Groundwater, Surface Water Interactions Along the Blanco River

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The Blanco River and surrounding aquifers have become an area of interest for ground water hydrologists due to the extreme flooding of the summer of 2015. For almost a decade previous, the hill country region experienced severe drought conditions which caused low flow rates and a depletion of aquifers in the region's river systems. It is likely that the dramatic flooding and precipitation rates which interrupted the extended drought altered groundwater dynamics. This would imply different contributions from the surrounding spring systems and a theoretical increase in total input from the underlying aquifers of the region. Discharge measurements taken along the Blanco River were used in this research to track the inputs and outputs of various springs along a nine mile stretch of the Blanco River in Wimberley, Texas. The stretch in question includes four major springs, Little Park Spring, Main Park Spring, Miller Spring, and Pleasant Valley Spring. Discharge measurements above and below each spring resulted in a net difference equivalent to the springs' input and output. After measurements were taken, they were plotted, mapped, and compared with flow data from the past as a proxy for high flow aquifer conditions. Similar measurements were last taken in 2013 during a low flow drought period. The purpose of this project is to determine how the groundwater dynamics have changed from the previous drought conditions. It is expected that an increase in discharge will be found, suggesting a greater contribution from spring systems that are fed by recently recharged aquifers.

Introduction

The Hill Country of Central Texas is prone to intermittent periods of extreme drought. Most decades experience substantial drought for at least a year, often several (Smit et al. 2015). For more than a decade prior to 2013, Central Texas experienced one of the most severe and intermittent long lasting droughts since the decadal drought of 1947 to 1956 (BSEACD 2014). Drought conditions caused water bodies in the region to reach record lows, and flow ceased in many springs. In 2000 the well-known artisanal spring Jacob's well quit flowing for the first time in recorded history (Broun et al. 2008). The decrease in water volume was the result not only of a decrease in precipitation, but a decrease in input of groundwater from underlying springs and aquifers as well. The relationship between the surface water in the region's water bodies and the groundwater in aquifers beneath is complex, and is dependent not only on rainfall or drought, but the karst features that allow water to either enter or discharge into the surface water. Rainfall in the area can either flow into the rivers or creeks directly, or can infiltrate the soil and underlying karst features to recharge the aquifers (Smith et al. 2015). Aquifers are thus the source of inputs or outputs for the overlying surface water, depending on the geology of the setting and precipitation trends through time. As we observed through this study, even periods of significant rainfall, if experienced during severe drought conditions, can result in no appreciable increase in flow (Smith et al. 2011). On Halloween of 2013, in stark contrast to the dry conditions of the decade previous, Hays County experienced a flash flood with over ten inches of rain in one night. Discharge measurements along the gaining stretch of the Blanco River in the Wimberley area were taken just prior to this event. Less than two years later on Memorial weekend of 2015 the same region experienced even more severe rainfall,

resulting in the largest flooding event of the Blanco River in over 100 years. These major events combined with periodic precipitation caused the region to emerge from the prolonged drought conditions. When yet another flood of lesser magnitude occurred in 2016, the Blanco River experienced high-stand, non-drought conditions. The first measurements of this study were taken in late June of 2016, just after this period of heavy rainfall. The second set of measurements were taken two months later, on September 1st after a summer of moderate rainfall in which the Blanco River experienced non-drought, base level conditions. These measurements were compared with data taken in November of 2013, post flood yet still low stand due to drought. The focus of this paper is the comparison of groundwater and surface water interactions under these different climactic conditions. To understand and quantify how groundwater inputs via springs and aquifer systems change under varying conditions, discharge measurements taken at high, medium, and low stand have been recorded and compared.

Geologic Context and Background

The complexity of the surface water, groundwater relationship along the Blanco River is due largely to its geologic position along the Balcones Escarpment, formed by the Balcones Fault Zone. The fault zone developed during the late Oligocene or early Miocene (Kocis 2014) and divides Texas between the Edwards Plateau (Great Plains) to the west, and the Blackhead Prairie (Texas Coastal Prairie) to the east (Collins 2004). The margin of the created escarpment yielded a deeply dissected region of high relief which became known as the Texas Hill Country (Smith 2015). As a result of the generated thrust faults, older strata to the west were uplifted to come in contact with the younger strata to the east

(Schumacher and Saller 2014). The exposure of older, more permeable limestone layers coincided with the formation of aquifers, and the introduction of a groundwater, surface water dynamic based on faults, fractures, and variations in strata permeability. The aquifer providing the interactions specific to this study is the Trinity Aquifer, which can be divided into an Upper, Middle, and Lower member.

