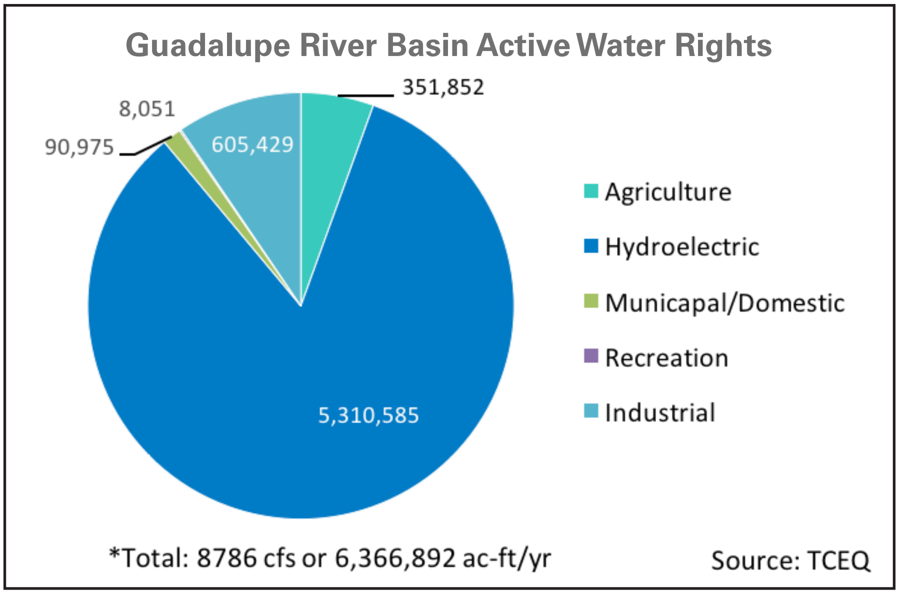


Figure 32 Guadalupe River Basin Active Water Rights

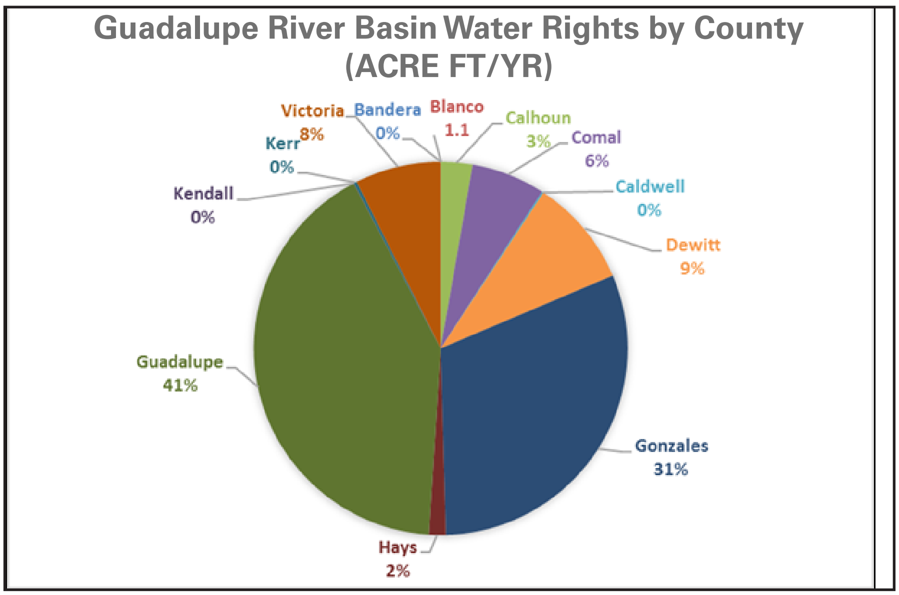


Figure 33 Guadalupe River Basin Water Rights by County (acre ft/year)

