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COLLEGE OF ENGINEERING

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# Monitoring the Effects of Birmingham Northern Beltline Construction in the Little Cahaba Creek Watershed

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*Submitted to*

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**16 Abstract**

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# ABSTRACT

The Alabama Department of Transportation (ALDOT) has proactively aligned new roadway development projects with sustainable principles, including roadway stormwater runoff management. The new Birmingham Northern Beltline (BNB), currently under construction, intercepts a number of streams and has drawn criticism of environmental groups. This research was conceived as a means to provide an objective assessment of roadway stormwater runoff impacts to streams in a watershed that is representative of the region spanned by BNB. This research also aims to provide baseline data in terms of watershed hydrology and water quality to assess eventual impacts of the BNB construction to the Little Cahaba Creek (LCC) watershed, at a site where Interstate 59 (I-59) intercepts LCC north of Trussville, AL. More specifically, the majority of the characterizations involving effects of I-59 to LCC are performed in the headwaters of the Little Cahaba Creek, at a tributary named Mill Creek. Various hydrological parameters and water quality parameters were monitored in LCC watershed. Measurements indicated hydrological impacts created by runoff in I-59, particularly a flashy behavior created by contributions from pavement and median runoff. Regarding water quality measurements, the concentration of nutrients and heavy metals were consistent with levels measured in runoff from comparable land uses. These metals' concentrations, however, were higher for samples collected in drainage ditches next to the roadway, as it would be anticipated. However, the macroinvertebrate evaluation performed at sites upstream and downstream from the crossing between I-59 and LCC indicates runoff has not impacted the biological diversity across the stream-roadway interception. These results indicate that with proper stormwater management, roadway stormwater runoff impacts may indeed be mitigated.

# 1. INTRODUCTION

The Alabama Department of Transportation (ALDOT) has an important mission of expanding and improving the state's transportation infrastructure as a means to support the state's economic growth for the benefit of society. To achieve this mission while promoting sustainable development, environmental impacts created by stormwater runoff discharges originating from newly constructed roads need to be addressed. State environmental regulations (ADEM, 2011) from the National Pollutant Discharge Elimination System (NPDES) Phase II require that stormwater runoff discharges originated from new roads be issued a NPDES Municipal Separated Storm Sewer Systems (MS4) permit. These permits have requirements that include the development, implementation, and enforcement of a stormwater management program (SWMP) designed to reduce pollutant levels from MS4 discharges to the maximum extent practicable (MEP). To achieve the goals outlined in the permit, the SWMP includes the use of best management practices (BMPs) to avoid in-stream exceedances of water quality standards, as well as exceeding pre-development flows of streams.

Post-construction runoff control is an integral part of SWMP and an emerging new requirement for new road and highway construction efforts. An example project that will need to comply with new stormwater regulations requiring post-construction runoff control is the Birmingham Northern Beltline (BNB) project. The BNB project consists of a proposed 50 mile (80.5 km) bypass around Birmingham, through northern and western Jefferson County. This proposed interstate would, along with the existing Interstate 459 (I-459), complete the bypass loop of central Birmingham for all interstate traffic not requiring access to the central business district, as indicated in Figure 1.


**Figure 1**: **Proposed alignment of Birmingham Northern Beltline (BNB) project.**

The proposed alignment, however, has raised the attention and opposition from groups such as Southern Environmental Law Center and the Black Warrior Riverkeeper whom are concerned about impacts that this project would have on local water resources.  Various watersheds are intercepted by the proposed BNB alignment. One location of interest is the section of BNB located at the eastern portion, where it links with Interstate 59 (I-59), close to Argo, AL.  At this location the BNB intercepts the Little Cahaba Creek (LLC) watershed. This watershed is a tributary of the Cahaba River, one of the most important rivers in the State of Alabama.

