Surface Water-Groundwater Interaction of the Trinity and Edwards Aquifer Systems in the Blanco River Basin, Texas

Applied Karst Hydrogeology
Spring 2018

A collaborative project between:

Contents

Preface 4
Abstract 5
1. Introduction 5
Problem Statement 6
Background 6
Project Area and Description 7
Geologic History 8
Hydrogeology 9
Texas Water Resource Management 10
2. Surface Water Flow 11
Regional Overview 11
Blanco Basin Overview 12
Previous Study of Blanco River Flow Patterns 12
Methods 14
Site Selection 14
Stream Gauging with FlowTrackers 16
Results 17
3. Geochemistry 24
Purpose and Scope 24
Materials and Methods 24
Field Measurements 24
Geochemical Sampling 24
Post sampling Procedure 25
Data Quality 25
Field VS lab Alkalinities 25
Charge Balance 26
Results and Discussion 27
Carbonate Geochemistry 27
Stable Isotopes 31

4. Dye Tracer Test 35
Purpose and Scope 35
Overview of Study Area 35
Hypothesis 36
Methods 36
Selection of Dye and Dye Injection Point 37
Sample Collection 39
Testing Phases 41
Lab Analysis 42
Quality Control and Duplicate Samples 42
Detection Limits 42
Results 42
Discussion 45
Conclusion 45
5.Groundwater Levels 47
Introduction 47
Methods 47
Groundwater Elevation 48
Potentiometric Surface Map 50
Results 50
Discussion 53
Conclusion 54
6. Overall Discussion 55
7. Conclusion 56

Preface

“”

Abstract

The Edwards and Trinity aquifers provide water resources for millions of people in Central Texas. Although these two karst aquifers are regulated separately from each other as well as surface water, all three systems are connected through karst features and process. This study aims to further our understanding of the Blanco River system and its connection and geochemical contributions to the Edwards and Trinity aquifers. First, river discharge measurements were taken along the length of the Blanco to identify reaches that are losing water and reaches that are gaining. The information allowed us to identify the location of springs (groundwater to surface) and karst features that provide drainage of surface water directly into the ground. Additionally, we used geochemical samples from throughout the river, springs, and wells from the watershed to quantify water quality, but also to link the connections of the different parts of the system. With the identification of two major features that provide direct conduits for surface water to move quickly into the ground, we conducted a dye tracing experiment to follow where that water goes. The results of the tracing experiment identified which springs and wells were connected to the drainage features, and interestingly showed that the water entering the swallet was not connected to the spring at BLA-20, despite being directly downstream of the swallet. Lastly, we created a potentiometric surface map of groundwater levels across the study area by measuring groundwater levels from private and public wells and springs across the area. The combination of these datasets provides new insights into the connections of surface water to the Edwards and Trinity aquifers, and of the aquifers themselves. This study can be used to inform groundwater recharge models and tracing contaminants in the watershed. Moreover, these results demonstrate the direct connection between surface and groundwater, and the need for coordinated water management in the region.

1. Introduction

This investigation partnered with the Edwards Aquifer Authority (EAA) in order to understand the relationship between surface and groundwater interactions between the Blanco River and the Edwards-Trinity aquifer system. The Edward and Trinity aquifers are critical for water resources. These aquifers provide water to millions of people in the greater Austin-San Antonio region of central Texas, USA (Gary et. al. 2013). Groundwater and surface water are regulated separately under Texas legislation, interactions between the two poses potential threats to water quality and quantity. The Edwards and Trinity Aquifers are both karstic. Karst systems have not been well modeled in the past and are more complicated to understand. The Edwards and Trinity aquifers have also been regulated by different entities though past and current studies have shown groundwater interaction between the two. The Edwards has typically faced stricter regulatory guidelines than the Trinity.

Understanding karst systems is important in quantifying groundwater flow in Central Texas as well as many other regions across the world. Karst aquifers are aquifers that contain dissolution-generated conduits and are typically characterized by distinctive features such as streams, sinkholes, and dissolution conduits. Having insight on the evolution and current condition of karst carbonate aquifers is key in characterizing these systems as a whole. The use of water budgets, tracer studies, hydrograph analysis and chemical analysis of karst aquifers have all contributed to helping characterize karst aquifers. These systems are important sources for water storage and supply, and about 25% of the world depends on karst for water (Ford 1988). There are many aspects that differentiate karst systems from regular aquifer systems. Karstic conduits the characterizing features of these carbonate systems (White 2002), and flow through these conduits often have more in common with surface water than groundwater. On a geologic time scale, aquifers evolve very rapidly with significant modifications of flow paths as well as development of new flow paths. Due to this, karst aquifers must be regarded as works in progress (White 2002), and as such should be constantly researched and studied in order to maintain sufficient management of water resources.

Surface and groundwater interactions are present between the Trinity and Edwards Aquifer of the Hill Country and Balcones Fault Zone (BFZ). The geology in the area as well as watersheds of Onion Creek and the Blanco are important from a hydrogeological standpoint. The geology and watersheds of Onion Creek and the Blanco River are characterized by hilltops capped by the Edwards Group units and Upper Glen Rose members. Both regions have both been subjected to faulting due to the BFZ. The Trinity and Edwards aquifers differ in recharge ability. The Trinity aquifer experiences low recharge, about 4% of rainfall manages to recharge the aquifer, whereas, the Edwards Aquifer is primarily recharged by surface water from creeks and streams flowing into karst features. Past studies have shown that during extreme drought conditions the Blanco River is the only source of recharge to the Edwards Aquifer (Hunt et al. 2017). In order to understand the relationship of surface water and groundwater, multiple disciplines have been used, and were also used in this investigation. These include geochemical analysis, gain loss surveys, dye tracing, and groundwater levels.

Problem Statement

This project was conducted in order to better quantify groundwater-surface water interactions between the Blanco River and the Edwards Trinity aquifer system.

Background

This study included streamflow and geochemical water quality measurements that were collected along the Blanco River in conjunction with the Edwards Aquifer Authority (EAA) Interformational Flow Investigation. This study is an ongoing investigation to determine the interconnectivity between the Edwards and Trinity Aquifers of Central Texas. In the past the two aquifers have been treated and regulated separately. The Edwards Aquifer having many more restrictions because of its sensitivity and ecological importance. However, the interconnectivity of the two aquifers result in great influence from one aquifer to the next. Recent studies have begun to prove more interconnectivity between the two aquifers than previously thought. This was done by streamflow gain loss characterization, upland recharge variability, well monitoring systems (Wong et al. 2014). Additional gain loss stream gaging studies, geochemical sampling analysis, dye tracer testing, groundwater level mapping performed in this investigation will aid in the understanding of groundwater surface water interactions in the study area.

Project Area and Description

The study was focused in the Central Texas Hill Country; Hays and Comal counties. The study focused on the Trinity and Edwards group in relation to surface water from the Blanco River.

The younger Edwards Group has been juxtaposed over the Trinity Group due to BFZ faulting events in the Miocene. Rapid population growth of central Texas results on more dependence on these aquifers for public water supply, industrial, and domestic use. Continued population growth will result in increased aquifer pumping and could have dramatic effects on aquifer stability predictions. The Blanco River watershed and Cypress Creek watershed lie atop karst features and soluble rock, meaning topography is especially sensitive to surface water. Creeks and rivers have downcut the topography, creating steep topography (BSEACD 2014). The Blanco River watershed encompasses approximately 1100km^{2}at its confluence with the San Marcos River. The watershed is oriented in an east-southeast direction and forms the northern headwaters of the larger Guadalupe river system. The Colorado river bounds the watershed to the north, and the upper Guadalupe to its south (Furl 2015).

The Blanco River extends approximately 75km through karst landscape of the Edwards Plateau before flowing past the Balcones Escarpment in the lower portion of the watershed. The geology west side of the escarpment consists of lower Cretaceous limestones, while the east side consists of relatively nonresistant upper Cretaceous limestone, which results in a flat terrain (Furl 2015). Significant surface water – groundwater interaction along the Blanco River and Edwards-Trinity aquifer system make it a significant area of focus for groundwater research.

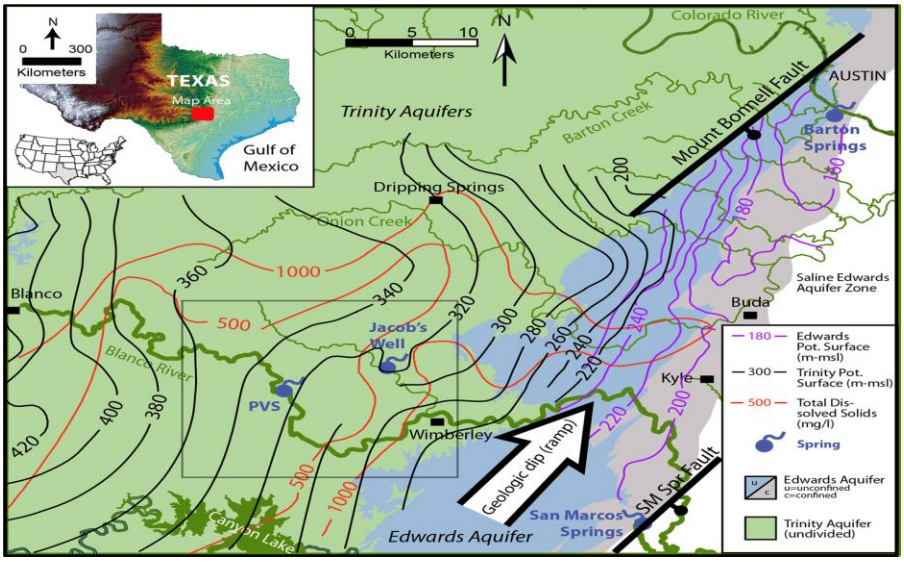


Figure 1.1: Map Showing the full extent of the Blanco River and indicating which sections are wet or dry during moderate drought conditions (Smith et. al. 2015)

Geologic History

The Edwards and Trinity aquifer system is about 42,000 square miles in west-central Texas. The aquifer system is mainly Lower Cretaceous in age and comprised of Comanche strata. The aquifer thins northwestward where massive impermeable pre-Cretaceous rocks dominate the subsurface. The system is predominantly terrigenous clastic sediments in the east and fluvial deltaic terrestrial deposits to the west. The system grades upwards from early Rrinitian age into supratidal evaporitic and dolomitic strata, intertidal limestone and dolostone, and shallow-marine, open-shelf, and reefal strata of the late Trinitian, Fredricks-burgian and Washitan age, The Trinity Aquifer is comprised of the Trinity Group and was deposited atop pre-Cretaceous rocks during three transgressive cycles. Fredericksburg and Washita Group were deposited later, lying atop the Trinity group. The area was subjected to major faulting during the late Oligocene through early Miocene that produced large-scale normal faulting, forming the Balcones Fault Zone (BFZ). Highly faulted areas fractured rock and in turn extended depth of freshwater diagenesis, displacing terrain and steeping the hydraulic gradient. The newly steepened gradient allowed for high flow velocities near surface. Dynamic groundwater flow enhanced transmissivity of the Edwards Group in the juxtaposed Edwards Aquifer. While transmissivity of the Edwards was enhanced, cementation, recrystallization, and mineral replacement diminished the transmissivity capabilities and hydraulic conductivity of the Trinity Group. The Trinity Aquifer transmissivity values average ~10,000 feet squared per day while the Edwards aquifer averages 750,000 feet squared per day due to the BFZ (Barker et al. 1994).

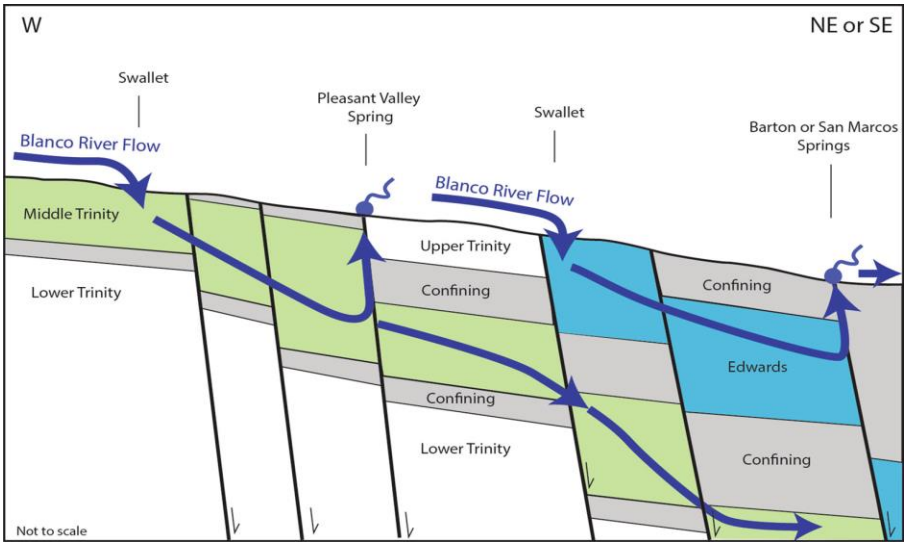


Figure 1.2: Geologic cross section of the Blanco River baseflow. Smith et al, 2015

Hydrogeology

The aquifers of the Edwards-trinity aquifer system are in rocks of Cretaceous age. The major aquifers are the Edwards-Trinity aquifer underlying the Edwards Plateau, the Trinity aquifer in the Hill Country, and the Edwards aquifer in the BFZ. Our focus is on the latter two aquifers.

The Trinity aquifer in the Hill Country is composed of dolomitic limestone with interbedded sand, shale, and clay. The lowest member of the Glen Rose Limestone and Hensel Sand are the most productive units in the aquifer. In the Hill Country, most of the Edwards group has been eroded and only caps a few hills. The upper Glen Rose Limestone has also been eroded and exposes rocks of the lower Glen Rose Limestone along the Blanco river. The lower member of the Glen Rose Limestone ranges from 0 to 300 ft thick, and the Hensel Sand ranges from 0 to 200 ft thick. Underlying the Hensel Sand is the less productive part of the Trinity aquifer, Cow Creek Limestone (90 ft thick) (Kuniansky 2004).

The Edwards aquifer is unconfined along a narrow outcrop of Edwards Group Limestone along the southern edge of the Hill Country. The Edwards aquifer is confined primarily downdip from the outcrop and ranges from 200 to 700 ft thick in the BFZ (Maclay and Small 1986). Along the BFZ, higher dissolution of rocks parallel to faults and joints has resulted in numerous karstic features along the faults including caves, sinking reaches, springs, etc.

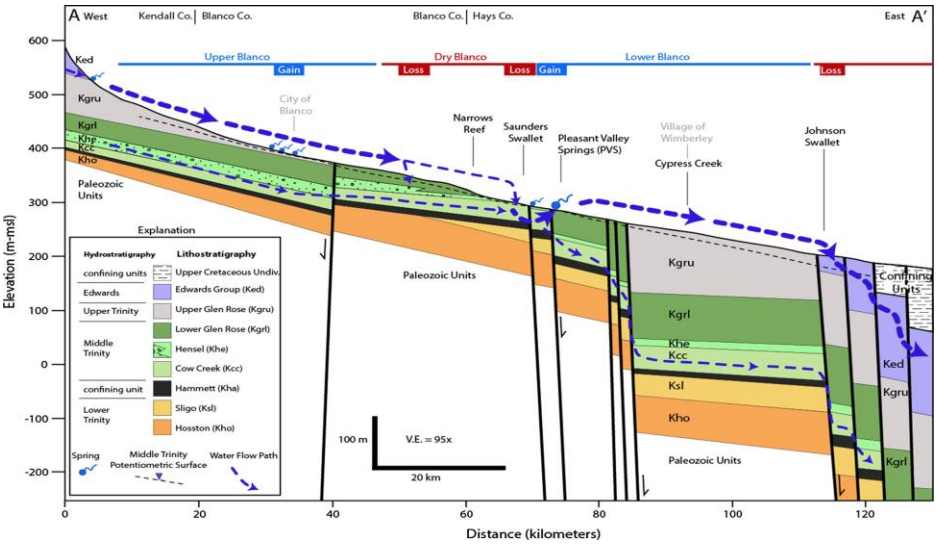


Figure 1.3: Generalized hydrogeologic cross section A–A' along the Blanco River during moderate drought conditions including generalized stratigraphic section (Smith et al. 2015).

Texas Water Resource Management

In Texas, management of water and water rights is crucial for future protection and efficient use of water as a resource. Surface water and groundwater are inevitably connected environmentally, but in Texas they are legally separated. Texas law governs that surface water in Texas belongs to the state of Texas and can be used by the landowner with state's permission. However, groundwater law in Texas states that groundwater belongs to the owner of the land above it and may be used or sold as private property, also known as "absolute ownership".

This legal distinction between surface water and groundwater in Texas has led to the creation of water management agencies. Certain agencies focus on groundwater resource management while others are solely surface water management agencies. Some agencies, such as the Texas Water Development Board (TWDB), manage both surface water and groundwater. Formed in 1957, the TWDB is one of the biggest state agencies that focuses on water resource management and conservation. The TWDB manages flood mitigation, develops statewide and regional water plans, and funds research on water supply and management projects in the state.

The existence of water management in Texas is crucial in maintaining the ecological health and productivity of rivers, aquifers, and reservoirs in the state as well as ensuring the continued availability of water supplies from surface water and groundwater.

2. Surface Water Flow

Regional Overview

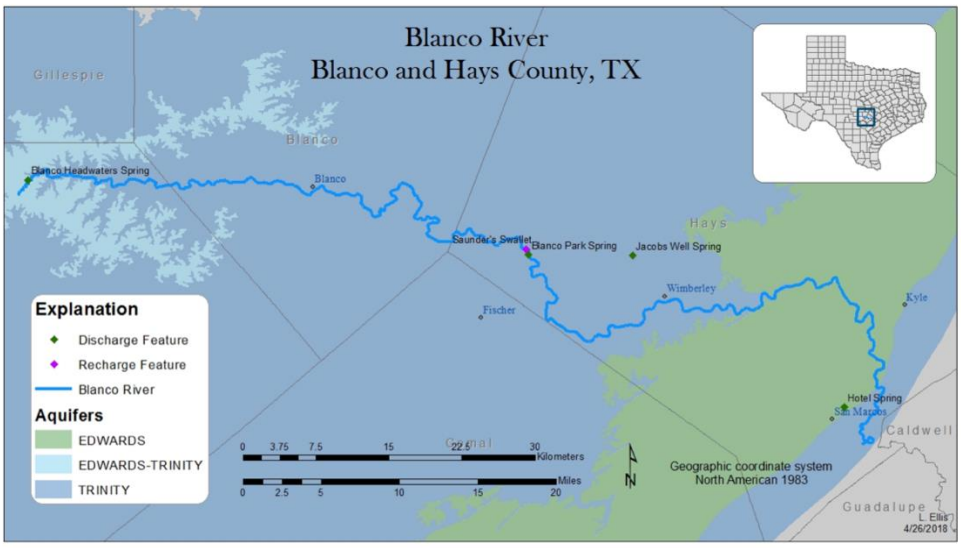


Figure 2.1: The Blanco River, including recharge and discharge features.