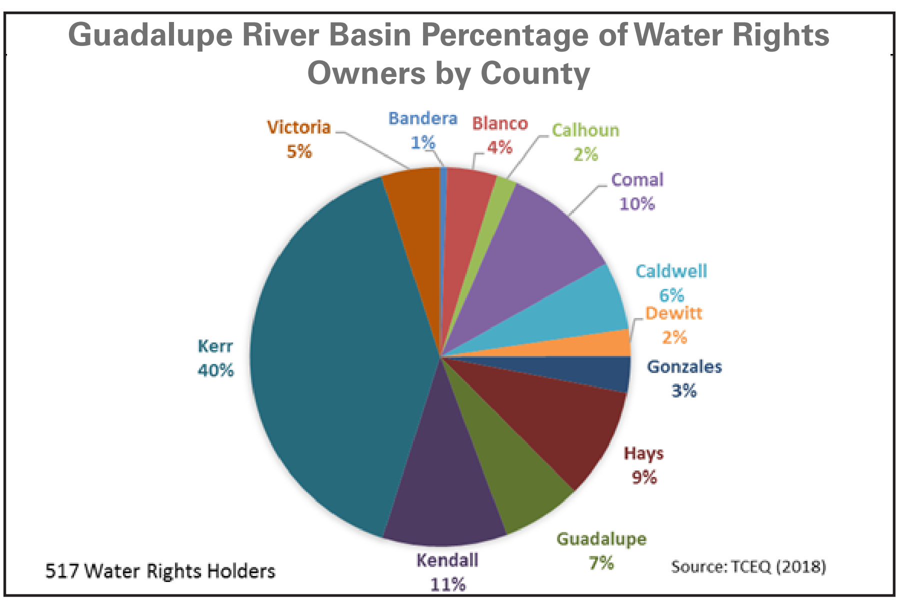


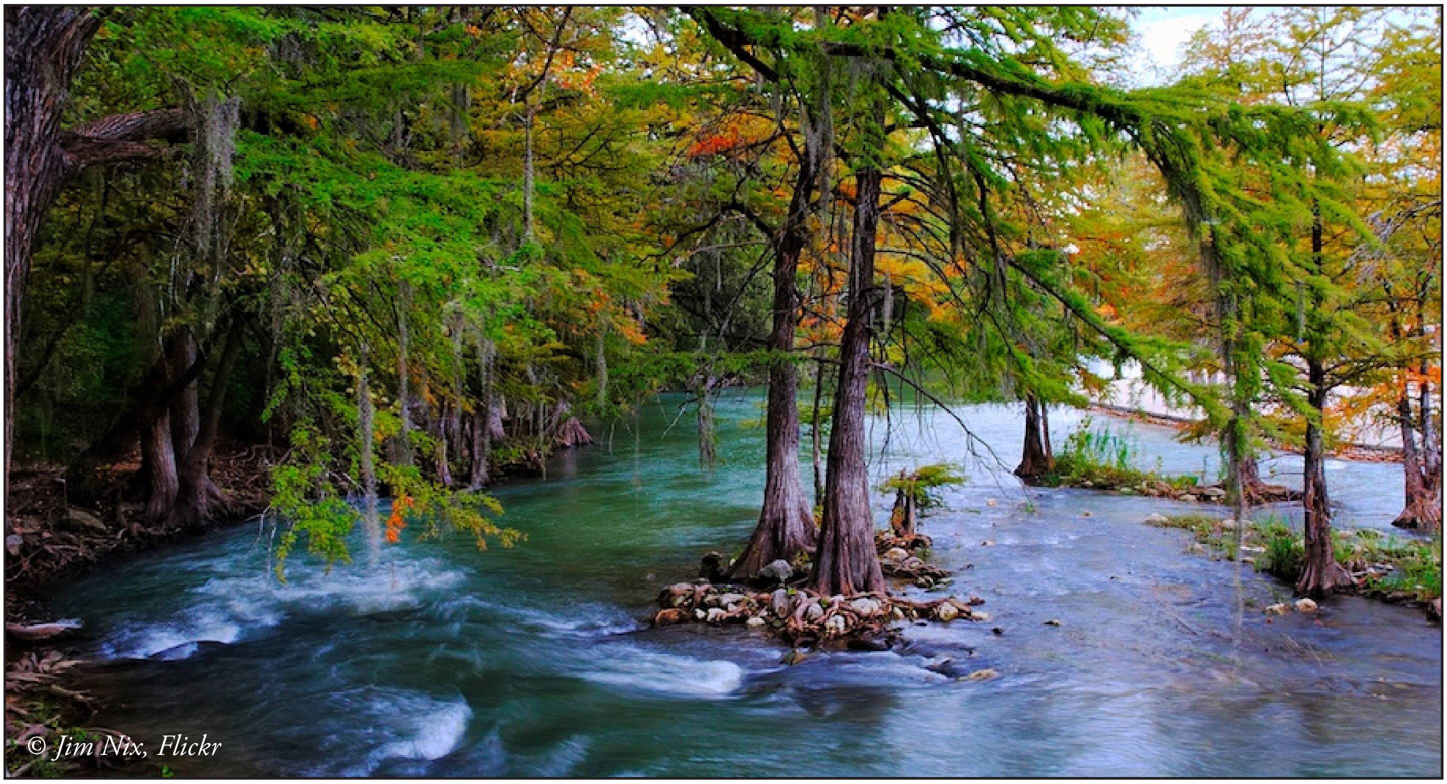
Figure 34 Guadalupe River Basin Percentage of Water Rights Owners by County

DATA GAPS AND NEXT STEPS

The Meadows Center is positioned to continue research that seeks to answer the question, "How Much Water is in the Hill Country?" to inform policy, regulatory, growth, and source water protection planning and land conservation decisions that will ensure future sustainability of water resources in the Hill Country. In the next phase of this research, we have the opportunity to further investigate the data gaps identified in this initial year of the project, along with consideration of anthropogenic and natural trends of basin-wide flow rates of tributaries, contributing aquifers, and the main stem of the Guadalupe River.

The group will dissect the natural baseflow for both recent and historic contributions to help gain a better understanding of whether aquifer levels are changing due to changes in pumping activities, climate, diversion, and other causes. To the extent data is available, research will also be performed to quantify inflows and outflows that correlate with weather patterns to understand how much water is being discharged during normal weather and times of drought at various locations.

The group will perform GIS analysis of where inflows and outflows are occurring using TCEQ data to locate water rights relative to headwaters spring protection where the largest number of water rights holders in the basin are located. A prioritization effort of inactive water right holders will also be performed according to location and historical amount withdrawn that may potentially be available and useful to other ongoing prioritization studies. The group also aims to characterize changes in groundwater pumpage in the basin according to total water demand and population projections increasing from 2020 to 2070 (SCTPWP, 2016).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CONCLUSION

The implications of these findings help quantify how much of the surface flows of the Guadalupe River and tributaries come directly from groundwater and vice versa. The Hill Country continues to be faced with the ever-growing pressure of depleting surface and groundwater resources in terms of water quantity and quality. These findings have direct relevance to many cities, farmers, landowners, and industries that rely on the Guadalupe River as the source of their drinking water, as well as for agricultural, municipal, and industrial needs, recreation, and critical habitat for fish and wildlife.

There are many organizations performing great work in studying Hill Country rivers and aquifers, but there is little coordination. Through this project, the Guadalupe River flows and its use are better understood which helps develop common goals and, through strength of numbers, works to inform policy makers, allows stakeholders to make informed decisions regarding best management practices, and guides future research efforts to ensure the sustainability of the Guadalupe River and water supply needs into the future.

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APPENDIX A

Springs of Western Kerr County

ID. No.	State Well No.	Spring Name	Tributary	Latitude	Longitude	Elev.	Topo Location	Remarks
CONTRARY CREEK QUADRANGLE								
1	56536--		Johnson Creek	30.1795	-99.3793	1898	Yes	Rough Hollow and Johnson Creek
2	56539--	Contrary	Contrary Creek	30.1608	-99.3761	1900	Yes	
MOUNTAIN HOME QUADRANGLE								
3	5654402	Welch	Welch Creek	30.1697	-99.3636	1900	No	
4	5654403	Ellebracht	Fessenden Branch	30.1667	-99.3423	1898	Yes	Supplies water for TP&W Hart of the Hills Fisheries Science Center.
5	56547--	Zock	Fessenden Branch	30.1658	-99.3459	1900	No	Complex of at least 4 main springs along west bank of lake.
6	5654701	Byas	Byas Branch	30.1385	-99.3511	1900	Yes	Complex of at least 4 main springs.
7	5654802		Dry Branch	30.1604	-99.3094	1900	No	
8	56549--		Fall Branch	30.1551	-99.2784	1910	Yes	Located in Gillespie County.
BONEYARD DRAW QUADRANGLE								
9	5660501		Unnamed	30.0759	-99.5724	2060	No	
10	5660601		Flat Rock Creek	30.0457	-99.5296	2020	No	
11	56606--	Headwaters	North Fork Guadalupe	30.0602	-99.5032	1940	Yes	Large flow from several main springs issuing from both sides of the river.

ID. No.	State Well No.	Spring Name	Tributary	Latitude	Longitude	Elev.	Topo Location	Remarks
BEE CAVES CREEK QUADRANGLE								
12	5661402		North Fork Guadalupe	30.0538	-99.4856	1920	Yes	Callum Ranch. Two springs shown on topo.
13	56614--	Joy	Unnamed	30.0491	-99.4955	1998	Yes	
14	56614--	Cherry	Unnamed	30.0426	-99.4848	1998	Yes	
15	56614--	Lower Bee Caves	Bee Caves Creek	30.0584	-99.4583	1900	Yes	
16	56615--	Bear Creek 1	Bear Creek	30.0811	-99.4553	1960	Yes	Reported to be large springs.
17	56615--	Bear Creek 2	Bear Creek	30.0800	-99.4418	1900	Yes	Reported to be large springs.
18	56615--	BSA	Bear Creek	30.0705	-99.4285	1895	No	Multiple seeps and springs on north bank below low-water dam.
19	5661504		North Fork Guadalupe	30.0512	-99.4481	1880	Yes	
20	56616--		Unnamed	30.0574	-99.3865	1860	Yes	Two springs shown on topo.
21	5661702	Bee Caves	Bee Caves Creek	30.0352	-99.4651	1987	Yes	
22	56618--		Unnamed	30.0368	-99.4228	1950	Yes	
23	56618--	White Oak	White Oak Creek	30.0092	-99.4233	1970	Yes	
24	56619--	Muskhog	Unnamed	30.0340	-99.4132	1970	Yes	Two springs shown on topo.
25	56619--		Unnamed	30.0375	-99.4110	1980	Yes	Two springs shown on topo.
26	56619--		Lange Ravine	30.0340	-99.4013	2050	Yes	
27	56619--		Lange Ravine	30.0325	-99.3849	1950	Yes	