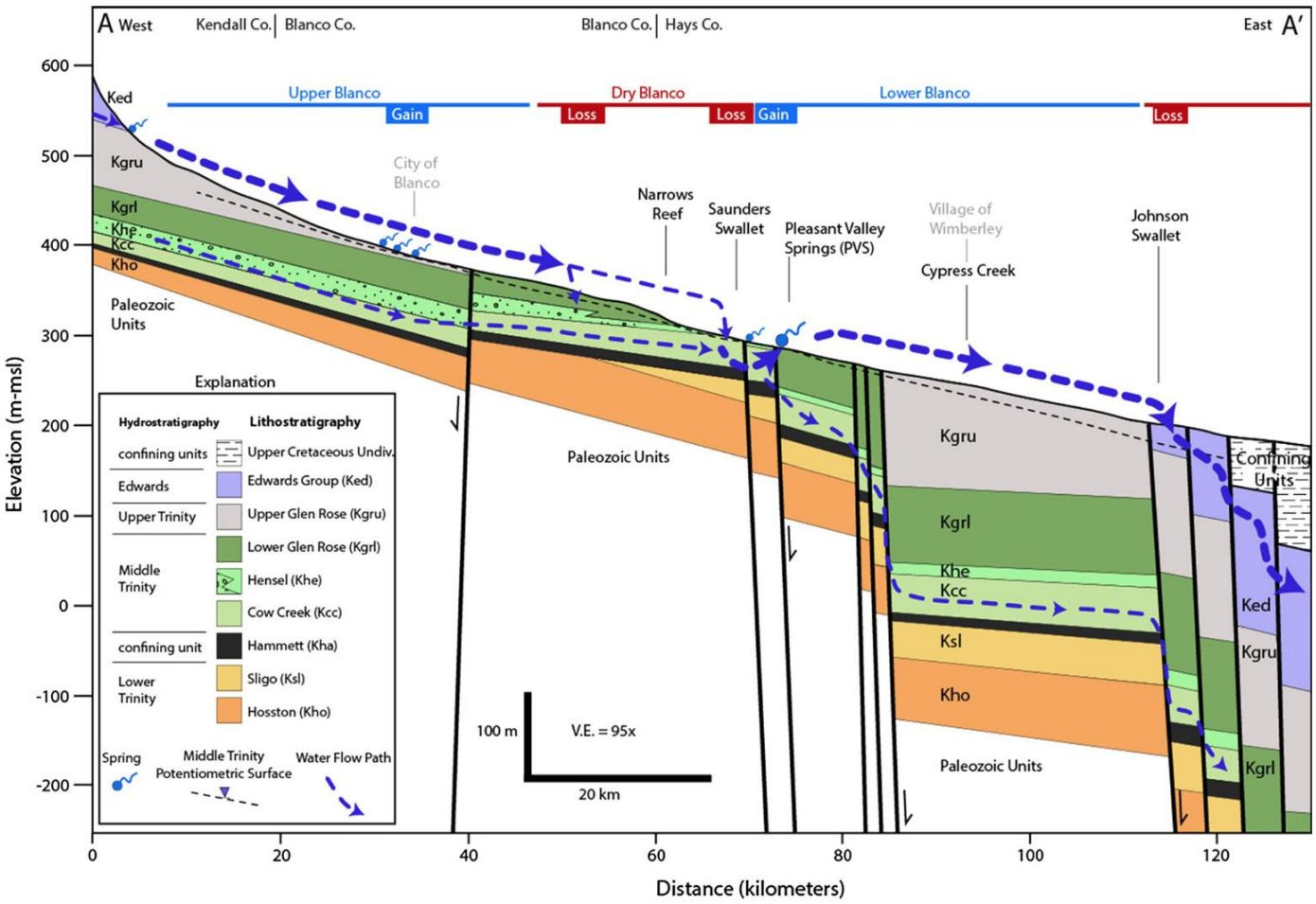


Figure 1: Hydrogeologic Cross Section of the Blanco River (Smith et al. 2015).

Each Trinity Aquifer varies in terms of thickness, fault direction, and water level, meaning their responsiveness to precipitation events is variant (Broun et al. 2010). The stretch of the Blanco River investigated in this study begins just above a group of springs, including

Little Park Springs, Main Park Springs, Miller Springs, and Pleasant Valley Springs, which serve as a source of groundwater from the Middle Trinity. The most upstream sites chosen for data collection are significant because they mark the beginning of the gaining portion of Blanco River, which extends for another 25 miles. As data from the 2013 drought shows, surface water flow and groundwater input were non-existent upstream from the first spring of this study. During drought conditions, the springs of this reach can be marked as the headwaters of the Blanco, and even in average rainfall conditions contribute a significant portion of surface water flow (Smith et al. 2015). The magnitude of their contributions, and the relationships of contribution variance with rainfall trends will be analyzed in this study.

Methodology

Volumetric Flow and Discharge

One method of quantifying the groundwater, surface water interactions involved a comparison of discharge measurements at various locations along the examined stretch of river. Discharge as measure of volumetric flow per unit of time is given by the equation:

$$Q = V \cdot A$$

Where Q = discharge, V = velocity, and A = cross sectional area. There are various methods and instruments for measuring both area and volume. Two instruments in particular are commonly used by the USGS, wading FlowTrackers and floating sensor boats. Both were used to calculate discharge, in cubic feet per second (cfs), for this report.

