Carters Creek Total Maximum Daily Load Implementation Project

Intensive Water Quality Monitoring Report: Task 7

Texas Water Resources Institute TR-486
January 2016

Texas Water Resources Institute
make every drop count

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Cooperating Entities:
Texas A&M AgriLife Research, Texas Water Resources Institute
Texas A&M AgriLife Research, Department of Soil and Crop Sciences
City of Bryan
City of College Station
Brazos County Health Department
Brazos County Road and Bridge Department
Texas A&M University - Environmental Health and Safety
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List of Acronyms

CFU	Colony forming units
COCS	City of College Station
COB	City of Bryan
GIS	Geographic Information System
I-Plan	Implementation plan
QAPP	Quality Assurance Protection Plan
SAML	Soil and Aquatic Microbiology Lab
SCSC	Soil and Crop Sciences Department
TAMU	Texas A&M University
TCEQ	Texas Commission on Environmental Quality
TMDL	Total maximum daily load
TWRI	Texas Water Resources Institute
USEPA	U.S. Environmental Protection Agency

Project Background

All states are required to identify waters that either do not meet or are not expected to meet water quality standards. After identifying these waters the state must develop a Total Maximum Daily Load (TMDL) for each pollutant that impairs the uses of the water body. In Texas, the responsibility of ensuring TMDLs are developed is tasked to the Texas Commission on Environmental Quality (TCEQ).

In 2007, TCEQ's TMDL Team began the process of developing a TMDL and a TMDL Implementation Plan (I-Plan) for the Carters Creek watershed. Watershed stakeholders were engaged in the process to develop recommendations for management measures needed to restore water quality in the Carters Creek watershed. Through discussions with stakeholders, a recurring need expressed was for an improved understanding of the current state of the waterbodies through a watershed source survey and a monitoring effort that provides a spatially and temporally robust evaluation of water quality in Carters Creek and its tributaries.

This project was developed to fill that need through enhanced water quality monitoring and a watershed source survey. Specific project goals are to:

1. conduct extensive water quality monitoring throughout the watershed on a spatial and temporal scale that will provide additional data to identify sub-watersheds where bacteria and other pollutant contributions are problematic
2. conduct a multi-faceted watershed source survey utilizing geo-referenced field observations, and geographic information system (GIS) to identify potential sources of bacteria and other pollutant loading in the watershed
3. document watershed source survey results using GIS so that information can be integrated with available digital data on existing nonpoint and point source pollutants in the watershed
4. organize and establish a volunteer monitoring group through the Texas Stream Team program as a means to provide supplemental water quality data that will help local watershed managers further refine their knowledge of the spatial and temporal distribution of instream water quality variability

Throughout the course of the project, the need for a more spatially refined evaluation of *E. coli* concentrations across the watershed arose. Working with the City of Bryan (COB) and the City of College Station (COCS), a plan to intensively sample selected tributaries of Carters Creek was developed to identify reaches along the stream where *E. coli* contributions were considerably higher than surrounding areas and further investigate those areas.

This report focuses specifically on the outcomes of this effort - Task 7: Exploratory Loading Area Sampling.

Introduction

Developing a clearer understanding of the spatial and temporal variability in *E. coli* concentrations monitored throughout the watershed and establishing a clear baseline of current *E. coli* loads at a sub-watershed scale were the goals for monitoring conducted through the project. Initially, these goals were to be achieved through routine monitoring (scheduled on a routine frequency) conducted at 13 locations across the watershed. This monitoring was carried monthly for two years and was completed in February 2015. While this approach provides valuable information, it did not provide the level of spatial detail needed to identify critical areas in the watershed where *E. coli* loading is more problematic than others.

After discussing initial monitoring findings with watershed stakeholders, an additional monitoring approach that utilized intensive sampling in selected areas of the watershed was developed. Tributaries of Carters and Burton Creeks that were commonly found to have the highest *E.coli* levels in the watershed or where no prior information had been collected were selected for this intensive sampling. The approach utilized a one-time sampling regime where numerous samples were taken along the stream on the same date to roughly identify potential problem areas within the stream. Following the initial sampling, the data were reviewed to further refine the understanding of *E. coli* loading areas across the watershed. Stream reaches found to have rapid increases in *E. coli* numbers were then sampled with a second intensive sampling event to further refine understanding of water quality within that reach.

Data Collection

Data collection and sample analysis was conducted in accordance with the project Quality Assurance Protection Plan (QAPP) and TCEQ's most recently published *Surface Water Quality Monitoring Procedures, Volume 1: Physical and Chemical Monitoring Methods*. These documents describe proper sampling locations within the stream, sample labeling, sample collection techniques, sample handling and transport techniques that were utilized by the sampling team. Briefly, the sampling approach was as follows:

- label sample container with date, time, location, sampler initials, preservative use prior to sample collection
- record temperature, pH, dissolved oxygen, and specific conductance from the centroid of flow
- collect *E. coli* sample from the centroid of flow (typically mid-point of the stream half way into the water column in the sampled creeks)
- place collected *E. coli* sample in a cooler on ice for storage until delivery to the lab
- record observational information on field data sheets including sampling depth, flow severity, present weather, water conditions, water color and clarity, water

odor, algae presence, condition of the water surface and notes on other observations

Water samples from each creek or segments within a creek were collected incrementally and delivered to Soil and Aquatic Microbiology Lab (SAML) at Texas A&M University within the 6 hour "regulatory" holding time for bacteria enumeration utilizing the USEPA 1603 method. In most cases, the time between sampling and delivery to the lab was 4 hours or less. Specific conductance, water temperature, pH, and dissolved oxygen was recorded in the field with a YSI EXO1 multi probe using the approach outlined in methods outlined in TCEQ's *Surface Water Quality Monitoring Procedures, Volume 1: Physical and Chemical Monitoring Methods*.

Data Management

Data collected through this intensive monitoring task was recorded in the field using automated instruments and personnel observations. Water quality readings collected using the YSI EXO1 multi probe were stored on the device and recorded on paper field data sheets. Data sheets also included the observations and notes mentioned previously in the Data Collection and Analysis section. Following sampling events, original data were inputted into a Microsoft Excel spreadsheet for easy access, interpretation and later sharing.

Once in electronic form, data were manually formatted by TWRI staff into the appropriate file types and structures for delivery to TCEQ and inclusion in their Surface Water Quality Management Information System. Data were uploaded to their database and attached to existing monitoring events in the Carters and Burton Creek watershed for future availability. These data were collected for a special monitoring project and will not be utilized by TCEQ for future water body assessment purposes. Instead, they will be utilized by local watershed managers for directing infrastructure inspections and repairs.

Exploratory Bacteria Loading Area Sampling

Tributary Monitoring

Texas Water Resources Institute (TWRI) cooperated with COB and COCS to plan targeted monitoring on 6 tributaries of Carters Creek. Initially, 69 sites were planned for monitoring (Table 1); however lack of access or lack of water prevented sampling at 5 of these sites. The tributaries sampled are illustrated in Figure 1 and maps provided in Appendix A illustrate the sites sampled.

Creeks were sampled by TWRI and Texas A&M University (TAMU) Soil and Crop Sciences (SCSC) Department staff. Sampling on each creek was conducted independently of each other; however, all samples collected within a particular stream were collected on the same day in a downstream to upstream order. The number of sampling sites was maximized for each waterbody but the ability to sample depended on ambient flow conditions on the sampling day. Of the 5 sites that were not sampled, 4 were due to unsafe conditions and 1 was due to no water being present in the stream.

Before sampling, all sites were surveyed for conditions and safety of sampling. Some sites were not sampled during the actual sampling event due to changes in conditions that resulted in unsafe sampling conditions or lack of water. The initial site surveys were conducted after an extensive period of heavy rainfall in the area that resulted in the sites predominantly having what was considered high flow conditions. Between the time site surveys were conducted and the first round of sampling, vegetation around the streams grew rapidly and flow conditions considerably decreased at many of the sites. During the initial Tributary Monitoring campaign conducted July 6, 7 and 8, 2015, 10 of the sampled sites had low flow, 9 had no apparent flow, and the rest had normal flow.

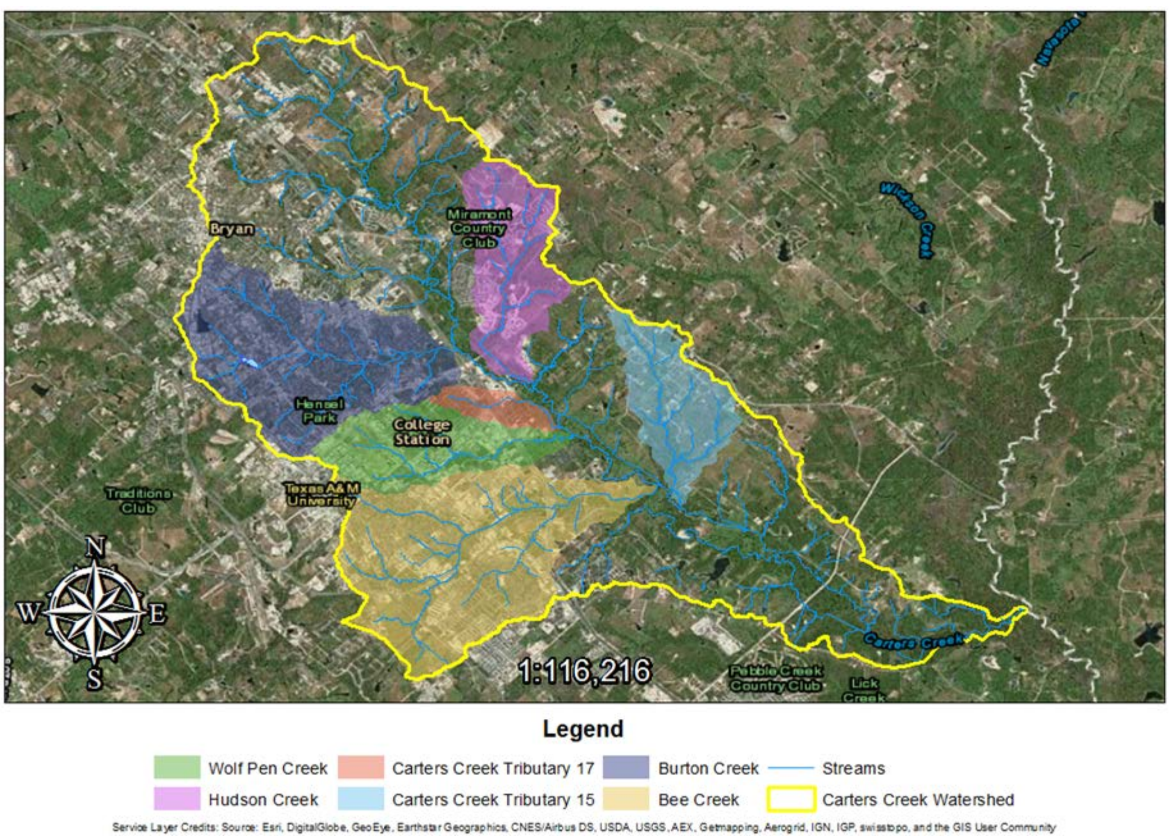


Figure 1. Targeted watersheds for intensive sampling

Table 1. Site descriptions for Round 1 of sampling.

