Ozarks Environmental and Water Resources Institute (OEWRI)
Missouri State University (MSU)

Flow and Water Quality Assessment of the Jordan Creek Underground, Springfield, Missouri

FINAL REPORT

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SCOPE AND OBJECTIVES

The City of Springfield has contracted the Ozarks Environmental and Water Resources Institute at Missouri State University to measure stream flow and sample water quality parameters in the Jordan Creek Underground to determine potential inputs from leaking sewer lines and other shallow groundwater sources. Exfiltration losses from leaking sanitary sewer systems can cause pollution problems in receiving streams and water quality surveys have been used to locate wastewater exfiltration from sanitary sewers into local streams (Dove et al., 2013, Owen et al. 2017, Owen et al. 2018). Jordan Creek is located in central Springfield, Missouri and flows through an underground box culvert that was built in 1928 within the old industrial area of downtown Springfield. The purpose of this study is to quantify variations in water quality at base flow along a 4,400 ft reach of the Jordan Creek that includes the portion that flows through the underground box culvert between Grant Ave. and Sherman Parkway in downtown Springfield.

The specific objectives of this assessment are to:
1. Perform a source risk assessment using GIS analysis of the segment to locate sewer line crossings, inflowing tributaries, local springs, faults and other geologic features, and permitted point discharges;
2. Collect stream discharge information to quantify flow changes within the box culvert;
3. Collect field-based temperature, dissolved oxygen, pH, and specific conductivity and water quality samples to be analyzed in the laboratory for total phosphorus, total nitrogen, chloride, and E. coli concentrations at equally spaced stream locations throughout the study reach and;
4. Make specific recommendations to the City of Springfield and its engineers regarding site prioritization based on results from this exfiltration risk assessment.

STUDY AREA

The Jordan Creek watershed (13.5 mi^2) drains the City of Springfield and is a main tributary to Wilson Creek within the James River Basin in southwest Missouri. The North and South branches of Jordan Creek begin along the city limit of Springfield a few miles east of Glenstone Avenue and flow west to the upstream end of the underground culvert of the stream near Phelps St. and Washington Ave. (Figure 1). The stream continues flowing west and resurfaces from the underground culvert at Main Avenue, continuing southwest to its confluence with Fassnight Creek just upstream of Scenic Ave. Land use within the watershed is a mix of high-medium density urban and low density residential land use. The underlying geology of the watershed is Mississippian age limestone within which a karst landscape has formed where sinkholes, losing streams, and springs are common (Bullard et al. 2001). The Pearson Creek fault system in the

southeast portion of the watershed is connected via karst to Jones Spring that redirects water across drainage divides.

This study focused on an approximately 4,400 ft reach of Jordan Creek between Sherman Parkway and Grant Ave. including the approximately 3,300 ft box culvert known as the Jordan Creek Underground (Figure 2). The original culvert was built to alleviate flooding between Boonville and Main Avenues in 1928 and was expanded upstream to Washington Ave. in 1934 (Oliver, 1939). The structure includes two separate culverts (north and south) that generally separates inflows from the two branches during low flow conditions. However, the two culverts do join together in two reaches where the middle partition wall is absent between Robberson and Boonville Avenues and again at Campbell Ave. In addition, several holes and archways (<4 ft wide) also occur in the partition wall allowing water to mix locally between the north and south culverts. Therefore, low flow discharges that enter the culvert upstream in separate culverts can mix to varying degrees at different points along the underground culvert.

METHODS

Source Risk Assessment & Infrastructure Identification
Prior to sampling, GIS analysis of the Jordan Creek Underground was used to locate sewer lines, springs, and faults. This was accomplished using geospatial data from Missouri Spatial Data Information Service (MSDIS) and The City of Springfield.

Field Sampling
All sampling occurred during fair-weather, base flow conditions to try to isolate potential inflows of ground water or leaking sewer lines. Field sampling protocols followed previously tested procedures used for exfiltration assessment sampling in the area (Owen et al. 2017, Owen et al. 2018). Phase-one field sampling was conducted on December 11, 2018 when water samples were collected along with metered-physical water parameters every 200 ft for the entire length of the underground culvert, upstream of the culvert in the North and South Branches, and downstream of the culvert to Grant Avenue along Jordan Creek. Additional field sampling occurred on January 25, 2019 to verify trends in discharge and water quality. Field workers walked upstream from site to site to ensure that sampling occurred in the undisturbed water column in the middle of the channel. Care was taken to insure that any bottom sediment was not disturbed during measurement collection or sampling.

Field Measurements
In-stream field measurements of specific conductivity (SC), pH, dissolved oxygen (DO), and temperature (T) were collected using an YSI multiprobe environmental meter (Pro Plus Model; YSI, Inc. Yellow Springs, OH, USA) (OEWRI 2015). Instrument accuracy was maintained by

using the auto-calibration procedure before each sampling day and by re-conditioning and manually calibrating each sensor prior to each sampling day.

Discharge Measurements

Discharge measurements were collected on December 11, 2018 at Grant, Main, and Washington Avenues along the study segment outside of the box culvert using a SonTek FlowTracker Acoustic Doppler velocity meter to verify downstream variability of flow (OEWRI 2007b). A second round of discharge measurements were collected on January 25, 2019 again at Grant, Main, and Washington Avenues. However, additional measurements were collected inside the culvert near Campbell, Boonville, and Robberson avenues to verify changes in flow observed in the initial sampling. There is also an USGS gaging station located downstream of the confluence of Fassnight and Jordan creeks on Wilson Creek at Scenic Ave. (#07052000). This station has been in continuous operation since 1998.

Water Sample Collection

Surface water grab samples were collected for analysis of nutrients, chloride (Cl), and E. coli bacteria using two different plastic bottles. Samples for total phosphorus (TP), total nitrogen (TN), Cl analysis were collected using 500 mL polypropylene (Nalgene^{TM}) open-mouth bottles (OEWRI 2007). Sample bottles were triple rinsed with ambient water prior to sampling and water was collected in the deepest part of the channel. Samples were collected by inverting the bottle to approximately 0.6 of the water depth from the surface and then turning up the opening to allow water to enter. At the laboratory each 500 mL sample was split into two 250 mL samples. One 250 mL sample was preserved for nutrient analysis by adding 1 ml of concentrated sulfuric acid (H_2SO_4) to lower the pH below 2 standard units to stop all biological processes and preserve nutrient concentrations. The remaining 250 mL was used for Cl analysis and was not preserved. All samples were stored at ~ 4°C prior to further analysis. Additional surface water grab samples were collected in pre-sterilized 100 mL bottles and placed in a cooler to be analyzed for *E.coli* bacteria (OEWRI 2013).

Laboratory Analysis

Sample processing and analysis was performed at OEWRI's Water Quality Laboratory located on the campus of Missouri State University. Surface water grab samples were analyzed for TN and TP using a Genesys 10S UV-Vis Spectrophotometer using EPA standard method 365.2 and methods outlined by Crumpton et al. (1992) (OEWRI 2010a, OEWRI 2010b). Laboratory Cl was measured using an Accumet Excel XL25 Dual Channel pH/Ion Meter (OEWRI 2009). As determined by in-house QA/QC procedures, acceptable detection limits for these procedures are ≤ 0.1 mg/L TN, ≤ 0.005 mg/L TP, and 0.1 mg/L Cl$^-$ with all accuracy and precision checks within the range of + or – 20%. Samples were analyzed for the presence of *E. Coli* using the IDEXX Colilert® and Quanti-Tray® method for detection and enumeration (OEWRI 2013). The detection limit of this method is 1 MPN/100 mL with accuracy of + or – 20%. IDEXX MPN

Generator 3.2 software was used for confirming MPN of sample results, as well as calculation of 95% confidence intervals.