Stream Gauging by Wading Technique

Stream gauging by wading was used to calculate discharge in the shallowest environments of this study. The instrument used during the wade was a FlowTracker that measured stream depth and velocity at point intervals along a cross section. To use the instrument, a measuring tape was first stretched across the river at the most suitable location. The best measurement conditions included regions with a uniform flow rate and depth between 4-24 inches across the width of the river, a stream flow roughly parallel to the river bank, and a streambed with minimal heterogeneity in the form of large rocks or vegetation. Width at this location was measured in order to determine the interval of measure. USGS standards suggest that an interval of one tenth the total width should be used in manual stream gauging by wading. Once this interval was determined, measurement began by inputting the bank orientation, left or right when facing downstream, at the starting point and the depth at the bank's edge. From here the FlowTracker was moved to the first interval, the distance was input manually into the device and adjusted so that the velocity probe reached the midway point of that depth. This depth value was also manually input into the device, and initiated to begin velocity measurements over a 40 second interval. In taking these measurements, the instrument was held upstream and as upright as possible with the velocity probe oriented exactly perpendicular to the measuring tape. After 40 seconds of measurement, the point data was confirmed, the FlowTracker was moved to the next interval of measure, and the same process of adjusting for depth and initiating measurement was repeated. This process was continued until the other bank was reached, at which point a final depth measurement was input and measurement ceased. The calculated discharge function on the FlowTracker created a rough cross sectional profile

for depth which, combined with stream width, was used by the device to calculate cross sectional area. Calculated area and the average of the measured velocities were multiplied to yield a discharge measurement.

Due to the different characteristics of each cross section, adjustments were made conditionally based upon the heterogeneity of depth and flow rate across each gauging site. For cross sections with deeper, faster flow rate in specific stretches of the cross section, the interval was adjusted to allow for more measurements at these regions of higher volumetric flow rate. Conversely at regions of low volumetric flow rate, such as along shallower bank regions, the interval was extended so that fewer measurements were taken in these regions of shallow, homogeneous flow areas.

Acoustic Doppler Current Profiler

Segments of the river with a depth greater than two feet were measured using an Acoustic Doppler Current Profiler (ADCP). The instrument used was a SonTek RiverSurveyor M9 mounted atop a foam raft that was either pushed through the water by hand, or paddled across the river attached to the front of a kayak. An ADCP is used to measure the velocity of water through an entire water column using the Doppler effect. "Pings" of high enough frequency to be undetectable to human or animal ears are emitted into the water column from the instrument. The pings travel as sound waves and bounce off particles suspended in the water column. The resulting Doppler shift resulting from the change in frequency of sound waves emitted and received is used to calculate the velocity of the current. As with the FlowTracker, the boat with the mounted ADCP was kept perpendicular to the flow of the river, pointing upstream so that the user was positioned downstream from the sensor.

The speed of crossing depended on the velocity of the flow. Crossing speed needed to be less than or equal to flow velocity in order to record accurate velocity measurements for discharge calculations. Sonar beams were sent from the sensor down into the water column to determine depth and an internal GPS measured width throughout the duration of data collection so that no manual input of data was required. The device used the measured depth and width to derive a cross sectional area profile which it multiplied functionally by velocity to determine total discharge, measured in cubic feet per second, cfs.

Quantifying and Presenting Discharge

Discharge measurements were recorded at point sites along the Blanco River and Cypress Creek. Analysis of this data focused not only on the changes of these site-specific values through time, but also on the comparison of the discharge values recorded at each site under fixed conditions. Comparison of points through time yielded an understanding of how volumetric flow changed under the differing conditions of high rainfall in 2016, moderate rainfall in 2016, and minimal rainfall in 2013. Considering each condition individually, a comparison of discharge at each measurement site quantified contributions of underlying springs to the river system. These comparisons are essential to understanding groundwater, surface water interactions and controls under specific climactic conditions, which is the emphasis of this paper. A significant increase in discharge from one measurement site to another downstream suggests that there must exist some source of input between the two sites to result in such a differential in volumetric flow. Regions in which increased input was observed are therefore likely to

contain either a major spring or a network of several lesser springs that cumulatively result in a significant source of input.

Site Selection

The sites selected for measurement were chosen in order to obtain a general discharge profile over a stretch of the Blanco River that included four previously identified contributing spring systems. In order to gauge the inputs or outputs of the underlying springs, discharge measurements above and below each system were needed for comparison. Theoretically, without any sources or sinks to the river body, discharge measurements along its entirety would remain virtually the same. Significant differences in discharge signify therefore that a source or a sink is present in the system. These sources or sinks were attributed to springs, the magnitude of their input or output being the measured difference between each measurement site.