The Blanco River and other streams within this watershed are hydrologically linked to the Edwards and Trinity karst aquifer systems, which supply water to much of central Texas (Hunt et al. 2017). Flow moves between the aquifers and surface streams, and recharge moves in both directions (Figure 2.1).

Our study area includes the entire length of the Blanco River that flows east from Kendall County to Hays County and traverses both the Texas Hill Country and the BFZ that lies at the eastern edge of Hill Country (Figure 2.2).

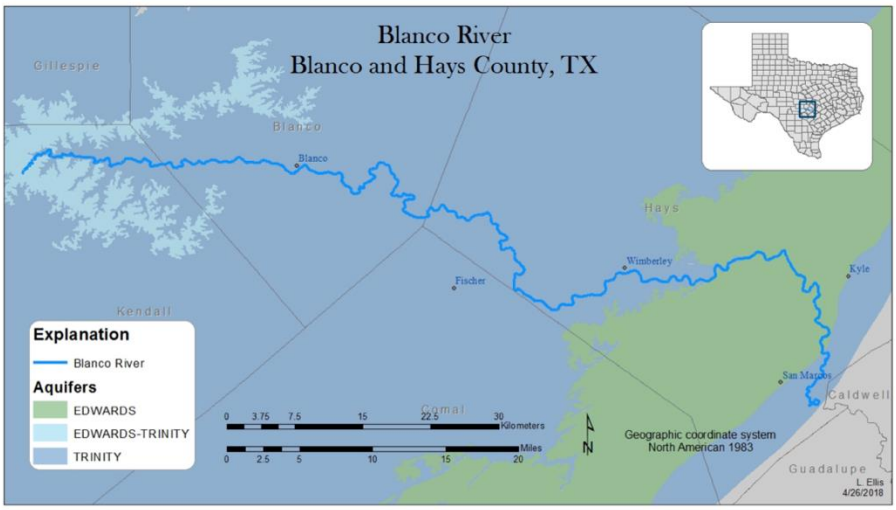


Figure 2.2: The Blanco River. The area underlain by the Edwards Aquifer roughly corresponds to the BFZ. West of the Edwards is the Hill Country.

Southeasterly stream flow across the Blanco River watershed of the Hill Country has eroded much of the Edwards Group from the surface, leaving the Trinity exposed at the surface (Barker et al. 1994). The Blanco River and major streams of the region tend to have steep gradients as they flow from west to east across Hill Country. Upgradient reaches are enclosed in steep, vertical-walled canyons. Downstream, canyons become broad, flat-bottomed valleys that tend to maintain their near-vertical walls. As these streams flow into the BFZ, their valleys narrow as they begin to flow on top of the relatively permeable Edwards Aquifer (Wermund and

Woodruff 1977). This section of the Edwards Aquifer in the BFZ is of great ecological importance: it is one of the most productive reservoirs in the country (Barker et al. 1994), and the springs that flow out of it also provide a unique habitat for over 50 species (Bush et al. 2000). High hydraulic heads in confined parts of the Edwards Aquifer produce several large springs, including Comal and San Marcos Springs.

Blanco Basin Overview

The Blanco River is a tributary to the Guadalupe River by way of the San Marcos River. The Blanco River flows east from Headwater Spring in Kendall County to Hays County, where is discharges to the San Marcos River. The San Marcos River then flows into the Guadalupe River, which eventually outlets into the Gulf of Mexico in San Antonio Bay. The river passes through the cities of Blanco, Wimberley, and San Marcos. The river is 75 miles long, with a drainage area of 412 square miles (USGS 2016). Headwater elevation is 1960 ft-msl and elevation near the mouth of the Blanco is 620 ft-msl. Climate along the Blanco River in the Hill Country is extremely dynamic and includes both massive flash flooding events and severe, prolonged drought (Hunt et al. 2017). The majority of precipitation falls during the spring and fall, with an average annual rainfall of 770 mm per year (NOAA 2016). Under average to dry conditions, the Blanco River is made up of long stretches of dry streambed and intermittent stagnant pools with no flow (Smith et al. 2015). Average daily flow is 143 cfs where the river passes through Wimberley (USGS 2016). Peak flow and low flow measurement were recorded at the same gauge and are 175,00 cfs (measured during the May 2015 flooding event) and 0.7 cfs (measured in July 1956), respectively. A number of streams and rivers flow into the Blanco River. Some of these are, from west to east, Meier Creek, Delaware Creek, Cottonwood Creek. Little Blanco River, Cypress Creek, and Halifax Creek (Guadalupe-Blanco River Authority 2008). Our study includes measurements taken at Halifax Creek.

Previous Study of Blanco River Flow Patterns

The Blanco River is considered to be a perennially gaining stream (Jones et al. 2011), and it has not stopped flowing in Wimberley since 1925 (Hunt et al. 2017). The upper Blanco River catchment upstream of Pleasant Valley Spring includes both gaining and losing reaches that flow intermittently depending on hydrologic conditions (Watson et al. 2014). About 12 miles downstream of the City of Blanco, when flowing, the Blanco River becomes a losing stream due to loss of surface flow to subsurface recharge features (Smith et al. 2015). Downstream of this losing reach, and just upstream of Park Spring at Saunders Swallet, the river is usually dry. During periods of high rainfall Saunders Swallet, located in the bed of the Blanco River where the Cow Creek limestone is exposed at the surface, provides recharge to the Blanco (Hunt et al. 2017). It is probable that some

surface flow enters the Cow Creek here, and discharges downstream at Pleasant Valley Spring. About 0.5 miles downstream of Saunders Swallet, the Blanco resumes a more consistent flow regime due to groundwater discharge from several springs, the furthest upstream of which is Park Spring (Smith et al. 2015).

Pleasant Valley Spring, located 2.5 miles south of Park Spring, is a significant source of recharge to the downstream portion of the Blanco River. The upper Blanco catchment is a likely source of recharge to Pleasant Valley Spring, but not to the adjacent Jacob's Well Spring (Watson et al. 2014). The stretch of river into which Pleasant Valley Spring discharges is characterized by numerous solution-widened fractures discharging groundwater into the Blanco (Smith et al. 2015). Pleasant Valley Spring is by far the largest of these, and is the largest documented spring of the Hill Country Trinity Aquifer system. It is located where a northeast-trending fault crosses the Blanco River. During drought conditions, Pleasant Valley Spring is the headwaters of the Blanco, providing 100% of base flow (EAA Report). Total spring flow has been recorded at as much as 0.7 m^3s (May 2013; Smith et al. 2015). Pleasant Valley Spring has a similar water surface elevation, structural location, and lithologic setting to Jacob's Well Spring. Jacob's Well Spring supplies most of the base flow to Cypress Creek, which is a major tributary of the Blanco River (Watson et al. 2014). Historically, Cypress Creek was perennial, but more recently it has become ephemeral due to increased groundwater pumping and recent severe drought.

Downstream of Pleasant Valley Spring and Wimberley, the Blanco River continues to flow for about 25 miles at which point it reaches the Edwards Aquifer recharge zone. Here, the permeable rock and recharge features like Johnson Swallet can divert enough water to cause the river to go dry under certain conditions. Hauwert et al. (2011) showed that some of the surface flow from the Blanco River that recharges the Edwards Aquifer may then provide significant recharge to Barton Springs. When Blanco River flow is high enough, some surface water will continue to flow past the Edwards Aquifer recharge zone, eventually reaching the San Marcos River in San Marcos (Smith et al. 2015). The Blanco River provides an important connection between the Trinity Aquifer System and the Edwards

Figure 2.3: Generalized gain-loss map of Blanco basin from Smith et al. 2015.

Aquifer. Gain-loss surveys conducted by the United States Geological Survey and summarized by Slade et al. (2002) and compilation of historical flow data and additional flow measurements completed by Wierman et al. (2010) show complex surface-groundwater interactions along the Blanco River (Figure 2.3; Hunt et al. 2017). Through our work, we seek to increase the corpus of knowledge related to surface water-groundwater interactions in the Texas Hill Country. This is important for efficient management of water resources.

Methods

Site Selection

In March 2018 we collected flow measurements at 18 sites in the Blanco River (Figure 2.4). One of these measurements was manually collected at Headwater Spring at the headwaters of the Blanco River (not shown on map). The sites were selected based on previous and ongoing studies that focus on water resources in the Blanco River Basin, and the Edwards and Trinity Aquifer systems. Measurement points were selected based on ease of access, as well as ability to enable us to accurately quantify gaining and losing stream reaches. The USGS maintains 7 gauges along the Blanco River (Figure 2.5; USGS 2018), which offer points of comparison. From these measurements, we compiled a gain-loss flow map, which we will discuss below. Prior to collecting measurements, we expected to see similar flow patterns to those documented by Smith et al. (2014), the Karst Hydrogeology Class of 2015, and Hunt et al. (2016). We did, however, think it likely that overall flow might show a slight downward trend over the last four years due to continued increase in pumping and a prolonged period of drought.

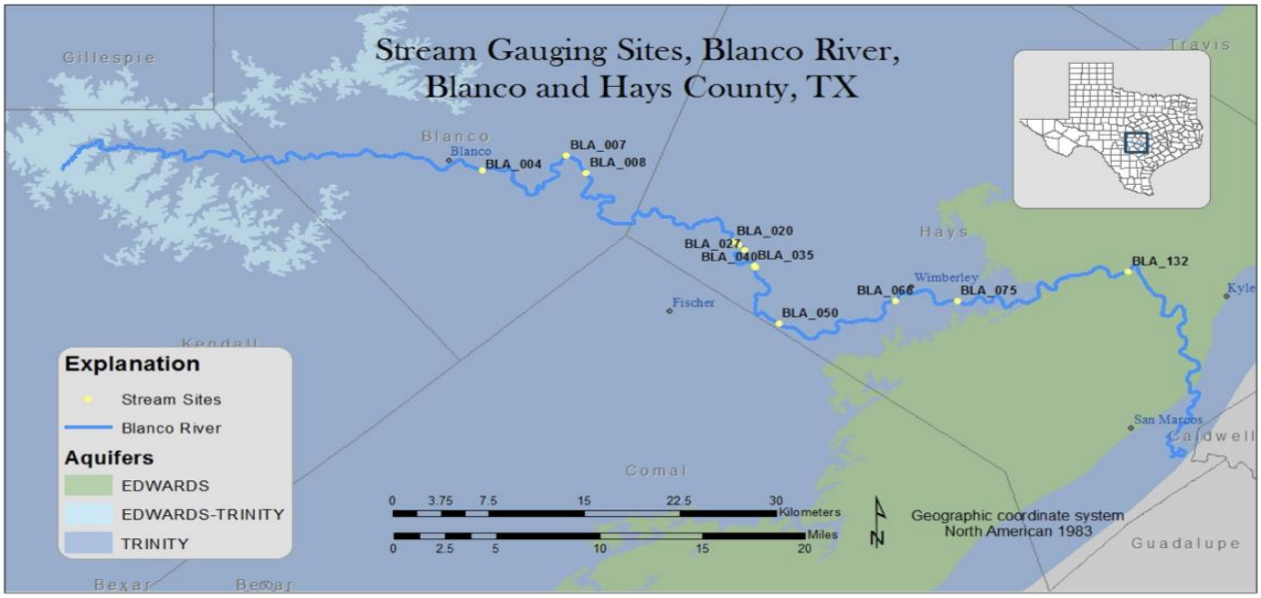


Figure 2.4: Flow measurement sites

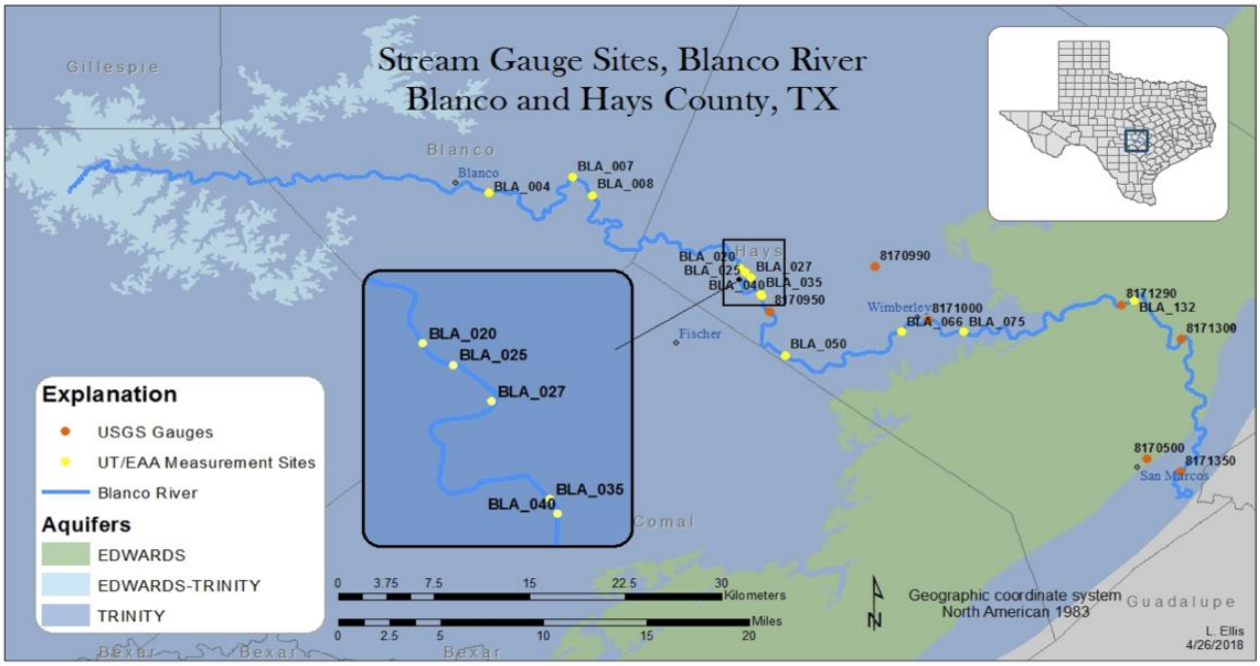


Figure 2.5: USGS gauge sites and our flow measurement sites, as well as those monitored by the Edwards Aquifer Authority (EAA).

Stream Gauging with FlowTrackers

Figure 2.6: FlowTracker and FlowTracker2. From SonTek Operation Guide.

Discharge measurements were collected with a SonTek FlowTracker and FlowTracker2 (Figures 2.6 and 2.7), which are both handheld Acoustic Doppler Velocimeters (ADV). Measurements were collected at areas where the channel was a wadeable depth. The FlowTracker's acoustic transmitter emits an acoustic signal, which then travels through the sampling volume (water volume between the acoustic receivers; Figure 2.8) and is reflected in all directions by particles suspended in the water (Environment Canada 2015). The receiver samples this reflected sound at the exact time corresponding to the return from the sample volume, based on the speed that sound travels in water. The change in frequency, which is called the Doppler shift, is measured between the transmitted and received signals. The measured Doppler shift is proportional to the velocity of the moving particles, which is assumed to be the same as that of the flowing water.

Figure 2.7: Team members using FlowTrackers to stream gauge. Duplicate measurements were collected at some sites to ensure accuracy of results.

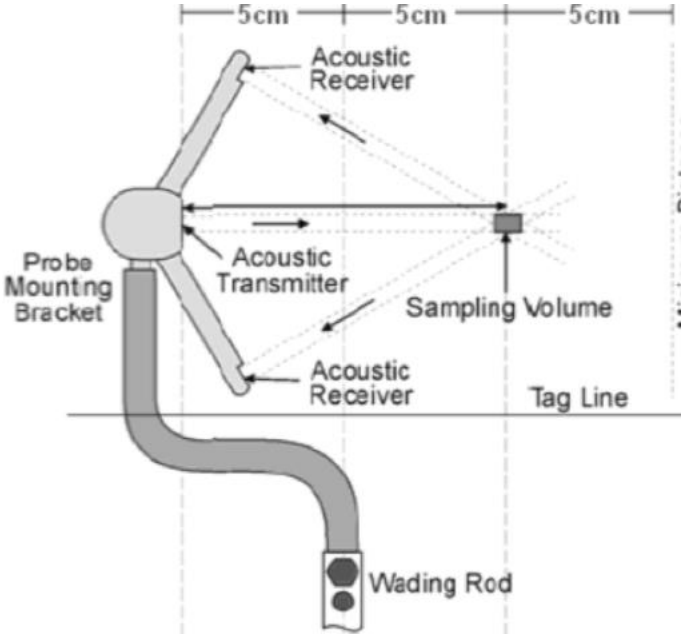


Figure 2.8: Diagram of acoustic components of FlowTracker Modified from Environment Canada 2015.

After selection of measurement site, the transect was cleared of rocks and any other obstructions. Then a measuring tape was oriented perpendicular to channel flow and tied across the river with no slack. The measuring tape served two purposes: it provided us with the width of the river, enabling us to divide the river into measurement intervals, and it served as a guideline as we collected flow measurements, ensuring that we oriented the FlowTracker perpendicular to flow. The FlowTrackers were mounted on wading rods with bubble level attachments to ensure that the instruments remained level during use. Flow measurements were then collected at 0.5- to 1-foot increments, at 3/5 of the total water depth at each measurement point. The FlowTracker data were processed using standard QA/QC procedures. FlowTracker output data sheets are included in Appendix 1.

There are several things that can negatively affect FlowTracker discharge readings. These include signal-to-noise ratio (SNR), standard error of velocity, measured flow angle, and boundary controls. SNR provides a measurement of the acoustic signal strength emitted from the instrument in proportion to the ambient noise generated by the instrument. Any SNR value for a beam less than 4dB should not be used (Turnipseed 2010). When orienting the FlowTracker, the wading rod must be oriented perpendicular to the flow with a flow angle that is less than 20 degrees. If the flow angle is larger than 20 degrees, the FlowTracker will generate an error message. Additionally, underwater objects such as rocks and vegetation, can prevent the FlowTracker from collecting measurements, so any potential obstructions must be removed before measurements can be collected.

Results

Table 2.1 shows the discharge measured with each method, with trials run simultaneously and their average value taken for use in our analysis, and the change in discharge from the nearest upstream gaging site. Negative change represents a losing reach between

sites and positive ΔQ indicates an increase in streamflow. These gains and losses are primarily the result of surficially exposed conduits (generally fractures in bedrock), i.e. springs and recharge features on the wetted perimeter. Fig. 2.9 shows the corresponding Site IDs on a hydrogeologic map, indicating underlying hydrogeology of the Trinity and Edwards aquifer units, where flow measurements were taken on the 3rd and 4th of March, 2018.