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RESULTS AND DISCUSSION

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Channel Distance Locations

On December 4, 2018, 100 ft stations were marked along the south wall of the underground starting just upstream of Main Ave. (station 0 ft). Stations were located by pulling a tape every 100 ft and marking the wall with yellow paint and spray-painting the station number. This was used during sampling to know where in the culvert the sample was collected from in relationship to the infrastructure maps in GIS. The total length of the culvert is approximately 3,350 ft.

Source Risk Assessment

The source risk assessment identified multiple potential exfiltration source locations along the study reach using GIS data provided by the City of Springfield. A sewer line is mapped directly below the floor of the box culvert from Robberson Avenue near station 1,500 ft to Main Avenue downstream of the outlet at station -100 ft (Figure 2). Through this reach sewer lines join the main trunk line in five places, at stations 0 ft, 200 ft, 510 ft, 990 ft, and 1,500 ft. Additionally, a sewer line runs parallel to the box culvert along Water St. from station 1,200 ft to the end of the box culvert at 0 ft. Lyman Spring is located near the corner of Robberson Ave. and Water St. approximately 200-300 ft south of the culvert. Upstream of Robberson Ave. the main sewer line generally runs along the south side of the box and sewers cross the culvert at five locations at stations 1,600 ft, 2,000 ft, 2,300 ft, 2,475 ft, and 2,825 ft.

Discharge Trends

Discharge measurements were collected at both the upstream and downstream ends of the culvert and at Grant St. on December 11th (Table 1). The December 11th sampling was during a period of very low base flow conditions with no rainfall during the week prior to sampling. Discharge at the USGS gaging station on Wilson Creek at Scenic Ave during this sampling period was around 5.8 ft^3/s with no high flows being recorded the week prior (Figure 3). The discharge entering the culvert was 0.65 ft^3/s with the majority of the flow entering in the north culvert. At Main Ave., discharge was 0.97 ft^3/s, which is about a 50% increase in flow. Since flow was measured during base flow conditions, the increase in discharge in the box is likely due to seepage into the box culvert at some point along its length. Discharge at Grant Ave. increases to 1.13 ft^3/s which is in a section where the bed is natural downstream open culvert, which is about 19.5% of the flow at the USGS age downstream. Observations of flow through the culvert

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during sampling suggests discharge increased near Robberson Ave. where the north and south culverts come together.

A second round of discharge measurements were collected on January 25th inside the culvert to try and quantify the observed increase within this section of the culvert. This sampling was conducted during a relatively high base flow period after a series of small rain events occurred a week prior to collection (Figure 4). There was a total of 0.79" of rainfall the week prior to sampling, with 0.32" of rainfall recorded three days prior to sampling. Discharge at the USGS gaging station during this sampling period was around 13.0 ft^3/s. The observed increase in flow in the larger combined culvert from the initial sampling was verified. Discharge increased about 60% in the large combined culvert going from 3.04 ft^3/s at station 1,400 ft near Robberson to 4.79 ft^3/s at station 1,100 ft near Boonville (Table 1). While the source of this additional water is unknown it could be connected to the spring located just south of the culvert near Robberson Ave. and Water St. Furthermore, a "flush pipe" was identified at 1,380 ft and likely supplies water to the stream from a sump pump from an overhead building but the volume is unknown. The 4.79 ft^3/s measured inside the culvert is about 37% of the flow at the USGS gage downstream.

Water Quality Trends

A total of 28 field measurements by meter and 28 water bottle samples were collected on December 11th. There were 20 samples collected along the south culvert and in the portions of the culvert where the two culverts combine between Robberson and Boonville, and again at Campbell Ave. An additional eight samples were collected in the north culvert where the culvert was separated as a check. Depth of the water, or stage, in the south culvert and combined rooms varied from 0.1-0.4 ft with an average of 0.3 ft (Table 2). Stage in the north culvert varied less, but had a similar average depth. The highest stage (0.8 ft) was recorded downstream of the culvert at Grant Ave. A second round of sampling was conducted on January 25th to verify trends, 12 samples were collected for E. coli analysis. A total of 8 samples were collected in the south/combined culvert and four were collected in the north culvert. Major seeps were also noted along both the north and south walls of the culvert on January 25, 2019 when base flow was a little higher than the initial sampling and are plotted with sample parameters below. In general, seeps only occurred along the north wall from station 1,600-3,350 ft. They are found along both outside walls of the culvert from stations 0-1,600 ft.

Physical Water Parameters
Measurements of DO, pH, and SC decreased downstream through the culvert, while T also decreased downstream to station 1,600 ft, it then increased to the outlet. The pH decreased downstream in both north and south culverts (Table 2, Figure 5). Readings of DO were higher in the north culvert compared to the south culvert, but after flow mixes in the single culvert room

near Robberson, DO concentration in both culverts remains similar. SC in the north culvert is lower than the south culvert where flow enters the culvert and mix in the combined culvert. Values for T were similar in both culverts upstream of the culvert and decrease until station 1,600 ft, here the two culverts mix and start to warm as flow moves downstream. This is an indication that there may be an influx of warmer groundwater entering the culvert near Robberson at station 1,600 ft. Some of the outliers in the dataset, such as the very low SC numbers, are likely the result of poor readings due shallow water depth. Therefore, any odd extreme values were taken into consideration in the analysis.

Nutrients

Total nitrogen concentrations increase and total phosphorus concentration decrease downstream through the study reach. At base flow, sources of nutrients to the underground would likely be from sewer exfiltration or other types of point sources (Vystavana et. al 2018). However, TN concentrations have been known to be high at base flow in urban streams within Springfield (Miller 2006, Owen and Pavlowsky 2014, Owen et al. 2015). Nutrient concentrations from this study were relatively low compared to a previous water quality study in the mid-2000s (Miller, 2006). In the present study, TN concentrations ranged from 1.74-1.98 mg/L in both culverts with average concentrations of 1.87 mg/L in the south culvert and 1.84 mg/L in the north culvert (Table 2). In general, TN concentrations increase through the box culvert with a spike near station 1,600 ft suggesting perhaps an influx of groundwater in the vicinity near Robberson Ave. (Figure 6). Total phosphorus concentrations ranged from 0.008-0.014 mg/L in the two culverts with an average of 0.009 mg/L in the north culvert and 0.012 mg/L in the south culvert. In 2004-2005, base flow TN in December and January ranged from 2.55-3.35 mg/L and 0.017-0.023 mg/L for TP at Main Ave. (Miller, 2006). Nutrient concentrations from this study are low compared to winter base flow nutrient concentrations from other area urban streams. In recent studies of other urban streams in Springfield, winter base flow concentrations of TN ranged from 1.54-3.53 mg/L and TP concentrations ranged from 0.009-0.023 mg/L (Owen and Pavlowsky 2014, Owen et al. 2015).

Chloride

Chloride concentrations decrease downstream through the underground with the south culvert having higher concentrations than the north culvert until they mix together near Robberson Ave. At base flow, sources of chloride to the underground would likely be from either sewer exfiltration, application of road salt in the winter, and from treated water in the distribution system (Vystavana et. al 2018). Concentrations of Cl range from 37.0-57.2 mg/L in the south culvert with an average of 48.8 mg/L (Table 2). In the north culvert, concentrations range from 33.7-42.1 mg/L with an average of 37.0 mg/L. In general, concentrations are >50 mg/L in the south culvert and <40 mg/L in the north culvert until they mix in the large room near Robberson Ave. and stay in the 40-50 mg/L range to the end of the study reach (Figure 6). The abrupt

decrease in Cl at station 1,600 ft near Robberson suggests dilution from water in the south culvert but also may indicate an influx of relatively "clean" groundwater at this location.