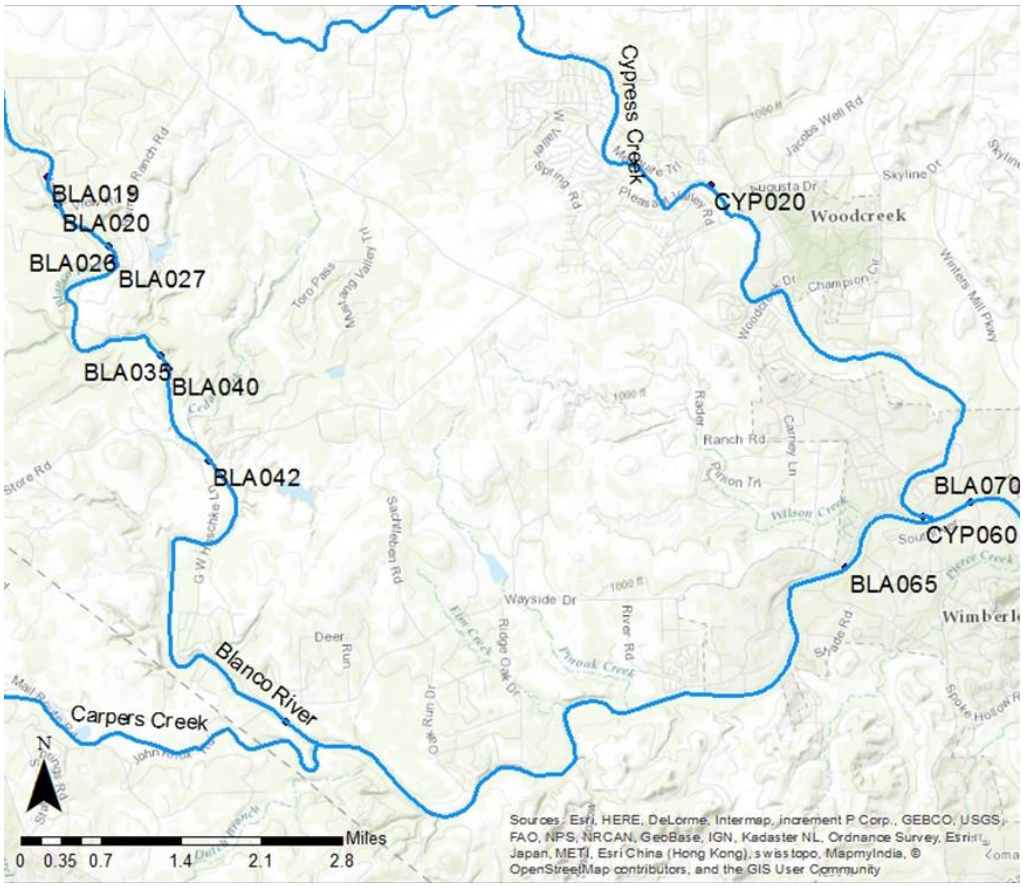


Figure 2: Site Map of study reach

Little Park Springs: BLA019 & BLA020

BLA019 and BLA020 were both located along a neighborhood park with a low water crossing upstream of a contributing spring system known as Little Park Springs. The setting of this spring was on the far bank of the river from the road, discharging from the bank as from a miniature cave in the rock face. The surrounding park, though accessible by the neighborhood, remained fairly natural with many overhanging trees and un-manicured river base. Due to obstruction by boulders and large islands of vegetation between the banks, ideal measurement sites were difficult to select immediately above or below the spring. BLA019, though completely dry in the second round of data collection, yielded a base level for comparison to BLA020, the best cross sectional stretch downstream of Little Park Springs. Input was determined to be 13.92 cfs in June and 6.81 cfs on September 1st.

Main Park Springs: BLA020 & BLA026

Main Park Spring discharges into the Blanco River just downstream of Little Park Springs. The measurement site BLA026 was selected because it falls downstream of Main Park and could be compared with BLA020 to find the inputs from the second park spring. Discharge from Main Park Springs was measured as 12.61 cfs in June and 13.9 cfs on September 1st.

Miller Springs: BLA027 & BLA035

The next major spring system was Miller Springs, located half a mile downstream from BLA027. Discharge from BLA027 was compared with the discharge at site BLA035, described below, to quantify the inputs of Miller Springs. BLA027 and BLA026 both lie upstream of the spring, and both yield similar discharge measurements. Therefore, data at

only one of these sites was needed to quantify discharge of either Main Park Spring or Miller Spring. In July, discharge of Miller Spring was measured using BLA027 and BLA035 as 68.35 cfs. In September, it was measured using BLA026 and BLA035 as 31.82 cfs. These measurements find Miller Springs to be the largest contributor of the four major springs.

Pleasant Valley Springs: BLA035 & BLA040

BLA035 and BLA040 correspond with a private property that includes a newly discovered spring system, Pleasant Valley Springs. There is one primary source of input into the river, a very powerful spring in the near middle of the river that resembles a young Jacob's Well. Discharge was taken upstream of the spring, at BLA035, and below the spring, at BLA040, to determine its input. In the first round of data collection, discharge was 54 cfs. In the second round, discharge was 35.35 cfs.

Other Measurement Sites and Inputs

Four other discharge measurements were taken on the Blanco River downstream of Pleasant Valley Springs and BLA040: BLA042, BLA050, BLA065, and BLA070. The total length of the stretch from BLA042 and BLA070 was more than five times the length of the stretch covering the four main springs from BLA019 to BLA040. These measurements allowed for a comparison of discharge flux across reaches of high spring activity and large volumes of input versus areas with minimal spring input. Measurements along Cypress Creek were taken mainly for scale.