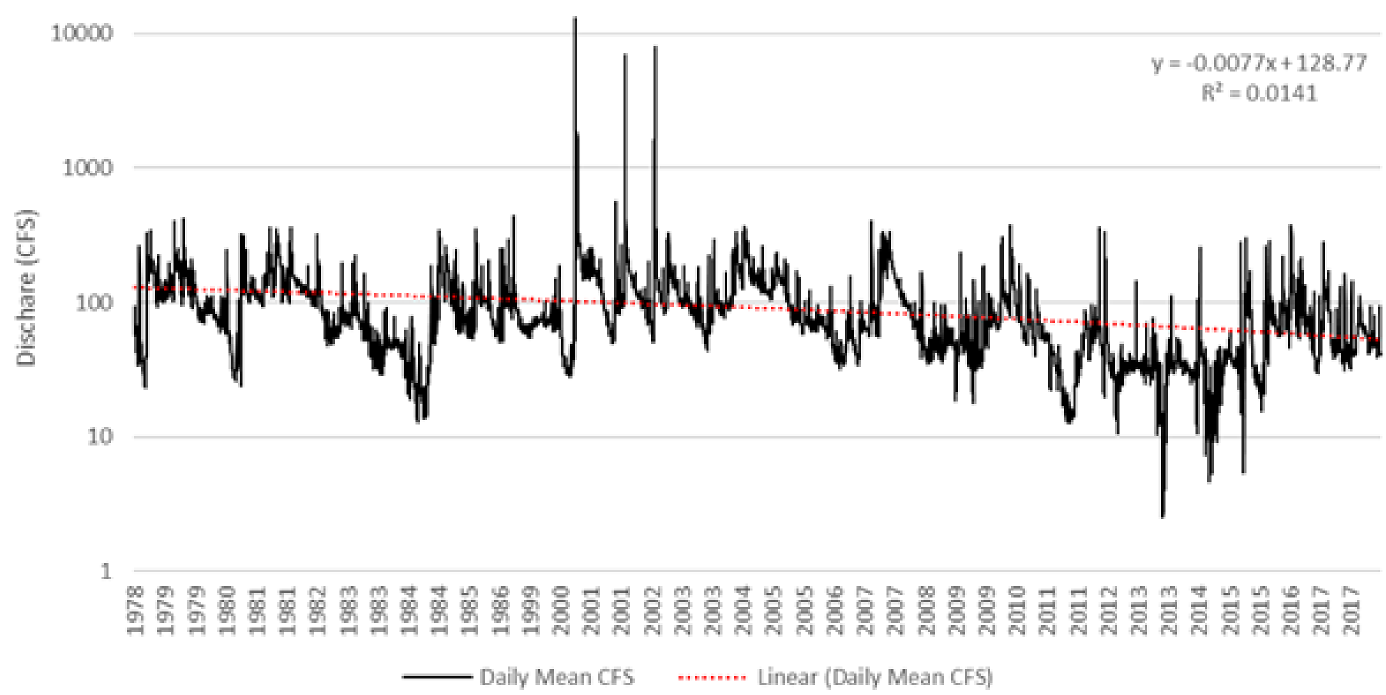
ID. No.	State Well No.	Spring Name	Tributary	Latitude	Longitude	Elev.	Topo Location	Remarks
28	56619--		Cherry Creek	30.0098	-99.4110	1910	Yes	
29	56619--		Panther Creek	30.0101	-99.3890	1900	Yes	Springs located in two spring boxes on south side of creek.
30	56619--		Panther Creek	30.0068	-99.3852	1880	Yes	
HUNT QUADRANGLE								
31	5662101		Honey Creek	30.1033	-99.3687	1895	Yes	Conrad Meadows Ranch.
32	5662102		Honey Creek East	30.1066	-99.3532	1935	Yes	
33	5662103		Honey Creek East	30.1006	-99.3501	1880	Yes	
34	5662104		Honey Creek	30.0971	-99.3651	1860	No	
35	5662105	Whetstone	Honey Creek East	30.1024	-99.3413	1990	Yes	
36	5662106	Duncan	Honey Creek	30.0885	-99.3534	1780	No	Misslocated in TWDB database.
37	56622--		Unnamed	30.0883	-99.3207	1875	Yes	
38	56623--	Colleen	Fall Branch	30.1157	-99.2884	1770	No	Spring is submerged under lake near west end of dam.
39	56623--		Fall Branch	30.1201	-99.2872	1780	No	At least 2 springs on west bank. Star Ranch
40	56624--		Unnamed	30.0789	-99.3646	1855	Yes	
41	5662603	Indian	Unnamed	30.0496	-99.2711	1880	No	
42	56627--	Mystic	Edmunson Creek	30.0064	-99.3620	1900	Yes	
43	5662802		Tegener Creek	30.0242	-99.3259	1920	Yes	East of two springs.

ID. No.	State Well No.	Spring Name	Tributary	Latitude	Longitude	Elev.	Topo Location	Remarks
44	5662803		Tegener Creek	30.0235	-99.3288	1935	Yes	West of two springs.
DIAMOND S RANCH QUADRANGLE								
45	69051--		Sycamore Draw	29.9817	-99.4617	2000	Yes	
46	6905201		South Fork Guadalupe	29.9806	-99.4438	1955	No	Lynxhaven Ranch.
47	6905202		Sycamore Draw	29.9792	-99.4506	1975	No	Lynxhaven Ranch.
48	69052--		Indian Creek	29.9987	-99.4318	1980	Yes	
49	69053--		Buffalo Creek	29.9871	-99.3825	1900	Yes	
50	69055--		Mullen Creek	29.9569	-99.4529	2015	Yes	Diamond S Ranch.
51	69055--	Green	Mullen Creek	29.9369	-99.4396	2155	Yes	