Bacteria

Concentrations of E. coli in the south culvert gradually increase from about 100 MPN/100 mL at the inlet to 200 MPN/100 mL at the outlet. At base flow, sources of E. coli to the underground would likely be from sewer exfiltration or possibly from wildlife, such as waterfowl (Dove et al. 2013, Mira et al. 2018). Bacteria concentrations then peak about 400 ft below the outlet at 400 MPN/100 mL, just downstream of the MS4 tributary west of Main Avenue, suggesting possible sewer exfiltration between Main and Grant (Figure 6). Overall, E. coli concentrations in the south culvert range from 105.4-365.4 MPN/100 mL with an average of 165.0 MPN/100 mL (Table 2). There was a different trend in the north culvert, with higher E. coli concentrations ranging from 105.0-770.1 MPN/100 mL with an average of 277.4 MPN/100 mL. Concentrations of E. coli in the north culvert increased from about 150 MPN/100 mL at the inlet to almost 800 MPN/100 mL at station 2,000 ft near Jefferson Avenue. There is a junction of several sewer lines at Jefferson Avenue suggesting that sewer exfiltration may be entering the north culvert upstream from station 1,800 ft. to station 3,200 ft.

During the second sampling event on January 25, 2019, E. coli concentrations were much higher overall and exhibited different trends, particularly for the North Branch and culvert samples, compared to those previously observed during low flow conditions in December. E. coli concentrations along the south/combined culvert ranged from 38-1,553 MPN/100 mL with an average of 825 MPN/100 mL (Table 3). Peak concentrations were again measured downstream stream of the underground outlet near Main and Grant Avenues at levels near 1,600 MPN/100 mL (Figure 7). In contrast, North Branch and culvert E. coli concentrations ranged from 1,300-2,240 MPN/100 mL with an average of 1,716 MPN/100 mL. Peak concentrations at 2,400 MPN/100 mL were measured in North Branch above the underground inlet and then decreased to to about 1,400 MPN/100 mL at station 2,000 ft. near Jefferson Avenue (Figure 7). Results from this second round of sampling were considerably higher than the December 11, 2018 sampling. Since the concentrations were 5-6x higher than the first sampling, downstream peaks are not apparent in the dataset. Furthermore, these trends show the North Branch of Jordan Creek delivering relatively high E. coli concentrations almost two orders of magnitude higher than from the South Branch of Jordan Creek at the time of sampling. There results suggest that bacteria transport and flow concentration in Jordan Creek may be highly variable over discharge/stage and potentially between the rising and falling limbs for runoff hydrographs.

CONCLUSIONS

An assessment of the Jordan Creek Underground was performed on December 11, 2018 that included field measurements of discharge, dissolved oxygen, pH, specific conductivity, and temperature along with water sampling for laboratory analysis of nutrients, chloride and bacteria. A second bacteria sampling and discharge measurements were collected on January 25, 2019 to verify initial trends. The purpose of this study is to quantify variations in water quality at base flow along a 4,400 ft reach of the Jordan Creek that includes a reach that flows through the underground box culvert between Grant Ave and Sherman Parkway in downtown Springfield. There are three main conclusions from this assessment:

1. **Nutrients coming into the culvert during base flow are low compared to monitoring in the mid-2000s.** Average TN concentrations in the culvert were around 1.87 mg/L and average TP concentrations were about 0.012 mg/L. These are nearly half that of the concentrations of samples collected in December and January of 2004-2005 at Main Ave. during base flow. Nutrient concentrations from this study are low compared to winter base flow nutrient concentrations from other area urban streams.

2. **There is a possible influx of groundwater from stations 1,400 ft to 1,100 ft within the large single culvert between Robberson and Boonville Ave**. Observations of discharge in this area show a 60% increase in flow between stations 1,100 ft and 1,400 ft in the combined culvert between Robberson and Boonville. Temperature increased and chloride concentrations decreased within this area indicating a groundwater source here rather than an exfiltration source. Possible sources may be Lyman Spring located just south of this location and the "flush pipe" observed at station 1,380 ft.

3. **E. coli concentrations appear to be much higher in the North Branch of Jordan compared to the South and downstream peaks suggest possible wastewater exfiltration in the north culvert near station 2,000 ft and near Grant Ave.** During the December 11, 2018 sampling the highest concentrations of E coli inside the underground were found in the north culvert at station 2,000 ft and downstream of the outlet near Grant Ave. This suggests a possible exfiltration source along the north culvert near Jefferson and downstream of the MS4 channel west of Main Ave. The attempt to replicate these findings during a January 25, 2019 sample collection were unsuccessful as very high E. coli concentrations coming down the N. Branch of Jordan Creek which were 5-6 times higher than the December 11, 2018 samples overwhelmed the downstream trends. However, concentrations coming into the culvert from the S. Branch of Jordan Creek were only 38 MPN/100 mL.

SUMMARY AND RECOMMENDATIONS

1) Jordan Creek has losing/gaining sections within the underground and downstream of Main in the uncovered reaches of the channel. However, there was a 60% increase in flow between Robberson and Boonville avenues within the large combined culvert between 1,100 and 1,400 ft that should be accounted for if the stream is to be rerouted outside of the underground. Seeps were identified along the north wall from station 1,600-3,350 ft. However, they are found along both outside walls of the culvert from stations 0-1,600 ft.

2) There is potential sewer exfiltration at the sewer line on the north side of the underground at Jefferson Ave. Additionally, N. Branch Jordan Creek had much higher E. coli concentrations entering the culvert than the S. Branch on January 25, 2019.

3) A stage gage should be installed in the underground to collect continuous flow data to help understand the range of base flow that likely change seasonally. Gages are already installed at the N. Branch at Division, S. Branch at Fremont, and Jordan Creek at Fort.

4) Well data near underground should be reviewed to correlate with locations of flow inputs identified from this study.

5) Concentrations are variable with flow conditions/source pulses that makes spatial assessment of source points difficult with only 1-2 sampling events.

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TABLES

Table 1. Discharge summary for December 11, 2018 and January 25, 2019.

Street Location	Station (ft)	Culvert	Dec 11, 2018 Discharge (ft³/s)	Jan 25, 2019 Discharge (ft³/s)
Grant	-675	combined	1.13	3.93
Main	-100	combined	0.97	4.08
Campbell	550	combined	-	4.57
Boonville	1,100	combined	-	4.79
Robberson	1,400	combined	-	3.04
Washington	3,400	north	0.60	2.75
Washington	3,400	south	0.05	1.04

Table 2. Summary statistics for December 11, 2018 surveying for south/combined culvert (top) and north culvert (bottom). (USGS discharge = 5.8 ft³/s)

South/ Combined	Stage (ft)	Temp (°F)	pH (std.)	SC (µS/cm)	DO (mg/L)	Cl (mg/L)	TN (mg/L)	TP (mg/L)	E Coli (MPN/100mL)
n	20	20	20	20	20	20	20	20	20
Min	0.1	43.0	6.1	477	11.7	37.0	1.81	0.008	105.4
Mean	0.3	43.6	7.5	631	12.7	48.8	1.87	0.012	165.0
Median	0.2	43.6	7.7	638	12.4	49.2	1.86	0.012	158.0
Max	0.8	45.1	7.8	692	15.7	57.2	1.98	0.014	365.4
Stdev	0.2	0.6	0.5	57.9	1.0	6.3	0.04	0.001	55.9
CV%	57.1	1.5	6.3	9.2	7.7	12.8	2.1	12.5	33.9

North	Stage (ft)	Temp (°F)	pH (std.)	SC (µS/cm)	DO (mg/L)	Cl (mg/L)	TN (mg/L)	TP (mg/L)	E Coli (MPN/100mL)
n	8	8	8	8	8	8	8	8	8
Min	0.2	43.0	7.0	546	12.3	33.7	1.74	0.008	105.0
Mean	0.3	43.6	7.7	576	13.9	37.0	1.84	0.009	277.4
Median	0.2	43.4	7.9	575	13.5	36.1	1.84	0.009	162.4
Max	0.4	44.4	8.0	605	16.6	42.1	1.94	0.011	770.1
Stdev	0.09	0.5	0.3	21.0	1.5	3.1	0.08	0.001	235.9
CV%	33.6	1.2	4.1	3.7	11.1	8.3	4.1	12.5	85.1