Results and Discussion

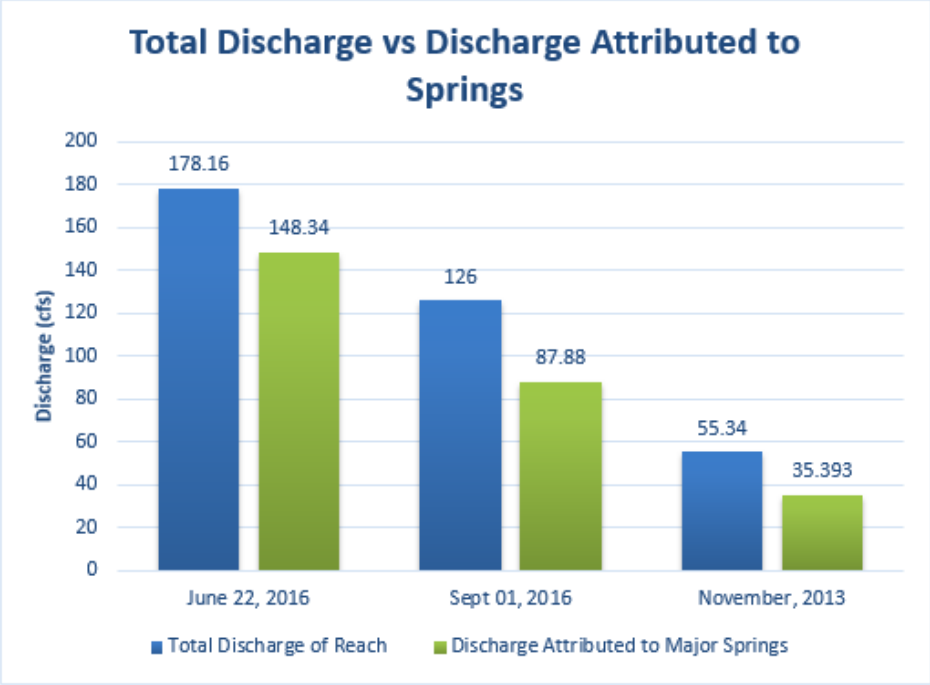


Figure3: Discharge from 2013 taken by Kocis, 2015.

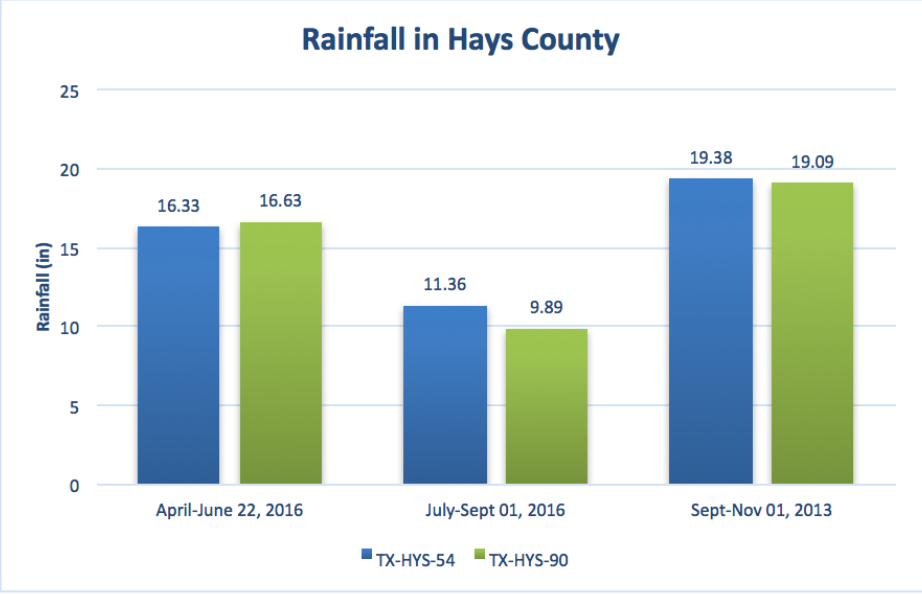


Figure 4: Two-month rainfall totals at rainfall gauges in Wimberley, Tx (CoCoRaHS).

The first set of measurements taken on June 22, 2016 served as a representative of high-stand, non-drought conditions. The second set of measurements taken September 1st, 2016 represented normal-stand, non-drought conditions and the measurements from 2013 represent low-stand after prolonged drought conditions. The discharge values were compared to quantify changes in groundwater, surface water dynamics as climactic conditions changed. The total discharge along the reach measured June 22 of 2016 was 178.16 cfs, more than three times the measured discharge of 55.34 cfs taken in late June of 2013. Rainfall recoded by the TX-HYS-54 Wimberley rain gauge two months prior to the measurement date in 2016 was 16.33 inches. Rainfall two months prior to the 2013 data collection was even greater, 19.38 inches as recorded by the TX-HYS-54 gauge. The significantly lower discharge of the Blanco River in 2013 cannot be explained therefore by the short-term precipitation rates of the contributing region.