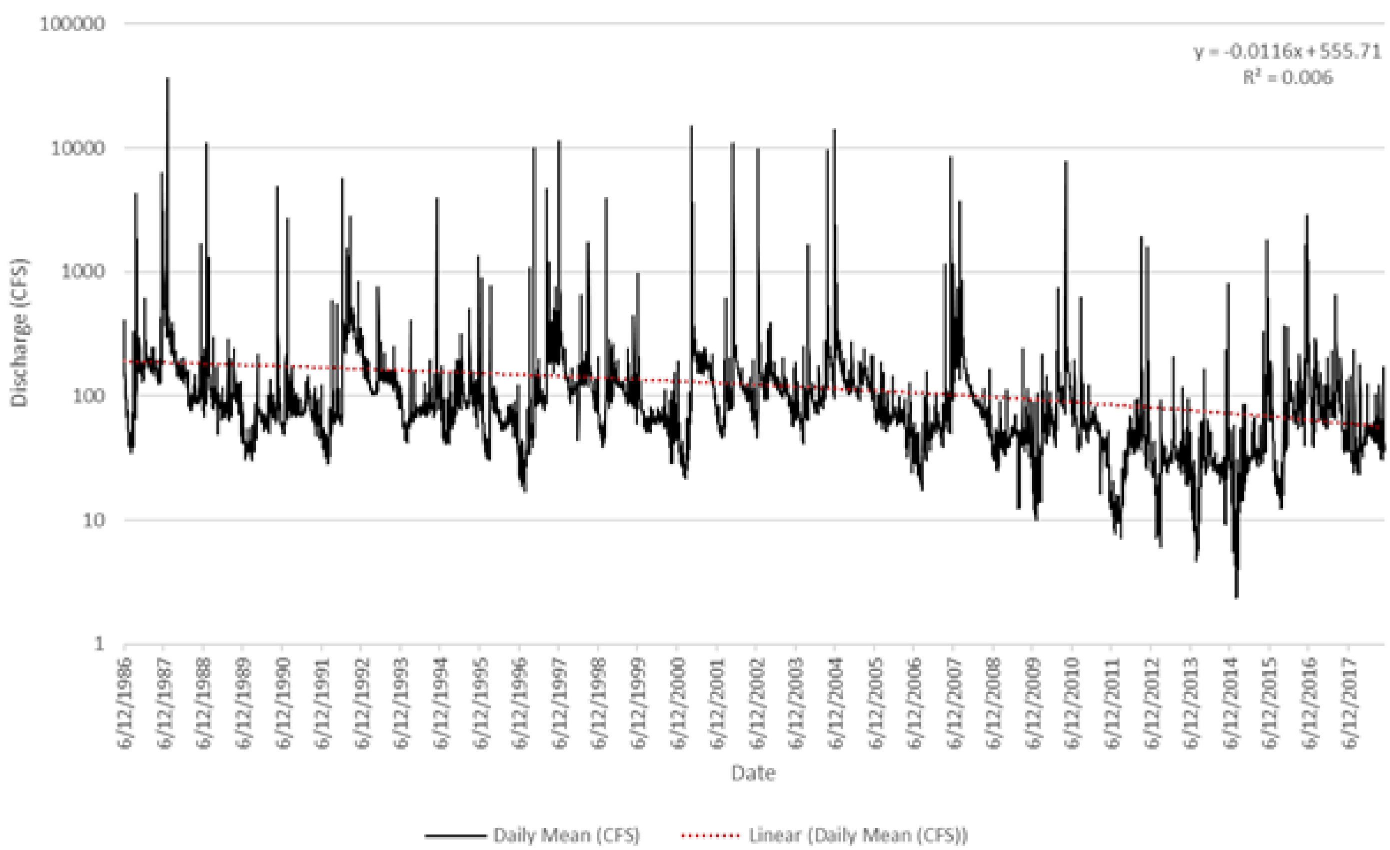
APPENDIX B

Guadalupe River USGS Gaging Station Hydrographs

Discharge for Period of Record (USGS 08166140 - at Kerrville, TX)

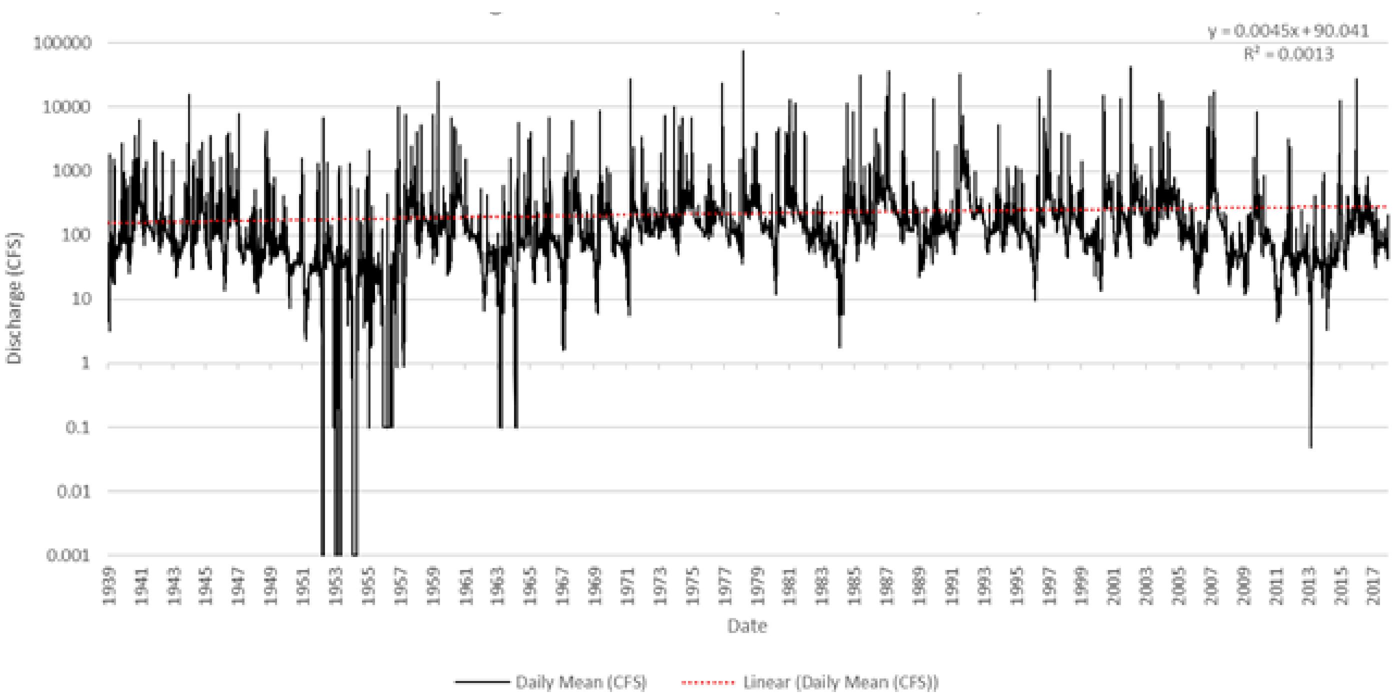


Discharge for Period of Record (USGS 08166200 - at Kerrville, TX)