Table 2.1. Average and net change from the prior site for Blanco River discharge, March 3-4, 2018. Results from the gain/loss survey completed March 3-4, 2018.

site_ID	Date	Method 1	Q (cfs) 1	Method 2	Q (cfs) 2	Average Q	Gain/loss - ΔQ (cfs)
Headwaters	03-Mar-18	pen cap	0.5	-	-	0.5	0.5
BLA_004	03-Mar-18	flowtracker	3.99	flowtracker2	3.956	3.973	3.473
BLA_007	03-Mar-18	flowtracker	3.2756	flowtracker2	3.346	3.3108	-0.6622
BLA_008	03-Mar-18	flowtracker	2.9948	flowtracker2	2.802	2.8984	-0.4124
BLA_020	03-Mar-18	flowtracker	0.9084	flowtracker2	0.415	0.6617	-2.2367
BLA_025	03-Mar-18	flowtracker	4.7208	flowtracker	4.4933	4.60705	3.94535
BLA_027	03-Mar-18	flowtracker	4.7204	flowtracker	4.7342	4.7273	0.12025
BLA_035	03-Mar-18	flowtracker	0.6945	-	-	0.6945	-4.0328
BLA_040	03-Mar-18	flowtracker	18.4625	-	-	18.4625	17.768
BLA_050	04-Mar-18	flowtracker	20.3103	flowtracker2	20.329	20.31965	1.85715
BLA_066	04-Mar-18	flowtracker	27.1482	flowtracker2	27.32	27.2341	6.91445
BLA_075	04-Mar-18	flowtracker	29.4852			29.4852	2.2511
BLA_132	04-Mar-18	flowtracker	27.8345	flowtracker	26.3739	27.1042	-2.381

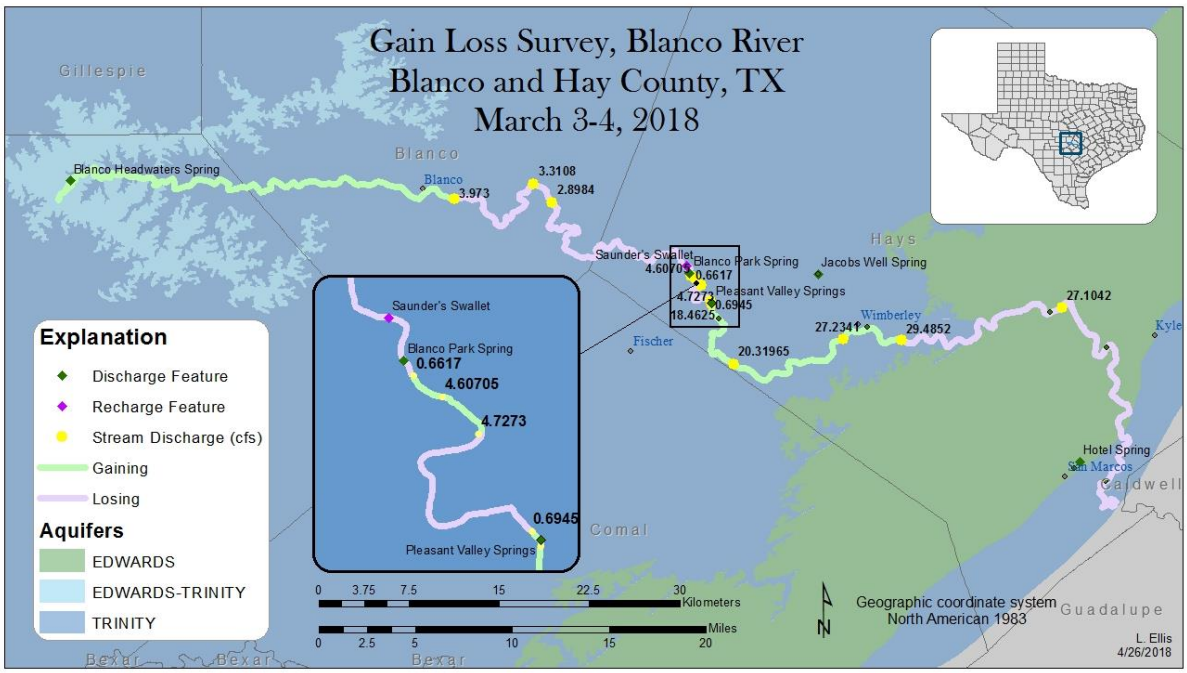


Figure 2.9 Gain/Loss Survey results on a hydrogeologic map of the Blanco River watershed.

Our results that clearly define these segments are consistent with gain/loss surveys of the Blanco River completed in 2013 and 2015. Personal communication with Dan Peavy, who has studied the local history of his property which contains the Blanco headwaters springs, revealed that the main pool where fracture flow first feeds the Blanco River has no reports of going dry (Fig. 2.10). Our on-site flow estimates made with an approximate area and rudimentary stream velocity measurement indicated a 0.5 ft^3/s flow from this pool, confirmed by the landowner to be common and persistent. Sites downstream from PVS, specifically around the town of Wimberley, exhibit the greatest discharge. A flow of 29.5 ft^3/s was measured just after the confluence with Cypress Creek, whose headwaters are at Jacob's Well, which produces a remarkably constant baseflow of around 3-4 cfs.

Fig. 2.10: Headwaters springs on Dan Peavy's property. Perennial springs that mark the start of the Blanco River. Students from The University of Texas, all authors of this report, take discharge and geochemical measurements.

Discussion

Our study area can be broken down into five prominent sections for the purposes of a gain/loss survey: (1) The Headwaters-Gaining region is defined by generally diffuse recharge across the westernmost hills, predominantly Upper Glen Rose limestone with some Edwards formation in situ at hilltops, all west of the town of Blanco; (2) the Trinity-Losing recharge zone beginning at site BLA 004 and terminating at the Burnet Ranch

Park karst features including Saunders Swallet, Park Spring, Little Park Spring, and downstream to PVS; (3) PVS marks the start of the Trinity-Gaining section, where springs flow from Trinity Aquifer units such as the Lower Glen Rose limestone and the well-tapped Cow Creek Formation; (4) the Edwards-Losing recharge zone, beginning just downstream of Wimberley and coincident with a density of surficial fractures in the BFZ which provide preferential flow pathways, solution-enhanced over millions of years, to recharge the Edwards Aquifer and perhaps deeper water-bearing Trinity units; and finally, (5) the End segment, characterized by significant faulting which yields great changes in flow depending on variable conditions not limited to the Blanco watershed, but the connected groundwater flow pathways to Barton Springs and Spring Lake in San Marcos.

Table 2.2 Reach length, geology, and notes for each of the five described regions, with max flow data from Smith et al. (2014)

Reach Name	Creek	Length (mi)	Flow (cfs)	Geology	Comments
Upper Gaining	Blanco	32	+10	Edwards Hilltops, Upper Glen Rose	Shallow Upper Trinity aquifer and gravity springs
Trinity Recharge Zone	Blanco	11	-10	Lower Glen Rose, Hensel, and Cow Creek	Saunders Swallet recharge feature in Cow Creek
Middle Gaining	Blanco	27	+75	Lower Glen Rose and Upper Glen Rose	Upper and Lower Glen Rose springs; Middle Trinity artesian springs: PVS and JWS
Edwards Aquifer Recharge Zone	Blanco	5	-20	Edwards Group	Karst features: Halifax Sink, Johnson Swallet
Lower Gaining	Blanco	ND	ND	Upper Cretaceous and Quaternary	

Discrete karst features were not analyzed in the lowest reaches of the Blanco in our study, however the location within the BFZ suggests a remarkable lack of correlation between geographic extent of springsheds and surface watersheds in the area, and leads us to believe antecedent conditions in this area much larger than the Blanco catchment play the most important role in the gaining and losing qualities of this farthest downstream End section.

On the upstream reaches, clays of allogenic deposition (sourced from historic mountain belts to the north of this shallow ocean shelf) in the Cretaceous period are evident in Glen Rose limestones, but not observed in the Edwards. These clays act to fill in fractures and impede flow in karst features, namely swallets and springs along the Blanco. Evidence of these Glen Rose clays was found at a clay plug between BLA 016 and 017, hindering induced infiltration at Saunders Swallet in the Cow Creek Formation (directly underlying the Lower Glen Rose) during our dye trace. This further explains the nature of our losing sections of the stream, and perhaps why the Blanco so readily loses its water in the Edwards Recharge Zone as compared with the losing segments over Trinity Aquifer units.

We can further discuss our results in comparison that USGS gauges that fall within our study area. Here we will present discharge results from three USGS gauges from January through May 2018, which are located from northwest to southeast along the river: Blanco River at Fischer Store Road (Figure 2.11), Blanco River at Wimberley (Figure 2.12), and Blanco River at Halifax Ranch (Figure 2.13). The Fischer Store gauge shows a discharge level around 20 cfs. The Wimberley data is difficult to interpret because since it was collected every 15 minutes the discharge line is very jagged. However, it looks like discharge in general ranges from an average of 20 cfs to 30 cfs, slightly higher than the discharge at Fischer Store. The gauge at Halifax ranch ranges from just above 30 cfs to around 20 cfs. All three gauges show a rain event in late March, likely around the time that we took discharge measurements. This probably affected our discharge measurements, and the gauges show a clear increase in flow after peak discharge is reached around March 31.

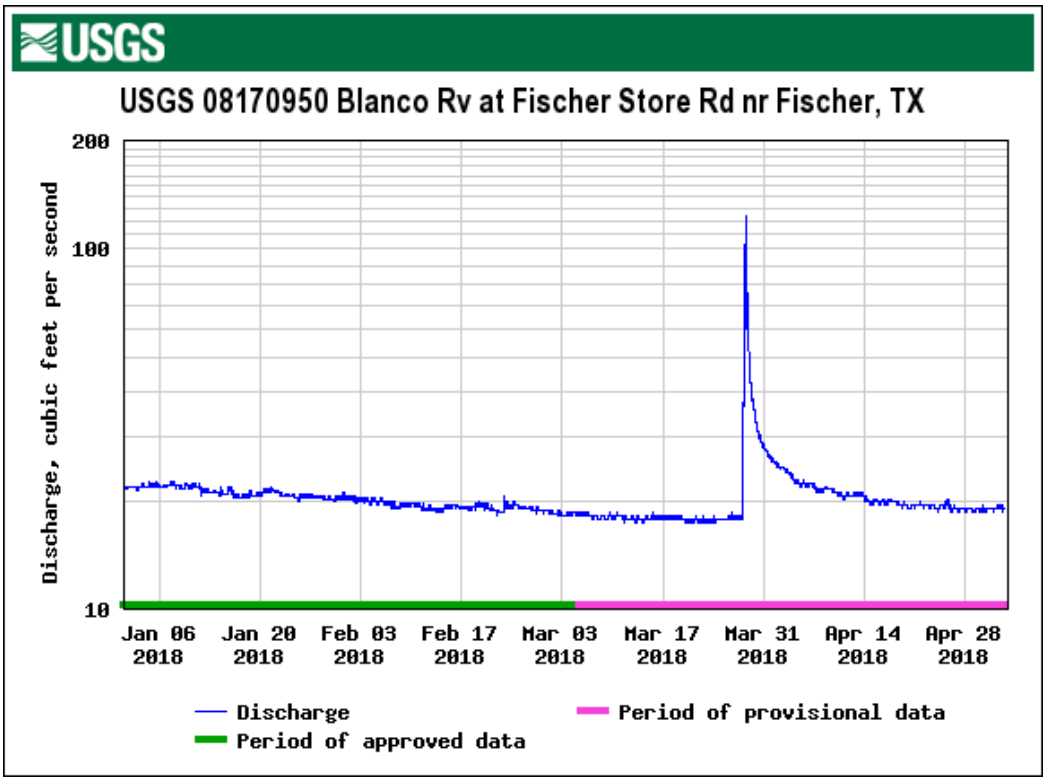


Figure 2.11: USGS gauge - Blanco River at Fischer Store Road

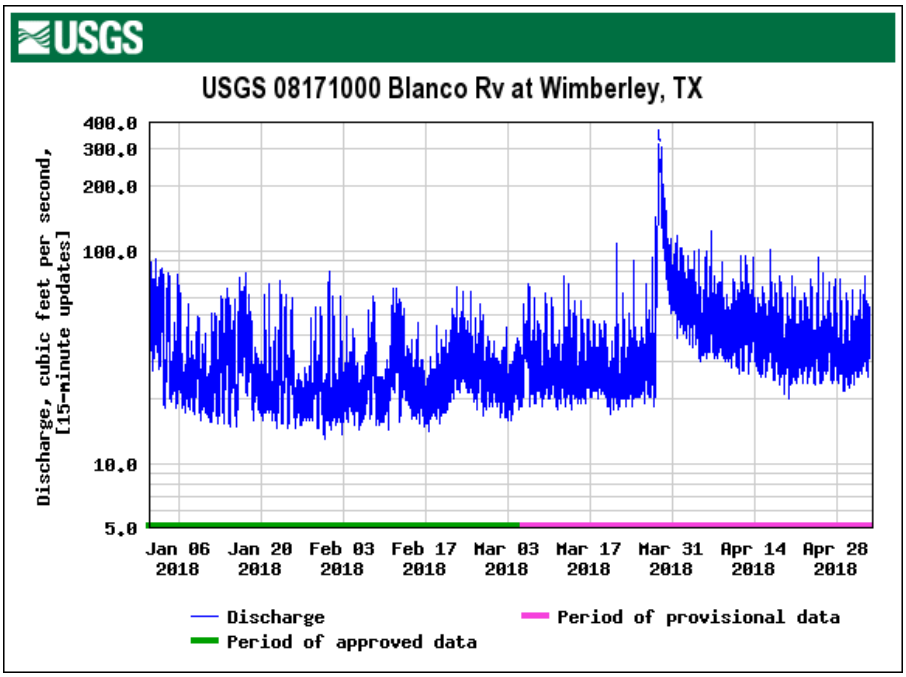


Figure 2.12: USGS gauge – Blanco River at Wimberley

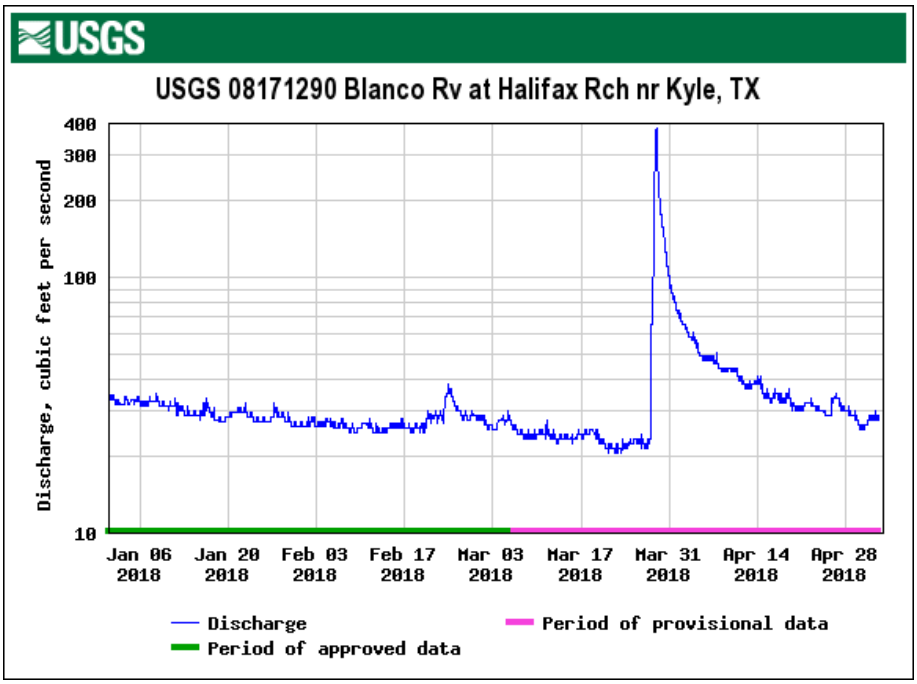


Figure 2.13: USGS gauge – Blanco River at Halifax Ranch

The Fischer Store gauge is located just downstream of a reach that our study found to be losing. However, while the area in which the gauge is located has historically been losing, we found the two sample sites located on either side of the USGS gauge (BLA 40 and 50) to show an overall gaining trend in our study. The Fischer Store gauge appears to be

in a region that is just at the edge of the Edwards recharge zone and as such is sometimes gaining and sometimes losing. During the time period of our study, the Fischer Store gauge shows the lowest discharge of all three USGS gauges. The Wimberley and Halifax gauges show very similar patterns, with the Wimberley gauge showing the highest overall discharge values. The Wimberley gauge is located in a reach that our study found to be gaining, while the Halifax gauge is in a reach that our study found to be losing. It therefore makes sense that the Wimberley gauge has the highest discharge values of all three gauges. Given that the Halifax gauge is located in a losing reach, it's surprising that its discharge values are as high as they are. These values may be reflecting rainy months preceding the study period, and the summer months may result in much lower discharge values.

3. Geochemistry

Purpose and Scope

To establish a robust understanding of the geochemistry of the Edwards and Trinity Aquifer system, we undertook sampling from two types of settings - surface water and groundwater. Field parameter sampling and geochemical sampling varied for surface and groundwater (wells with pump) sites. For our field mission conducted on February 17 and February 18, 2018, we had a total of 4 surface water sites and 5 well sites.

Materials and Methods

Field Measurements

Continuous sampling of field parameters including temperature, dissolved oxygen, pH, and specific conductivity was carried out using the Manta+ Sub3 Multiprobe Water Quality Instrument, manufactured by Eureka Water Probes. The Manta+ Sub3 instrument was calibrated following the EAA Water Quality Monitoring Plan, 2017 a day before sampling procedure.

For groundwater sites (wells with pumps), Manta+ flow cell was connected to the well spigot with a lab-clean sample hose and a y-splitter. The field parameters were logged every 5 minutes using the Manta Control Software Andriod app via Bluetooth. Simultaneously, field data was recorded on Field Sheets associated with every corresponding sample site. After 4 sets of parameter readings were recorded, the time of sample collection was noted. For surface water field sites, the Manta+ flow cell was directly lowered into the body of until the probe was fully submerged. Similar sampling and data logging procedure to well sites were followed.

Geochemical Sampling

Simultaneous to field measurements, bottle kits were collected for geochemical analyses that were analyzed in various laboratories. Geochemical parameters included a suite of variables that included: Dissolved Organic Carbon (DOC), Dissolved Inorganic Carbon (DIC), specific conductivity, alkalinity , pH, cations, anions, $\delta^{18}O$, δD, $^{13/14}C$, $^{87/86}Sr$, Total Dissolved Solids (TDS), and Total Suspended Solids (TSS).