In the context of Alabama's roads and the NPDES, the Alabama Department of Environmental Management (ADEM) recently issued MS4 permit coverage to the ALDOT (ADEM 2013). The permit, AL000006, regulates stormwater discharges from ALDOT properties located within urban municipal boundaries. Among the elements and requirements of the permit is the need to implement controls to minimize impacts of the stormwater during and after construction. To attain the goals of post-construction stormwater management, considering that stormwater runoff impacts may also originate from other land uses in the watershed, it is essential to obtain pre-development information on the hydrological and water quality characteristics.

One of the streams is the LLC, a headwater perennial stream that is at the eastern most point of the BNB. The stream's watershed is also intersected by I-59 at various points, and the focus of this research was to monitor the effects of the roadway to a perennial tributary of LCC named Mill Creek. For sake of brevity, this monitoring site is referred to as LCC at all chapters of this report. While baseline information for assessing any potential post-construction stormwater runoff impacts in the LLC is needed, the existence of I-59 also provides a chance to evaluate any long term post-construction impacts of I-59 into the LLC. This is the primary motivation for the research that is presented in this final report, as elaborated herein.

## 1.1. Stormwater runoff from highways.

Human activities in watersheds, such as construction and urbanization, will lead to impacts on land, streams and other environmental systems. Stormwater drainage is one important cause of environmental impacts, both hydrological (increases of peak flows and runoff volumes) and in constituents in stormwater. In this context, roadways are a source of short and long term impacts, though in stormwater management, most of the focus is placed on short term impacts (Wheeler et al. 2006). Roadways and vehicular traffic can be potential sources of various pollutants from tire wear, brake linings, oil leakage, pavement degradation, and atmospheric deposition (Shaheen 1975; Han et al. 2006). However, if there is development in the watersheds where roads are located, these other types of land uses will also create impacts.

Paved roadway surfaces result in a decrease of pervious areas located in watersheds, yet the relative area occupied by a given road can be relatively small, and thus results in a minimal effect. With regards to water quality impacts, various constituents may be present in the runoff in roadways. The National Stormwater Quality Database version 1.1 (NSQD, Pitt and Maestre 2005) compares runoff constituent concentrations for different land uses with data collected across the U.S. (200 MS4 systems). Relative to other land uses, runoff from roadways are a significant source of total suspended solids (TSS), oil and grease, chemical oxygen demand, organic nitrogen, ammonia, copper and petroleum hydrocarbons. Wu et al. (1998) determined that 20% of TSS loadings, 70% to 90% of nitrogen loadings, and between 10% and 50% of other constituents are sourced from atmospheric deposition. A summary of some of the data in the NSQD is presented in Table 1.

**Table 1: Summary of available data from the NSQD (Pitt et al 2004) for mixed open space and mixed freeways; Cv is the ratio between standard deviation of sample and average**

| Land Use | Parameter | Median | Cv |
|---|---|---|---|
| Mixed Open Space | pH | 7.9 units | 0.08 |
| | Conductivity | 113 μS | 0.5 |
| | TSS | 48.5 mg/L | 1.5 |
| | $NO_3$ | 0.7 mg/L | 0.8 |
| | $NH_3$ | 0.51 mg/L | 1.2 |
| | TN | 2.21 mg/L | – |
| | TP | 0.25 mg/L | 1.1 |
| Mixed Freeway | pH | 7.7 units | 0.1 |
| | Conductivity | 353 μS | 0.6 |
| | TSS | 88 mg/L | 1.1 |
| | $NO_3$ | 0.9 mg/L | 0.7 |
| | $NH_3$ | 1.07 mg/L | – |
| | TN | 3.2 mg/L | – |
| | TP | 0.34 mg/L | 0.7 |

Federal Highway Administration-sponsored research (FHWA; Driscoll et al., 1990) presented summary data for a variety of stormwater roadway runoff related parameters from multiple states. The average values for parameters relevant to this study from this FHWA report includes: 143 mg/L of TSS, 432 mg/L of TS, pH of 6.5, 103 mg/L of COD, 0.84 mg/L of nitrite, 1.79 mg/L of total organic nitrogen, and 0.435 mg/L of phosphate. In addition to this study, Schueler et al. (1992) determined that atmospheric deposition accounts for 70 to 95% of nitrogen and 20 to 35% of phosphorous in stormwater runoff, indicating that vehicular traffic is not the sole nutrient input in highway stormwater runoff.