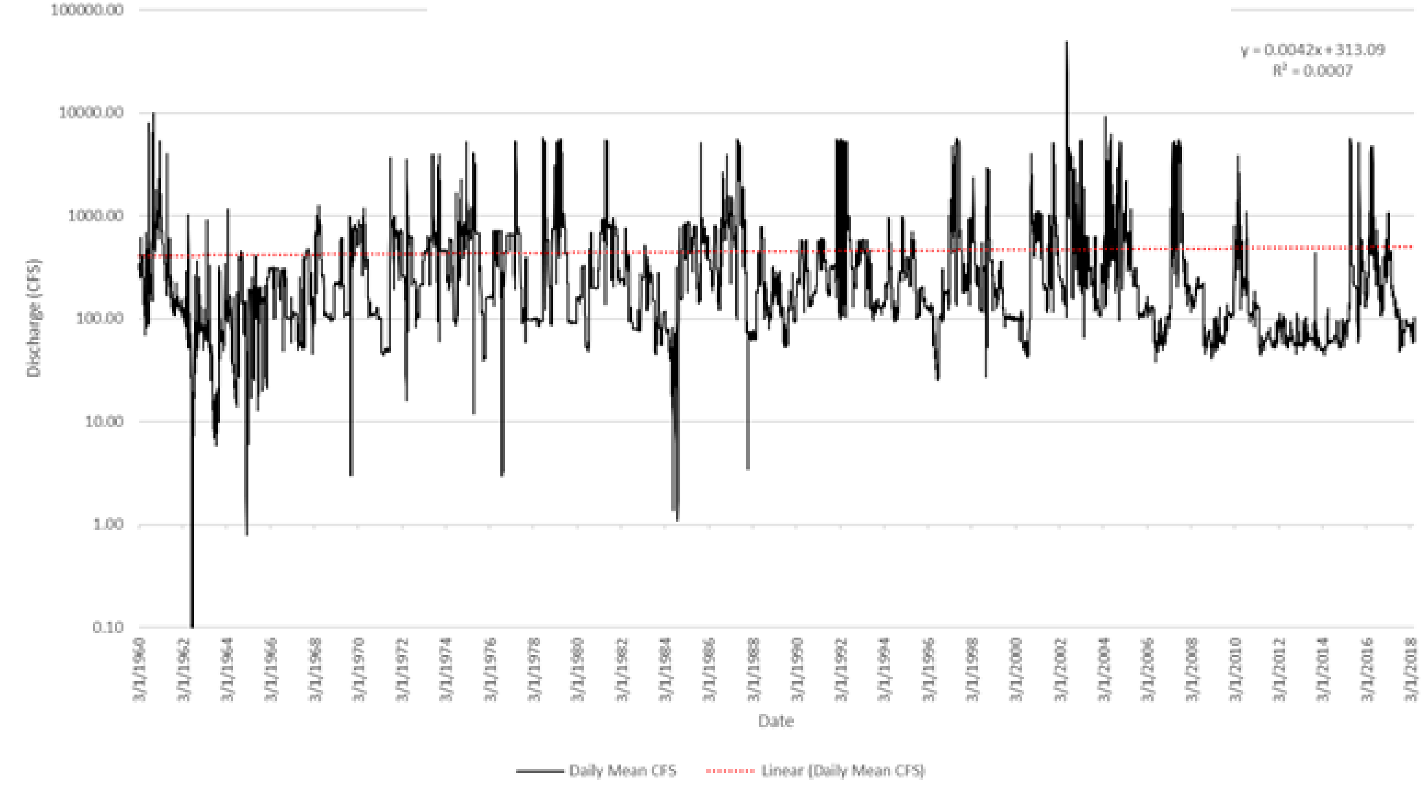


Discharge for Period of Record (USGS 08166250 - at Center Point, TX)

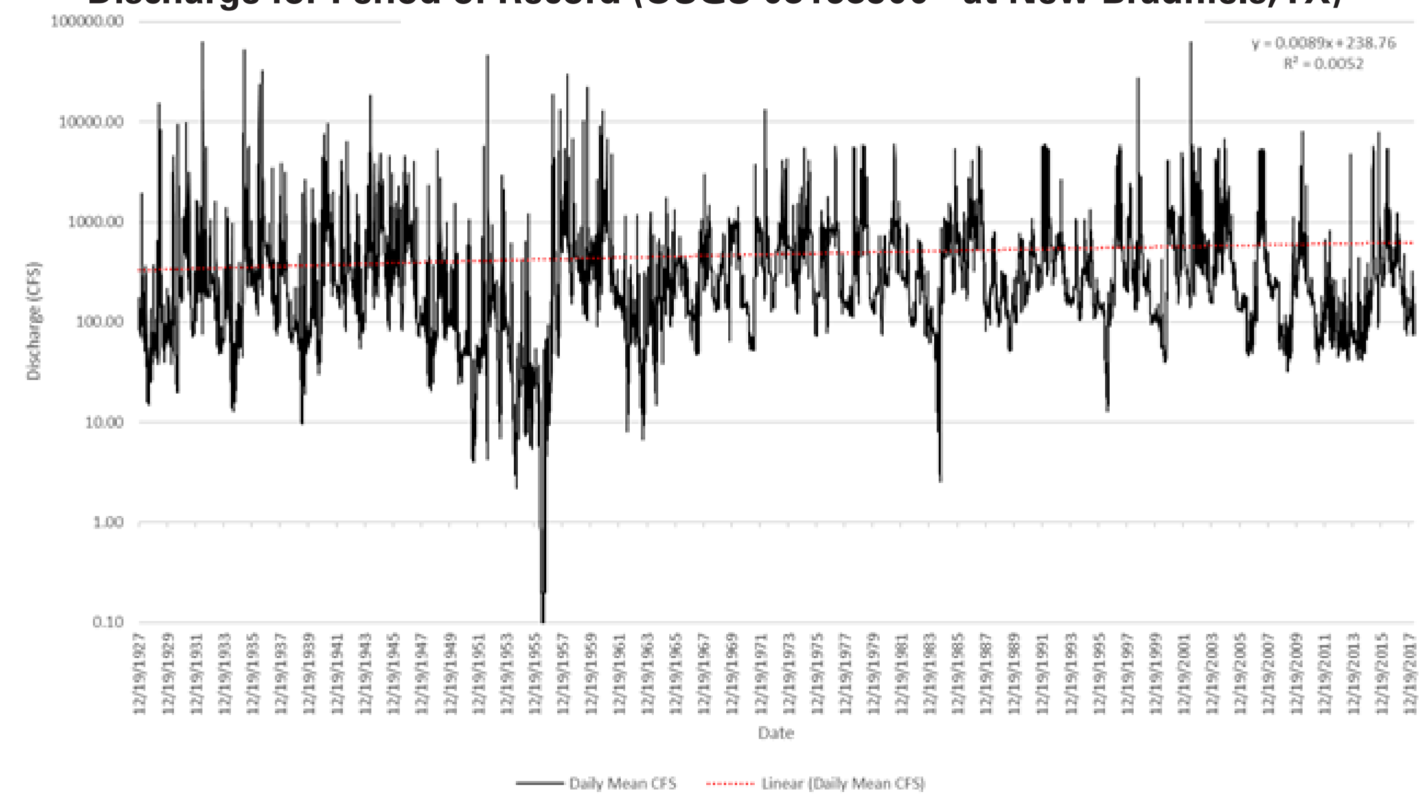
Discharge for Period of Record (USGS 08167000 - at Comfort, TX)