Site_ID	Description of Location
BC1	Burton Creek upstream of E 29th St
BC2	Burton Creek downstream of N Rosemary
BC3	Burton Creek downstream of confluence with Burton Creek Tributary 3
BC4	Burton Creek downstream of Tanglewood Park
BC5	Burton Creek at start of Tanglewood Park
BC6	Burton Creek downstream side of Broadmoor Dr
BC7	Burton Creek at confluence with Burton Creek Tributary D
BC8	Burton Creek upstream of E Villa Maria
BC9	Burton Creek @ Burton Dr
BC10	Burton Creek @ Esther
BC11	Burton Creek @ Avondale Ave
BCT1	Unnamed Burton Creek Tributary upstream of confluence with Burton Creek
BCT2	Burton Creek Tributary 1 downstream of University Park
BCT3	Burton Creek Tributary 1 upstream of University Park
BCT4	Burton Creek Tributary 2.1 upstream of confluence with Tributary 2
BCT5	Burton Creek Tributary 2 upstream of confluence with Tributary 2.1
BCT6	Burton Creek Tributary C @ confluence with Burton Creek
BCT7	Burton Creek Tributary C @ Hensel Park
BCT8	Burton Creek Tributary 5 @ confluence with Burton Creek
BCT9	Burton Creek Tributary C downstream of HEB shopping center
BCT10	Burton Creek Tributary D downstream Country Club Lake 4
BCT11	Burton Creek Tributary D downstream Country Club Lake 3
BCT12	Burton Creek Tributary D downstream Country Club Lake 2
BCT13	Burton Creek Tributary D downstream Country Club Lake 1 (nearest)
BeC1	Bee Creek @ Appomattox Dr, downstream of Emerald Forest Park
BeC2	Bee Creek @ Frontage 6 Rd E (downstream)
BeC3	Bee Creek @ Frontage 6 Rd W (upstream)
BeC4	Bee Creak upstream of confluence with Bee Creek Tributary 4
BeC5	Bee Creek downstream of confluence with Bee Creek Tributary 5
BeC6	Bee Creek @ Texas Ave S, downstream of Bee Creek Park
BeC7	Bee Creek downstream of confluence with Bee Creek Tributary B
BeC8	Bee Creek upstream of confluence with Bee Creek Tributary B
BeC9	Bee Creek downstream of Lemon Tree Park @ start of Bee Creek Park
BeC10	Bee Creek @ Lemon Tree Park
BeC11	Bee Creek @ Glade St
BeC12	Bee Creek downstream of Brison Park @ Thomas St
BeC13	Bee Creek upstream of Brison Park @ Old Jersey Street
BeT1	Bee Creek Tributary upstream of confluence at Emerald Forest Park

BeT2	Bee Creek Tributary B upstream of confluence with Bee Creek
BeT3	Bee Creek Tributary B downstream of Georgie K Fitch Park
BeT4	Bee Creek Tributary B upstream of confluence with Bee Creek Tributary B.3
BeT5	Bee Creek Tributary B.3 upstream of confluence with Bee Creek Tributary B
BeT6	Bee Creek Tributary B.3 @ Steeplechase Park
BeT7	Bee Creek Tributary upstream of Southwest Park @ Southwest Pkwy
BeTx	Bee Creek Tributary A @ intersection of Harvey Mitchell Pkwy S & Hwy 6
BeTy	Bee Creek Tributary A upstream of Longmire Park
HC1	Hudson Creek downstream of Veterans Park @ Harvey Rd
HC2	Hudson Creek upstream of Veterans Park @ University Dr E
HC3	Hudson Creek downstream of confluence with Tributary 2 @ Copperfield Dr
HC4	Hudson Creek downstream of confluences with Tributaries 3 & 4
HC5	Hudson Creek upstream of confluences with Tributaries 3 & 4
HT1	Hudson Creek Tributary 3 upstream of confluence with Hudson Creek
HT2	Hudson Creek Tributary 4.1 upstream of confluence with Hudson Creek Tributary 4
UN1	Carters Creek Tributary 15.1.1 upstream of confluence with Tributary 15.1
UN2	Carters Creek Tributary 15.1 upstream of confluences with 15.1.2 & 15.1.1
UN3	Carters Creek Tributary 17 @ Harvey Rd
UN4	Carters Creek Tributary 17 @ Merry Oaks Park & University Oaks Blvd
WP1	Wolf Pen Creek @ Raintree Park
WP2	Wolf Pen Creek @ Frontage Rd 6 E
WP3	Wolf Pen Creek @ Holleman Dr E
WP4	Wolf Pen Creek Tributary A @ confluence with Wolf Pen Creek
WP5	Wolf Pen Creek @ George Bush Dr E
WP6	Wolf Pen Creek Tributary B before confluence
WP7	Wolf Pen Creek @ Texas Ave S
WP8	Wolf Pen Creek @ Anderson St
WP9	Wolf Pen Creek @ George Bush Dr
WPT1	Wolf Pen Creek Tributary C @ Redmond Dr
WPT2	Wolf Pen Creek Tributary C @ George Bush Dr
WPT3	Wolf Pen Creek Tributary C.1 @ New Main Dr

Tributary Monitoring Assessment

Following data collection, *E. coli* enumeration results were reviewed to identify areas where spikes in *E. coli* levels occur. Areas found to have rapid increases in *E. coli* levels were further investigated. A rapid increase was considered to be a rate of change equal to 0.1 CFU/100 ml per foot of stream or more. GIS and watershed survey information produced in Task 3 was reviewed to provide information on potential *E. coli* sources and identify potential contributors within these areas that may have contributed to the increases observed. Table 2 lists the summary statistics for the incremental rates of *E.*

coli increase and decrease observed between sites within each stream. Figure 2 illustrates the variations in *E. coli* concentrations observed during this sampling event in an upstream to downstream fashion within a single waterbody. Maps illustrating the location of specific sampling sites are located in Appendix A and are separated by subwatershed. Data for Carters Creek Tributaries 15 and 17 are not included in Figure 2 as observed *E. coli* concentrations at all four monitoring sites in each watershed were less than 150 colony forming units (CFU) per100 mL. All *E. coli* observations are included in tables included in Appendices A – E.

Waterbodies exhibiting considerably larger increases in *E. coli* concentrations between sampling locations were noted during the first sampling event. Two reaches of Bee Creek and one of its tributaries; two reaches of Burton Creek and two of its tributaries; and two reaches of Wolf Pen Creek and two of its tributaries were found to have the highest rates of increase. These sites were further investigated during a second sampling event.

Table 2. . Summary statistics for rates of increase and decrease between sites on the same stream during Round 1.

	Increases (CFU/100 ml/ft)	**Decreases (-) (CFU/100 ml/ft)**
Mean	1.438	2.675
Std Dev	4.168	7.523
N	18	22
Minimum	0.012	0.004
Maximum	17.747	35.921
Median	0.152	0.634
Geometric Mean	0.193	0.518
Range	17.735	35.918

Two unnamed tributaries of Carters Creek (Carters Creek Tributary 15 & 17 in this report) did not produce *E. coli* concentrations that warranted further investigation as they did not exhibit rapid rates of increase nor were they at high levels (≤150 cfu/100 mL). Hudson Creek did exhibit *E. coli* concentrations that were considerably higher than the State's primary contact recreation standard of 126 cfu/100 mL; however, observed levels were relatively consistent throughout the stream. These three waterbodies were not sampled further.

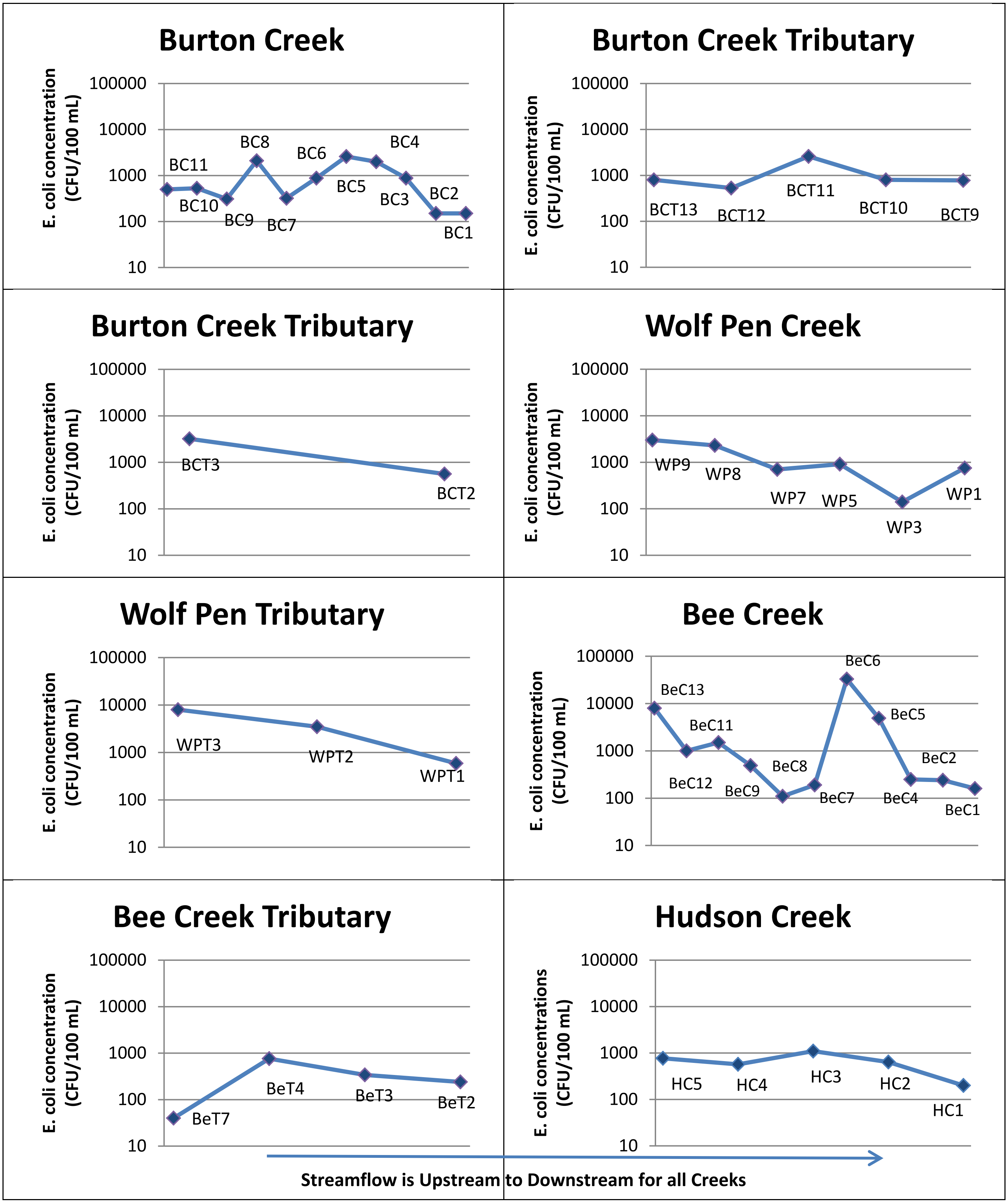


Figure 2: ***E. coli*** **concentrations by waterbody during July 2015 intensive sampling event**

Investigative Sampling

A second round of intensive sampling was planned for selected areas within the stream reaches monitored during the first round of sampling. Sampling sites for the second round were mostly selected to represent stream reaches found to have rapid increases in observed *E. coli* concentrations during the first round of sampling and/or elevated *E. coli* concentrations. Some segments that showed a rapid increase, but still displayed low *E. coli* counts were not resampled due to placing higher priority on investigating segments with more extreme *E. coli* counts. When selecting sampling locations, the presence of potential *E. coli* sources such as parks, stormwater outlets, and wastewater infrastructure in the immediate vicinity of the creek was also considered. Specific sampling locations were selected to capture water quality immediately downstream or upstream of potential influences where access was available.