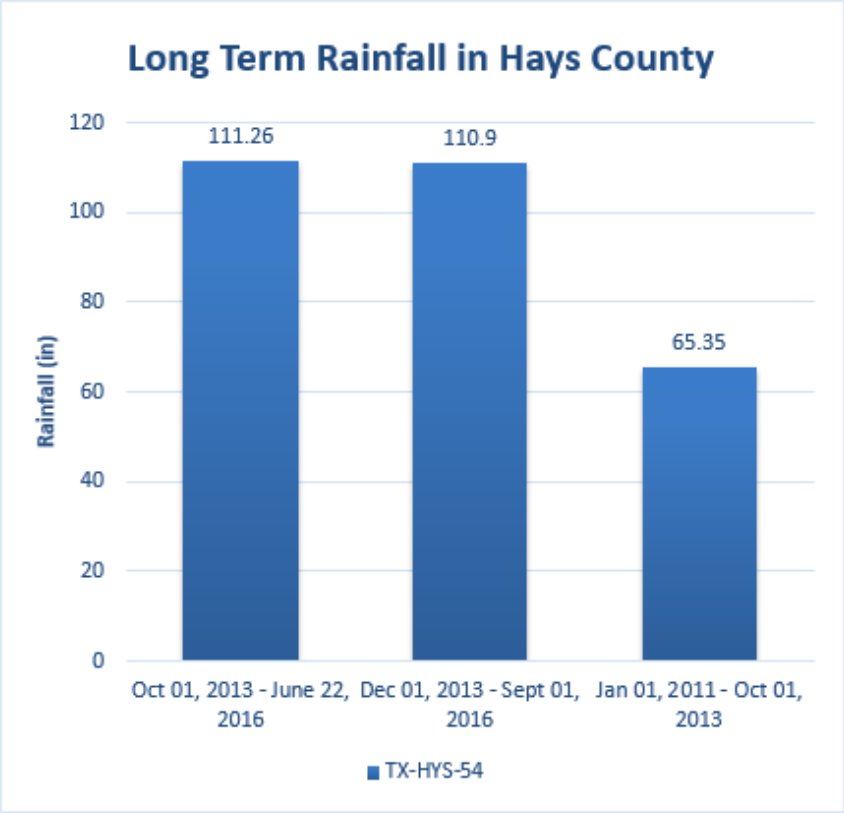


Figure 5:: Two year, nine-month rainfall totals at rainfall gauge in Wimberley, TX (CoCoRaHS).

Long term precipitation rates provide a better explanation for the discharge trends observed. Collectively in almost three years before the June, 2016 measurements, the TX-HYS-54 gauge recorded 111.26 inches. In almost three years prior to the November, 2013 measurement, the same gauge received only about half of that, 65.35 inches in total.

Rainfall two months prior to the September 1st measurement in 2016 was 11.36 inches, approximately half the measured 19.38 in 2013. The total discharge of the reach on September 1st, 2016 of 126 cfs was still more than two times that of the 55.34 cfs measured in 2013. Once again considering the long term precipitation trends, rainfall over a previous three year span was almost double the three year span of drought in 2013. These results suggest that the relationship between precipitation and spring discharge is primarily based upon long term precipitation trends. Despite the greater short term precipitation rate of 2013, discharge still remained significantly lower than in 2016 because the long term precipitation rates were less by almost half. Variations can be observed as the result of short term precipitation changes, as shown by the two 2016 measurements. Discharge on September 01 was less than in June, but not by a significant order of magnitude. The decrease in short term rainfall two months prior can explain this slight decline in discharge. A delayed reaction is therefore observed between precipitation rate changes and discharge rate changes. The higher discharge rates signify greater amounts of groundwater input into the surface water. These larger volumes are not generated by short term fluxes in rainfall, but by long term precipitation trends. Discharge increases require multi-year precipitation increases, and discharge will decline if rainfall is not sustained. Periods of prolonged drought will reduce groundwater contributions as the underlying springs and aquifers are fed by less runoff and precipitation.

Discharge (cfs)			
	June 2016	September 2016	2013
Little Park Springs	13.92	6.81	<0.3
Main Park Spring	12.61	13.90	6.36
Miller Springs	68.35	31.82	6.87
Pleasant Valley Springs	54.00	35.35	23.06