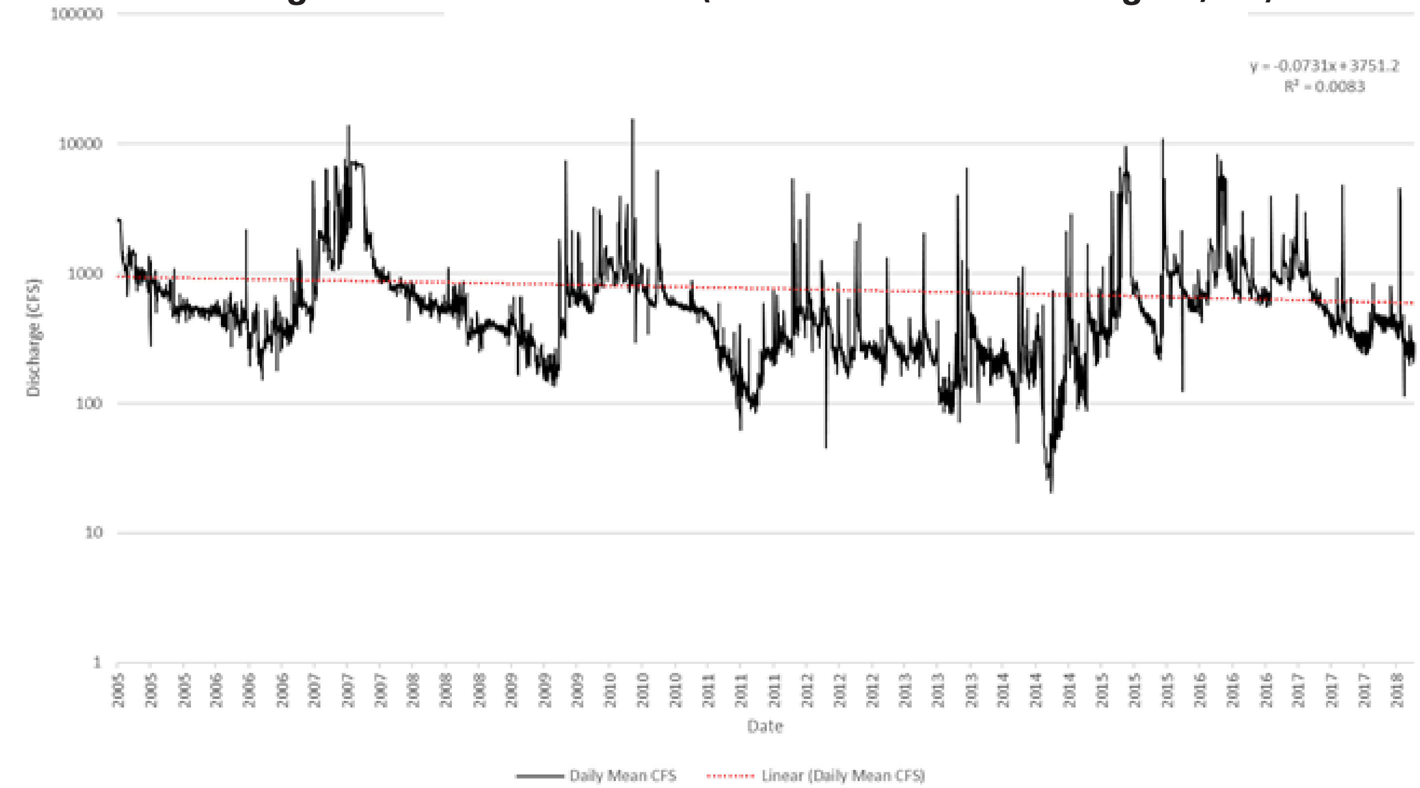
Discharge for Period of Record (USGS 08167800 - at Sattler, TX)



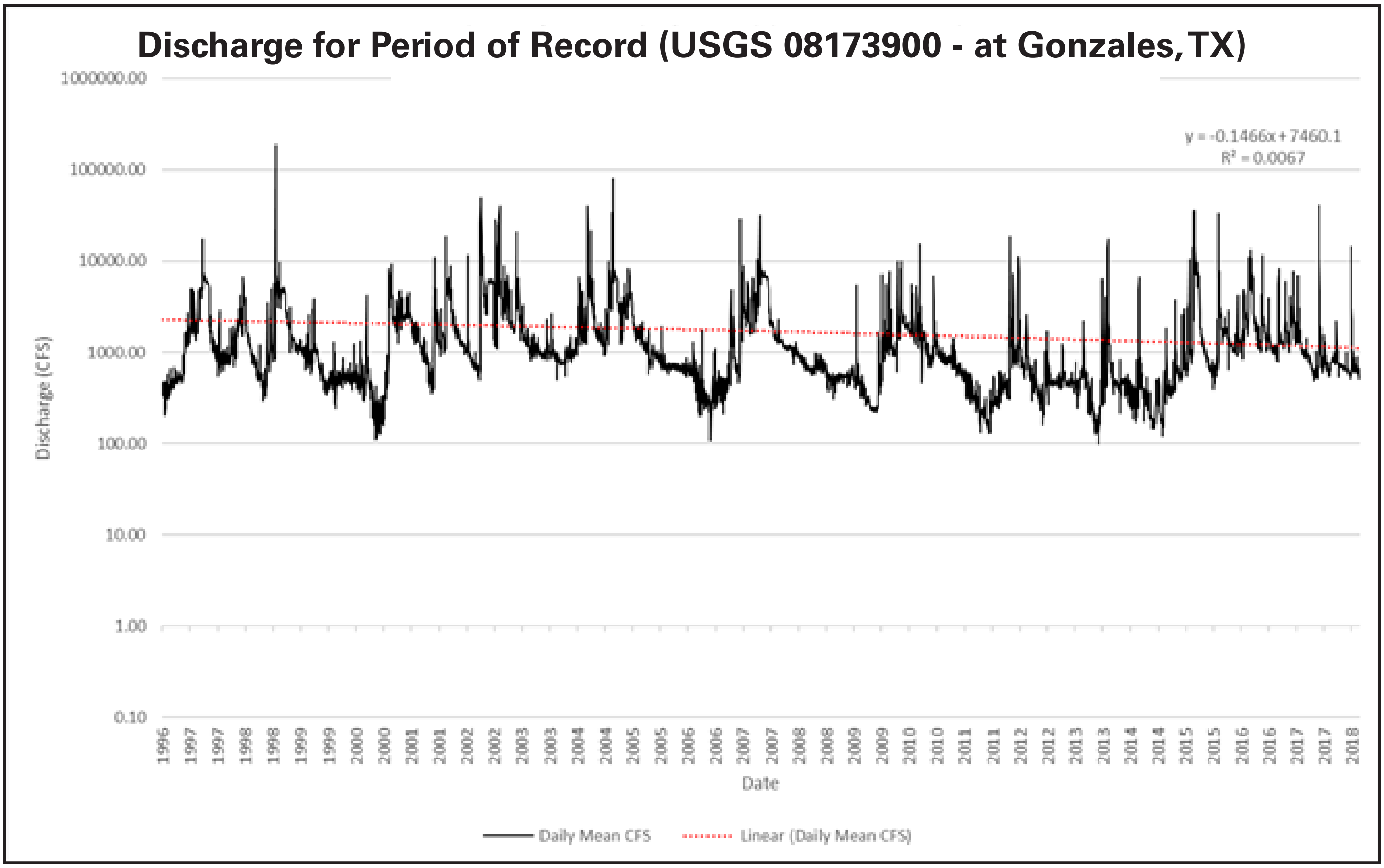
Discharge for Period of Record (USGS 08168500 - at New Braunfels, TX)