Table 3. Summary statistics for January 25, 2018 sampling for south/combined culvert (top) and north culvert (bottom). (USGS discharge = 13.0 ft^3/s)

South/ Combined	E Coli (MPN/100mL)
n	8
Min	38
Mean	825
Median	778
Max	1,553
Stdev	599
CV%	72.6

North	E Coli (MPN/100mL)
n	4
Min	1,300
Mean	1,716
Median	1,573
Max	2,240
Stdev	503
CV%	29.3
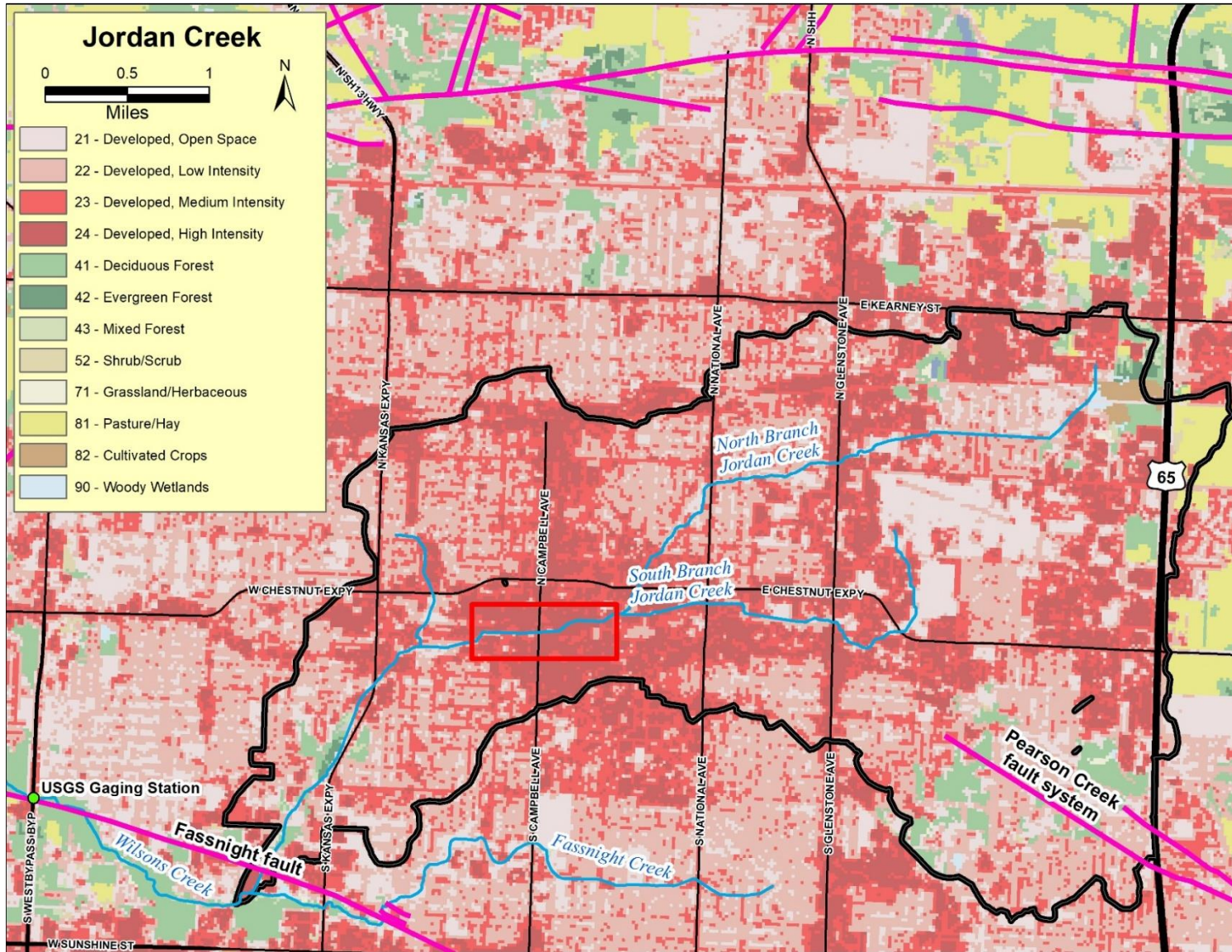
Figure 1. Jordan Creek watershed and land use with study area noted in red.