Geochemical water samples were collected wearing nitrile gloves to prevent contamination and sampling bottles were rinsed in triplicate. Water samples were collected using a 1L bailer and filter. For surface water sites, the bailer and filter used was

lowered in the water till the bailer was filled with water. For groundwater collection, a filter was attached to a hose, and the nozzle of filter was placed in bottles to fill. The filter was removed to collect TDS, TSS, and alkalinity samples.

Post sampling Procedure

Collected samples were placed in labeled bags, in site corresponding coolers. In-house alkalinity was completed in lab within a 24 to 48-hour period. Isotopes were stored in the fridge until sent to labs for analyzing.

Isotope analyses for water $\delta^{18}O$, δD, DIC were sent to Beta Analytic. The samples were analyzed using a Delta V Isotope Ratio Mass Spectrometry (IRMS) attached to a Gasbench II following Beta Analytic Guidelines.
Radiocarbon dating was carried on 31 samples at Beta Analytic using a Accelerator Mass Spectrometer (AMS). The data were reported as years B.P. where BP is before 1950 A.D. and calculated using the Libby 14C half-life of 5568 years. For the purposes of the project, water data from $\delta^{18}O$ and δD will be discussed. $\delta^{18}O$ and δD are reported on the widely accepted V-SMOW scale.

Samples for geochemical analyses were sent to TestAmerica Laboratories. TestAmerica Laboratories provided metals, anions, alkalinity, conductivity, DOC, TDS, and TSS results. Metals were analyzed using an Inductively coupled plasma - Mass Spectrometry (ICP-MS) and anions were analyzed using an Ion Chromatograph following the Methods for Chemical analysis of Water and Wastes, EPA-600/4-79-020, March 1983 and Subsequent Revisions and Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, Third Edition, November 1986 and its Updates.

Data Quality

Field VS lab Alkalinities

There is a discrepancy between the field calculated alkalinities and the lab calculated alkalinities. Field alkalinities are systematically larger than lab alkalinities, which supports using field alkalinities in analysis since a systematically lower value can be attributed to the partial pressure of CO2 being higher underground and degassing occurring within the sample bottles would reduce alkalinity values. The systematically lower values provide evidence for this occurring. This discrepancy is predictable as alkalinity should be calculated as promptly as possible and lab alkalinities were calculated beyond the holding period. Field pH and field alkalinity were utilized in calculating chemical constituencies as

lab samples for alkalinity were not preserved in any fashion and were outside of their holding period.

Charge Balance

Charge balances errors reported in the water quality summary provided by the analyst (index 3) were relatively large. These values, however, are not likely indicative of poor analysis, but rather of utilizing lab alkalinities and ph. If utilizing the field pH and alkalinities as described above, the charge balance errors are all below 5% indicating high quality data. They are compared for each water sample in Table 3.1.

Table 3.1: Charge Balance Comparison

Sample ID	Using Lab Alkalinity		Using Field Alkalinity	
	HCO_3- (mg/l)	CBE %	HCO_3- (mg/l)	CBE %
RB_57_58_2HW	339.16	7.27	359.0459851	4.686727
LR_57_63_707	261.08	8.17	301.8279926	2.567314
LR_57_63_905	292.8	9.67	335.0120074	3.912471
LR_57_64_607	274.5	2.07	305.2439963	1.561904
LR_58_57_813	187.88	9.14	227.8960037	2.10588
LR_57_64_717	280.6	5.44	319.3959851	0.698452
LR_57_64_606	370.88	8.81	418.2159851	3.731291
LR_58_57_802	319.64	8.22	370.0259851	1.466761
LR_67_01_801	280.6	8.62	314.15	4.012365

Results and Discussion

Carbonate Geochemistry

Dolomite has a chemical formula of $CaMg(CO_3)_2$ while Calcite has a formula of $CaCO_3$. Plots were created of Calcium vs Magnesium (Figure 3.1) to display trends in the ratio of the two and explain potential sources of dissolution. Samples of Edwards aquifer water (coming from 2 wells and a spring) showed a higher proportion of calcium than magnesium, and clustered closely was the headwater sample, which emitted from the base of the Ft. Terret formation of the Edwards group. The high levels of magnesium in all samples are consistent with the facies descriptions of the source aquifers in Barker et al. (1994) and Barker & Ardis (1996) with a large abundance of dolomitized limestones in both the Edwards and Trinity source rock. These results support the active dissolution of parent rock by slightly acidic rainwater resulting in the mineral assemblage observed in the samples.

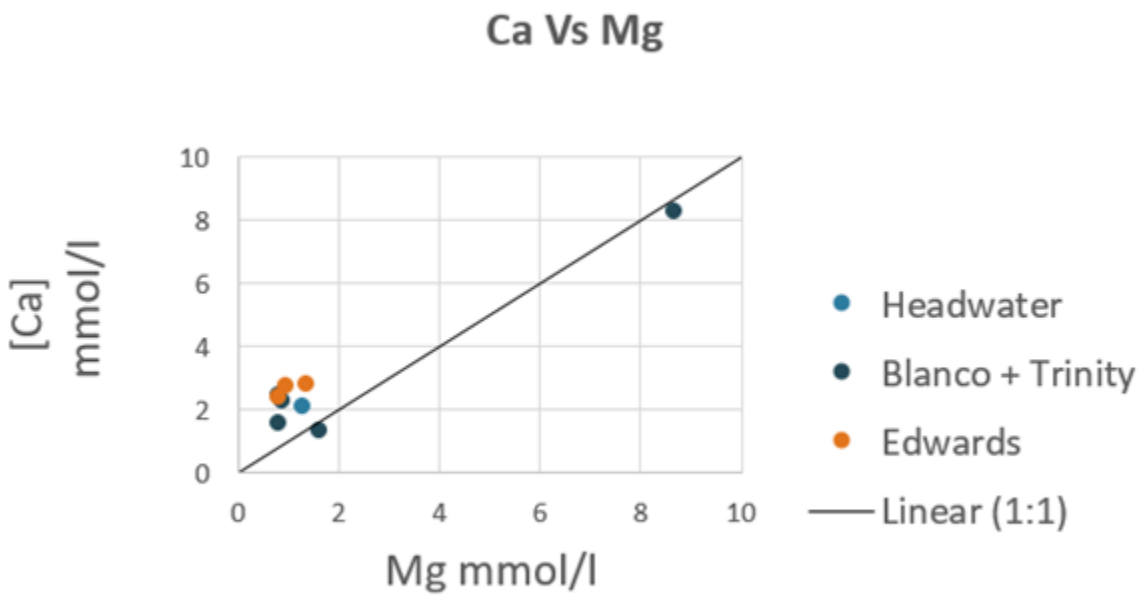


Figure 3.1: Calcium vs Magnesium plot for all of the water samples. The 1:1 line demonstrates dolomite dissolution. Most of the points grouping above and the non 1:1 ratio suggests calcite as well as dolomite dissolution.

The marine carbonate geologic history of the aquifers and subsequent karstification as well as calcium and magnesium plots suggest that carbonate geochemistry is important in the aquifer. A Calcium+ Magnesium VS Bicarbonate plot (Figure 3.2) of the concentrations in the samples helped elucidate the relationships of carbonates and the water chemistry in the water samples. At the measured pH's of the water samples, the

carbonate species would be dominated by bicarbonate, and therefore the dissolution of calcite and dolomite would result in a 1:2 ratio of Ca^{2+} + Mg^{2+} to HCO_3-. All but one point shows this relationship, indicating that dolomite and calcite dissolution in the aquifers is the predominant reaction controlling the carbonate chemistry.

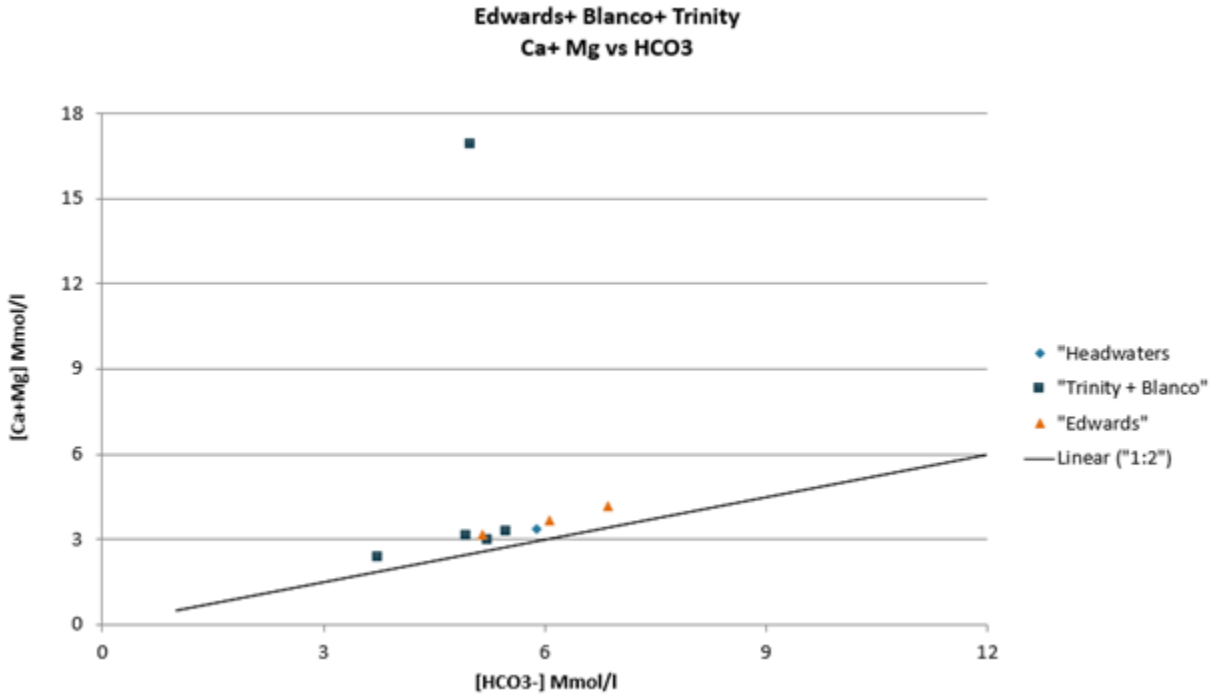


Figure 3.2: Plots of Water samples Ca + Mg vs HCO_3. The line shows the expected ratio at this pH if calcite and dolomite dissolution are the primary reactions controlling chemical constituents. Most points fall along this line. The elevated levels of Ca and Mg in one sample indicate another process is contributing to Ca and Mg concentrations.

The point plotting way above the line had high levels of sulfates and came from a well within a unit confirmed by researchers to have elevated levels of gypsum (Marcus Gary, Personal Communication). For this reason, a plot was made where SO_4 concentrations were subtracted from Ca and Mg to account for the addition of Ca through the dissolution of gypsum. Figure 3.3 shows this plot. The results demonstrate that the dissolution of gypsum can explain the chemical constituents in that well, and that otherwise all other water samples carbonate chemistry are characterized by calcite and dolomite dissolution.

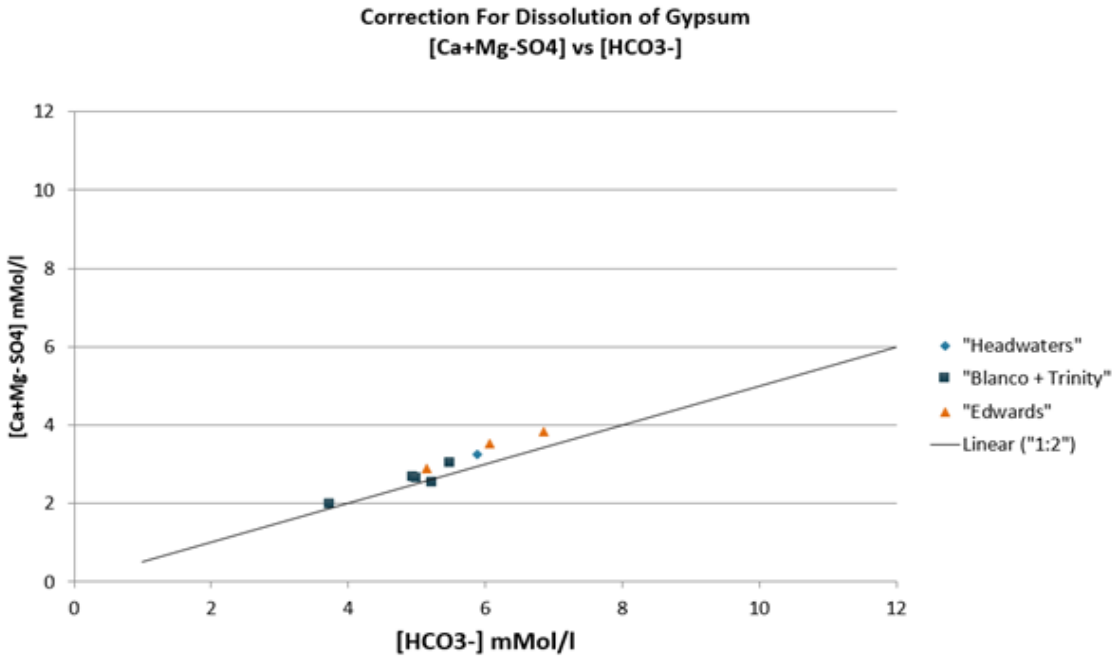


Figure 3.3: Plots of Ca Mg vs HCO_3 adjusted for the dissolution of gypsum. Most points fall closer to the line and the one well that was completely off the line now follows the trend. This supports the hypothesis that dissolution of gypsum is driving an increase in Ca.

Piper plots were made of all samples to analyze geochemical relationships. The majority of samples plotted as calcium and magnesium bicarbonate waters, with the exception of one trinity sample that plotted as a calcium and magnesium sulfate water. This well has been discussed previously, and this grouping provides further evidence for the active dissolution of gypsum. Figure 3.4 demonstrates these piper plots and the locations of samples shown on a conceptual geologic cross section taken from Hunt et al. (2017). The flowpaths described are validated by the groupings on the piper plots. The Edwards and Headwater samples cluster closely together, supporting the idea that meteoric water reacting with parent Edwards/Edwards equivalent rock is dissolving. Some of the trinity samples read higher in Sulfates, which matches geologic description referred to earlier. There is broad overlap between Edwards and trinity wells, which suggests that there is connectivity between the two, be it from the surface or subsurface (likely both) that results in overlapping chemical signals.

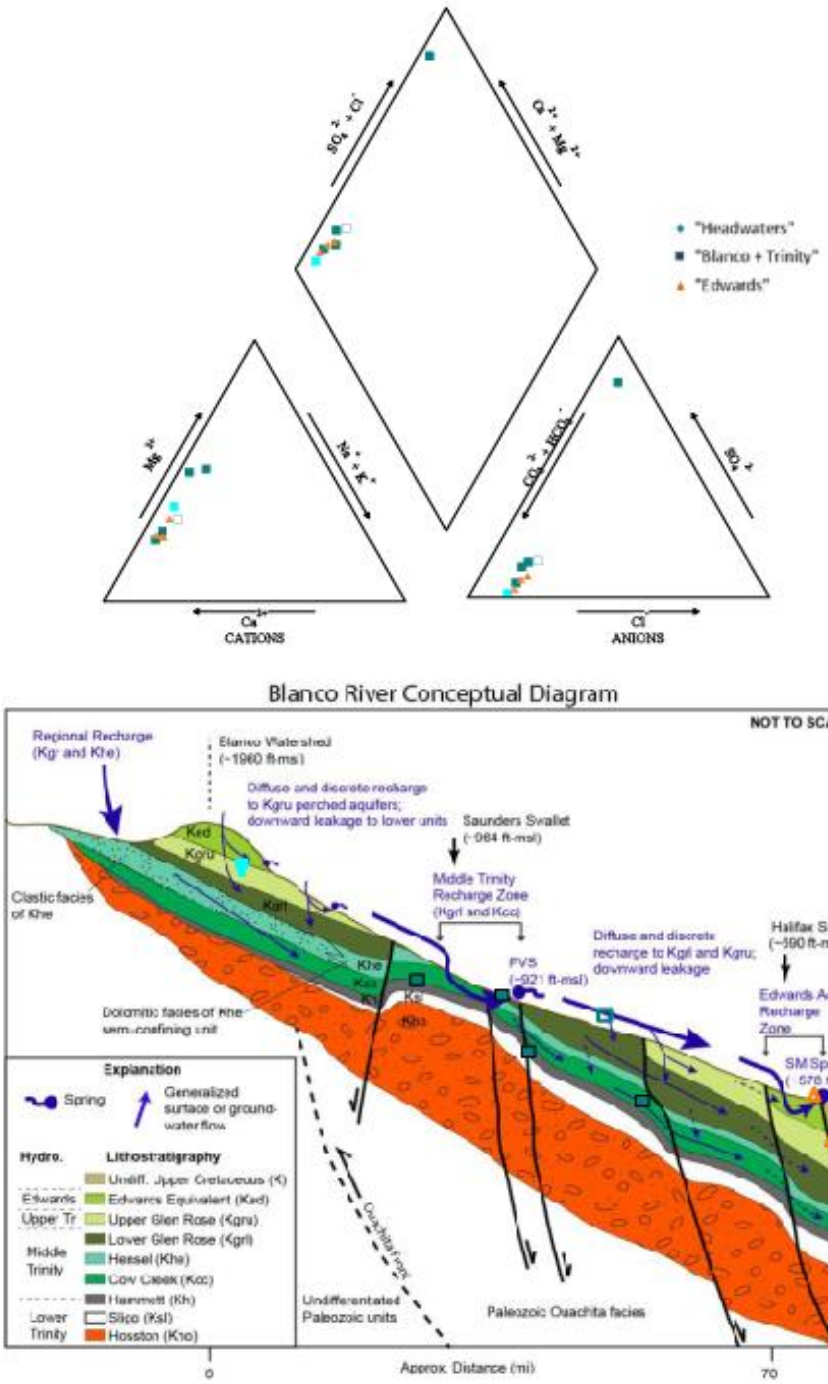


Figure 3.4: Piper plots and a conceptual diagram showing chemical constituents as well schematic locations along the hypothesized flow paths. Bottom panel modified from Hunt et. al. 2017.

Stable Isotopes

Oxygen has three stable isotopes, ^{16}O,^{17}O, ^{18}O; hydrogen has two stable isotopes, ^{1}H and ^{2}H (deuterium). Natural variation of the oxygen isotopic composition of water, when combined with hydrogen isotopes, can be used to study precipitation sources as well as evaporation effects. Furthermore, the oxygen and hydrogen isotope ratio of solid phases (e.g. carbonate minerals and volcanic glass) can record paleo-climate, paleo-hydrologic, and paleo-altimetric information. However, we focus solely on the results from water samples. Ratios of ^{18}O to ^{16}O and ^{2}H to ^{1}H in waters are reported in ‰ (permil) relative to Vienna Standard Mean Ocean Water (V-SMOW) and expressed in δ notation.