Table 3: Site descriptions for Round 2 of sampling

Site_ID	Description of Location
BC4	Burton Creek downstream of Tanglewood Park
BC5	Burton Creek at start of Tanglewood Park
BC5a	Burton Creek @ Edgewood
BC5b	Burton Creek downstream of confluence with Burton Creek Tributary 4
BC6	Burton Creek downstream side of Broadmoor Dr
BCT8	Burton Creek Tributary 5 before confluence with Burton Creek
BC8	Burton Creek upstream of E Villa Maria
BC8a	Burton Creek ~100 ft upstream of BC8
BC8b	Burton Creek ~100 ft upstream of BC8a
BCT11	Burton Creek Tributary D upstream of Maloney
BCT11a	Burton Creek Tirbutary D ~200 ft upstream of BCT11
BCT11b	Burton Creek Tributary D downstream of E Villa Maria
BCT12	Burton Creek Tributary D upstream of E Villa Maria
BCT2	Burton Creek Tributary 1 downstream of University Park
BCT2a	Burton Creek Tributary 1 at inlet of pond in University Park
BCT2b	Burton Creek Tributary 1 ~125 feet upstream of BCT2a
BCT3	Burton Creek Tributary 1 upstream of Autumn Circle
WP2	Wolf Pen Creek upstream of Hwy 6
WP2b	Wolf Pen Creek at bridge in Wolf Pen Creek Park, north of Eastmark Drive terminus
WP2a	Wolf Pen Creek downstream of Wolf Pen Creek Park amphitheater
WP6	Wolf Pen Creek Tributary B upstream of confluence with Wolf Pen Creek
WP6a	Wolf Pen Creek Tributary B downstream of Harvey Rd
WP8	Wolf Pen Creek upstream of Anderson St
WP9	Wolf Pen Creek upstream of George Bush Dr

WP9a	Wolf Pen Creek downstream of golf course service road
WP9b	Wolf Pen Creek ~100 ft upstream of WP9a
WPT2	Wolf Pen Creek Tributary C upstream of George Bush Dr
WPT3	Wolf Pen Creek Tributary C.1 downstream of New Main Dr
WPT4	Wolf Pen Creek Tributary C downstream of New Main Dr
WPT3a	Wolf Pen Creek Tributary C.1 upstream of New Main Dr
BeC5	Bee Creek downstream of confluence with Bee Creek Tributary 5
BeC5a	Bee Creek Tributary 5 @ confluence with Bee Creek downstream of Cy Miller Park
BeC6	Bee Creek upstream of Texas Ave S
BeC6a	Bee Creek 400 ft upstream of BeC6
BeC6b	Bee Creek 400 ft upstream of BeC6a
BeC6c	Bee Creek 400 ft upstream of BeC6b
BeC6d	Bee Creek 400 ft upstream of BeC6c
BeT6	Bee Creek Tributary B.3 downstream of Steeplechase Park
BeT6a	Bee Creek Tributary B.3 near middle of Steeplechase Park
BeT6b	Bee Creek Tributary B.3 downstream of Wellborn Rd
BeC11	Bee Creek upstream of Glade St
BeC11a	Bee Creek upstream of Holleman Dr
BeC12a	Bee Creek downstream of Dexter Dr S
BeC13	Bee Creek downstream of George Bush Dr
BeC14	Bee Creek upstream of George Bush Dr

Monitoring focused on portions of the Bee, Burton and Wolf Pen Creek watersheds. Collectively, 11 reaches within these watersheds were monitored during the second round of intensive sampling. TWRI and SCSC staff used the same sampling approach in Round 2 where samples were collected in a downstream to upstream manner. In total, 41 individual sampling points were monitored during the two-day sampling campaign that occurred on August 10 and 12, 2015. Three additional sites were planned for monitoring, but on the date of sampling one was dry and the other two were not safely accessible. *E. coli* concentrations observed are shown in Figures 3 and 4 as well as Appendices A – E.

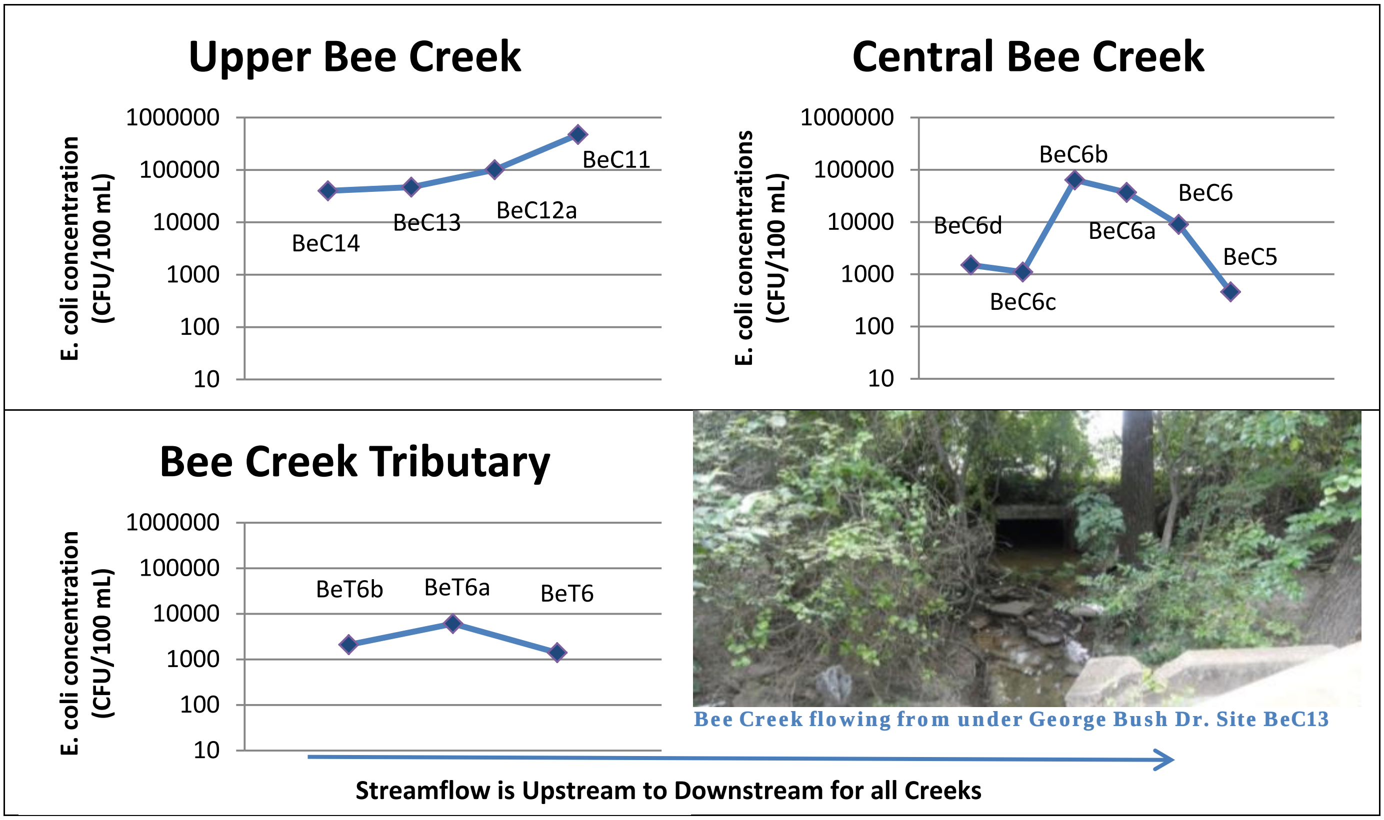


Figure 3: *E. coli* concentrations observed in Bee Creek and its tributaries during the second round of intensive sampling

The second round of intensive sampling provided additional insight into the specific loading areas within the sampled reaches. As in the first round of sampling, the portion of Bee Creek immediately upstream of Texas Ave. exhibited rapid increases and decreases of *E. coli* concentrations. The most upstream portion of the creek that drains from Spence Park on the TAMU campus also exhibited a considerable increase in *E. coli* concentrations that were 2 – 3 orders of magnitude higher than the primary contact recreation standard. Several reaches within the Burton Creek watershed also showed considerable changes in *E. coli* concentration within short distances. The unnamed tributary of Burton Creek that flows from Country Club Lake across Villa Maria and Texas Ave showed a rapid increase in *E. coli* immediately upstream and downstream of Villa Maria before levels declined to near the primary contact recreation standard. Downstream on Burton Creek between Broadmoor Ave. and the downstream end of Tanglewood Park, *E. coli* also increased steadily before beginning to decline. In the Wolf Pen Creek watershed, the two tributaries monitored contained the highest observed *E. coli* concentrations. These areas included the headwaters of a tributary that drain the Bonfire Memorial and an unnamed tributary that flows under Harvey Rd. from Thomas Park into the Wolf Pen Creek park greenway immediately upstream of George Bush Dr. East.

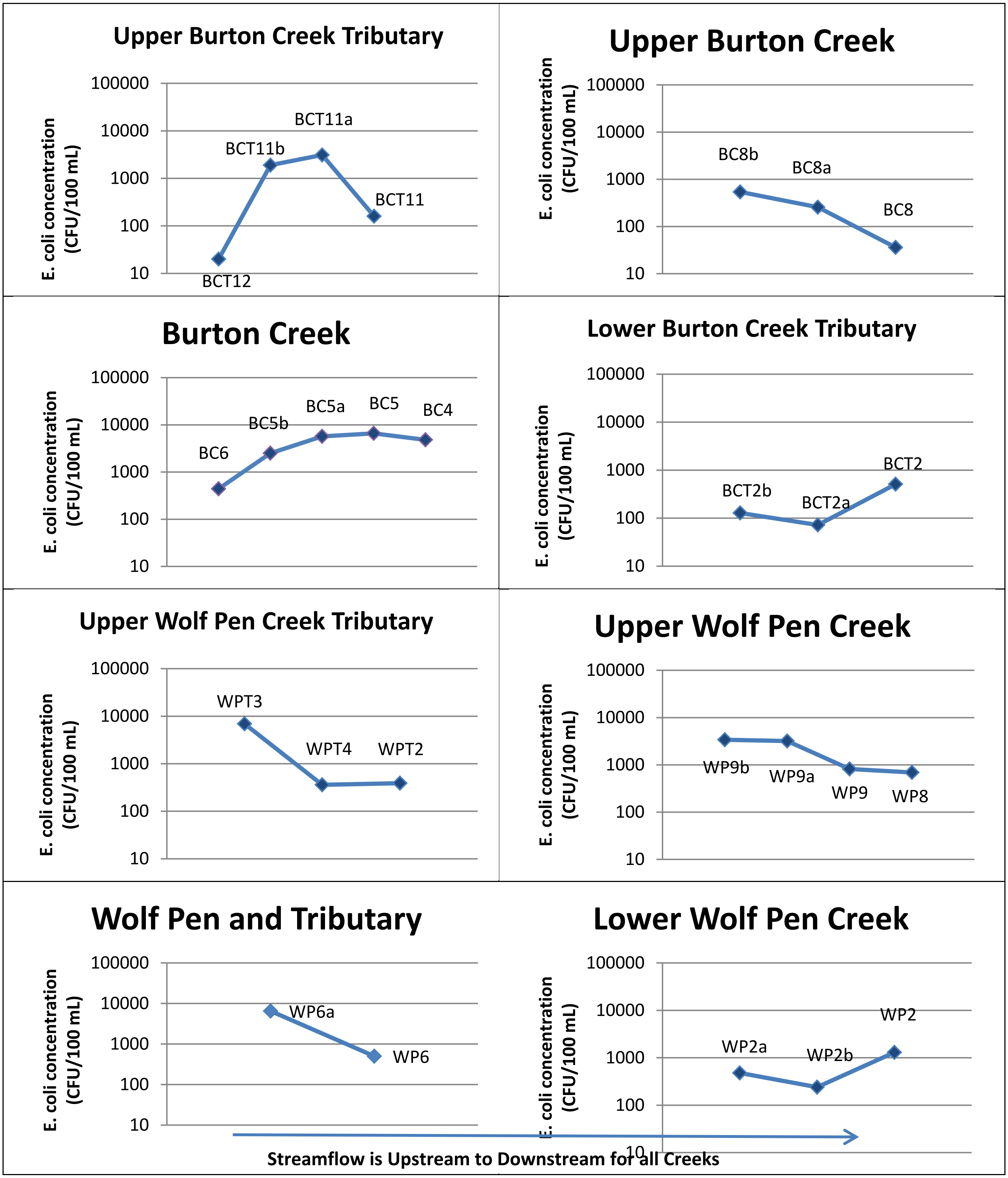


Figure 4: ***E. coli*** **concentrations observed in Burton and Wolf Pen Creeks and their tributaries during the second round of intensive sampling**

Data Analysis

In addition to determining the rates of increase between sampling sites as discussed earlier, relationships between observed water quality parameters were evaluated. Review of collected data revealed that high *E. coli* concentrations are sometimes associated with high recorded specific conductance or water temperature levels while low *E. coli* concentrations are occasionally associated with low specific conductance or water temperature levels. To evaluate the extent of this occurrence, the correlation between monitored parameters was evaluated using the Spearman Rho correlation coefficient. Spearman Rho was selected for defining correlations due to the inclusion of outliers within the data set as its results are not skewed due to their presence. Simple linear regression was also performed to describe the relationship between parameters.