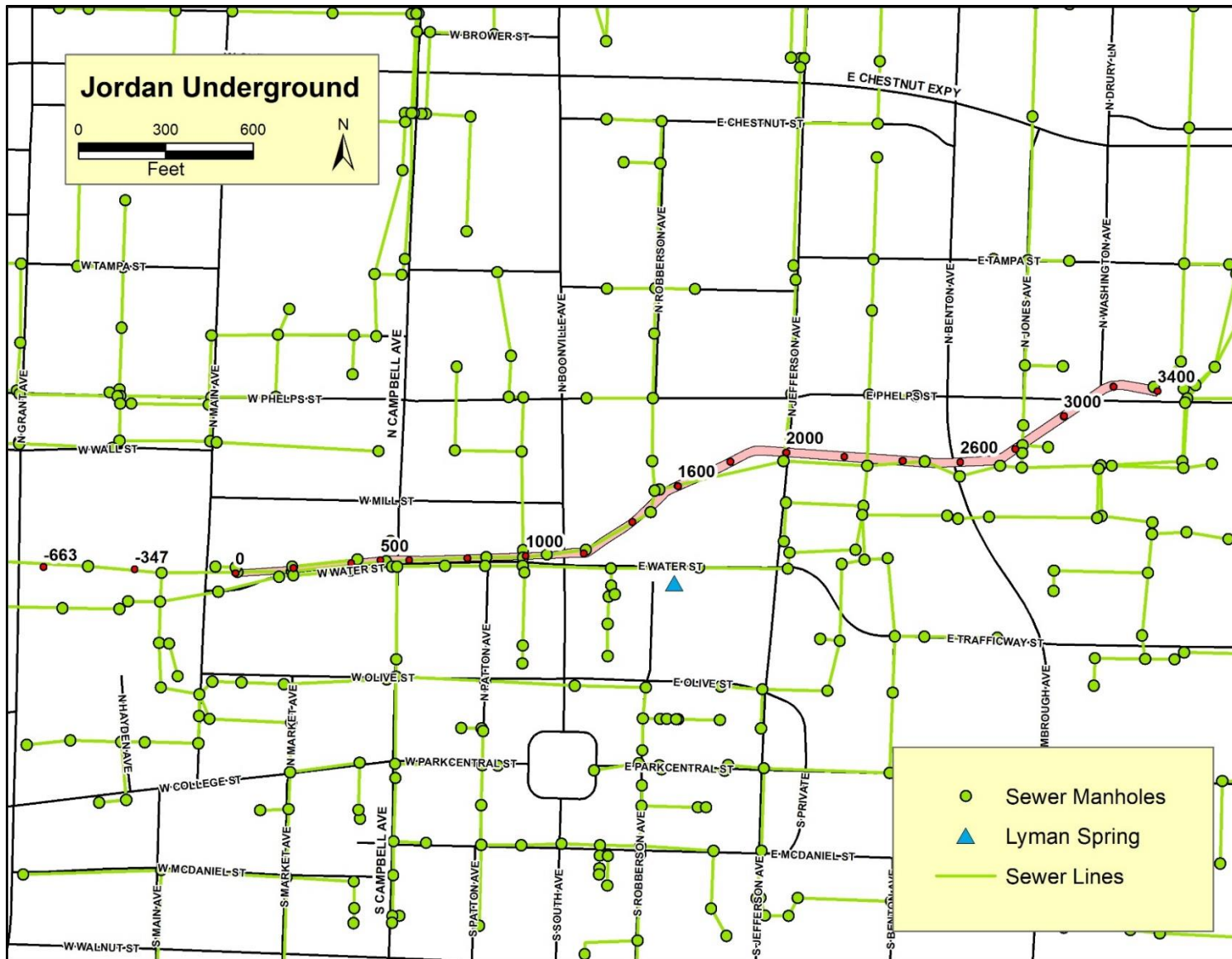
Figure *2*. Jordan Creek Underground with sewer infrastructure noted.
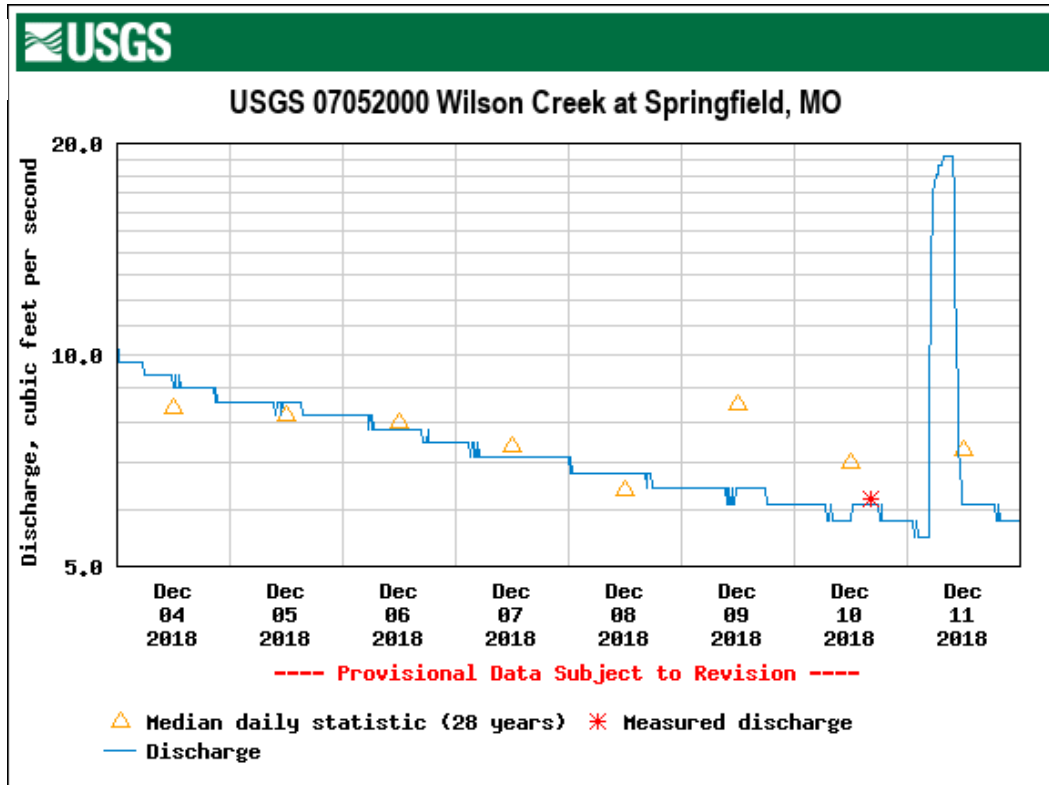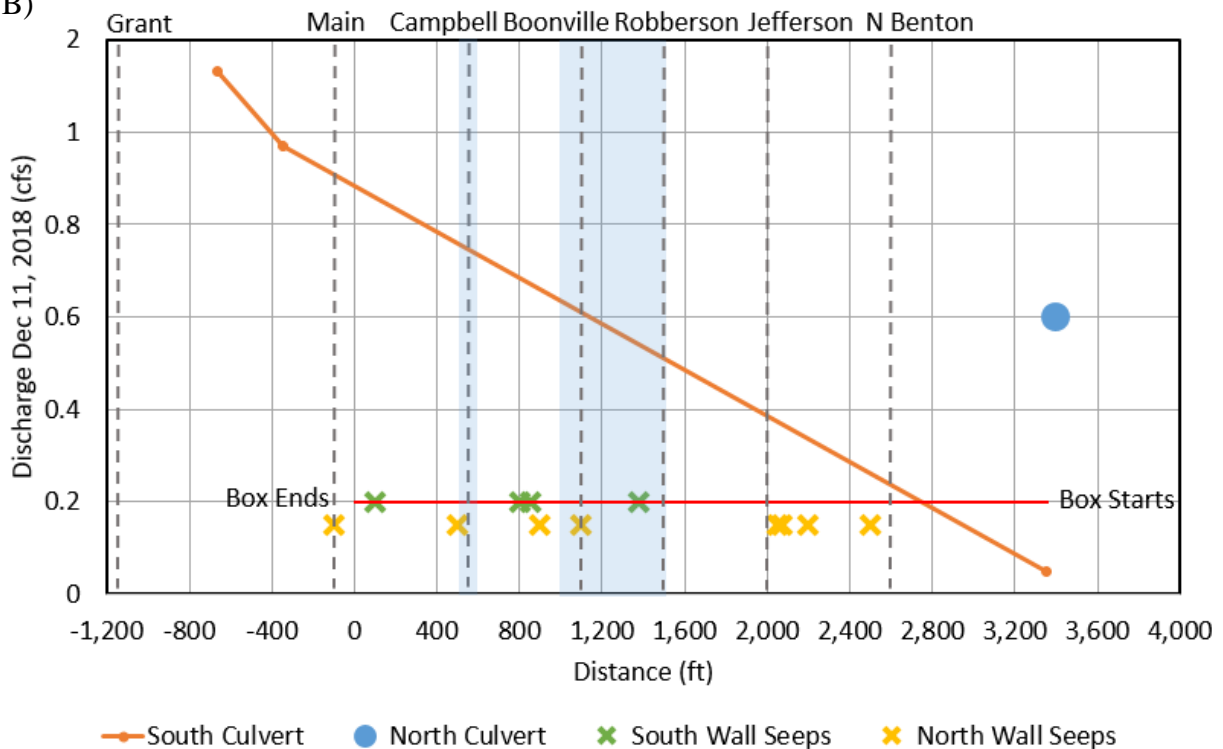
Figure 3. A) Stage and discharge at the USGS gaging station on Wilson Creek at Springfield for one week prior to sampling on December 11, 2018 and B) downstream changes in discharge collected during sampling.
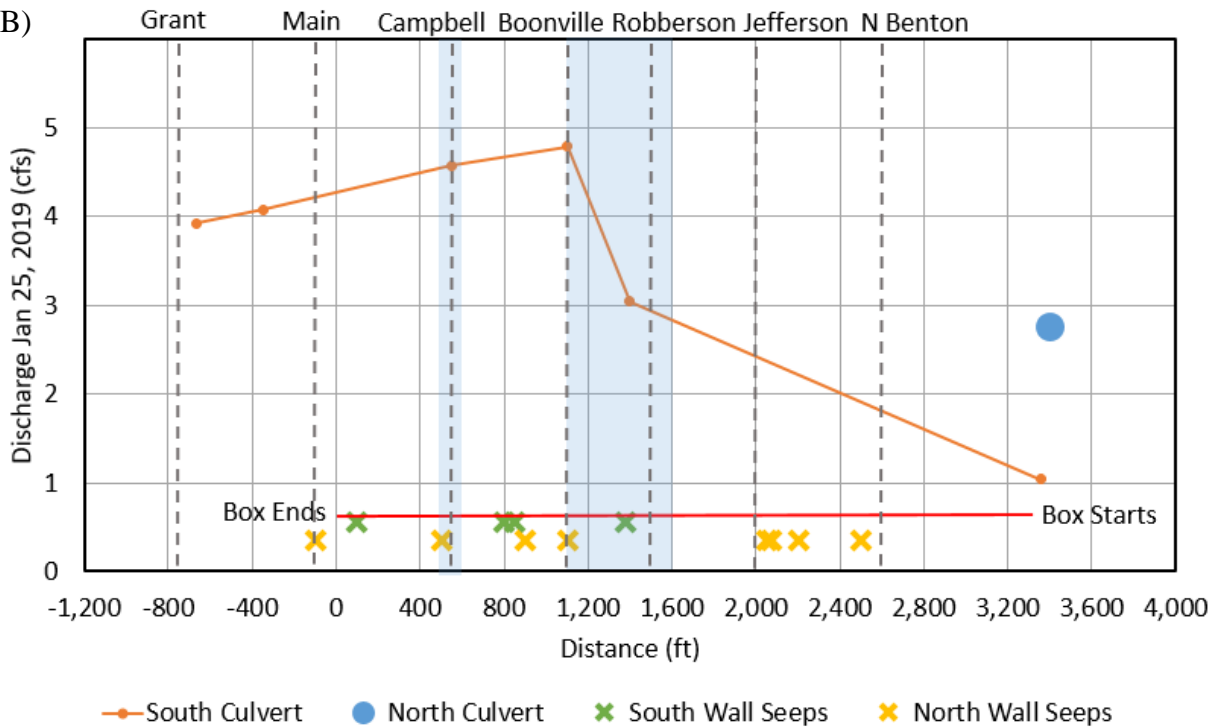
A)
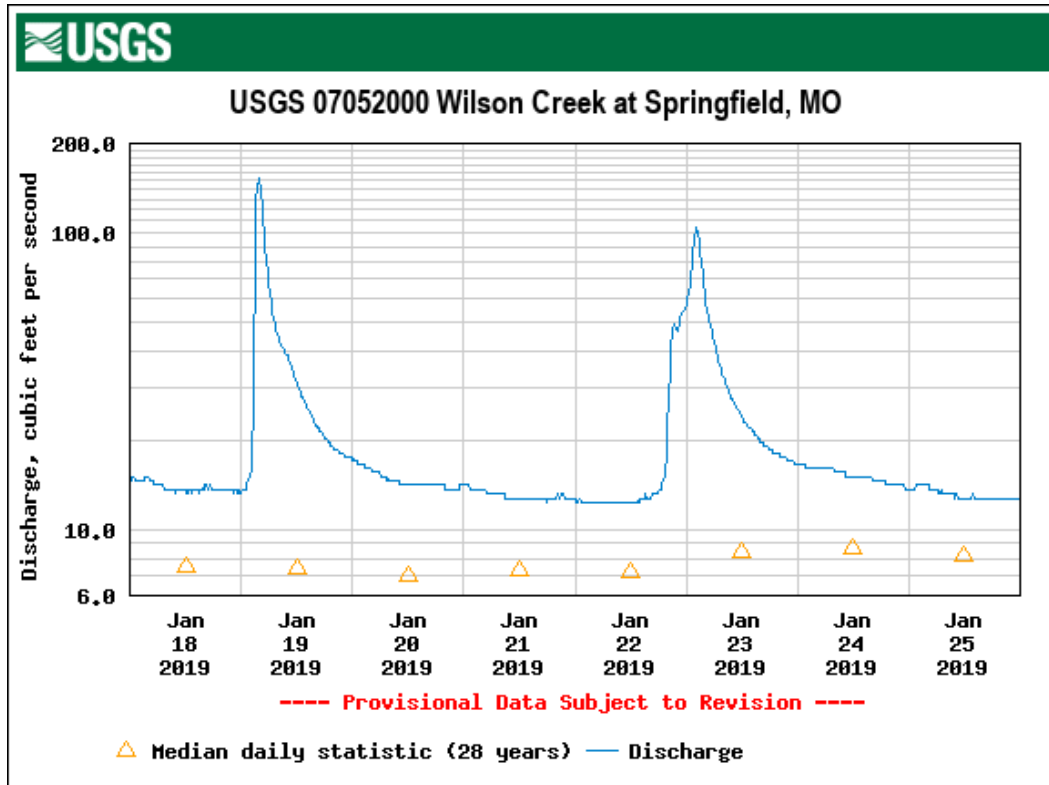
B)