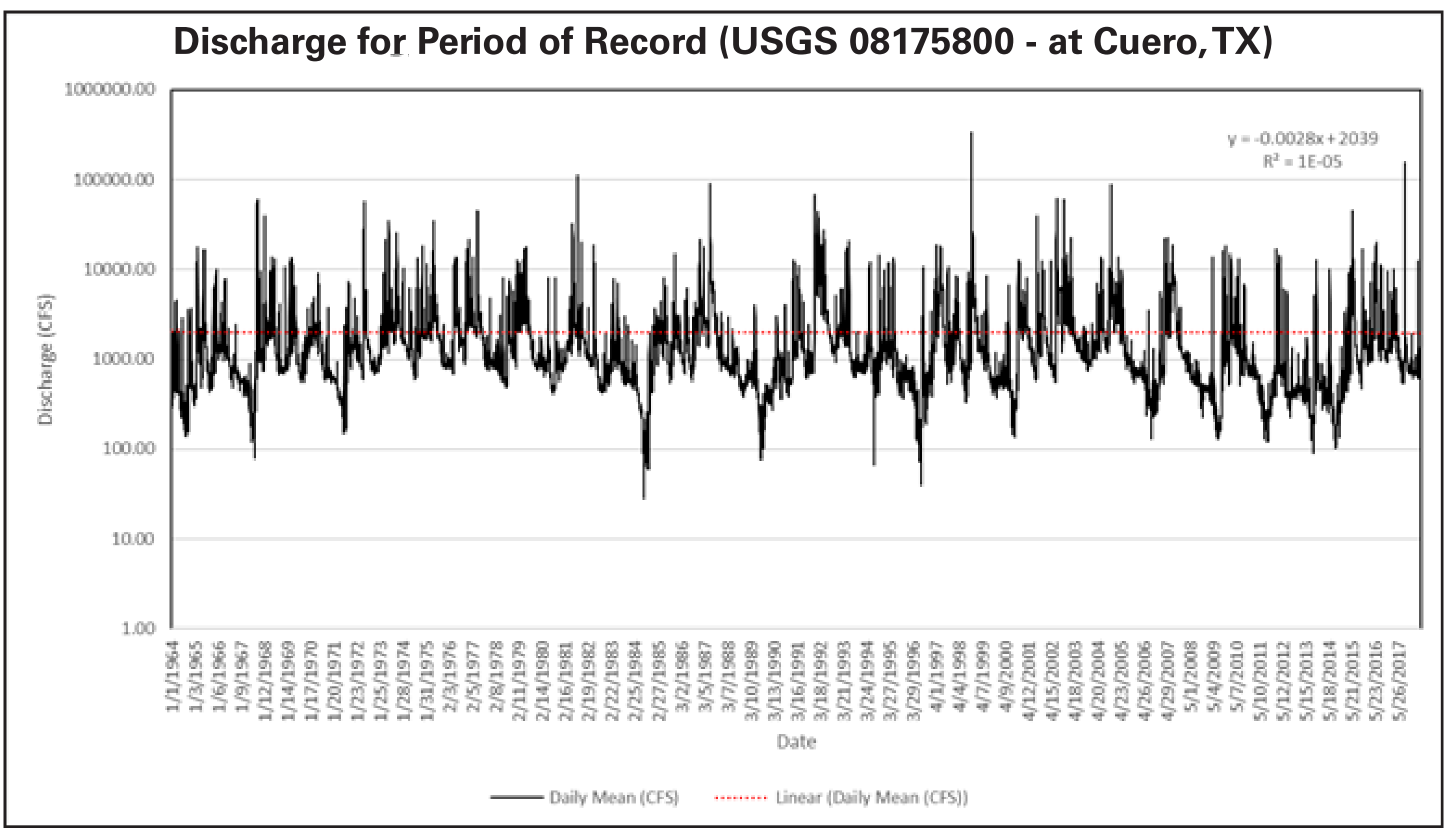
Discharge for Period of Record (USGS 08169792 - at Seguin, TX)



Discharge for Period of Record (USGS 08169845 - at Gonzales, TX)

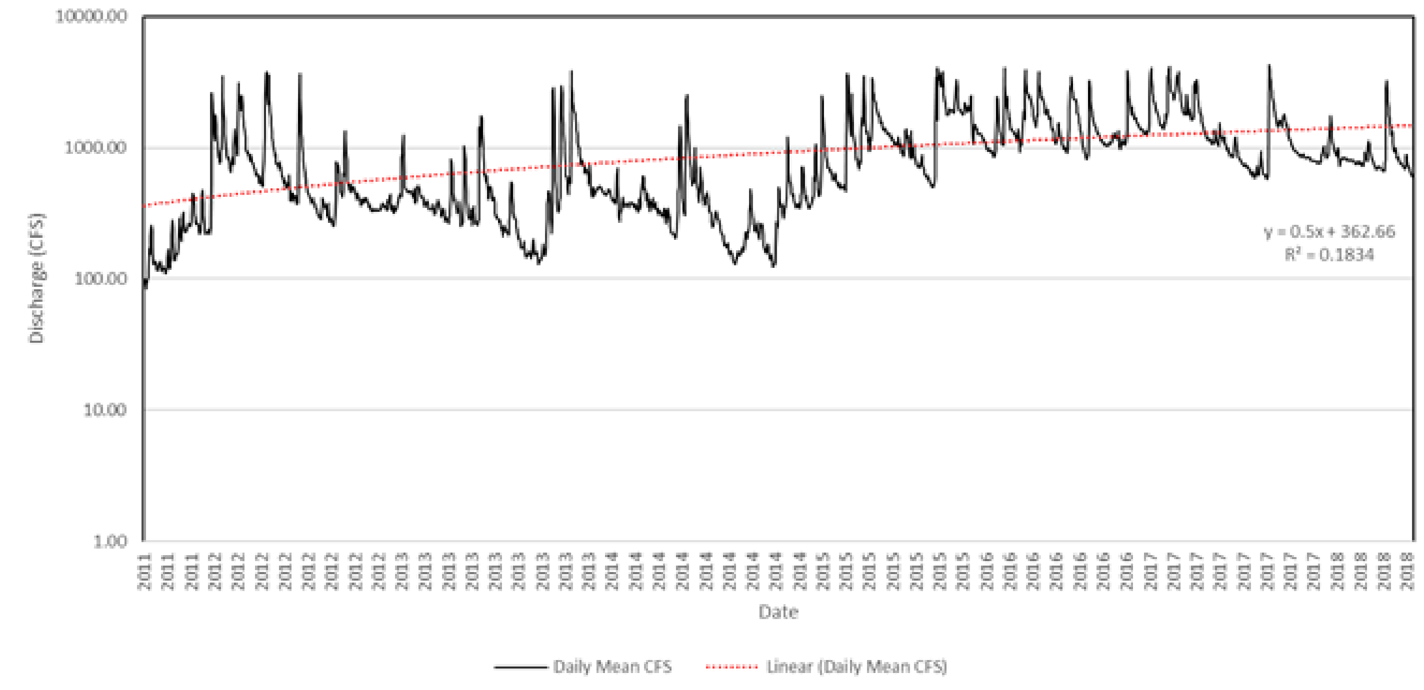


Discharge for Period of Record (USGS 08173900 - at Gonzales, TX)