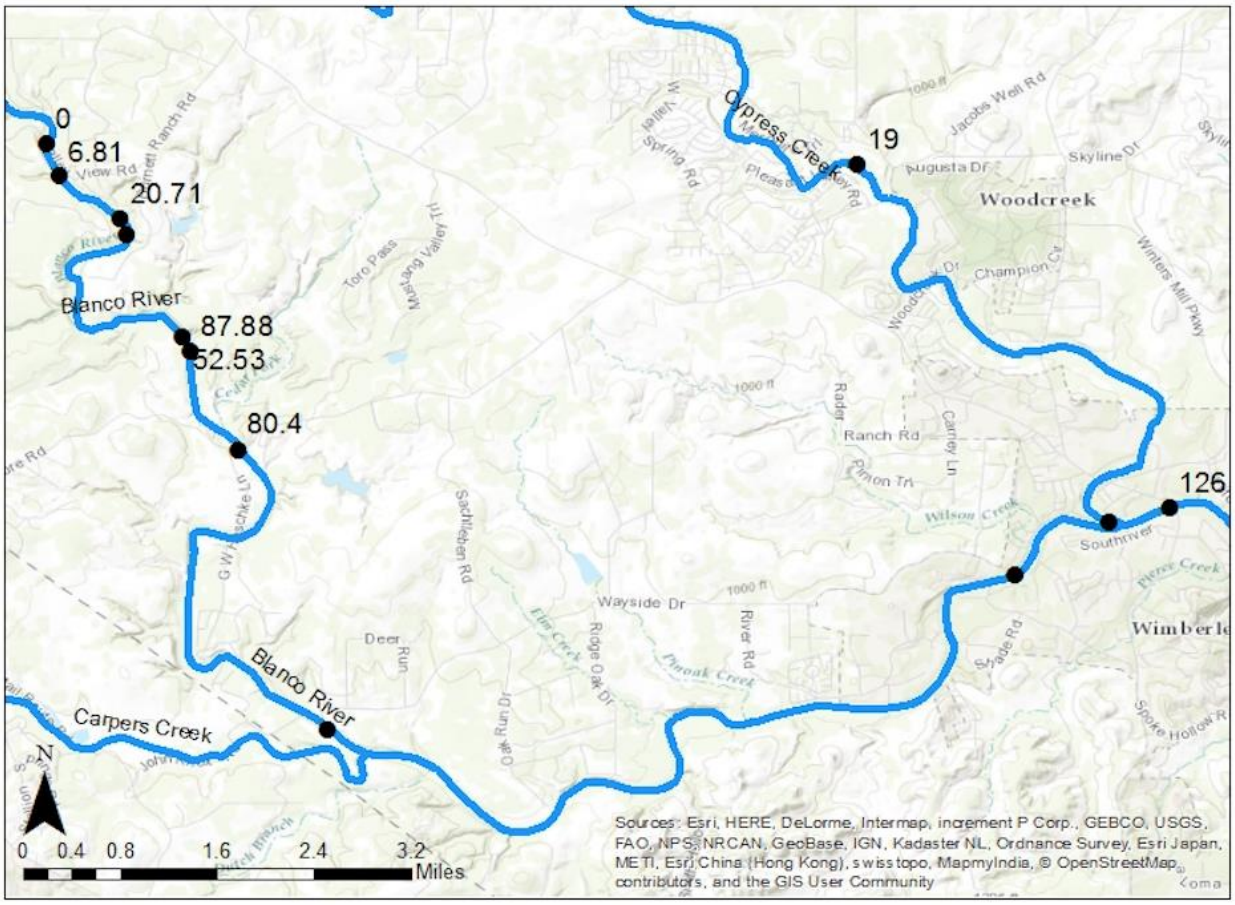
A comparison of discharge at each site during each period of data collection quantifies the amount of input that can be attributed to underlying springs. The four major springs fall between the point sites BLA019 and BLA040 and the total change in discharge from each site can be attributed to volumetric input from the springs. In June of 2016 this value was 148.34 cfs, in September 126 cfs, and in 2013 55.34 cfs. This change in discharge is consistent with the trend observed in discharge over the entire reach. Comparing the total reach discharge with the discharge attributed to the springs contextualizes the magnitude of the springs' contribution to the river system. Under each condition of high, medium, and low-stand, input via the four major springs accounted for over 60% of the total contribution along the entire stretch. This is a significant contribution considering the stretch of springs from BLA019 to BLA040 is only 5.34 miles, while the remaining distance of the reach between BLA040 to BLA070 is 14.84 miles. One third of the stretch contributes more than 60% of the groundwater discharging into the river system. These four springs therefore are the primary sources of discharge into the Blanco along the stretch of the river analyzed.

Stream ID	Date	Discharge (cfs)	Mean Depth (ft)	Stream Width (ft)	Total Area (ft^2)	Collected By
BLA019	6/22/16	84.84	1.55	89.93	142.00	KAY
BLA020	6/22/16	98.76	3.81	55.81	233.59	KAY
BLA026	6/22/16	111.37	2.02	50.69	100.76	KAY
BLA027	6/22/16	110.84	1.98	68.68	126.23	KAY
BLA035	6/22/16	179.19	3.37	70.77	241.49	KAY
BLA040	6/22/16	233.19	3.24	86.76	310.02	KAY
BLA042	6/24/16	229.84	1.31	74.33	105.38	KAY
BLA050	6/24/16	231.75	2.98	88.26	270.45	KAY
BLA065	6/27/16	253.34	2.71	125.96	393.52	KAY
BLA070	6/12/16	263.00	4.56	ND	ND	USGS
CYP020	6/20/16	33.90	3.19	ND	ND	USGS
CYP060	6/20/16	36.86	0.90	54.00	48.51	KAY