Figure 4. A) Stage and discharge at the USGS gaging station on Wilson Creek at Springfield for one week prior to sampling on January 25, 2019 and B) downstream changes in discharge collected during sampling.
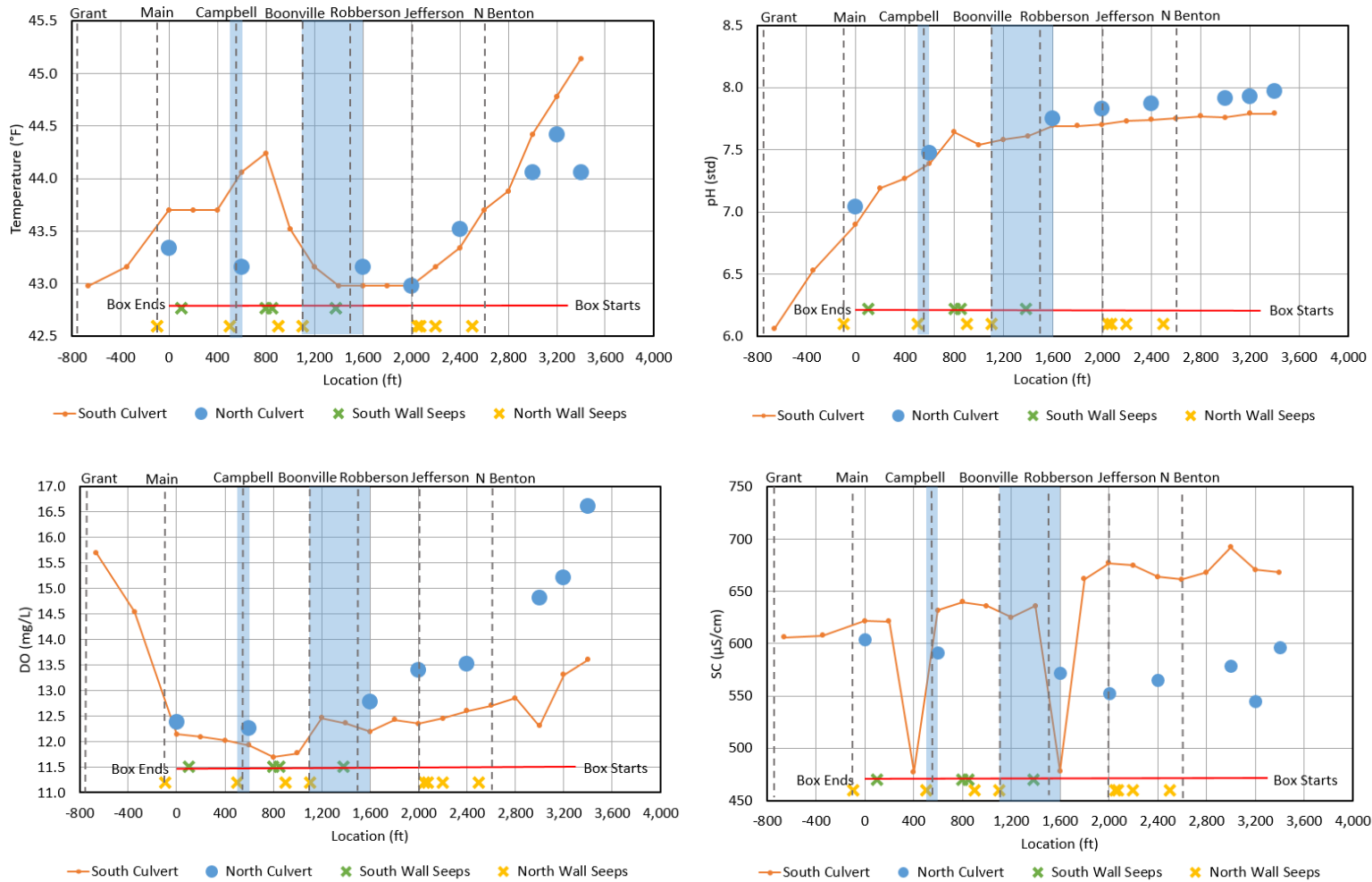
Figure 5. Downstream trends of physical water parameters from December 11, 2018. Combined culverts noted in blue.