The δD and $\delta^{18}O$ values for precipitation worldwide behave in a predictable manner, falling along the Global Meteoric Water Line (GMWL) as defined by Craig (1961). The equation is based on precipitation data from locations around the globe and has an r2>0.95. Local Meteoric Water Line (LMWL) is derived from precipitation collected from a single site or set of local sites and can be significantly different from GMWL. Several processes (Figure3.5) cause waters to plot off the GMWL. The data usually dictates temporal and spatial coverage for interpretation. At a given location, it is the altitude, latitude, rainout effects observed through seasonal variations that is used. Additionally, seasonal changes in moisture sources and storm tracks can be of value to interpret the variability in the water isotope data.

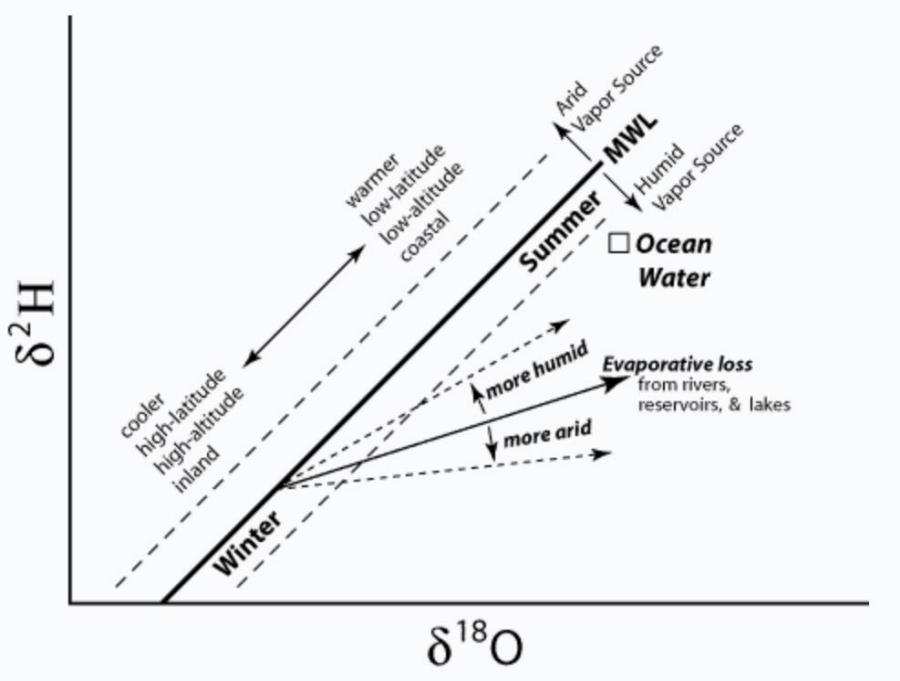


Figure 3.5 Summary diagram of how hydrologic processes raise variability in the oxygen and hydrogen isotopic composition of water (figure from Gat 2010).

Figure 3.6 represents the sample site water isotopic data in relation to the GMWL and LMWL. The GMWL was calculated following Carig's equation (1961b) and the LMWL was calculated following Pape et al., 2010. The data from samples falls around the quadrant that is symbolic of warm regions. In addition, historical data measured previously in Blanco county was plotted for comparison. The data (Table3.2) downloaded from the Texas Water Development Board aligns tightly with the current Geochemical Field Campaign.

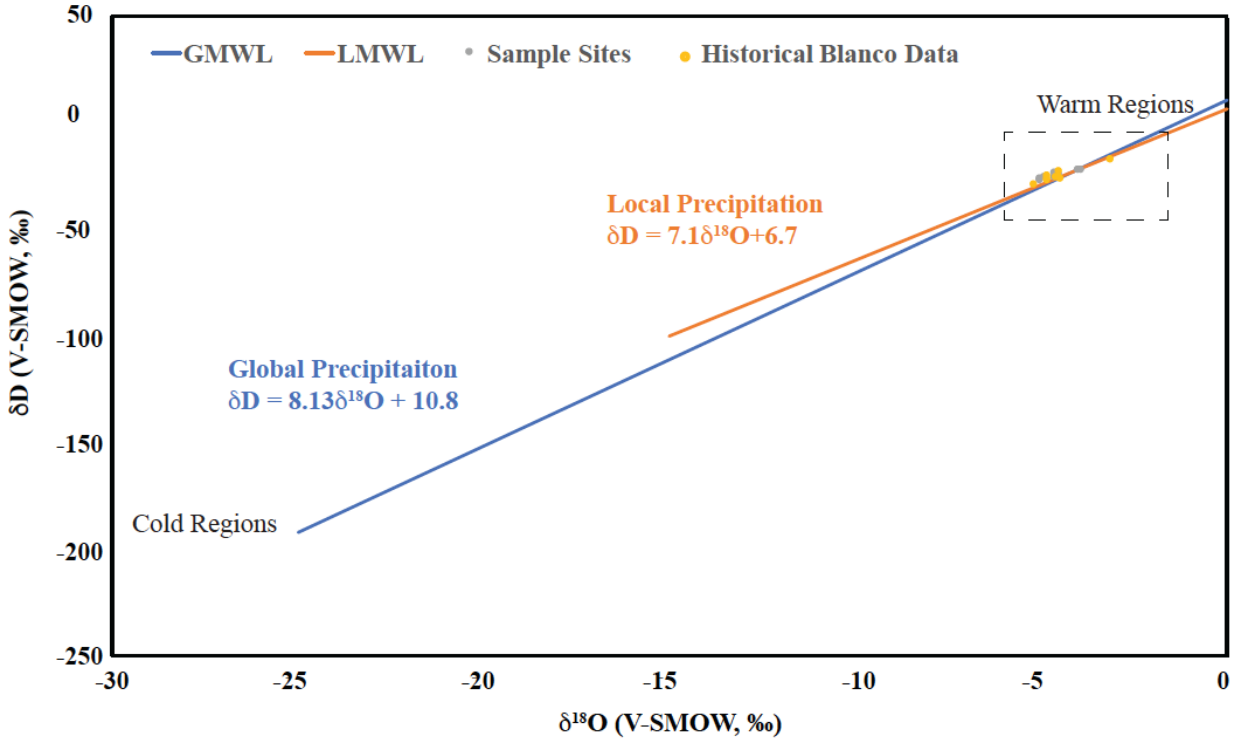


Figure 3.6: GMWL (blue line) calculated following Craig, 1961b and LMWL (red line) calculated following Pape et al., 2010. Sample water isotopic data (grey points) and Historical data (yellow points) are plotted in the black dashed box. A zoom in of the black dashed box is shown in Figure 3.7.

Jacob's well (site number 3) falls directly on the LMWL (Figure3.7) and can be interpreted as being the most representative of the local precipitation data. Furthermore, Park Springs (site number 9) and Blanco at Halifax (site number 5) are the only two sites that fall below both the GMWL and LMWL indicative of lighter (greater abundance of ^{18}O) $\delta^{18}O$ values suggesting possible evaporation or mixing of waters. Furthermore, the headwaters are indicative of potential mixing between the Blanco+Trinity and Edwards aquifers. Blanco+Trinity isotope data is the most variable with the greatest range in both 18-oxygen and deuterium values.

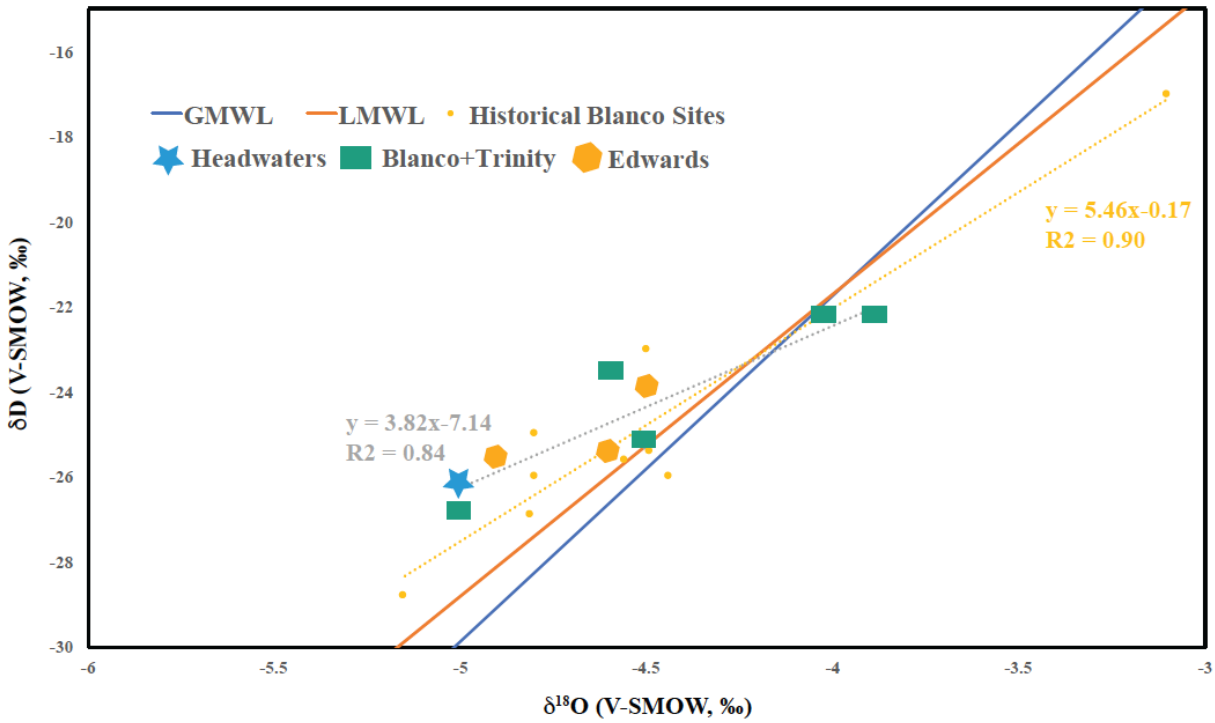


Figure 3.7: A zoom in of the isotopic data for sample sites. The data follows the following equation: $\delta D = 3.82\delta^{18}O - 7.15$ with an $r^2 = 0.84$. Historical Blanco sites are represented by yellow circles. The data follows the following equations: $\delta D = 5.46\delta^{18}O - 0.17$ with an $r^2 = 0.90$.

The similar slopes for our Geochemical Campaign and Historical Blanco Sites suggests a similar underlying water isotope evolution that occurs in this region. However, the dissimilarity between the deuterium excess (y-intercept) values could be because of the possible outlier in the Historical dataset. On removing the outlier point, the new y-intercept is 2.31. The result is indicative of additional processes (relative humidity, moisture source) dictating the difference between the two datasets. Further research would be required to address the questions raised.

Chart 3.2: Isotope data downloaded from the Texas Water Development Board for Blanco County. The chart details isotope data from Edwards and Trinity aquifers.

Texas Water Development Board

Texas Water Development Board (TWDB) Groundwater Database (GWDB)
Well Water Quality Report
Sampled Year: All
County: Blanco
Aquifer: Edwards (Balcones Fault Zone), Trinity
Water Quality Parameter: DEUTERIUM, EXPRESSED AS PERMIL VSMOW; OXYGEN-18, EXPRESSED AS PERMIL VSMOW

groundwater division

State Well Number	Coordinates	Aquifer	Aquifer Code	Well Depth (ft. below land surface)	Date	Time	Sample #	Entity Id	Lab Id	Reliability Id	Collection Remarks	Parameter Code	Parameter Description	Flag	Value	Unit	Plus/ Minus
5753405	30° 11' 44.86" N 098° 28' 09.54" W	Edwards (Balcones Fault Zone)	218GLRSU		6/21/2017	1540	1	16	23	7	Analysis Balanced.	50791	DEUTERIUM, EXPRESSED AS PERMIL VSMOW		-26.9	0/00	
												50790	OXYGEN-18, EXPRESSED AS PERMIL VSMOW		-4.81	0/00	
5753404	30° 10' 51" N 098° 28' 27" W	Edwards (Balcones Fault Zone)	218EDRDA		6/21/2017	1450	1	16	23	7	Analysis Unbalanced.	50791	DEUTERIUM, EXPRESSED AS PERMIL VSMOW		-28.8	0/00	
												50790	OXYGEN-18, EXPRESSED AS PERMIL VSMOW		-5.15	0/00	
5761912	30° 02' 21" N 098° 22' 37" W	Trinity	218GLRS		4/4/2006	0000	1	1	24	7	Analysis Unbalanced.	50791	DEUTERIUM, EXPRESSED AS PERMIL VSMOW		-17	0/00	1
												50790	OXYGEN-18, EXPRESSED AS PERMIL VSMOW		-3.1	0/00	0.3
5761604	30° 03' 33" N 098° 23' 37" W	Trinity	218GLRSU		4/4/2006	0000	1	1	24	7	Analysis Unbalanced.	50791	DEUTERIUM, EXPRESSED AS PERMIL VSMOW		-25	0/00	1
												50790	OXYGEN-18, EXPRESSED AS PERMIL VSMOW		-4.8	0/00	0.3
5761225	30° 05' 13" N 098° 26' 02" W	Trinity	218HSCC		7/21/2017	1030	1	21	23	7	Analysis Balanced.	50791	DEUTERIUM, EXPRESSED AS PERMIL VSMOW		-25.4	0/00	
												50790	OXYGEN-18, EXPRESSED AS PERMIL VSMOW		-4.49	0/00	
5760609	30° 04' 40.63" N 098° 31' 34.35" W	Trinity		300	7/21/2017	1405	1	16	23	7	Analysis Balanced.	50791	DEUTERIUM, EXPRESSED AS PERMIL VSMOW		-25.6	0/00	
												50790	OXYGEN-18, EXPRESSED AS PERMIL VSMOW		-4.56	0/00	
5747802	30° 17' 06" N 098° 12' 25" W	Trinity	218CCRK		6/16/2011	1004	1	16	23	7	Analysis Balanced.	50791	DEUTERIUM, EXPRESSED AS PERMIL VSMOW		-26	0/00	
												50790	OXYGEN-18, EXPRESSED AS PERMIL VSMOW		-4.44	0/00	
5747405	30° 17' 54" N 098° 14' 18" W	Trinity	218CCRK		4/7/2006	0000	1	1	24	7	Analysis Unbalanced.	50791	DEUTERIUM, EXPRESSED AS PERMIL VSMOW		-26	0/00	1
												50790	OXYGEN-18, EXPRESSED AS PERMIL VSMOW		-4.8	0/00	0.3
5747404	30° 17' 34" N 098° 13' 46" W	Trinity	218CCRK		4/7/2006	0000	1	1	24	7	Analysis Unbalanced.	50791	DEUTERIUM, EXPRESSED AS PERMIL VSMOW		-23	0/00	1
												50790	OXYGEN-18, EXPRESSED AS PERMIL VSMOW		-4.5	0/00	0.3

State Well Number	Coordinates	Aquifer	Aquifer Code	Well Depth (ft. below land surface)	Date	Time	Sample #	Entity Id	Lab Id	Reliability Id	Collection Remarks	Parameter Code	Parameter Description	Flag	Value	Unit	Plus/ Minus
5753405	30° 11' 44.86" N 098° 28' 09.54" W	Edwards (Balcones Fault Zone)	218GLRSU		6/21/2017	1540	1	16	23	7	Analysis Balanced.	50791	DEUTERIUM, EXPRESSED AS PERMIL VSMOW		-26.9	0/00	
												50790	OXYGEN-18, EXPRESSED AS PERMIL VSMOW		-4.81	0/00	
5753404	30° 10' 51" N 098° 28' 27" W	Edwards (Balcones Fault Zone)	218EDRDA		6/21/2017	1450	1	16	23	7	Analysis Unbalanced.	50791	DEUTERIUM, EXPRESSED AS PERMIL VSMOW		-28.8	0/00	
												50790	OXYGEN-18, EXPRESSED AS PERMIL VSMOW		-5.15	0/00	
5761912	30° 02' 21" N 098° 22' 37" W	Trinity	218GLRS		4/4/2006	0000	1	1	24	7	Analysis Unbalanced.	50791	DEUTERIUM, EXPRESSED AS PERMIL VSMOW		-17	0/00	1
												50790	OXYGEN-18, EXPRESSED AS PERMIL VSMOW		-3.1	0/00	0.3
5761604	30° 03' 33" N 098° 23' 37" W	Trinity	218GLRSU		4/4/2006	0000	1	1	24	7	Analysis Unbalanced.	50791	DEUTERIUM, EXPRESSED AS PERMIL VSMOW		-25	0/00	1
												50790	OXYGEN-18, EXPRESSED AS PERMIL VSMOW		-4.8	0/00	0.3
5761225	30° 05' 13" N 098° 26' 02" W	Trinity	218HSCC		7/21/2017	1030	1	21	23	7	Analysis Balanced.	50791	DEUTERIUM, EXPRESSED AS PERMIL VSMOW		-25.4	0/00	
												50790	OXYGEN-18, EXPRESSED AS PERMIL VSMOW		-4.49	0/00	
5760609	30° 04' 40.63" N 098° 31' 34.35" W	Trinity		300	7/21/2017	1405	1	16	23	7	Analysis Balanced.	50791	DEUTERIUM, EXPRESSED AS PERMIL VSMOW		-25.6	0/00	
												50790	OXYGEN-18, EXPRESSED AS PERMIL VSMOW		-4.56	0/00	
5747802	30° 17' 06" N 098° 12' 25" W	Trinity	218CCRK		6/16/2011	1004	1	16	23	7	Analysis Balanced.	50791	DEUTERIUM, EXPRESSED AS PERMIL VSMOW		-26	0/00	
												50790	OXYGEN-18, EXPRESSED AS PERMIL VSMOW		-4.44	0/00	
5747405	30° 17' 54" N 098° 14' 18" W	Trinity	218CCRK		4/7/2006	0000	1	1	24	7	Analysis Unbalanced.	50791	DEUTERIUM, EXPRESSED AS PERMIL VSMOW		-26	0/00	1
												50790	OXYGEN-18, EXPRESSED AS PERMIL VSMOW		-4.8	0/00	0.3
5747404	30° 17' 34" N 098° 13' 46" W	Trinity	218CCRK		4/7/2006	0000	1	1	24	7	Analysis Unbalanced.	50791	DEUTERIUM, EXPRESSED AS PERMIL VSMOW		-23	0/00	1
												50790	OXYGEN-18, EXPRESSED AS PERMIL VSMOW		-4.5	0/00	0.3

4. Dye Tracer Test

Figure 4: Photograph of dye in the Blanco River at Big Park Springs

Purpose and Scope

The purpose of this study was to determine if water that enters Saunders Swallet exits out of Pleasant Valley Spring, and if water that enters Raccoon Cave exits from Jacob's Well Spring and other nearby wells. Since there are two different areas being tested here, two dye tracing tests occurred. Saunders Swallet is categorized as both a sink and source of water, which makes it a point of interest in keeping balance to the water table and providing surface water to the Blanco River. How Saunders Swallet may or may not feed into Pleasant Valley Springs (PVS) discharge is of huge importance to know considering Pleasant Valley Spring is the headwaters of the Blanco River during drought conditions and is a huge source of the river's water up to 40 km downstream, so it is important to know where the spring was sourced from. Jacob's Well is an important source of discharge for the Trinity Aquifer, so knowing where the water was sourced is valuable information.