Impacts of these constituents on natural systems are site specific due to a high variability between measurements and the receiving water body characteristics. While some past studies have highlighted impacts of roadway runoff to natural environments (Marsalek et al. 1999; Johnson et al. 2007), generalizations are not possible and field studies are necessary. In the context of streams, impacts from road runoff will be combined with impacts from other land use impacts. Thus stream water quality changes caused by roadway runoff need to account for other potential sources of runoff.

The introduction of stormwater runoff into a receiving water body involves complex systems of seasonal climate change, flow variations, and other various interactions. The hydrology of a perennial stream or similar water body includes groundwater–surface water interactions, the intersection of various stream channels, evapotranspiration, and other nonlinear hydrologic functions. The stream water quality within such systems is further complicated by other processes indirectly linked to stormwater runoff such as riverbank erosion, topsoil removal, upstream land use variability, aquatic organism interactions, and more. Because of these complexities, it is important to determine the impacts of stormwater runoff within the receiving water body, and not at the edge of the roadway or within drainage structures.

In summary, the task of determining the impacts of a roadway on a stream is not trivial as a variety of data is necessary. This includes, among others, rainfall regime, soil and geomorphologic characteristics, runoff constituents, other types of land uses in the watershed, and vehicular traffic volume. As a result, generalizations are difficult and such evaluations are site specific.

## 1.2. Description of the Little Cahaba Creek (LLC)

The LLC is formed in a watershed at the easternmost point of the BNB alignment, where it connects to I-59. This specific watershed was selected because it is the proposed site of the intersection between the existing highway (I-59) and streams within the beltline corridor, which is currently at the early stages of construction. One important research rationale is that eventual hydrological and water quality impacts created by I-59 would be able to mimic the impacts of BNB upon the completion of its construction. The LCC watershed is presented in Figure 2.