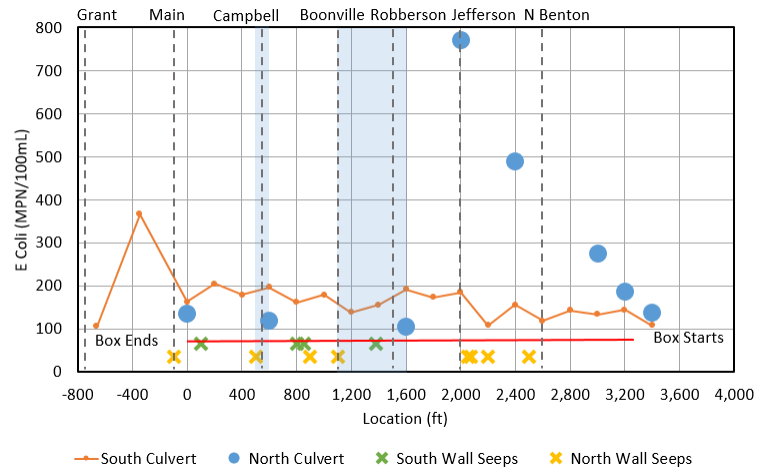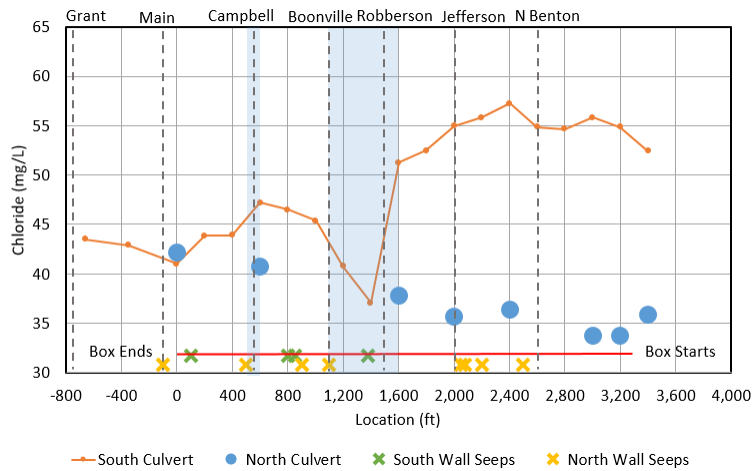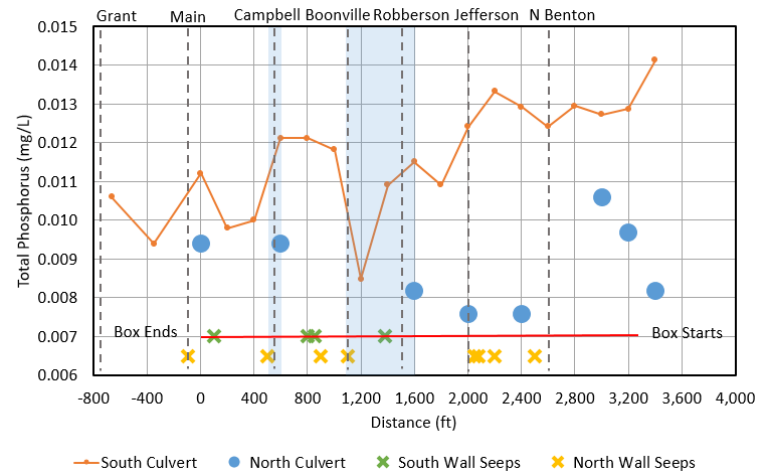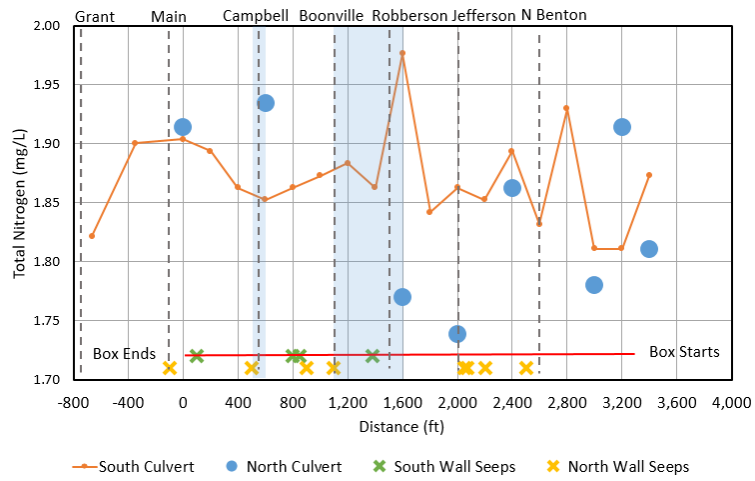
Figure 6. Downstream trends of nutrients and chloride from December 11, 2018. Combined culvert noted in blue.
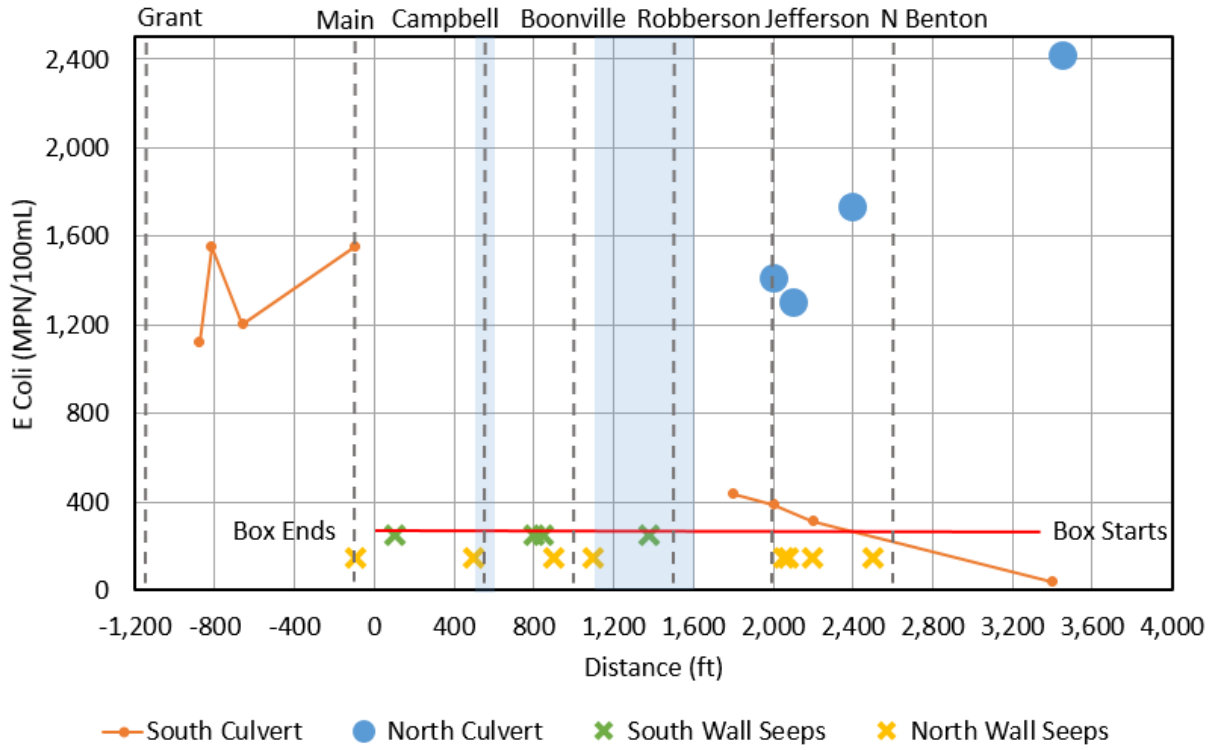
Figure 7. Downstream trend of E. coli from January 25, 2019. Combined culvert noted in blue.