Correlations were determined for all collected data and data collected within sampling rounds. Simple linear regressions were applied in identical fashion. Table 4. illustrates the Spearman Rho correlation coefficients, and the significance of the test (p-values) as well as the calculated regression equations, adjusted R-squared values and significance of the model (p-value). Appendices G and H contain scatter plots of evaluated scenarios.

In all tested scenarios, the correlation between *E. coli* and specific conductance concentrations was weak largely as a result of the variation of *E. coli* concentrations observed. Correlations between *E. coli*, specific conductance and water temperature were significant when Round 1 and Round 2 data were analyzed together. Simple linear regressions did not produce strong models for predicting *E. coli* concentrations from specific conductance or water temperature readings. Only the models for Round 1 & Round 2 combined were statistically significant; however, they only explained 11.96 and 4.08% of the variation observed in the data sets and are thus weak predictors of *E. coli* in this case.

Table 4: Correlations and relationships between *E. coli*, specific conductance, and water temperature

Data Set	Spearman Rho	Rho p-value	Regression Equation	Adjusted R-square	Model p-value
***E. coli* vs. Specific Conductance**					
Round 1	0.219	p=0.081	Log *E. coli*=2.486+0.000287*Spec. Conductance	2.02%	p=0.134
Round 2	0.389	p=0.013	Log *E. coli*=2.399+0.00055*Spec. Conductance	7.04%	p=0.054
Rounds 1 & 2	0.410	***p=0.000***	Log *E. coli*=2.331+0.000529*Spec. Conductance	11.96%	***p=0.000***
***E. coli* vs. Water Temperature**					
Round 1	0.223	p=0.077	Log *E. coli*=1.19+0.0545*Temperature	1.35%	p=0..175
Round 2	0.229	p=0.154	Log *E. coli*=-0.06+0.1125*Temperature	2.64%	p=0.160
Rounds 1 & 2	0.255	***p=0.009***	Log *E. coli*=0.29+0.0917*Temperature	4.08%	***p=0.022***

Discussion

This intensive monitoring study was developed and implemented as an approach to potentially identify areas within the Carters and Burton Creek watershed that may be contributing larger concentrations of *E. coli* than surrounding areas. Through this process, several stream segments were identified where *E. coli* concentrations increased rapidly as compared to adjacent stream reaches. This enabled further refined sampling where additional samples were taken within selected reaches with rapid increases in *E. coli* concentrations.

No obvious contributors of *E. coli* to any creek were identified through the watershed survey or multiple rounds of monitoring. Observations made within these reaches and the presence of stormwater and wastewater infrastructure in the vicinity of these areas could potentially contribute to the observed increases; however, no concrete evidence to support this suggestion was found.

Stormwater infrastructure seemingly contributed to the observed *E. coli* load in several locations. Insignificant volumes of water were present in these locations at the time of sampling and no runoff had occurred in more than two weeks; however, the limited amount of water draining from these outlets are potential sources of *E. coli*. It is suspected that storm drains and the conveyance system may provide a suitable habitat for *E. coli* to survive in water or sediment here as they have been found to in other watersheds around the world. This infrastructure shields *E. coli* from direct sunlight and prevents the inactivation of cells through UV exposure. Additionally, stormwater infrastructure could also intercept wastewater leaking from a failing sewer line or from an illicit connection.

An example of stormwater infrastructure being the suspected source of *E. coli* in the watershed is the Wolf Pen Creek tributary that is formed near the Bonfire Memorial. Water collected from this stormwater outfall had a considerably higher *E. coli* concentration than the adjacent site and downstream sites. The headwaters of Bee Creek also showed very high levels of *E. coli* where the stream drains out of Spence Park on the Texas A&M University campus. In addition to storm water infrastructure, the ongoing renovations to Kyle Field (at the time of sampling) represents a potential influence on the elevated *E. coli* concentrations observed as well. Further sampling at this location now that the Kyle Field renovations are complete may illustrate different *E. coli* concentrations.

Shading of the waterbody is also suspected as a factor that could potentially influence *E. coli* concentrations observed along a stream segment. In some cases, increases were observed where the stream flowed through predominantly shaded areas. Subsequently, when stream flowed into areas where there is limited or no shade and the stream is shallow, the *E. coli* levels begin to fall again. An example of a segment with extensive shade on the stream is shown in Figure 5. Within this reach, the *E. coli* concentration increased at a rate of 10.375 CFU/100 ml/ft from site BeC14 to BeC13, increased by 24.537 CFU/100 ml/ft from BeC13 to BeC12a, and by 137.837 CFU/100 ml/ft from BeC12a to BeC11. Other inputs of bacteria within this reach are possible as well and are likely given the drastic increase in observed *E. coli* concentrations.

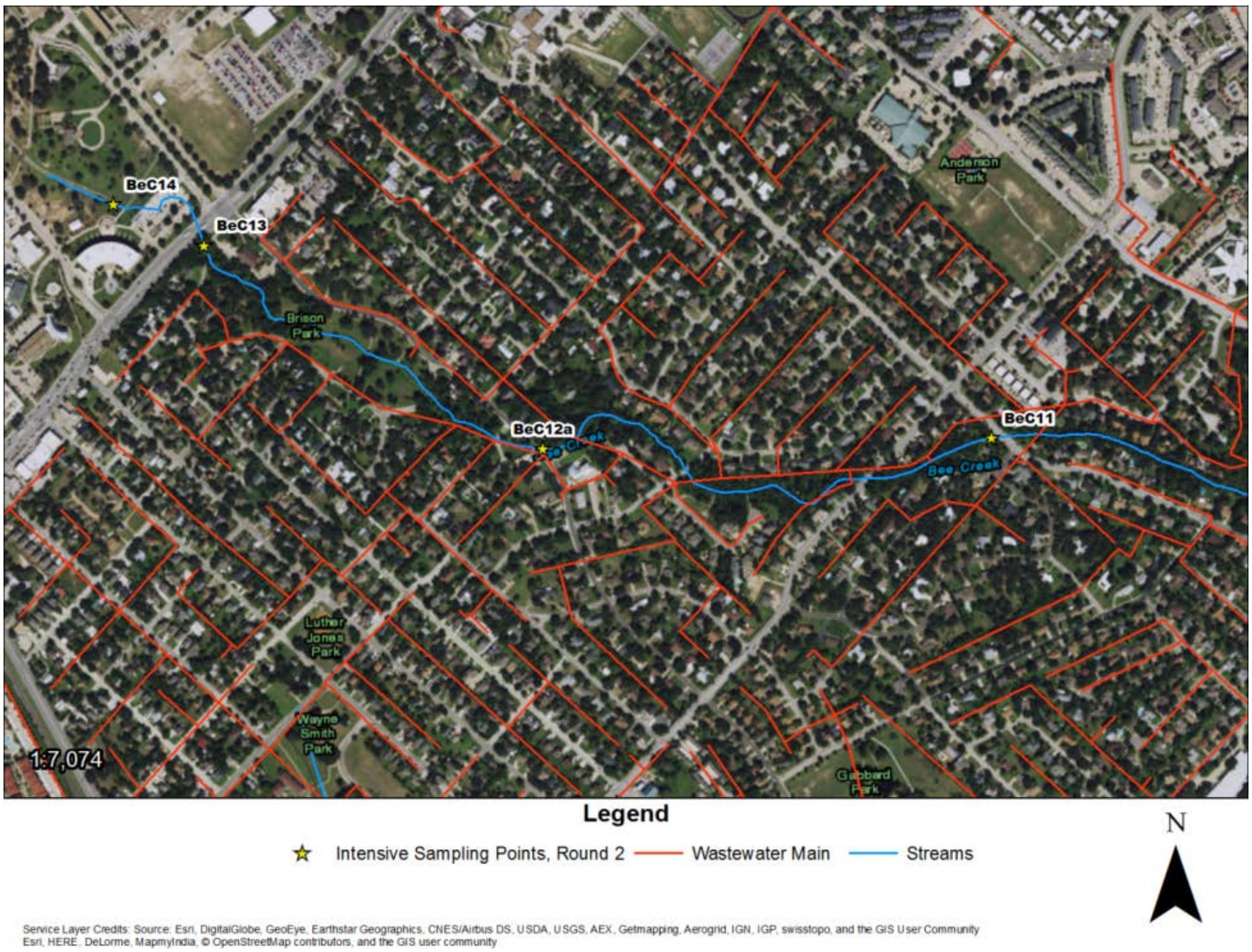


Figure 5. Section of Bee Creek from BeC14 through BeC11.

Wastewater infrastructure is also a potential source at many of the observed segments with spikes; however, there was no evidence of leakage when sampling or stream surveys were conducted. Several locations had unpleasant odors, but it is unknown whether the source of these smells came from wastewater infrastructure or another source. Inspection by the appropriate wastewater operators is recommended to further investigate potential sources *E. coli* sources in these segments. Segments with nearby wastewater mains are shown in Figures 5 & 6. In Figure 6, for example, the *E. coli* count increased from BeC6c to BeC6b at a rate of about 145 CFU/100 ml/ft over a distance of about 430 ft. During sampling, no obvious source or evidence of wastewater leakage was observed.