Overview of Study Area

This study was conducted for the Guadalupe/Blanco Study Area, with both of the study areas comprised of a surface of Upper Glen Rose Limestone and the surrounding areas comprised of Lower Glen Rose Limestone. The first dye was injected in Saunders Swallet, which is approximately 1 km upstream of Burnett Park Spring and approximately 3 km upstream of Pleasant Valley Spring. Further downstream of Pleasant Valley Spring are the Halifax Sinkhole and Johnson Swallet, followed by San Marcos Springs, but these locations are not part of the test because it is already known that their water comes from

Pleasant Valley Spring. The second dye will be injected in Raccoon Cave, which is approximately 1.6 km north of Jacob's Well. In the direction of water flow from Raccoon Cave comes Flocke, WVWA, and Graham Wells.

Hypothesis

Pleasant Valley Spring is hypothesized to have been sourced from Saunders Swallet, and Jacob's Well Spring is hypothesized to have been at least partially sourced from Raccoon Cave. The water that enters Saunders Swallet is expected to reach Pleasant Valley Spring (PVS) through the subsurface, where it will reappear at the surface of Pleasant Valley Spring. This is expected to take 1-2 days. The water will continue to infiltrate into the subsurface eastward and downstream, flowing through the Cow Creek Limestone. The surface water is expected to continue downstream, entering Halifax Sinkhole and Johnson Swallet and traveling through the Edwards Group until it passes through the Upper Cretaceous above it and resurfacing at San Marcos Springs. Water entering Raccoon Cave is expected to travel through the subsurface and resurface at Jacob's Well and its surrounding wells, including WVWA Well and Graham Well. This is expected to occur within 24 hours.

Methods

Uranine dye was injected into Saunders Swallet on March 24, 2018 as part of a two-part investigation into the Guadalupe/Blanco River study area headed by the Edwards Aquifer Authority. The first prong of this investigation is the injection of uranine into Saunders Swallet to determine if water entering at Saunders Swallet issues from PVS, approximately three miles away (Fig. 4.1). The second prong of this investigation was the insertion of dye into Racoon Cave in order to determine if water entering Racoon Cave issues from Jacob's Well. The purpose of both of these dye tests is to evaluate the groundwater flow paths in the Middle Trinity Aquifer, specifically within the Cow Creek and Hensel Formations. The focus of this report is the Saunders Swallet portion of the study.

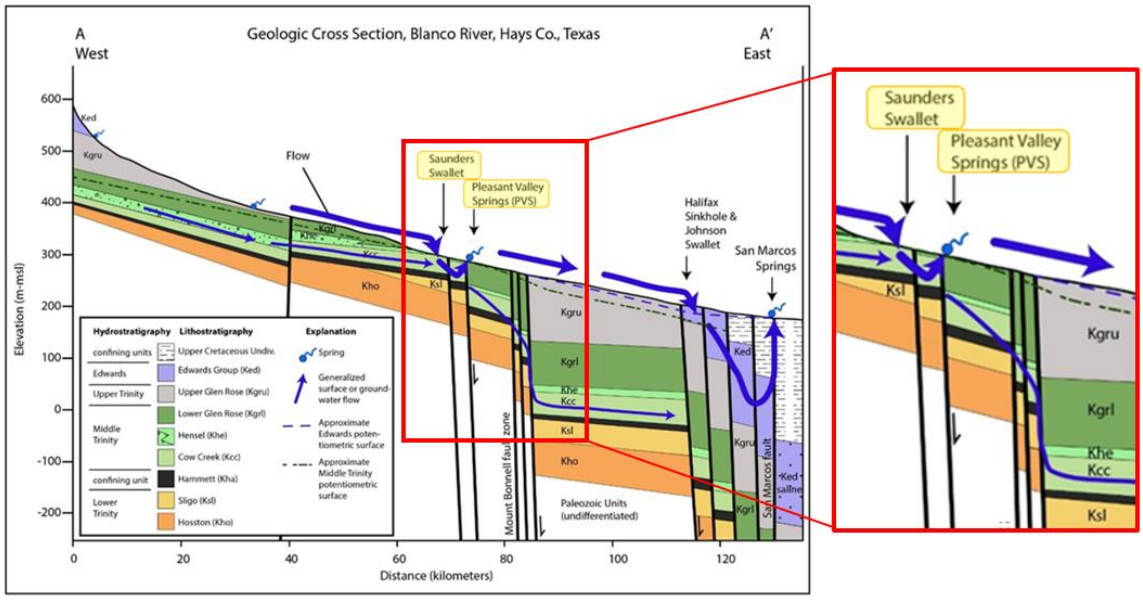


Figure 4.1: Conceptual model of Blanco River flow, both surface and subsurface. The flow path of interest for this report- showing water entering at Saunders Swallet, traveling through the subsurface, and exiting at Pleasant Valley Springs is highlighted in yellow and magnified in red. The straight-line distance between Pleasant Valley Springs and Saunders Swallet is approximately 3500m. Figure modified from Hunt et al, 2017.

Selection of Dye and Dye Injection Point

Uranine dye, a fluorescent green dye approved by the Food and Drug Administration, was injected into Sanders Swallet, located at 30°2’25”N and 98°13’31”W (Fig. 4.2). The injection site was chosen as a point source of recharge into the aquifer, as well as its ease of access. This dye was chosen because of its non-toxicity, ease of use, availability, low cost, and its fluorescent and detectable nature. Uranine has a fluorescence peak at 493nm and undergoes photodegradation.

Figure 4.2: Photograph of dye as it is being injected and flushed into Saunders Swallet, 13:18 on March 24, 2018

The minimum volume of dye needed for the test was determined using the equation *m=19(LQc)0.95* (Worthington and Smart 2003), where *m* is the mass of dye injected in grams (g), *Q* is the output discharge in meters cubed per second (m^3/s), *c* is the expected peak recovery dye concentration in grams per meter cubed (g/m^3), and *L* is the distance between the injection and recovery points in meters (m).

Saunders Swallet to Park Spring

L= 1025.31m

Q= 4.5 cfs= 0.13m^3/s

c= 30ppb = 0.03g/m^3

m= 19(1025.31 x 0.13 x 0.03)0.95

m= 70.89g

Saunders Swallet to Pleasant Valley Spring (PVS)

L= 3500m

Q= 0.51m^3/s

c= 0.03g/m^3

m= 19(3500 x 0.51 x 0.03)0.95

m= 833.83g

From these two calculations, the minimum volume of dye needed in order for a detectable amount to reach Pleasant Valley Spring is 833.83g. The final mass of dye injected at

Saunders Swallet was 960g, mixed with water to form a 40% solution with a weight of 2.4kg.

The site was primed with water beforehand, and the dye was injected at 13:18 on March 24, 2018. The dye was then flushed over the next 20 hours with 12000 gallons of water (Fig. 4.3).

Fig. 4.3: Photograph of students preparing to pack up one of the bladders used to flush Saunders Swallet with water, both prior to the dye injection (flushing) and after.

Sample Collection

Samples were collected at five sites along the Blanco River (Fig. 4.4). Types of samples collected include grab samples, charcoal receptors (bugs), those collected by autosampler, and fluorometer data. Not all types of data/ samples were collected at all sites (Table 4.1). Grab samples consist of 13mm glass test tubes filled with water at the site by hand, each grab sample collection involved three filled tubes. Grab samples were collected several times. These samples were labeled with permanent ink and grouped together by site and collection time. Charcoal bugs were used to detect the presence of dye in the water at any point, although not the time of dye appearance. The charcoal receptors were suspended in flow, within the Blanco River as well as at spring heads and consist of small nylon-screen-mesh packets containing activated coconut charcoal. Each bug was labeled with the site name and placement date, and upon collection the bugs were placed in bags and labeled with placement date and time, recovery date and time,

and initials of the sampler. Charcoal bugs were collected and replaced approximately every 24 hours.

Figure 4.4: Google Earth image showing the locations of the dye sample collection sites, as well as the injection point at Saunders Swallet and the anticipated recovery point at Pleasant Valley Spring (BLA_040).

Table 4.1: Table showing the different sample/data types collected at each sample site. *Bug was never retrieved

Site Name	Latitude	Longitude	Autosampler	Grab Sample	Charcoal Bug	Fluorimeter
BLA_020	30°1'59" N	98°13'17" W		x	x	
BLA_023	30°1'54" N	98°13'13" W		x	x	
BLA_025	30°1'50" N	98°13'3" W	x	x	x	x
BLA_027	30°1'34" N	98°12'48" W		x	x*	
BLA_040	30°0'44" N	98°12'21" W		x	x	
Sonny Well	30°2'19" N	98°13'24" W		x		

The autosampler, a Teledyne Isco 3700 Portable Sampler (Fig. 4.5a), was placed at site BLA_025 and was set to collect 350 ml of water every hour for 24 hours. At the end of each sampling cycle, the collected water was decanted into 13mm glass vials, which were labeled with site and collection time with permanent marker. The two fluorimeters (Fig. 4.5b), Eureka Manta 2 models, were placed at BLA_025. The first fluorimeter was placed on March 23 and retrieved March 30 by the Barton Springs Edwards Aquifer conservation district. The second fluorimeter was placed March 24 and retrieved March 26 by UT Austin GEO377K.

Figure 4.5: a) Photograph of Isco autosampler at BLA_025. b) Photograph of Manta fluorimeter

All water samples and charcoal bugs were stored to avoid exposure to sunlight as the dye is susceptible to photodegradation.

Testing Phases

The initial charcoal receptors were deployed the day before the dye trace, as was the autosampler. One fluorimeter was deployed by students of the UT Austin GEO377K class three hours prior to dye injection and remained running for two days. The second fluorimeter was deployed by the Barton Springs Edwards Aquifer Conservation District (BSEACD) on the 23rd of March, one day before dye injection, and remained in place for a week, until March 30th.

Lab Analysis

Autosampler samples and grab samples required no preparation prior to analysis. Dye was ejected from the charcoal receptors (bugs) by eluting the receptors for one hour in a solution that was 95% composed of a 70% 2-propanol solution, with the remaining 5% composed of sodium hydroxide. The eluent was then transferred to labeled glass vials and stored in the dark until ready for analysis.

Both the autosampler/grab samples and the charcoal effluents were analyzed for uranine using a Perkin Elmer LS50B Luminescence Spectrometer. The analysis spanned wavelengths of 401-650 nm, and uranine fluoresces at 492nm (Fig. 4.6). Results of the analysis reported the excitation wavelength for the samples in intensity units, which were converted to concentrations by comparisons with known standards by the Edwards Aquifer Authority lab.

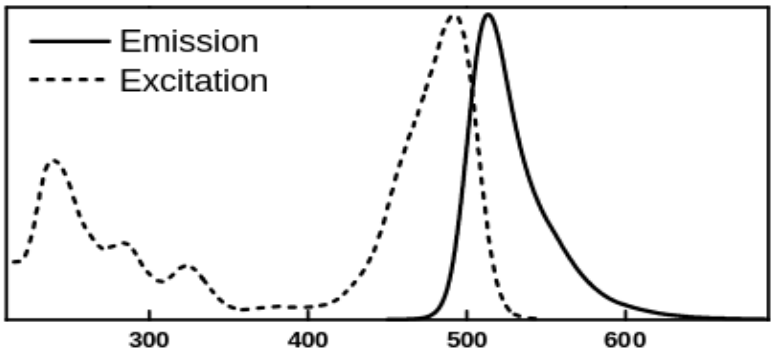


Figure 4.6: Emission and excitation spectra of uranine dye. X-axis is in nanometers. Figure from http://www.wikiwand.com/en/Fluorescein.

Quality Control and Duplicate Samples

Approximately one in every twenty samples was duplicated in order to determine the precision of the Perkin Elmer LS-50B Luminescence Spectrometer. In-house standards with known values were used in order to determine the level of accuracy of the instrument.

Detection Limits

The Perkin Elmer LS50B Luminescence spectrometer has a reported signal to noise ratio of 500:1 rms. The wavelength accuracy of the instrument is ±1 nm, with a reproducibility of ±0.5 nm.

Results

The injection of 2.468kg of Uranine occurred at 13:18 on 3/24/18 at Saunders Swallet (30°2’25’’, 98°13’31’’) along the Blanco River. The dye was flushed with approximately

20,000 gallons of water. An autosampler at site BLA_025 had a breakthrough dye concentration of 2.0 ppb that was detected at 14:00 on 3/26/18 and a peak concentration of 12.7 ppb that occurred at 6:00 on 3/27/18. The autosampler water dye concentration dropped down to a non-detectable amount at 3/27/18 8:00 AM. A small spike occurred at 3/27/18 14:00 with a max concentration of 4.6ppb. A large final surge of 18.9 ppb recorded at 3/28/18 8:00 is perceived to have a strong correlation with heavy rainfall in Hays County. The autosampler detected dye until 4/3/18 8:00 AM (0.42ppb). (Fig. 4.7). The Manta fluorimeter measurements show a similar pattern.

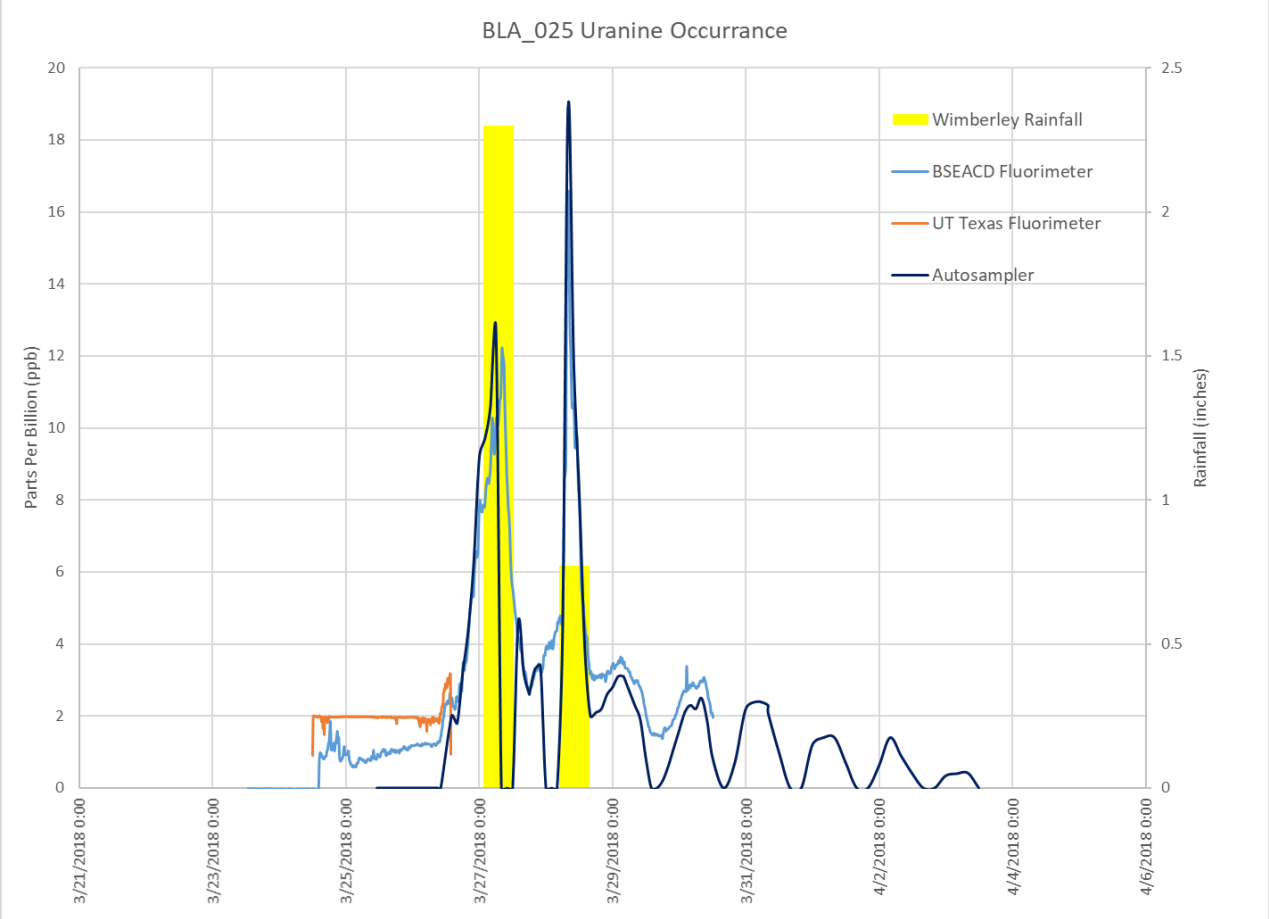
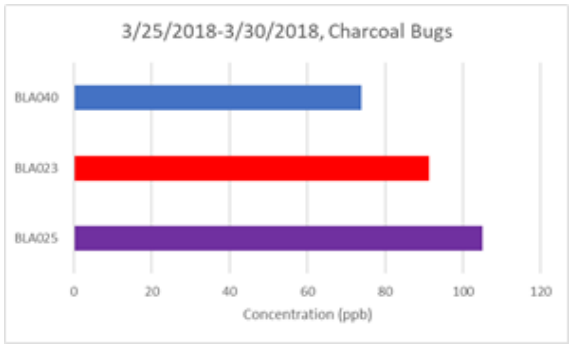


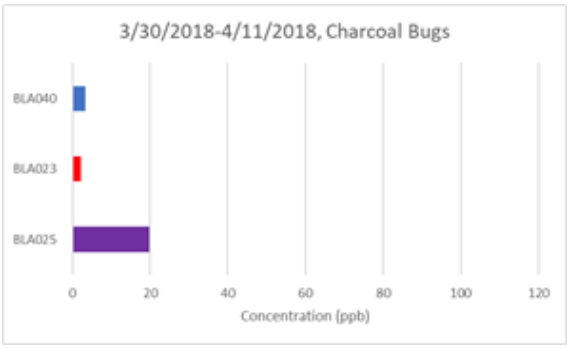
Figure 4.7: Comprehensive figure showing the occurrence of dye at BLA_025 based on fluorimeter dye measurements and autosampler water sample analysis. Rainfall during the measurement period is also included (in yellow). Rainfall data was retrieved from NOAA.