PHOTOS

Photo 1. Two sewer manholes and a large culvert located at 876 feet downstream of the underground along the north bank. (Photo taken January 25, 2019)

Photo 2. Building over creek located 816 feet downstream of the underground looking upstream. (Photo taken January 25, 2019)

Photo 3. Grant Ave Bridge located 663 feet downstream of the underground looking upstream. (Photo taken January 25, 2019)

Photo 4. MS4 channel near Main Ave. located 256 ft downstream of the underground on south bank. (Photo taken January 25, 2019)

Photo 5. Storm drain under Main Ave Bridge 100 ft downstream of the underground along north bank. (Photo taken January 25, 2019)

Photo 6. Larger drain at 800 ft in the south culvert along south exterior wall. Several other drains and seeps enter the south culvert downstream of Campbell Ave. (Photo taken January 25, 2019)

Photo 7. Sump pump at 1,380 feet in the combined culvert on the south side. (Photo taken January 25, 2019)

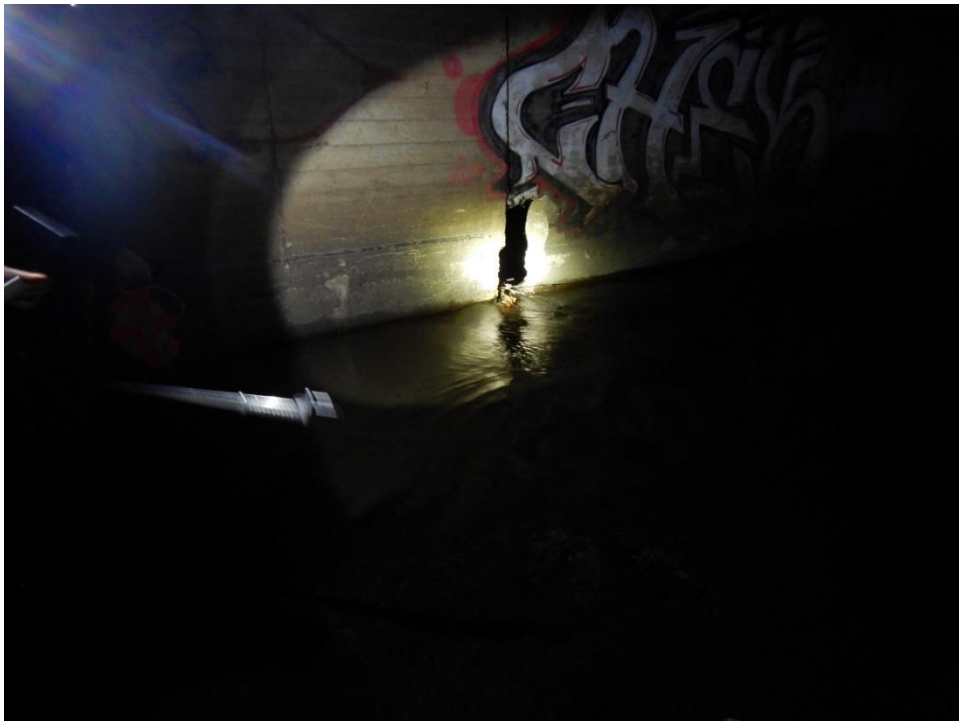Photo 8. Hole in between north and south culvert walls located at 2,040 feet. (Photo taken January 25, 2019)

Photo 9. Large drain pipe at 2,200 feet along the north exterior wall of the north culvert. (Photo taken January 25, 2019)

Photo 10. Seep at 2,500 feet on the exterior wall of the north culvert. These types of seeps are common throughout the underground. (Photo taken January 25, 2019)

APPENDIX

December 11, 2018 Database

Location	Culvert	Stage (ft)	Temp F	pH (std)	SC (uS/cm)	DO (mg/L)	Cl (mg/L)	TN (mg/L)	TP (mg/L)	E coli. (MPN/100mL)
-663	S/C	0.8	43.0	6.1	605.9	15.7	43.5	1.82	0.011	105.4
-347	S/C	0.4	43.2	6.5	607.9	14.5	42.9	1.90	0.009	365.4
0	S/C	0.3	43.7	6.9	621.9	12.1	41.0	1.90	0.011	162.4
200	S/C	0.3	43.7	7.2	621.3	12.1	43.9	1.89	0.010	204.6
400	S/C	0.2	43.7	7.3	477.4	12.0	43.9	1.86	0.010	178.2
600	S/C	0.3	44.1	7.4	631.9	11.9	47.2	1.85	0.012	195.6
800	S/C	0.3	44.2	7.6	640.0	11.7	46.5	1.86	0.012	160.7
1,000	S/C	0.2	43.5	7.5	636.0	11.8	45.4	1.87	0.012	178.5
1,200	S/C	0.3	43.2	7.6	625.2	12.5	40.8	1.88	0.008	137.6
1,400	S/C	0.2	43.0	7.6	636.1	12.4	37.0	1.86	0.011	155.3
1,600	S/C	0.2	43.0	7.7	478.0	12.2	51.2	1.98	0.012	191.8
1,800	S/C	0.1	43.0	7.7	662.0	12.4	52.5	1.84	0.011	172.5
2,000	S/C	0.2	43.0	7.7	677.1	12.4	55.0	1.86	0.012	184.2
2,200	S/C	0.2	43.2	7.7	674.9	12.5	55.8	1.85	0.013	108.1
2,400	S/C	0.2	43.3	7.7	664.0	12.6	57.2	1.89	0.013	155.3
2,600	S/C	0.2	43.7	7.8	661.2	12.7	54.9	1.83	0.012	117.8
2,800	S/C	0.2	43.9	7.8	668.0	12.9	54.7	1.93	0.013	142.1
3,000	S/C	0.2	44.4	7.8	692.2	12.3	55.8	1.81	0.013	133.4
3,200	S/C	0.2	44.8	7.8	670.6	13.3	54.9	1.81	0.013	143.9
3,400	S/C	0.3	45.1	7.8	668.2	13.6	52.4	1.87	0.014	107.1
0	N	0.4	43.3	7.0	604.5	12.4	42.1	1.91	0.009	135.4
600	N	0.4	43.2	7.5	591.7	12.3	40.7	1.94	0.009	119.8
1,600	N	0.2	43.2	7.8	571.9	12.8	37.8	1.77	0.008	105.0
2,000	N	0.2	43.0	7.8	552.5	13.4	35.7	1.74	0.008	770.1
2,400	N	0.2	43.5	7.9	565.6	13.5	36.4	1.86	0.008	488.4
3,000	N	0.2	44.1	7.9	578.8	14.8	33.7	1.78	0.011	275.5
3,200	N	0.3	44.4	7.9	545.5	15.2	33.7	1.91	0.010	187.2
3,400	N	0.2	44.1	8.0	596.6	16.6	35.9	1.81	0.008	137.6

January 25, 2019 Database

Location	Culvert	E coli. (MPN/100mL)
-876	S/C	1,120
-816	S/C	1,553
-663	S/C	1,203
-100	S/C	1,553
1,800	S/C	435
2,000	S/C	387
2,200	S/C	313
3,400	S/C	37.9
2,000	N	1,414
2,100	N	1,300
2,400	N	1,733
3,450	N	2,420