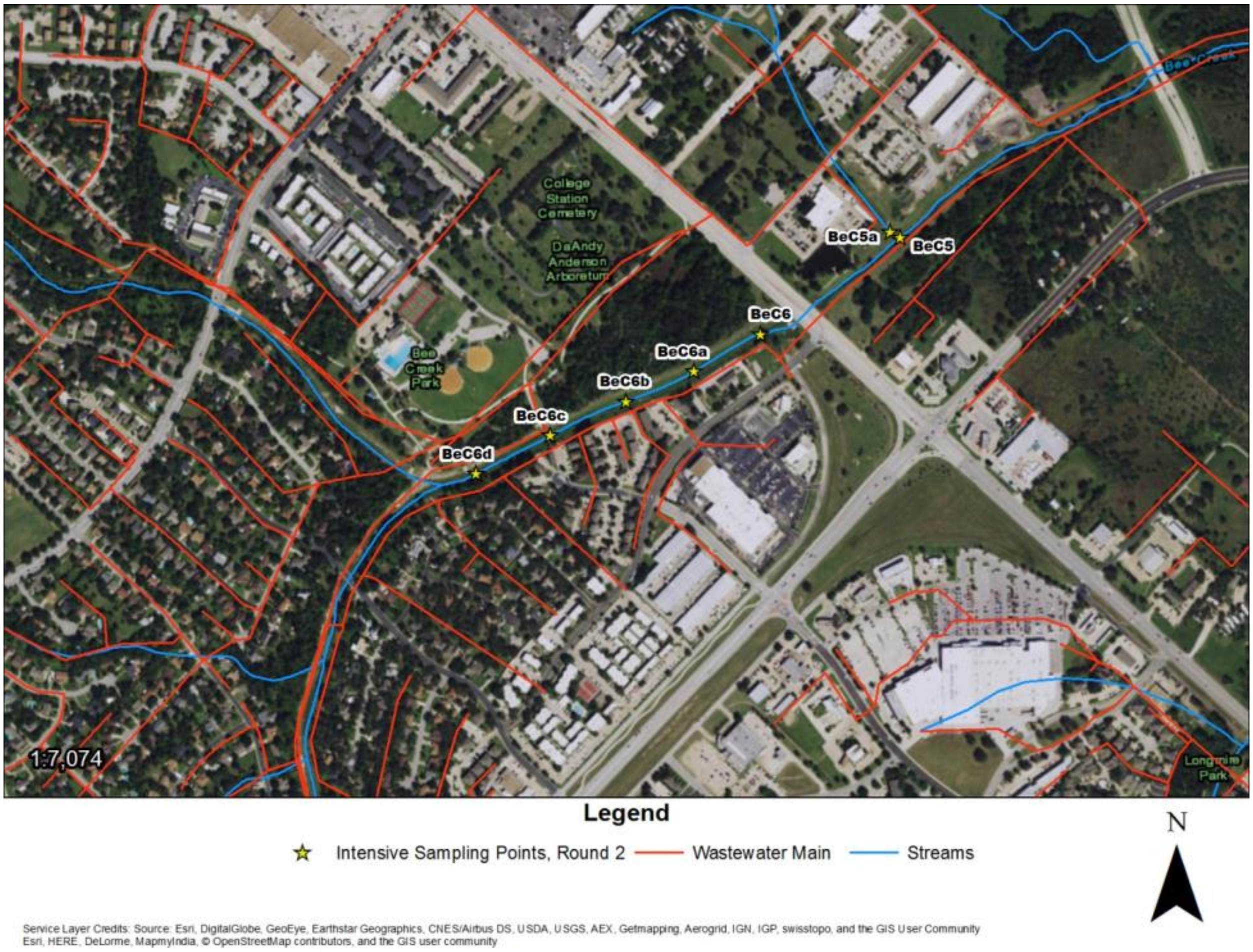


Figure 6. Bee Creek stream segment from BeC6d through BeC5

After sampling data assessment and review, several areas should be considered for further investigation. City or TAMU personnel with knowledge of the potential sources of *E. coli* in these areas (stormwater or wastewater infrastructure) would be the ideal persons to perform these inspections as they may be able to identify problems that can be readily addressed. Also, if infrastructure smoke testing or camera inspections that are currently underway in the watershed could be applied in these areas, they too may be able to identify the underlying cause of the observed *E. coli* loading in these areas. Table 5 includes the sites and descriptions of areas where inspections have the greatest potential to considerably reduce *E. coli* concentrations in stream if a specific issue can be found and subsequently corrected.

Table 5. Recommended inspection areas in the watershed

Creek Name	Description of Area	Area of Watershed
Bee Creek	Tributary of Bee Creek beginning in Spence Park on TAMU campus to the Glade St. creek crossing	TAMU and City of College Station
	Bee Creek near Bee Creek park from the footbridge connecting the park to the River Walk apartment complex downstream to Texas Ave.	City of College Station
Burton Creek	Segment of Burton Creek from Broadmoor Ave to approximately 500 ft downstream of Tanglewood Ave.	City of Bryan
Wolf Pen Creek	Upstream of George Bush Dr. near Bizzell St. and the TAMU golf course	TAMU
	Tributary of Wolf Pen Creek forming at the detention pond drain outlet near the Bonfire Memorial	TAMU
	Tributary of Wolf Pen Creek flowing from under Harvey Rd between Wolf Creek Car Wash and Taco Bell and into Wolf Pen Creek park	City of College Station

Recommended inspection area photos. Clockwise from top left: Bee Creek exiting from under George Bush Dr., Bee Creek upstream of Texas Ave., Wolf Pen Creek near George Bush Dr. and Bizzell St., Tributary of Wolf Pen Creek downstream of New Main Dr.

Appendix A: Bee Creek Sampling Sites and Results

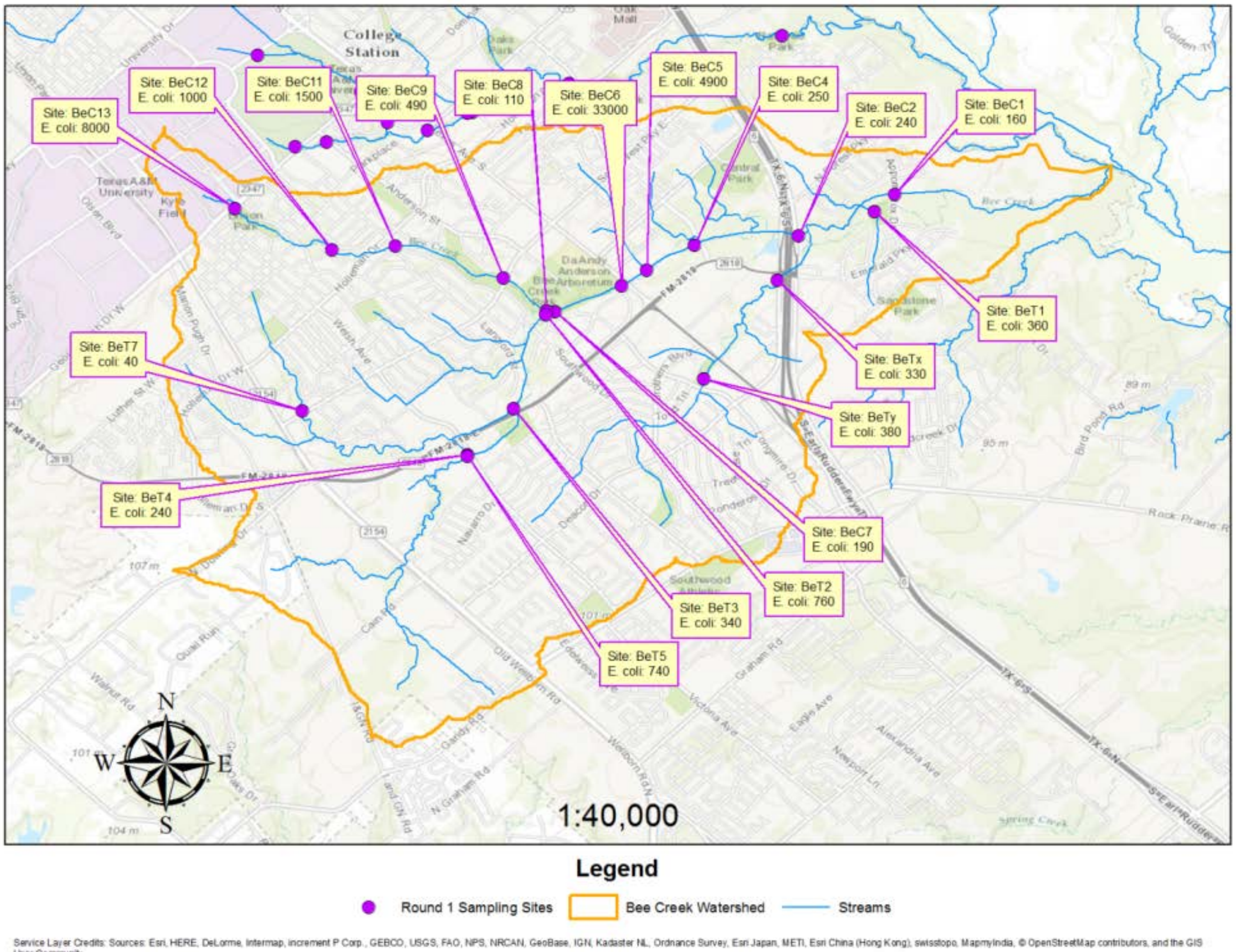
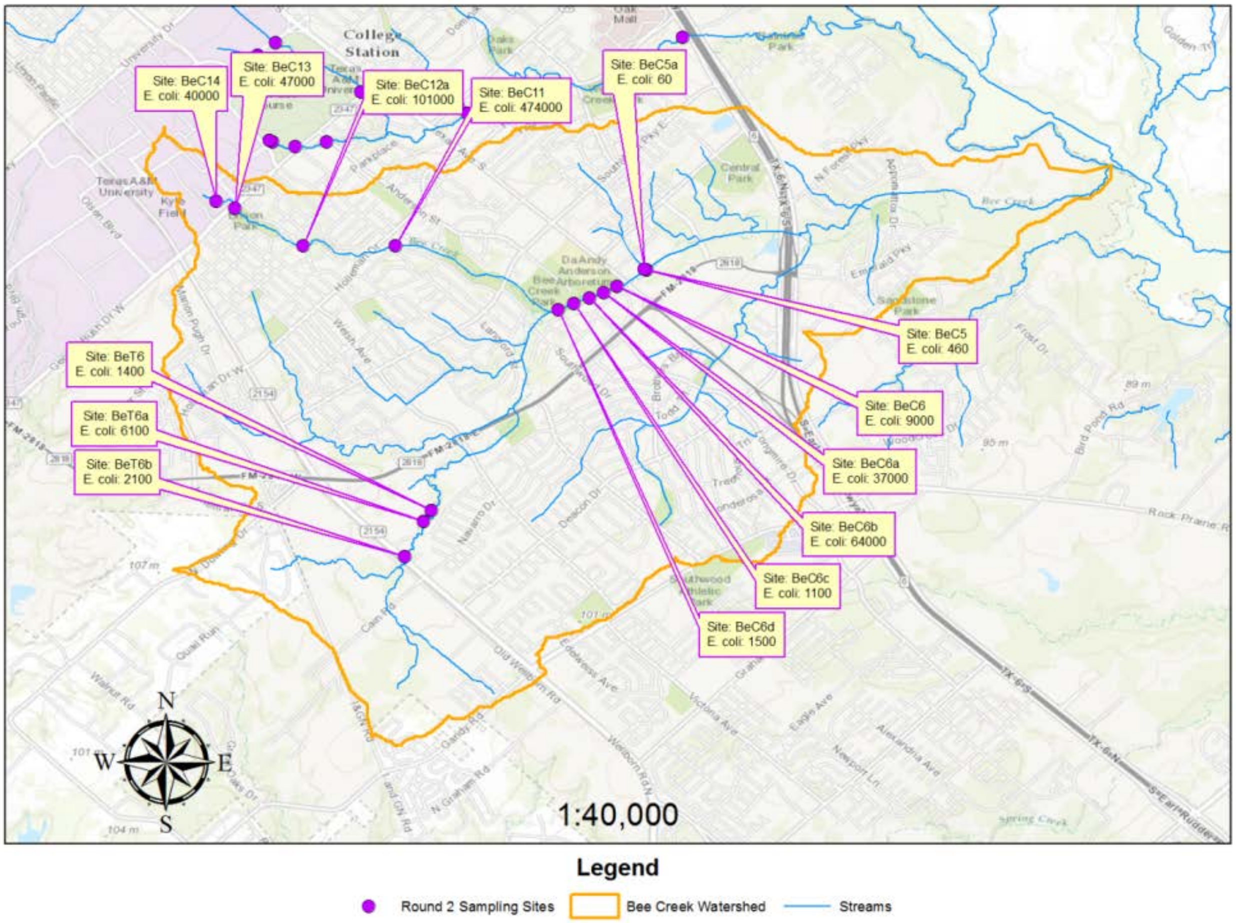


Figure 7. Bee Creek intensive sampling sites for round 1



Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Figure 8. Bee Creek intensive sampling sites for round 2