No dye was detected at BLA_020 (Little Park Spring) throughout the sampling period, and the charcoal bug for site BLA_027 was lost. Dye was detected in charcoal bugs from sites BLA-025, BLA_040 (PVS), and BLA_023 (Fig. 4.8). Please note that grab samples have not yet been analyzed.

a)



b)



c)

Figures 4.8: a) Map showing the occurrence of dye, those sites with currently unknown dye presence, and sites where no dye was recorded. b) Chart showing the uranine concentrations, in ppb, in charcoal bugs left at BLA_040, BLA_023, and BLA_025 3/25-3/30. c) Chart showing the uranine concentrations, in ppb, in charcoal bugs left at BLA_040, BLA_023, and BLA_025 3/30-4/11.

Discussion

Firstly, it is clear that site BLA_020 is fed by a different flow path than the other sampled sites in this study as no dye was detected throughout the sample period. Secondly, using the data obtained, a minimum groundwater flow rate can be calculated:

Saunders Swallet to BLA_025: 1.31km, 1310m (straight line distance)

Time dye was injected at Saunders Swallet: 13:18 on March 24, 2018

Time of first dye pulse at BLA_025: 8:15 on March 26, 2018

Time between injection and appearance: 2583 minutes

Thus…

2583 minutes: 1310m

1 minute: 0.507m

1 day: 730.3m

For these calculations, the approximate time recorded by both Mantas of the first large pulse of dye was used, as opposed to the jump recorded by the BSEACD Manta when the UT Austin Manta was deployed. It is assumed that this first small jump is merely background noise. This flowrate, 730.3m/day, is a minimum flow rate as the path taken by the groundwater may not have been a straight line and may indeed have been more winding and tortuous.

The drop in uranine concentration between the 27th and 29th (see Fig. 4.7 above) is attributed to dilution of the dye by the rain on the 27th. This rainfall event probably did not dilute the dye in the groundwater, infiltration is not that fast and is too spread out to have made such a large impact, but as the charcoal bug and Mantas were in the river at BLA_025 it is likely that the dilution is due to runoff from the rain event making its way into the river and diluting the dye in the river.

Conclusion

The findings supported our hypothesis, as dye did indeed travel via subsurface flow from Saunders Swallet to Pleasant Valley Spring (PVS, site BLA_040), with a minimum groundwater velocity of approximately 730.3m/day. These findings show Saunders Swallet to be a recharge feature into the Edwards Aquifer, which has implications for contaminant flow and transport. It is also clear that the site/spring labeled as BLA_020 is not connected to the same flow path the rest of the samples sites are, as no dye showed up at that site. The flow path for feeding this spring could be coming from a higher or lower stratigraphic unit or could be coming from a different direction. On the flip side of

that, Saunders Swallet, BLA_023, BLA_025, and Pleasant Valley Spring (BLA_040) have all been shown to be connected to one another. BLA_027 and the Sonny Well site may also be connected, but until data from the grab samples is available this is unknown.

5.Groundwater Levels

Introduction

Pleasant Valley Spring (PVS) Jacobs Well Spring (JWS) are large karst features that supply water to the Blanco River and Cypress Creek, respectively, eventually recharging the Edwards Aquifer. A potentiometric map was created in effort to understand groundwater flow and recharge/discharge sources. The map was created using a series of water level measurements from wells in Hays County.

Potentiometric maps are useful tools for identifying subsurface flow paths and potential aquifer recharge locations in karst systems. The maps show the level to which water rises in a well. This chapter includes a potentiometric map produced from well level measurements in a series of wells in Hays County, including Jacobs Well. This map aides in understanding groundwater flow paths, karst springs, and potential identification of recharge locations in the study area.

Many studies have been performed in the Trinity Aquifer that are relevant to this investigation. In particular the investigation performed by Barton Springs and the Edwards Aquifer Conservation District (BSEACD) on potentiometric surface investigation of the Middle Trinity Aquifer in 2013. This investigation revealed groundwater flow paths and sources of recharge to PVS and JWS. The study revealed groundwater flow is generally northwest to southeast from the Blanco River catchment across the study area. Potentiometric gradients were also found to steepen down gradient of major faults in the BFZ that act as barriers to groundwater flow. A small potentiometric ridge was also revealed between PVS and JWS identifying a groundwater divide between portions of the Blanco River and Cypress Creek watersheds. Potentiometric troughs were also present for PVS and JWS proving that preferential flow paths feeding those springs. The JWS trough is more pronounced than the PVS trough. Responses to storm events were also determined in the study, PVS has a strong hydrologic connection to storms in the upper Blanco watershed. No response from the storm event to JWS indicates there is no hydrologic connection between JWS and the Blanco watershed. Head differences between the vertically adjacent Upper and Lower Trinity Aquifers suggest the Middle Trinity does not have good hydrologic connection with these aquifers over the study area (BSEACD 2014). This potentiometric map created in this investigation was successful, however more potentiometric maps must be created in order to understand the system at different hydrogeologic conditions.

Methods

Groundwater Elevation

In order to create a potentiometric surface map, we first measured groundwater levels in wells across the study area in the Edwards and Trinity Aquifers. We used a Leica Zeno 20 Multi-GNSS Triple-Frequency Compact Antenna and a bipod tool (Figure 5.1) to map well locations and elevation. The Leica was placed in a location near the well with no foliage or obstructing structures as to not interfere with GPS signal, providing measurements with sub-foot accuracy. Latitude and longitude were recorded using the World Geodetic System 1984 (WGS84), and elevation in feet above mean sea level. These data provide us with a very accurate reference for measuring the true elevation above mean sea level of the groundwater. Although more wells were measured as a collaboration across multiple agencies, we were able to obtain complete spatial and groundwater level information for 67 wells. These data were collected primarily from privately owned wells, monitoring wells, and natural springs (including Jacobs Well) by the 2018 Karst Class and the Edwards Aquifer Authority.

Figure 5.1: The Leica and bipod being used above Saunders Swallet to receive a clear signal.

With an accurate reference elevation datum established, we were able to reliably measure the depth from the surface to the water level. The class measured the depth to water in each well using both an electronic tape/line (E-line)(Figure 5.2) and a Sonic Water Level Meter model 300 RGI (Figure 5.3). The E-line proved to be the more reliable measurement tool, and therefore provided the data for this analysis. The E-line is a measuring tape that carries an electrical current with a probe on the end of the line. As the line is lowered into the well, the circuit becomes complete when the probe makes

contact with water and triggers a noise to indicate the tape has reached the water level (Figure 5.2). The ground water level at each point, therefore, is defined as the elevation of the surface measured with the GPS minus the depth to water measured with the E-line.

Figure 5.2: E-line (left) and how it was used to determine depth to water (right).

Figures 5.3. The Sonic Water Level Meter (left) and how it was used to estimate depth to water (right).

Potentiometric Surface Map

We used interpolation tools in ArcMap 10.2 to extrapolate the groundwater levels from individual points across the landscape and create a potentiometric surface map for the study area. The Kriging algorithm is often used in geology because the geostatistical method is appropriate when the data is spatially correlated with distance. Applying the Kriging algorithm to the potentiometric levels measured in the wells resulted in a smoothed surface representing approximate groundwater levels across the entire study area rather than just points. But as the interpolation is based only on 67 points, we created contours from the interpolation to generalize the potentiometric surface across the aquifer. These contours were then adjusted by the analysts based on knowledge of the study area, such as the location of caves and preferential flow.

Results

The groundwater levels measured in 67 wells across the study area ranged from 658.99 to 1238.22 fasl, with a mean of 883.9 fasl (See associated database). This large variation in water levels correlates with the change in elevation as the aquifer moves southeast (Figure 5.4).

The resulting potentiometric map using all 67 wells shows multiple directions of flow across the region (Figure 5.4). Using just the 24 wells in the study area along the Blanco River and Cypress Creek, however, gives us a more localized view of how groundwater

moves in this watershed, flowing toward southeast (Figure 5.5). The overall potentiometric map has some known issues and should not be used for decision making (Figure 5.4). Different wells in the database pull from different aquifers (Edwards or Trinity), but this was not marked in the dataset. As a result, large drops in groundwater levels over short distances are not actual drops in the potentiometric surface, it is because the wells are measuring the levels of the two different aquifers. The data must still be separated to update these results and create accurate potentiometric surface maps.

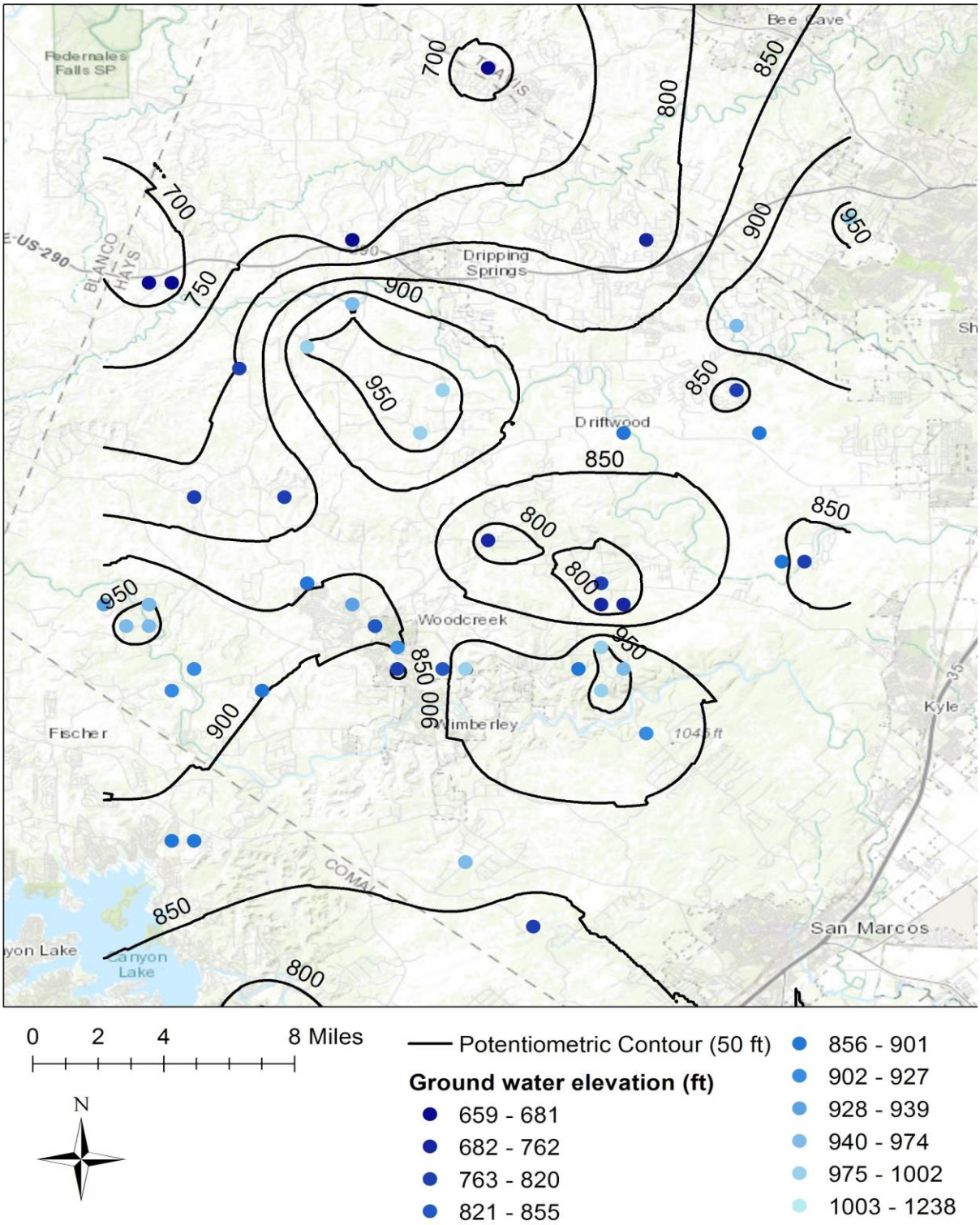


Figure 5.4: Potentiometric surface map of the Edwards and Trinity Aquifers in the Hays County area, Texas. NOTE: Well data coming from both Trinity and Edwards Aquifers

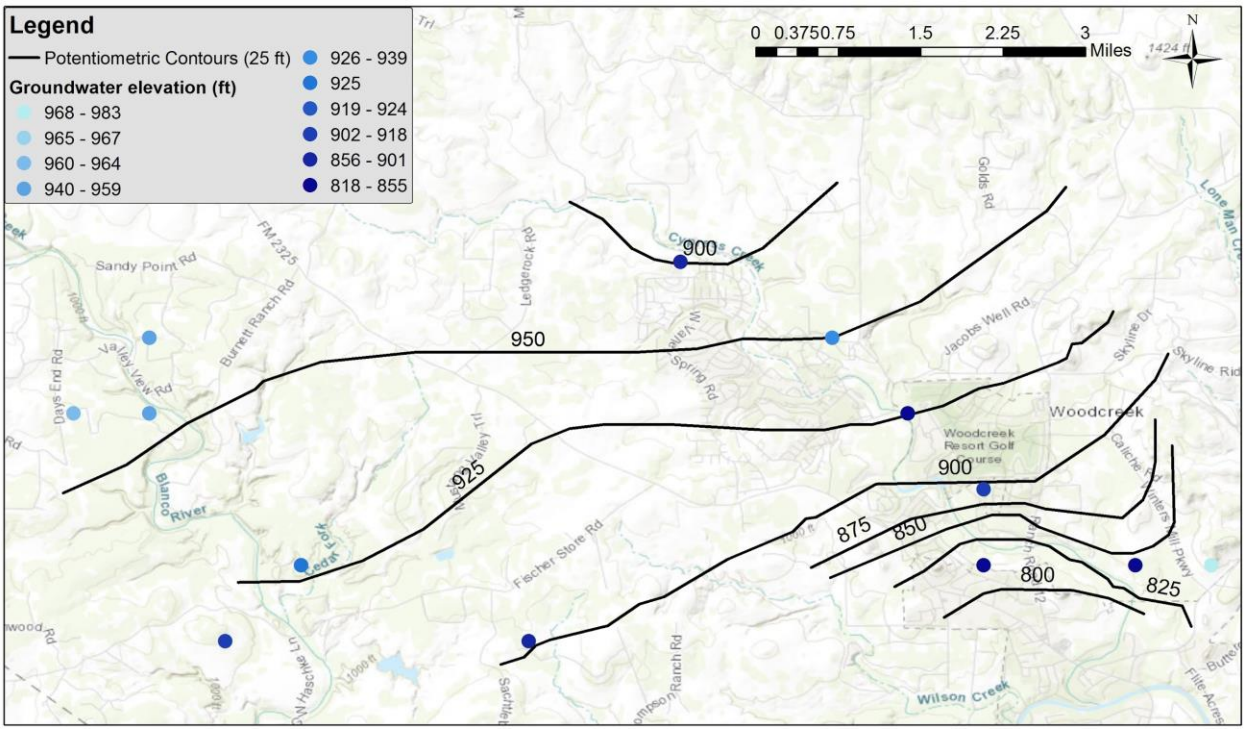


Figure 5.5: Potentiometric surface map of the Blanco River study area, Texas.

Discussion

Two potentiometric maps were generated using the data collected from wells across the study area (Figures 5.4 and 5.5). Figure 5.4 was generated using all 67 well measurements and resulted in some interesting contour patterns consisting of several high and low centers of potentiometric elevation. When the overall trends of these data were taken into account, a second potentiometric map (figure 5.5) was constructed that shows a more generalized gradient and flow path for groundwater near the Blanco River in western Hays County. The potentiometric map created from the data from April 2018 shows that the flow of groundwater in the Edwards and Trinity Aquifers is generally from NW to SE. The gradient of potentiometric contours increases from the NW to the SE with a major change just south of Jacob's Well. The potentiometric gradient in the NW is approximately 20 ft/mile and south of Jacob' Well it increases to approximately 55 ft/mile. This is consistent with findings in previous studies in western Hays County (BSEACD 2014). This shift in gradient correlates with faults that offset the Trinity Aquifer and, as determined by other studies, likely means faults in the BFZ act as a barrier for groundwater flow (BSEACD 2014). According to our generated map, there is a potentiometric ridge just to the SE of Jacob's well where there could be a groundwater divide. There is also a potentiometric trough along Jacob's Well, although not as pronounced as it was found to be in other studies. Much of the 2018 study's results

matches with the findings of the previous study conducted by the Barton Springs/Edwards Aquifer Conservation District; however, there are some differences. There are several wells to the north near the Blanco-Hays and Hays-Travis county lines that have significantly lower groundwater water levels. This contradicts previous findings of the BSEACD study which showed groundwater elevations increasing to the NW continuously up to 1,000 feet.

Conclusion

The potentiometric maps generated from the April 2018 data is helpful in determining groundwater flow paths in Western Hays County. Some conclusions from this study include:

- Generally, groundwater flow is from the NW to the SE
- The potentiometric surface gradient increases from the NW to the SE just south of Jacob's Well suggesting offset from faults hinder groundwater flow.
- Potentiometric ridge to the south SE of Jacob's Well suggests a groundwater divide.
- Potentiometric trough along Jacob's Well indicating a preferential flow path to the spring.
- According to groundwater level measurements the potentiometric water level decreases in the NE part of the county

6. Overall Discussion

From the various tests carried out in this study, several conclusions can be drawn concerning the Blanco River and its connection to the Edwards-Trinity aquifer system, as well as of the Edwards-Trinity aquifer system itself. The gain/loss survey done in early March, 2018 should be analyzed in the greater context of the paper, but especially with the potentiometric surface maps, Fig. 5.4 and Fig. 5.5. The five distinct reaches of the Blanco River outlined in Chapter 2 are the Headwaters-Gaining section, the Trinity-Losing section, the Trinity-Gaining section, the Edwards-Losing section, and the End Segment. Hydrologically, each section of the Blanco is characterized by an observed increase or decrease from site to site longitudinally downstream, along with the underlying units that take or return surface water to the river, or the generally diffuse recharge on hilltops far to the west that constitute the headwaters springshed. Geographically, these subregions are west of the town of Blanco (Headwaters-Gaining), between Blanco and the Burnet Ranch Estates Park (Trinity-Losing), between Park Springs and PVS and the town of Wimberley (Trinity-Gaining), beyond Wimberley in the density of faults known as the BFZ (Edwards-Losing), and the ever-variable End segment that is controlled by significant faulting near the towns of Kyle and San Marcos. The End reach shows some return flow to the Blanco River but predominantly takes water from the stream and provides groundwater flow paths to Barton Springs to the north in Austin and Spring Lake in San Marcos to the south.