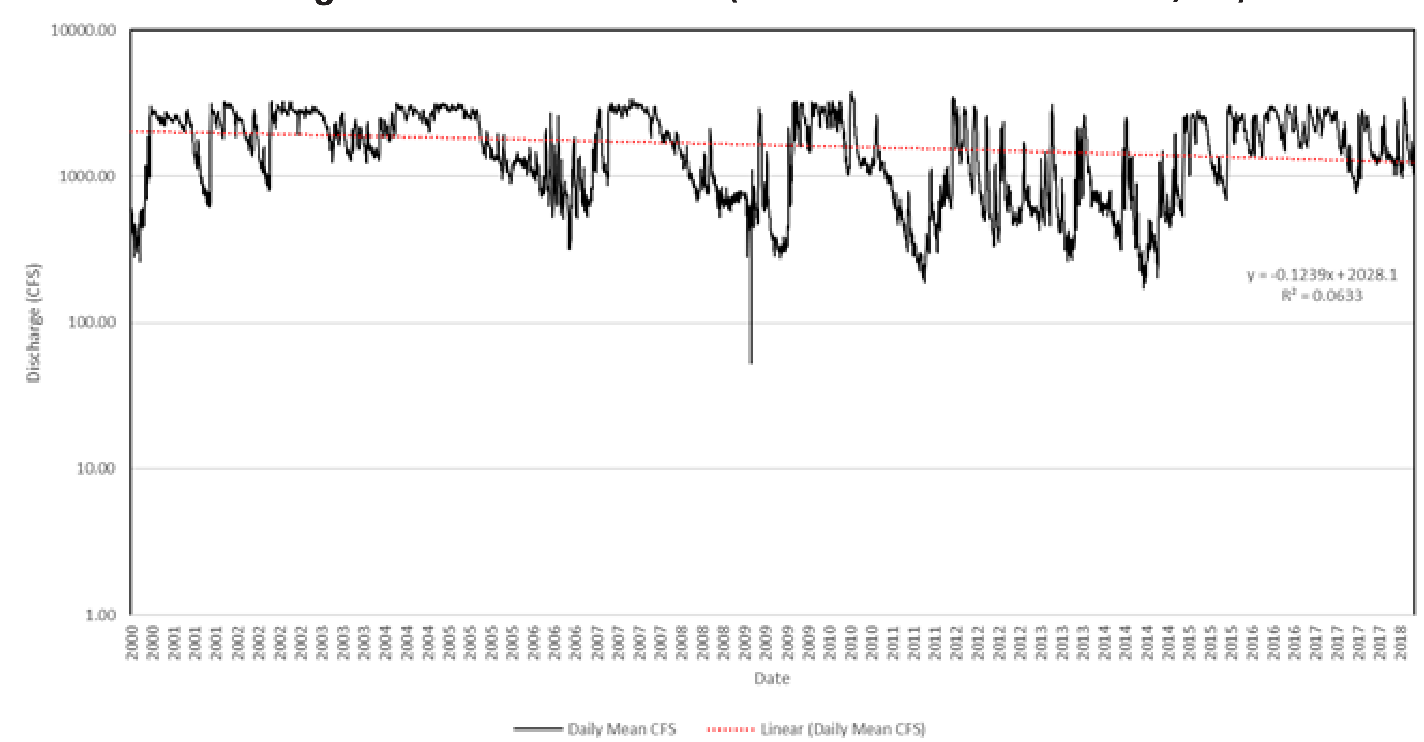


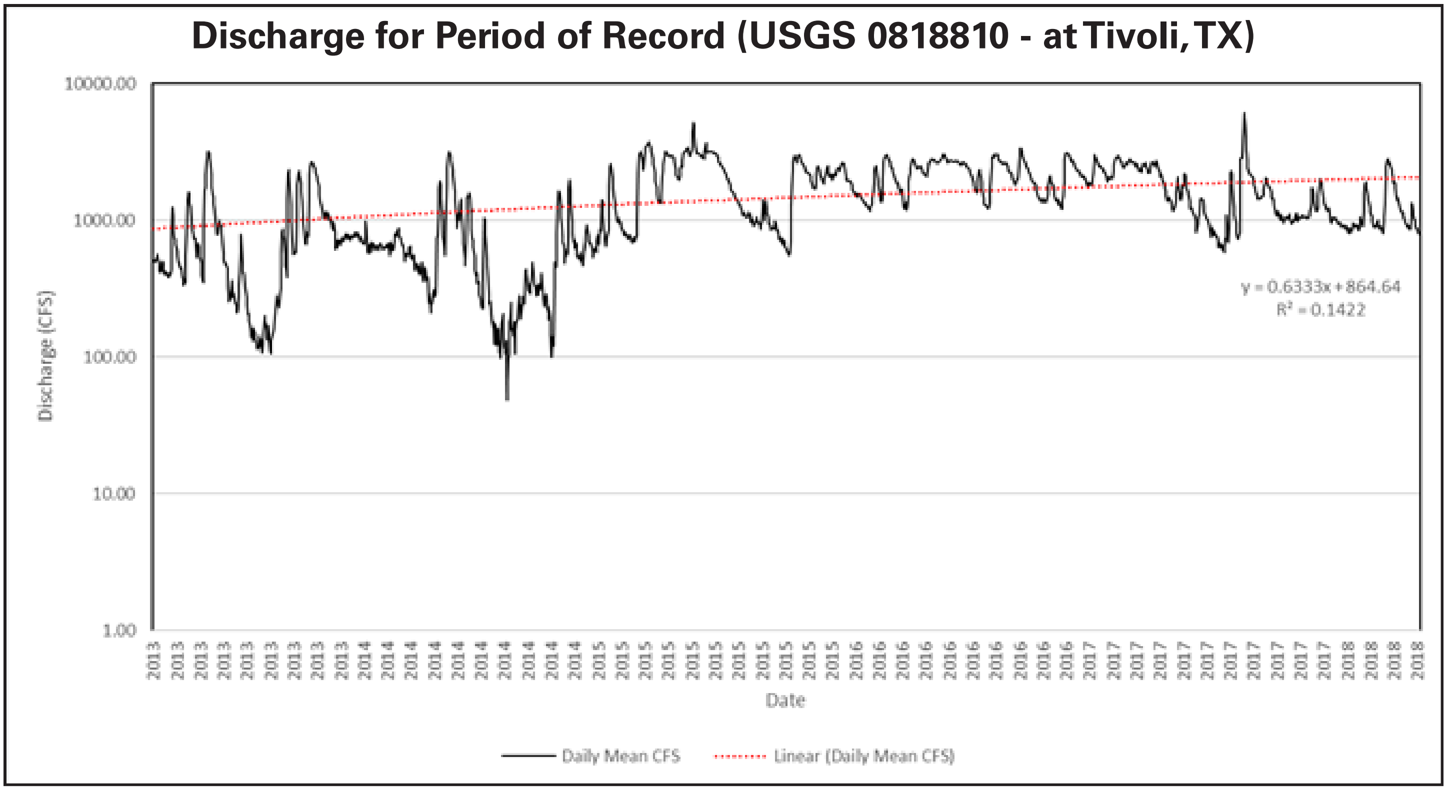
Discharge for Period of Record (USGS 08175800 - at Cuero, TX)

Discharge for Period of Record (USGS 08177520 - at Bloomington, TX)



Discharge for Period of Record (USGS 0818880 - at Tivoli, TX)




Discharge for Period of Record (USGS 0818810 - at Tivoli, TX)
10000.00
1000.00
100.00
10.00
1.00
Discharge (CFS)
y = 0.6333x + 864.64
R² = 0.1422
2013
2014
2015
2016
2017
2018
Date
Daily Mean CFS
Linear (Daily Mean CFS)

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