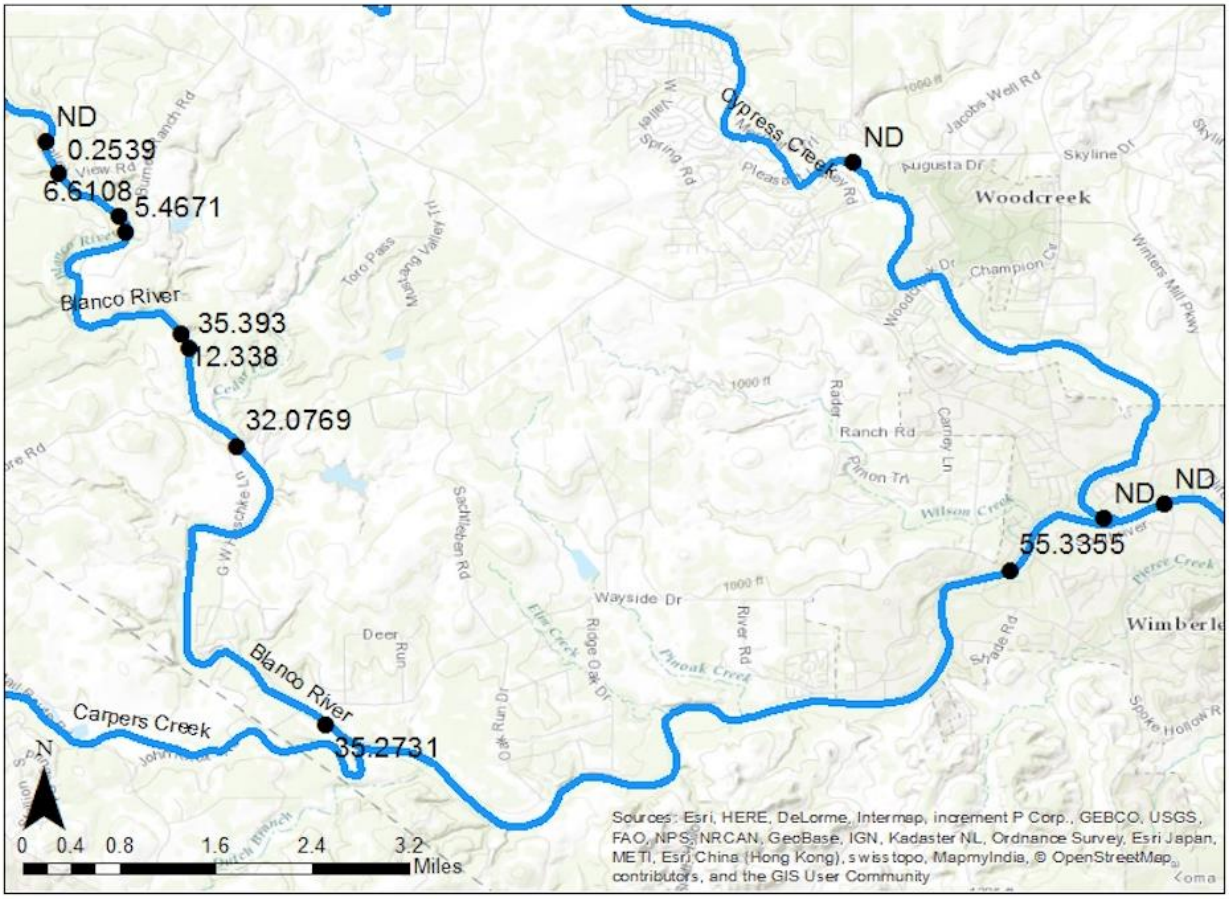
Stream ID	Date	Discharge (cfs)	Mean Depth (ft)	Stream Width (ft)	Total Area (ft^2)	Collected By
BLA019	9/1/16	0.00	0.00	0.00	0.00	KAY
BLA020	9/1/16	6.81	1.05	9.60	10.06	KAY
BLA026	9/1/16	20.71	1.14	44.50	50.54	KAY
BLA035	8/31/16	52.53	3.08	39.63	77.86	EAA
BLA040	8/31/16	87.88	4.55	77.71	262.76	EAA
BLA042	8/30/16	80.40	3.43	ND	ND	USGS
BLA070	8/31/16	126.00	4.20	ND	ND	USGS
CYP020	9/1/16	19.00	ND	ND	ND	USGS*

*calculated

Stream ID	Date	Discharge (cfs)
BLA019	11/2013	ND
BLA020	11/2013	0.2539
BLA026	11/2013	6.6108
BLA027	11/2013	5.4671
BLA035	11/2013	12.338
BLA040	11/2013	35.393
BLA042	11/2013	32.0769
BLA050	11/2013	35.2731
BLA065	11/2013	55.3355



Discharge (cfs) for June, 2016



Discharge (cfs) for August, 2013

Conclusion

Underlying spring systems contribute significant amounts of discharge into the Blanco River. The volumes are not generated by short term fluxes in rainfall, but by long term precipitation trends. Discharge increases require multi-year precipitation increases, and discharge will decline if rainfall is not sustained. Periods of prolonged drought will reduce groundwater contributions as the underlying springs and aquifers are fed by less runoff and precipitation. Surface water flows are influenced by groundwater contributions, which can account for high volumes of input as evidenced by the four major springs along the studied reach.

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