Table 6. Bee Creek *E. coli* results

First Round			Second Round		
Site ID	**Date Sampled**	***E. coli* count (CFU/100mL)**	**Site ID**	**Date Sampled**	***E. coli* count (CFU/100mL)**
BeC1	7/6/2015	160	BeC5	8/12/2015	460
BeT1	7/6/2015	360	BeC5a	8/12/2015	60
BeC2	7/6/2015	240	BeC6	8/12/2015	9000
BeC3	*Not sampled*	*Unsafe*	BeC6a	8/12/2015	37000
BeTx	7/6/2015	330	BeC6b	8/12/2015	64000
BeTy	7/6/2015	380	BeC6c	8/12/2015	1100
BeC4	7/6/2015	250	BeC6d	8/12/2015	1500
BeC5	7/6/2015	4900	BeT6	8/12/2015	1400
BeC6	7/6/2015	33000	BeT6a	8/12/2015	6100
BeC7	7/6/2015	190	BeT6b	8/12/2015	2100
BeC8	7/6/2015	110	BeC11	8/12/2015	474000
BeT2	7/6/2015	240	BeC12a	8/12/2015	101000
BeT3	7/6/2015	340	BeC13	8/12/2015	47000
BeT4	7/6/2015	760	BeC14	8/12/2015	40000
BeT5	7/6/2015	740			
BeT6	*Not sampled*	*No access*			
BeT7	7/6/2015	40			
BeC9	7/6/2015	490			
BeC10	*Not sampled*	*Unsafe*			
BeC11	7/6/2015	1500			
BeC12	7/6/2015	1000			
BeC13	7/6/2015	8000			

Appendix B: Burton Creek Sampling Sites and Results

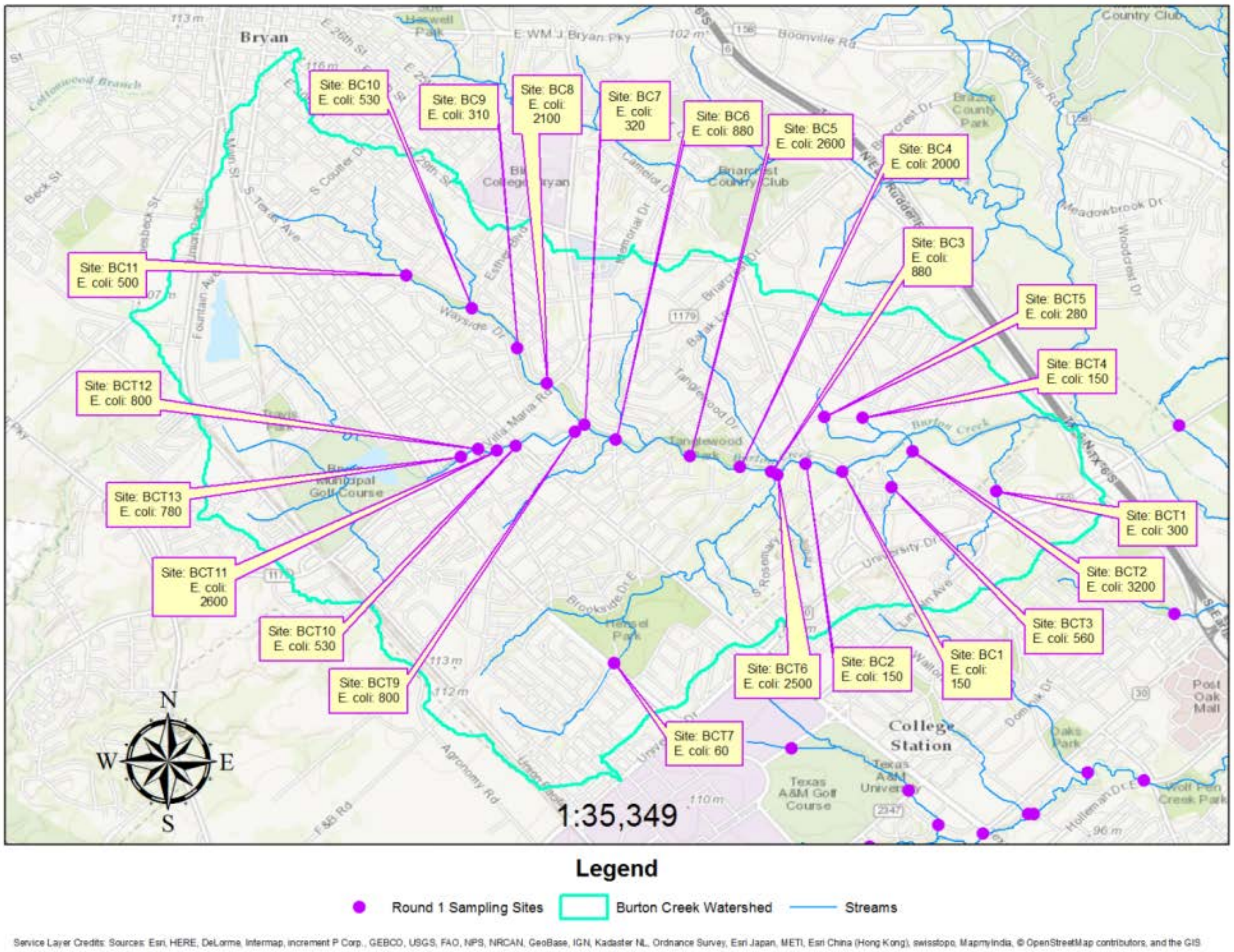
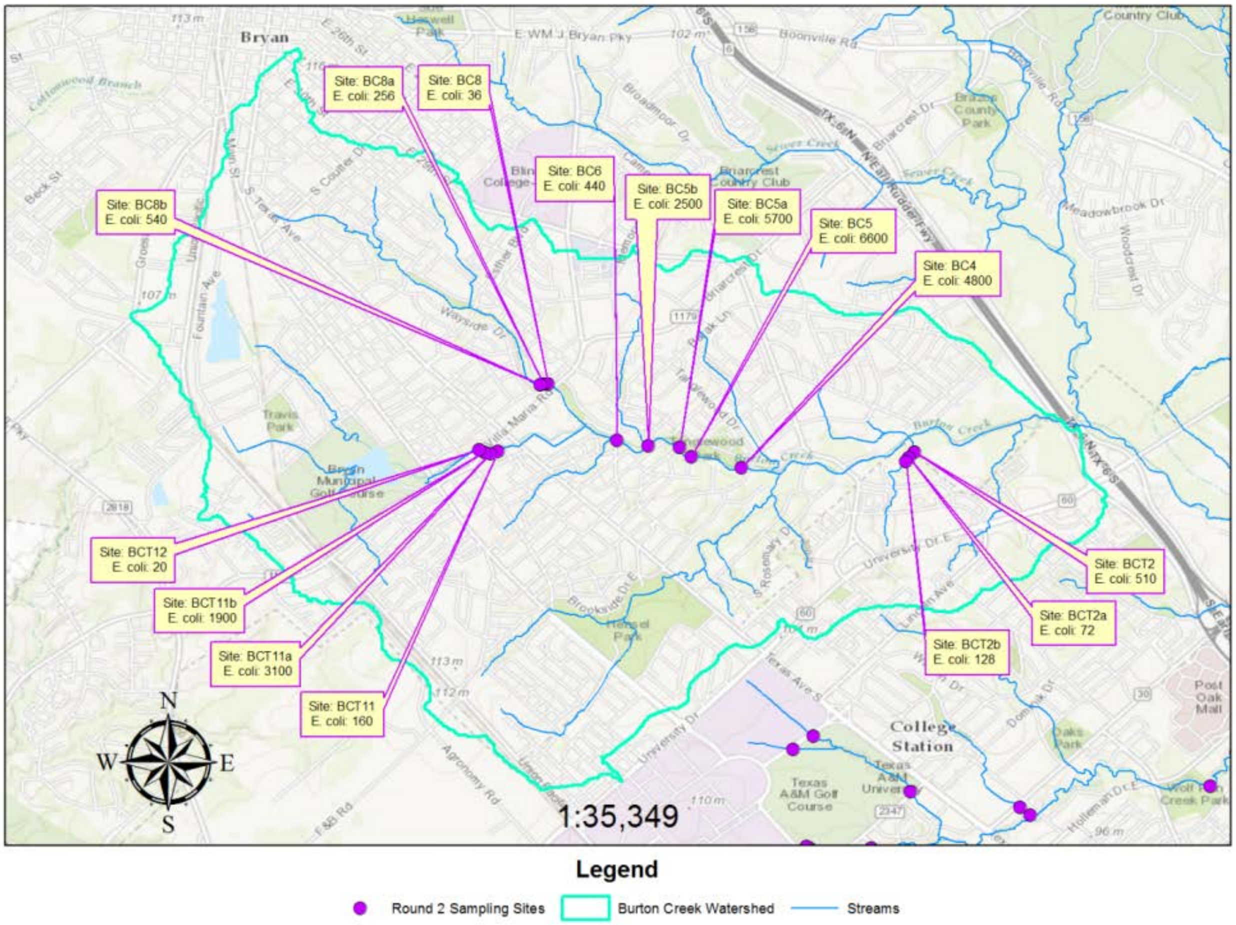


Figure 9. Burton Creek intensive sampling sites for round 1



Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS

Figure 10. Burton Creek intensive sampling sites for round 2

Table 7. Burton Creek *E. coli* results

First Round			Second Round		
Site ID	**Date Sampled**	***E. coli* count (CFU/100mL)**	**Site ID**	**Date Sampled**	***E. coli* count (CFU/100mL)**
BCT1	7/8/2015	300	BC4	8/10/2015	4800
BCT2	7/8/2015	3200	BC5	8/10/2015	6600
BCT3	7/8/2015	560	BC5a	8/10/2015	5700
BCT4	7/8/2015	150	BC5b	8/10/2015	2500
BCT5	7/8/2015	280	BC6	8/10/2015	440
BC1	7/8/2015	150	BC8	8/10/2015	36
BC2	7/8/2015	150	BC8a	8/10/2015	256
BC3	7/8/2015	880	BC8a	8/10/2015	540
BCT6	7/8/2015	2500	BCT11	8/10/2015	160
BC4	7/8/2015	2000	BCT11a	8/10/2015	3100
BC5	7/8/2015	2600	BCT11b	8/10/2015	1900
BCT7	7/8/2015	60	BCT12	8/10/2015	20
BC6	7/8/2015	880	BCT2	8/12/2015	510
BCT8	*Not Sampled*	*Dry*	BCT2a	8/12/2015	72
BC7	7/8/2015	320	BCT2b	8/12/2015	128
BCT9	7/8/2015	800	BCT3	*Sample lost*	*Sample lost*
BCT10	7/8/2015	530			
BCT11	7/8/2015	2600			
BCT12	7/8/2015	800			
BCT13	7/8/2015	780			
BC8	7/8/2015	2100			
BC9	7/8/2015	310			
BC10	7/8/2015	530			
BC11	7/8/2015	500			