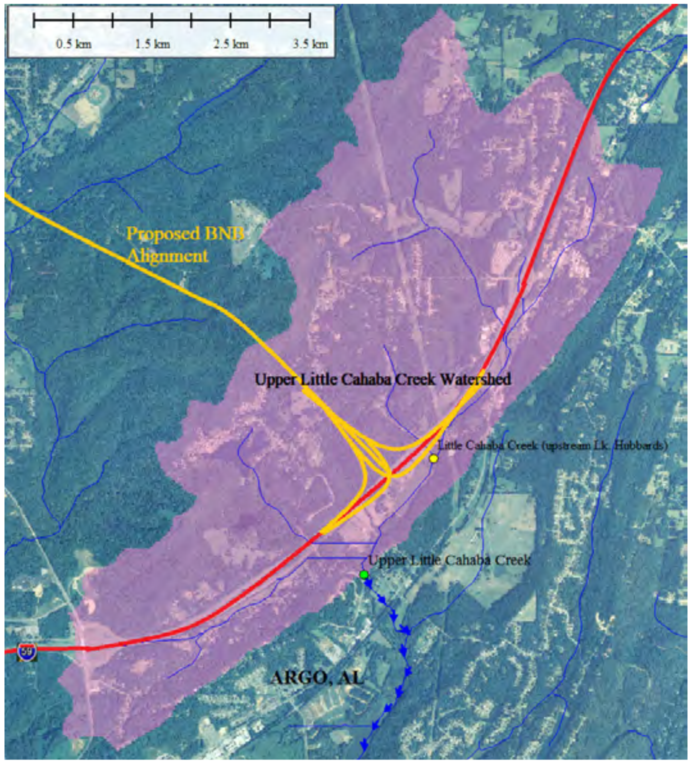



**Figure 2: BNB alignment and Little Cahaba Creek watershed.**

The LCC watershed has a perimeter of 20.2 miles (32.6 km) and area of 7.62 $mi^2$ (19.7 $km^2$), and is partially developed. LCC is a perennial stream, with a relatively constant baseflow throughout the year in most of the stream network due to groundwater flows and upstream reservoirs. The area includes a complex terrain, with elevations of minimum 726 ft (221 m), maximum 1374 ft (419 m), average 919 ft (280 m), and standard deviation of 11.9 ft (3.6 m). Slopes vary from a maximum of 33.91°, average of 8.25°, and a standard deviation of 5.23°. This area lies within a humid subtropical climate, with rainfall and temperature patterns shown in Table 2. This table gives a general representation of the average rainfall and temperature distribution throughout the year, averaged between 1977 and 2000. Land use in the area is largely forested, with less than 10% industrial, agricultural, and rural residential land. There has been minimal change in the land use over the past 20 years, as data from historical maps show. The soils in the LCC watershed have been documented by the United States Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS) Web Soil Survey. Soils data and characteristics are included in Table 2. In that table, the first lines shows the maximum, mean, and minimum temperatures (in Fahrenheit) for each month, and an annual value averaged between 1977 and 2000. Similarly, the second group of lines shows values for the average (from 1977-2000) precipitation for each month and an annual average. A large percentage of the soils in the LCC watershed belong to the Hydrological group B, with medium to high $K_{sat}$ values, which indicates fair infiltration of rainwater. However, many of these soils are layered with highly impermeable soils as well, with very low $K_{sat}$ values.

**Table 2: Data from the NAOO for two weather stations located near Little Cahaba Creek watershed**

| Station | Element | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Birmingham | Max | 52.8 | 58.3 | 66.5 | 74.1 | 81.0 | 87.5 | 90.6 | 90.2 | 84.6 | 74.9 | 64.5 | 56.0 | 73.4 |
| International | Mean | 42.6 | 46.8 | 54.5 | 61.3 | 69.3 | 76.4 | 80.2 | 79.6 | 73.8 | 62.9 | 53.1 | 45.6 | 62.2 |
| Airport | Min | 32.3 | 35.4 | 42.4 | 48.4 | 57.6 | 65.4 | 69.7 | 68.9 | 63.0 | 50.9 | 41.8 | 35.2 | 50.9 |
| | Max | 52.5 | 58.2 | 67.3 | 75.2 | 82.0 | 88.6 | 91.8 | 91.1 | 85.4 | 74.9 | 64.4 | 55.7 | 73.9 |
| Pinson | Mean | 41.1 | 45.1 | 53.1 | 60.2 | 68.4 | 75.7 | 79.5 | 78.7 | 72.8 | 61.1 | 51.4 | 43.9 | 60.9 |
| | Min | 29.6 | 32.0 | 38.8 | 45.2 | 54.8 | 62.7 | 67.2 | 66.2 | 60.2 | 47.2 | 38.4 | 32.0 | 47.9 |

| Station | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Birmingham | 5.45 | 4.21 | 6.10 | 4.67 | 4.83 | 3.78 | 5.09 | 3.48 | 4.05 | 3.23 | 4.63 | 4.47 | 53.99 |
| Pinson | 5.68 | 4.43 | 6.52 | 4.45 | 4.94 | 4.09 | 4.61 | 2.95 | 3.90 | 3.44 | 4.88 | 4.56 | 54.45 |

According to the EPA's Storage and Retrieval (STORET) Data Warehouse , most of the facilities are located in the northeastern portion of the watershed, as shown in **Error! Reference source not found.**. I-59 traverses the catchment from southwest to northeast in an extent of 5.2 miles (8.4 km), intercepting the stream and its tributaries four times. This facilitates the development of the analysis framework to assess post-construction stormwater runoff impacts from roads to streams, due to the link between some of these impacts and traffic volume that is reported in literature.