Geochemical analysis performed on water samples collected throughout the study area indicate an abundance of dolomitized limestones in both the Edwards and Trinity source rock. These results support the active dissolution of parent rock by slightly acidic rainwater resulting in the mineral assemblage observed in the samples. Some samples also show geochemical evidence of the dissolution of gypsum, although dissolution of calcite and dolomite are the main processes affecting the groundwater chemistry of the area.

The dye trace further solidified these interpretations. The dye trace was performed in the Trinity-Losing (recharge) zone, that is, where the Blanco River recharges the underlying aquifer through features such as Sander's Swallet. The dye did indeed travel via subsurface flow from Saunders Swallet to Pleasant Valley Spring (PVS, site BLA_040), with a minimum groundwater velocity of approximately 730.3m/day, although no dye appeared at Little Park Spring (site BLA_020). These findings show Saunders Swallet to be a recharge feature into the Edwards Aquifer, which has implications for contaminant flow and transport.

Figures 5.4 and 5.5 show the potentiometric surface in our study area as of April 2018, with data taken throughout the month. While the groundwater elevations maps here only show the Blanco in the southern part of Hays Co., the correlation with our gain/loss survey is clear at the potentiometric high just downstream of Wimberley in Fig. 5.4. Following the NE-SW trend of faulting, perpendicular to general streamflow, an equivalent potentiometric high can be seen in Fig. 5.4 on Onion Creek just downstream of Driftwood, and is evident in the data for Onion Creek's Middle Gaining segment shown in Table 2.2.

The gradient shown in Fig 5.5 exemplifies the sharp change in potentiometric gradient as you move downstream towards the BFZ. Northwest of the Edwards-Losing reach the gradient is roughly 20 ft/mi, and to the east of Wimberley, into the Edwards reaches, the gradient increases to approximately 55 ft/mi. The Barton Springs/Edwards Aquifer Conservation District (2014) found similar results when mapping the groundwater surface and suggests the most significant faulting in our study area along the Blanco found at this defining NE-SW trend just downstream of Wimberley is a barrier to groundwater flow. Discrepancies between our data and that of BSEACD (2014) are believed to be an effect of ongoing overpumping. In the same region, BSEACD found potentiometric surfaces over 1000 ft in elevation above msl (to the Northwest).

7. Conclusion

Stream flow measurements showed which sections of the Blanco were gaining or losing. Surface water flowing through the Blanco River has five distinct regions of gain and loss. Headwater Spring through site BLA004 is a gaining reach. This reach is characterized by diffuse recharge across the hills west of Blanco. The reach from BLA004 to Burnet Ranch Park is a losing reach because of recharge to the Trinity Aquifer. From Pleasant Valley Spring to Wimberley, springs flowing out of the Lower Glen Rose and Cow Creek provide recharge to the Blanco, which thus gains over this section. Immediately downstream of Wimberley, the Blanco flows over the Edwards Aquifer recharge zone, coincident with a high concentration of fractures in the bed of the Blanco. These fractures transmit recharge to the Edwards Aquifer, and possibly to the deeper Trinity Aquifer system. This reach is a losing reach. The easternmost end of the Blanco River is characterized by significant faulting and variable flow depending on hydrologic conditions in the Blanco basin, as well as conditions of Barton Springs and Spring Lake in San Marcos.

Geochemical analyses of water samples collected from across the study area were helpful in determining chemical trends and characterizing chemical attributes of the study area. Based on plots of calcium and magnesium compared to bicarbonate, it's clear that dolomite and calcite dissolution are the dominant reactions controlling carbonate

chemistry in the aquifers. Overlapping chemical signals from a broad range of samples suggest connectivity between the Edwards and Trinity Aquifers.
We injected dye into Saunders Swallet, an Edwards Aquifer recharge feature. Dye injected here moved through the subsurface karst to PVS (BLA_040) at a calculated minimum rate of 730 meters/day. This direct recharge and rapid flow rate has potential implications for contaminant transport. Dye was also detected at BLA_023 and BLA_025, indicating that these areas are directly connected to Saunders Swallet. There was no trace of dye at BLA_020, indicating that this is not connected to the same flow path as the other nearby wells in which dye was detected. There is potential that BLA_027 and Sony Well may be connected to the same flow path, but grab samples were not collected from these locations so this cannot currently be determined.

Groundwater flow measurements were translated into a potentiometric groundwater level map that gave insight to subsurface flow in Wester hays County. Groundwater flow in the study area is generally from the northwest to the southeast. The potentiometric gradient increases dramatically south of Jacob's Well Spring due to significant faulting acting as a barrier to flow. Water level measurements show a slight elevation decrease in the northeastern part of Hays County. There is a potentiometric ridge southeast of Jacob's Well Spring, which is interpreted as a groundwater divide. A slight potentiometric trough along Jacob's Well Spring suggests a preferential flow path to the spring.

The surface-groundwater interactions of the Edwards and Trinity Aquifer systems of the Blanco River Basin in Hill Country, Texas are complex. Combining a series of data analyses, both physical and chemical, help to create a collective picture of what is happening in this important area of central Texas. This study helps to continue to refine our understanding of this karst system, which is important for the future of central Texas's most important water resource.

Sources

Barker, A. Rene, Bush, Peter W., Baker Jr., E.T. 1994. “Geologic History and Hydrogeologic Setting of the Edwards-Trinity Aquifer System, West-Central Texas.” US Geological Survey Water-Resources Investigations Report 94-4039.

Barker, R.A., and Ardis, A.F. 1996, Hydrogeological framework of the Edwards-Trinity aquifer system, west-central Texas: US Government Printing Office 2330–7102.

Barker, R.A., Bush, P.W., and Baker, E.T. 1994, Geologic history and hydrogeologic setting of the Edwards-Trinity aquifer system, west-central Texas: US Department of the Interior, US Geological Survey.

Barton Springs and Edwards Aquifer Conservation District. 2014. "Potentiometric Surface Investigation of the Middle Trinity Aquifer in Western Hays County, Texas."

Bush, P.W., Ardis, A.F., Fahlquist, Lynne, Ging, P.B., Hornig, C.E., and Lanning-Rush, Jennifer. 1961. Water quality in south-central Texas, 1996–98: U.S. Geological Survey Circular 1212, 32 p.

Craig, H. Isotopic variations in meteoric waters, *Science, 133,* 1702-1703, 1961.
EAA. 2017. *Groundwater Quality Monitoring Plan, Version 1.5*. San Antonio, Texas: Edwards Aquifer Authority. 125 p.

Edwards Aquifer Authority Report. Edwards Aquifer-Trinity Aquifer: Informational Flow Investigation by the Edwards Aquifer Authority

Environment Canada. 2015. “Measuring Discharge with FlowTracker Acoustic Doppler Velocimeters.” *Water Survey of Canada, Revision 4.* http://www.wmo.int/pages/prog/hwrp/qmf-h/documents/qmsdoc/qSOP-Eng-LevelQ3/qSOP-NA022-04-2015%20Measuring%20Discharge%20with%20FlowTracker%20ADV.pdf

Furl, Chad, Sharif, Hatim, Zeitler, Jon W., El Hassan, Almoutaz, Joseph, John. 2018. “Hydrometeorology of the catastrophic Blanco river flood in South Texas, May 2015.” *Journal of Hydrology*: Regional Studies: 15: 90-104.

Gat, J.R. 1980. The isotopes of hydrogen and oxygen in precipitation. In *Handbook of environmental isotope geochemistry. Vol. 1*.

Guadalupe-Blanco River Authority. 2008. Basin summary.
https://www.gbra.org/documents/publications/basinsummary/2008g.pdf

Hauwert, N. M. 2011. Could Much of Edwards Aquifer “Matrix Storage” Actually be Trinity Aquifer Contributions from the Blanco River?, Karst Conservation Initiative February 17, 2011 Meeting Proceedings

Hunt, Brian B., Smith, Brian A., Gary, Marcus O., Broun, Alex S., Wierman, Douglas A., Watson, Jeff, Johns, David. 2017. “Surface-water and groundwater interactions in the Blanco River and Onion Creek Watersheds: Implications for the Trinity and Edwards Aquifers of Central Texas.” *Bulletin of the South Texas Geological Society* 76: 32-53.

Jones, I. C., R. Anaya, and S. C. Wade. 2011, Groundwater availability model: Hill Country portion of the Trinity Aquifer of Texas: Texas Water Development Board Report 377, Austin, 165 p.

NCDC (National Climatic Data Center). 2013, Climate data online, daily surface data for Blanco station, cooperative station ID 410832

NOAA (National Oceanic and Atmospheric Administration). 2013, Regional PDSI drought conditions

NOAA National Centers for Environmental Information. 2016. Climate Division Precipitation Archives.

Pape, J.R., Banner, J.L., Mack, L.E., Musgrove, M. and Guilfoyle, A. 2010. Controls on oxygen isotope variability in precipitation and cave drip waters, central Texas, USA. *Journal of Hydrology*, *385*(1-4), pp.203-215.

Slade, R.M., Jr. 2015, Recharge-discharge water budget based recharge rates for the Barton Springs segment of the Edwards aquifer, Austin Geological Society Guidebook No. 35, pg 87-93.

Slade, R.M., Jr., J.T. Bentley, and D. Michaud. 2002, Results of Streamflow Gain-Loss Studies in Texas, With Emphasis on Gains from and Losses to Major and Minor Aquifers, U.S. Geological Survey Open-File Report 02-068

Smith, B.A., Hunt, B.B., Andrews, A.G., Watson, J.A., Gary, M.O., Wierman, D.A., Broun, A.S. 2015. “Surface water-groundwater interactions along the Blanco River of central Texas, USA.” Environmental Earth Sciences 74: 7633-7642.

Turnipseed, D. Phil and Sauer, Vernon B. 2010. “Discharge measurements at gaging stations.” *USGS Techniques and Methods*: 3-A8.

USGS (U.S. Geological Survey). 2013. USGS Water Data For the Nation

USGS (U.S. Geological Survey). 2016, National Water Information System: Mapper

USGS. 2018. Texas Water Dashboard. https://txpub.usgs.gov/txwaterdashboard/index.html

Watson, J.A., Hunt, B.B., Gary, M.O., Wierman, D.A., Smith, B.A. 2014. “Potentiometric surface investigation of the Middle Trinity Aquifer in western Hays County, Texas.” *BSEACD Report of Investigations 2014-1002*.

Wermund, E.G., and Woodruff, C.M., Jr. 1977, Land resource units for planning in carbonate terranes, in Tolson, J.S., and Doyle, F.L., eds., International Asso- ciation of Hydrogeologists Memoirs: Huntsville, Alabama, University of Alabama in Huntsville Press, v. 12, p. 339-353.

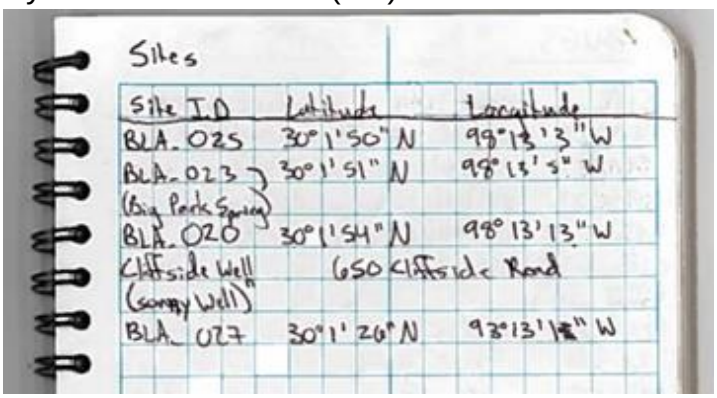
Wierman, D.A., A.S. Broun, and B.B. Hunt (Eds), 2010, Hydrogeologic Atlas of the Hill Country Trinity Aquifer, Blanco, Hays, and Travis Counties, Central Texas: Prepared by the Hays-Trinity , Barton/Springs Edwards Aquifer, and Blanco Pedernales Groundwater Conservation Districts

Worthington, S.R.H. and Smart, C. (2003). Empirical Determination of Tracer Mass for sink to spring tests in Karst. *American Society of Civil Engineers, Geotechnical Special Publications* no. 122, p. 287-295.

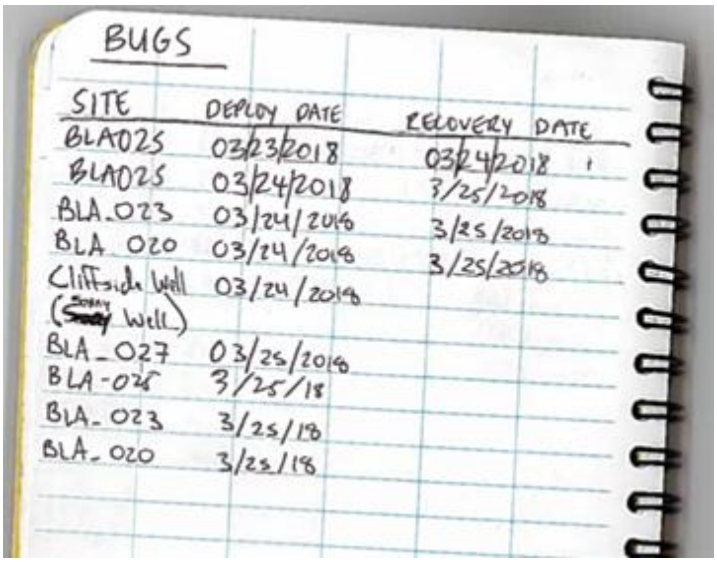
Appendix

See associated database for all raw data tables.

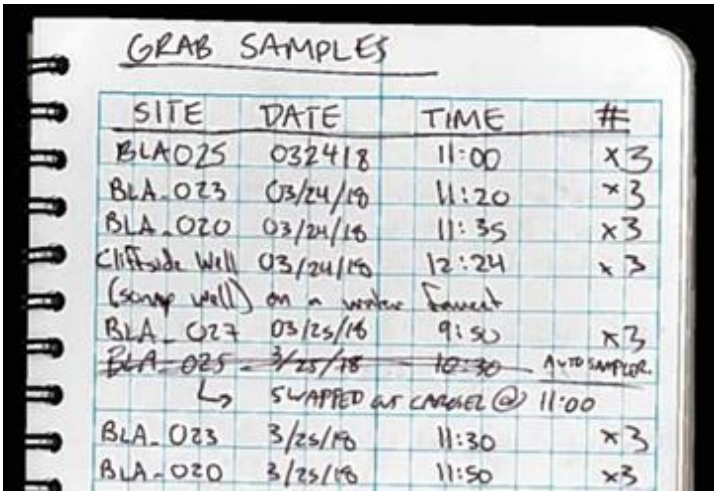
Dye Trace Field Notes (a-d)



Field notes a) Site ID codes, latitude, and longitude. Please note that these coordinates were taken with a phone and are slightly off reality



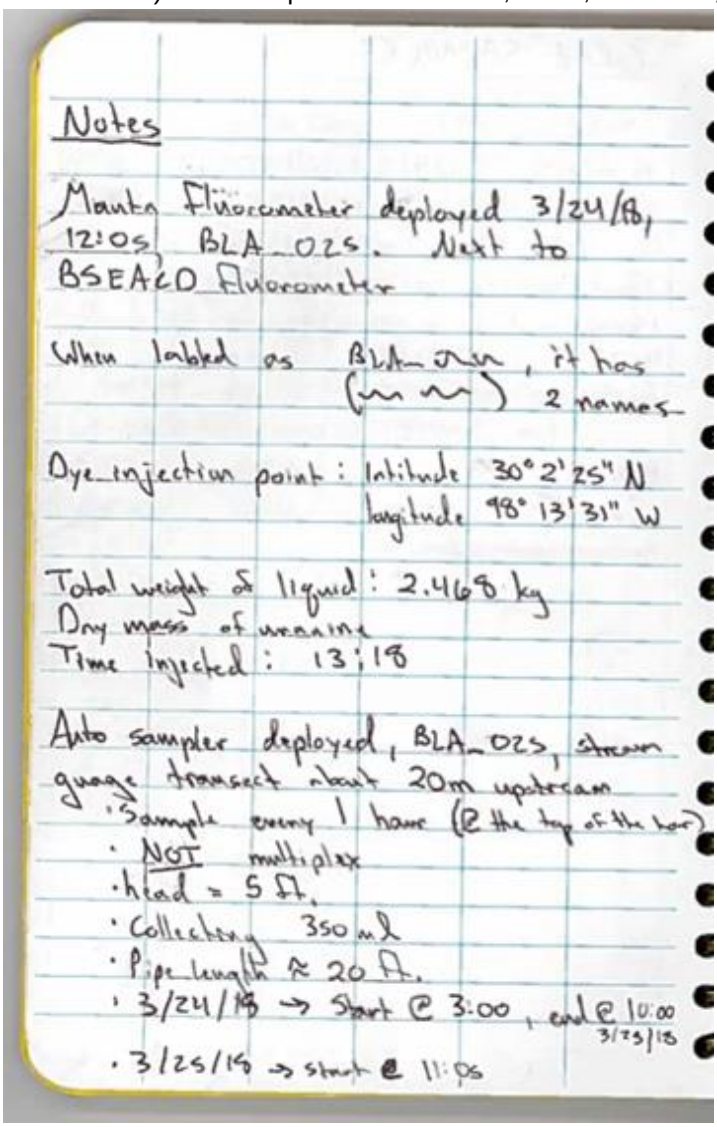
Field notes b) Charcoal bugs deployment sites, deployment dates, and recovery dates



GRAB SAMPLES

SITE	DATE	TIME	#
BLA025	032418	11:00	x3
BLA_023	03/24/18	11:20	x3
BLA_020	03/24/18	11:35	x3
Cliffside Well (sump well)	03/24/18	12:24 on a water faucet	x3
BLA_027	03/25/18	9:50	x3
~~BLA_025~~	~~3/25/18~~	~~10:30~~	AUTO SAMPLER.
↳	SWAPPED w/ CANNEL @ 11:00		
BLA_023	3/25/18	11:30	x3
BLA_020	3/25/18	11:50	x3

Field notes c) Grab sample collection sites, dates, and times, along with how many vials were collected



Notes

Manta Fluorometer deployed 3/24/18, 12:05, BLA_025. Next to BSEACO Fluorometer

When labled as BLA_027, it has (~~BLA_025~~) 2 names.

Dye injection point: latitude 30° 2' 25" N
longitude 98° 13' 31" W

Total weight of liquid: 2.468 kg
Dry mass of uranine
Time Injected: 13:18

Auto sampler deployed, BLA_025, ~~stream~~ guage transect about 20m upstream
- Sample every 1 hour (@ the top of the hour)
- NOT multiplex
- head = 5 ft.
- Collecting 350 ml
- Pipe length ≈ 20 ft.
- 3/24/18 → Start @ 3:00, end @ 10:00 3/25/18
- 3/25/18 → start @ 11:05

Field notes d) General dye trace notes, including deployment of autosampler and dye injection