Appendix C: Carters Creek Tributary 15 Site Maps and Results

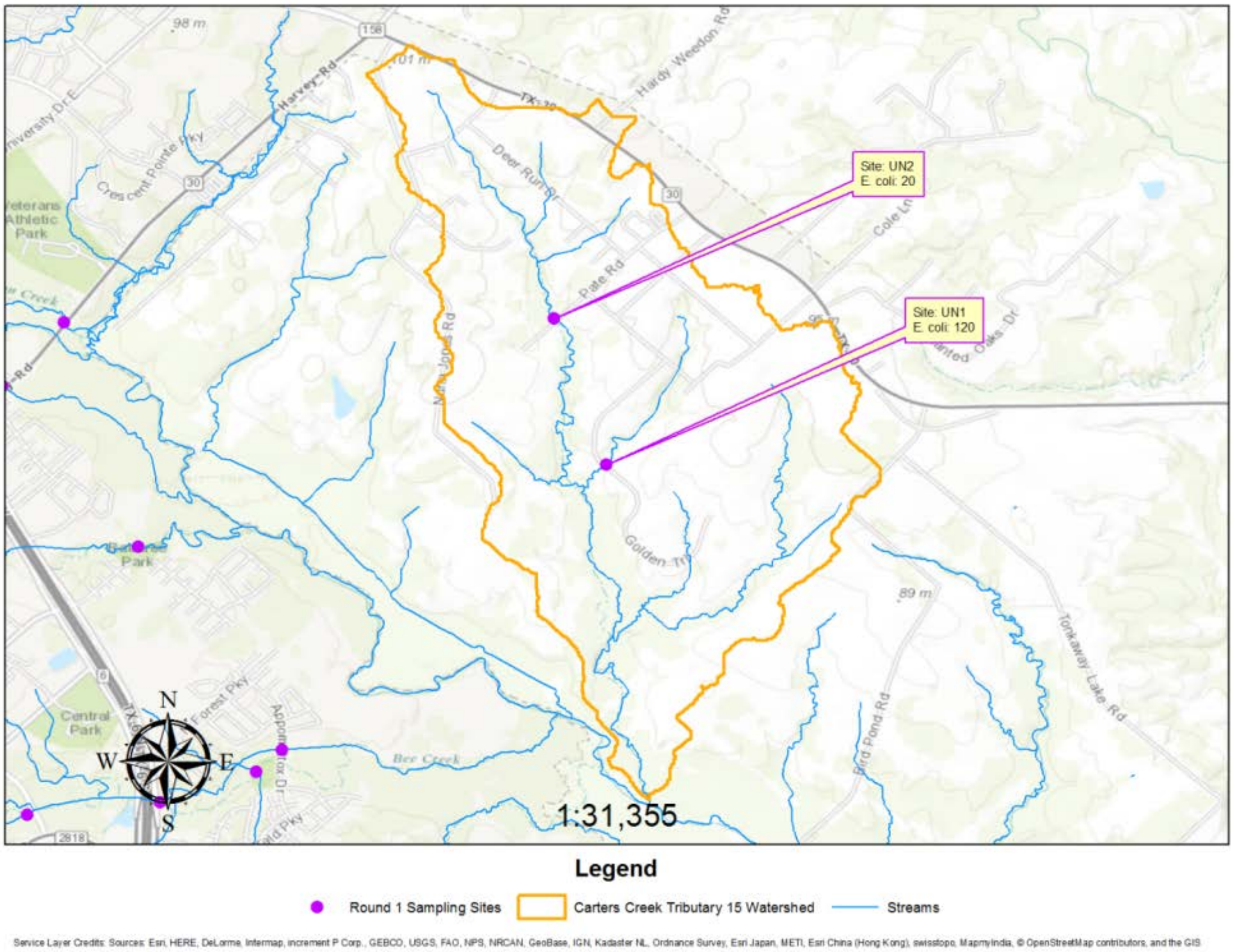


Figure 11. Carters Creek Tributary 15 intensive sampling sites for round 1

Table 8. Carters Creek Tributary 15 *E. coli* results

Site ID	Date Sampled	*E. coli* count (CFU/100 mL)
UN2	7/6/2015	20
UN1	7/6/2015	120

Appendix D: Carters Creek Tributary 17 Site Maps and Results

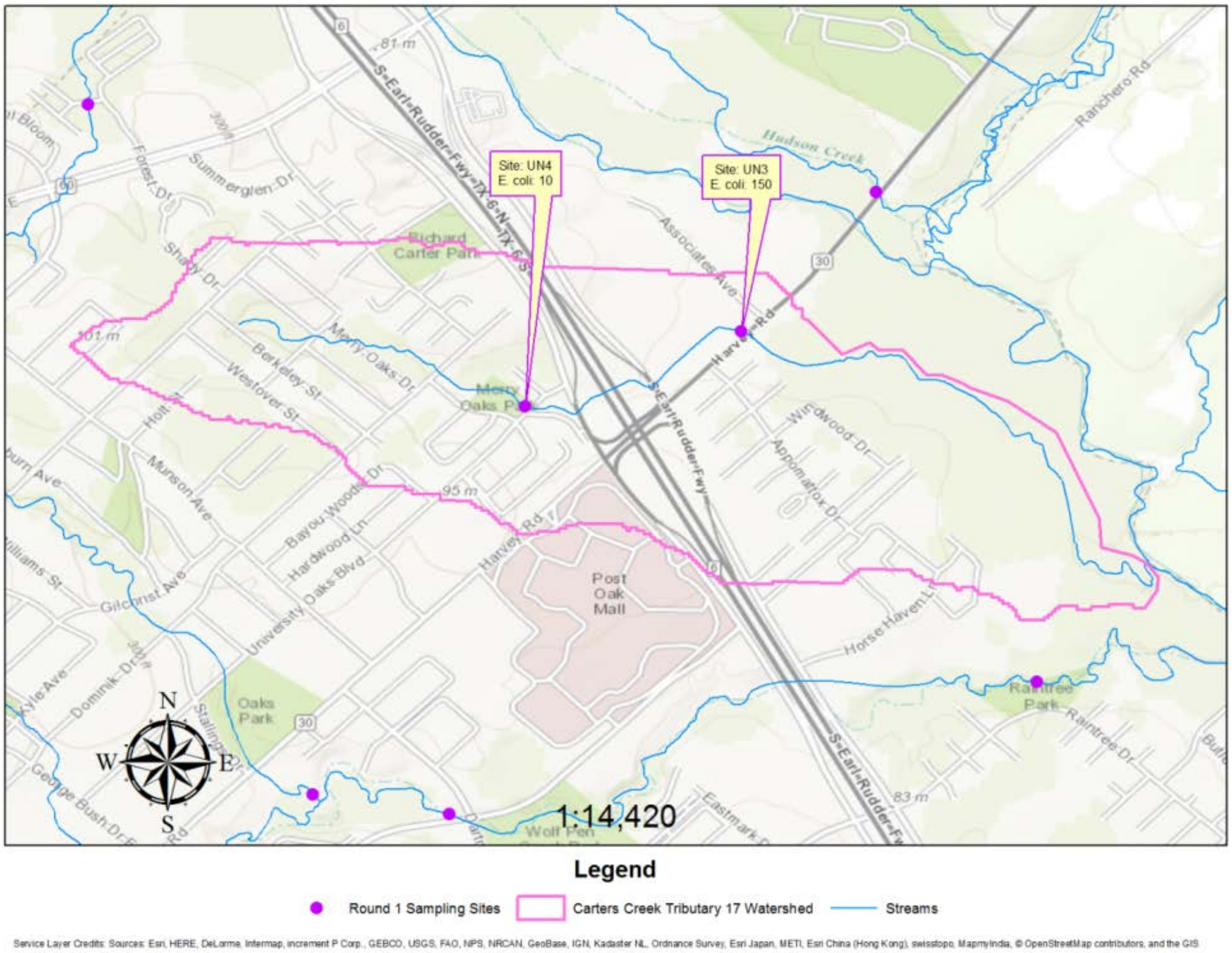


Figure 12. Carters Creek Tributary 17 intensive sampling sites for round 1

Table 9. Carters Creek Tributary 17 *E. coli* results

Site ID	Date Sampled	*E. coli* count (CFU/100 mL)
UN3	7/7/2015	150
UN4	7/7/2015	10

Appendix E: Hudson Creek Site Maps and Results

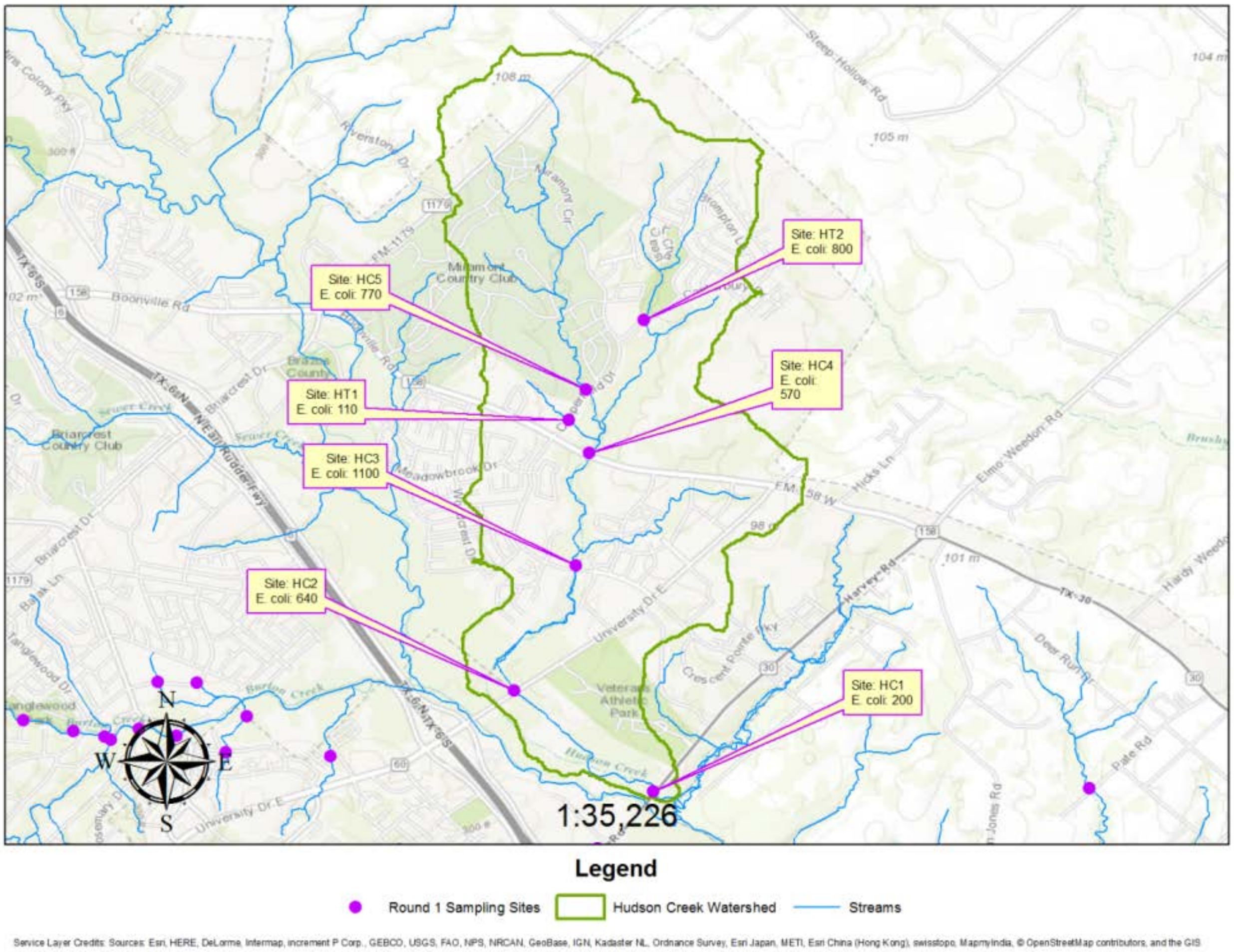
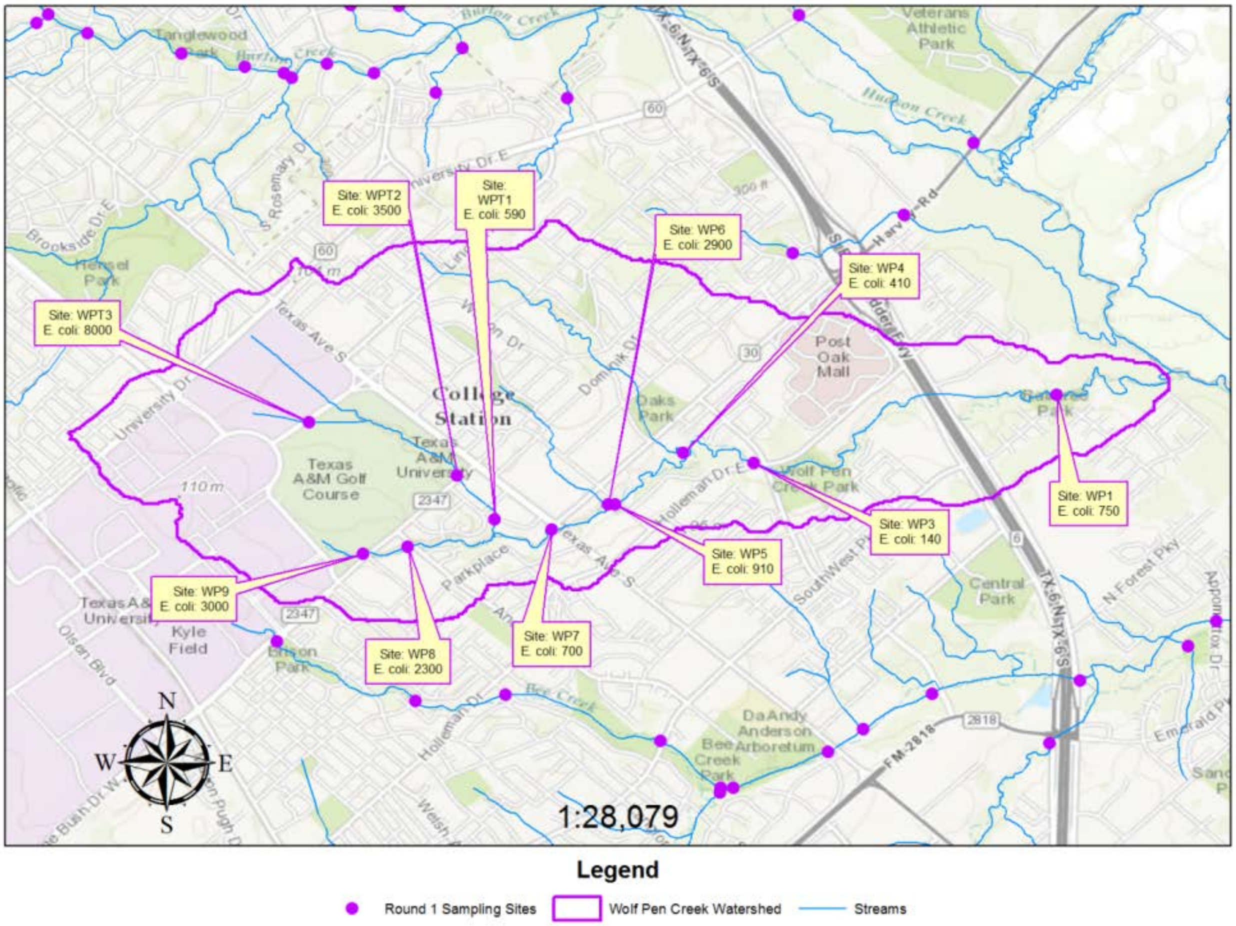