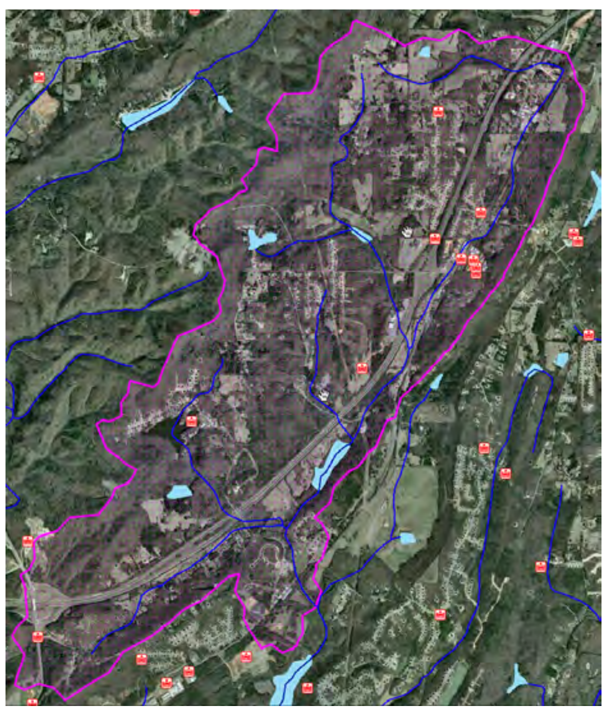


**Figure 3: Little Cahaba Creek watershed and EPA STORET facilities marked as red squares**

Soils in this watershed are primarily hydrological group B, gravelly silt loam (moderate $K_{sat}$, saturated conductivity), layered with fine grained clay layers (very low $K_{sat}$).As a result, there is a moderate amount of infiltration, yielding a relatively consistent groundwater influence on the watershed. Additionally, the soils are underlain by limestone, chert, and sandstone from the Knox Group, Sequatchie Formation and

Chickamauga Limestone, and Red Mountain Formation. These units are adequate for conveying groundwater. There is faulting and folding in the region, which the length of LLC parallels on the southeast portion of the watershed. These geologic features have produced springs in the area that feed lakes and ponds, adding to the constant flow of water in the creek.