Figure 13. Hudson Creek intensive sampling sites for round 1

Table 10. Hudson Creek *E. coli* results

Site ID	Date Sampled	*E. coli* count (CFU/100 mL)
HC1	7/7/2015	200
HC2	7/7/2015	640
HC3	7/7/2015	1100
HC4	7/7/2015	570
HC5	7/7/2015	770
HT1	7/7/2015	110
HT2	7/7/2015	800

Appendix F: Wolf Pen Creek Site Maps and Results



Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS

Figure 14. Wolf Pen Creek intensive sampling sites for round 1.

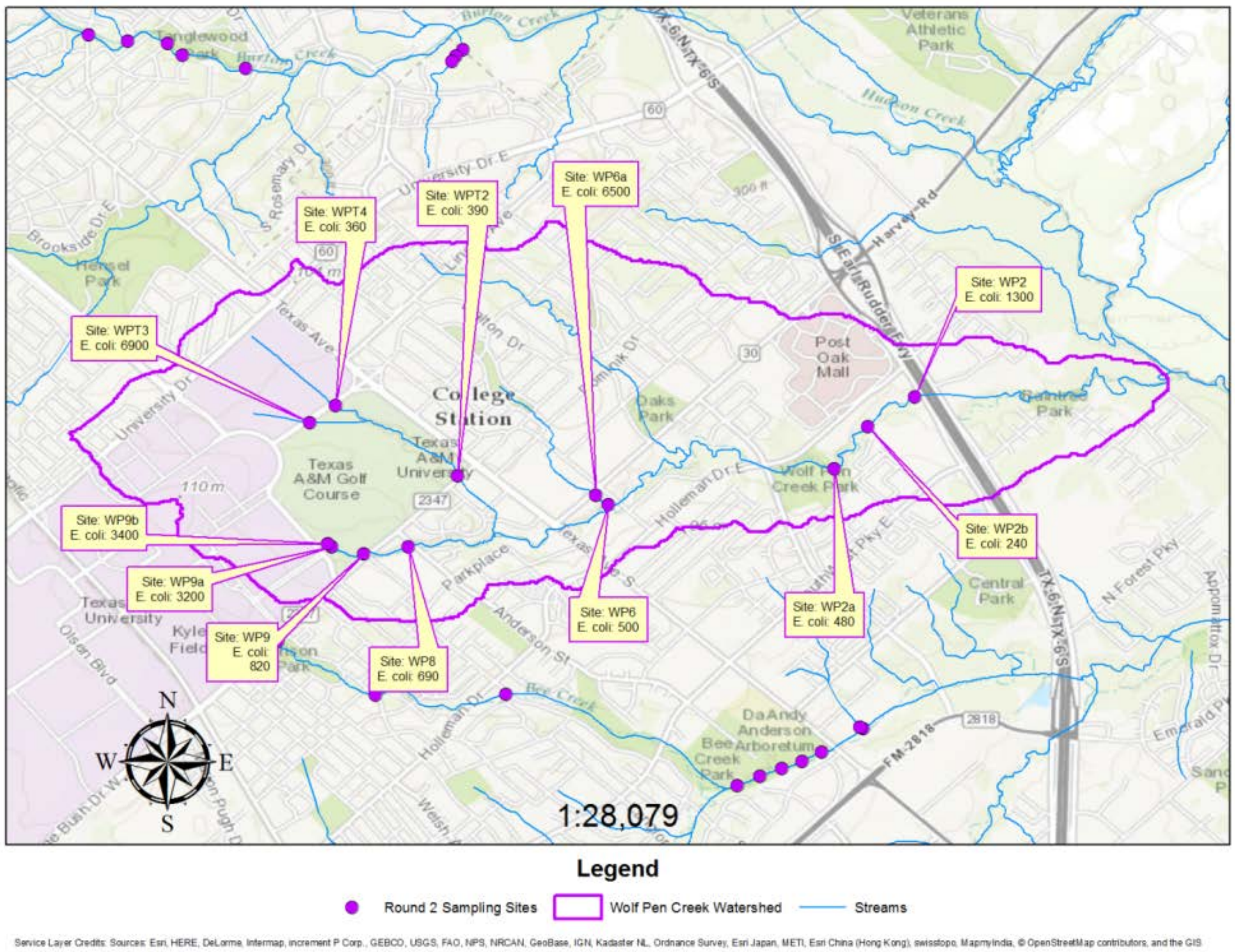
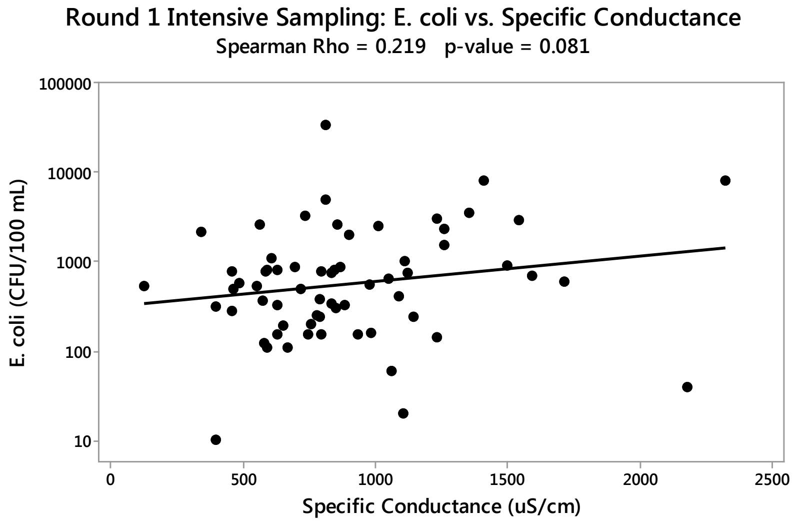


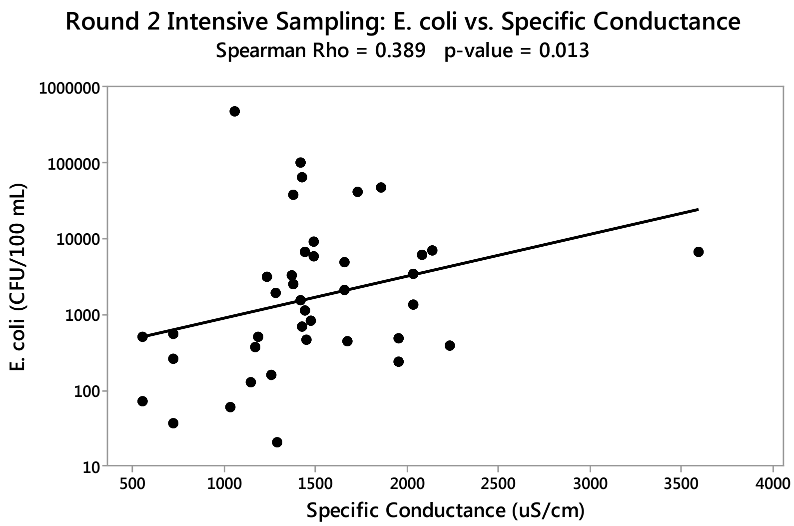
Figure 15. Wolf Pen Creek intensive sampling sites for round 2.

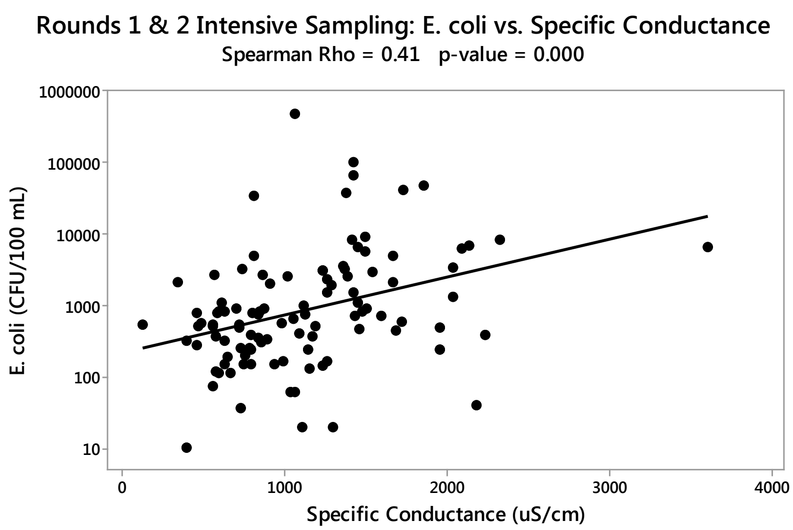
Table 11. Wolf Pen Creek *E. coli* results

First Round			Second Round		
Site ID	**Date Sampled**	***E. coli* count (CFU/100mL)**	**Site ID**	**Date Sampled**	***E. coli* count (CFU/100mL)**
WP1	7/7/2015	750	WP2	8/10/2015	1300
WP2	*Not Sampled*	*No access*	WP2a	8/10/2015	480
WP3	7/7/2015	140	WP2a	8/10/2015	240
WP4*	7/7/2015	410	WP6	8/10/2015	500
WP5	7/7/2015	910	WP6a	8/10/2015	6500
WP6*	7/7/2015	2900	WP8	8/10/2015	690
WP7	7/7/2015	700	WP9	8/10/2015	820
WPT1	7/7/2015	590	WP9a	8/10/2015	3200
WP8	7/7/2015	2300	WP9b	8/10/2015	3400
WP9	7/7/2015	3000	WPT2	8/10/2015	390
WPT2	7/7/2015	3500	WPT4	8/10/2015	360
WPT3	7/7/2015	8000	WPT3	8/10/2015	6900
			WPT3a	*Not Sampled*	*Dry*

Appendix G: Scatter Plots and Correlations of *E. coli* and Specific Conductance







Appendix H: Scatter Plots and Correlations of *E. coli* and Water Temperature