**Table 3: Soil survey data from the USDA shown in order of percentage area within the LCC**

| Name | Acres | % | Depth to Restrictive Feature (in) | Depth to water table (in) | Hydrological Soil Group | Ksat (in/hr) |
|---|---|---|---|---|---|---|
| Bodine-Birmingham Association, steep | 1984.4 | 23.1 | 20-40 / 80+ | 80+ | B | 1.98-5.95 / 0-0.14 |
| Bodine-Fullerton association, steep | 1253.7 | 14.6 | 80+ | 80+ | B | 1.98-5.95 / 0.57-1.98 |
| Nauvoo-Rock outcrop association, steep | 1178.1 | 13.7 | 40-60 / 0 | 80+ / 0 | B | 0.00-1.13 / 0.00 |
| Fullerton-Bodine complex, 8-15% slopes | 1078.2 | 12.5 | 80+ | 80+ | B | 0.57-1.98 / 1.98-5.95 |
| Minvale-Dewey complex, 15-30% slopes | 394.5 | 4.6 | 80+ | 80+ | B | 0.57-1.98 |
| Sullivan-Ketona complex, 0-2% slopes | 363.6 | 4.2 | 80+ / 40-60 | 80+ / 0-12 | B / D | 0.57-1.98 / 0.00-0.06 |
| Townley-Nauvoo complex, 8-15% slopes | 312.8 | 3.6 | 20-40 / 46-60 | 80+ | C / B | 0.00-0.20 / 0.00-0.57 |
| Etowah loam, 2-8% slopes | 272.6 | 3.2 | 80+ | 80+ | B | 0.57-1.98 |
| minvale Cherty loam, 8-15% slopes | 240.7 | 2.8 | 80+ | 80+ | B | 0.57-1.98 |
| Sullivan-State complex, 0-2% slopes | 211.9 | 2.5 | 80+ | 80+ / 48-72 | B | 0.57-1.98 |
| Holston loam, 2-8% slopes | 199.1 | 2.3 | 80+ | 80+ | B | 0.57-1.98 |
| Nauvoo-Rock outcrop association, rolling | 167.7 | 2 | 40-60 / 0 | 80+ / 0 | B | 0.00-1.13 / 0.00 |
| Nauvoo-Townley association, steep | 139.8 | 1.6 | 46-60 / 20-40 | 80+ | B / C | 0.00-0.57 / 0.00-0.20 |
| Allen fine sandy loam, 8-15% slopes | 137.6 | 1.6 | 80+ | 80+ | B | 0.57-1.98 |
| Wax loam, 0-3% slopes | 135.6 | 1.6 | 18-36 | 18-20 | C / B | 0.06-0.20 |
| Leesburg-Rock outcrop complex, steep | 118.7 | 1.4 | 80+ / 0 | 80+ / | B / D | 0.57-1.98 / 0 |
| Dewey loam, 8-15% slopes | 117.9 | 1.4 | 80+ | 80+ | B | 0.57-1.98 |
| Water | 64.3 | 0.7 | | | | |
| Minvale cherty loam, 2-8% slopes | 54.5 | 0.6 | 80+ | 80+ | B | 0.57-1.98 |
| Mooreville silt loam, 0-2% slopes | 44 | 0.5 | 80+ | 18-36 | C / B | 0.57-1.98 |
| Decatur silt loam, 8-15% slopes | 30 | 0.3 | 80+ | 80+ | B | 0.57-1.98 |
| Water | 26.8 | 0.3 | | | | |
| Docena complex, 0-4% slopes | 23.1 | 0.3 | 80+ | 18-36 | C | 0.06-0.2 |
| Ketona-Sullivan complex, 0-4% slopes | 18.4 | 0.2 | 40-60 / 80+ | 0-12 / 80+ | D / B | 0-0.06 / 0.57-1.98 |
| Townley silt loam, 6-15% slopes | 8.9 | 0.1 | 20-40 | 80+ | C / B | 0 |
| Dewey loam, 2-8% slopes | 8.1 | 0.1 | 80+ | 80+ | B | 0.57-1.98 |
| Nauvoo-Montevallo association, steep | 3.9 | 0 | 40-60 / 10-20 | 80+ | B | 0-0.57 |
| Minvale-Nella-Townley association, steep | 3.8 | 0 | 80+ / 20-40 | 80+ | B / C | 0.57-1.98 / 0.00 |

Four stations were selected to measure the water quality of the LLC and to assess the impact of I-59. At each of these stations, water samples are regularly collected to further analyze in the laboratory. These sites are indicated in Figure 2, where the watershed has been divided into subcatchments. Two sites are located within the same stream segment on opposite ends of I-59: the site downstream from I-59 crossing also referred to as Site 1; the site upstream from the roadway crossing, not affected by I-59 runoff, is also referred to as Site 3. These two sites are ideal to compare water quality before the interstate and after runoff from the interstate has entered the stream.

Further downstream from I-59 crossing, LCC receives flows from the entire LCC watershed presented in Figure 2. This site, is referred to either a Mill or as Site 2. A final site was selected for hydrology and water quality characterization. This site was positioned upstream from Hubbards Lake (northeast from the other three monitoring sites) and is also referred to as Site 4. Figures 5 and 6 presents photos of these sites.

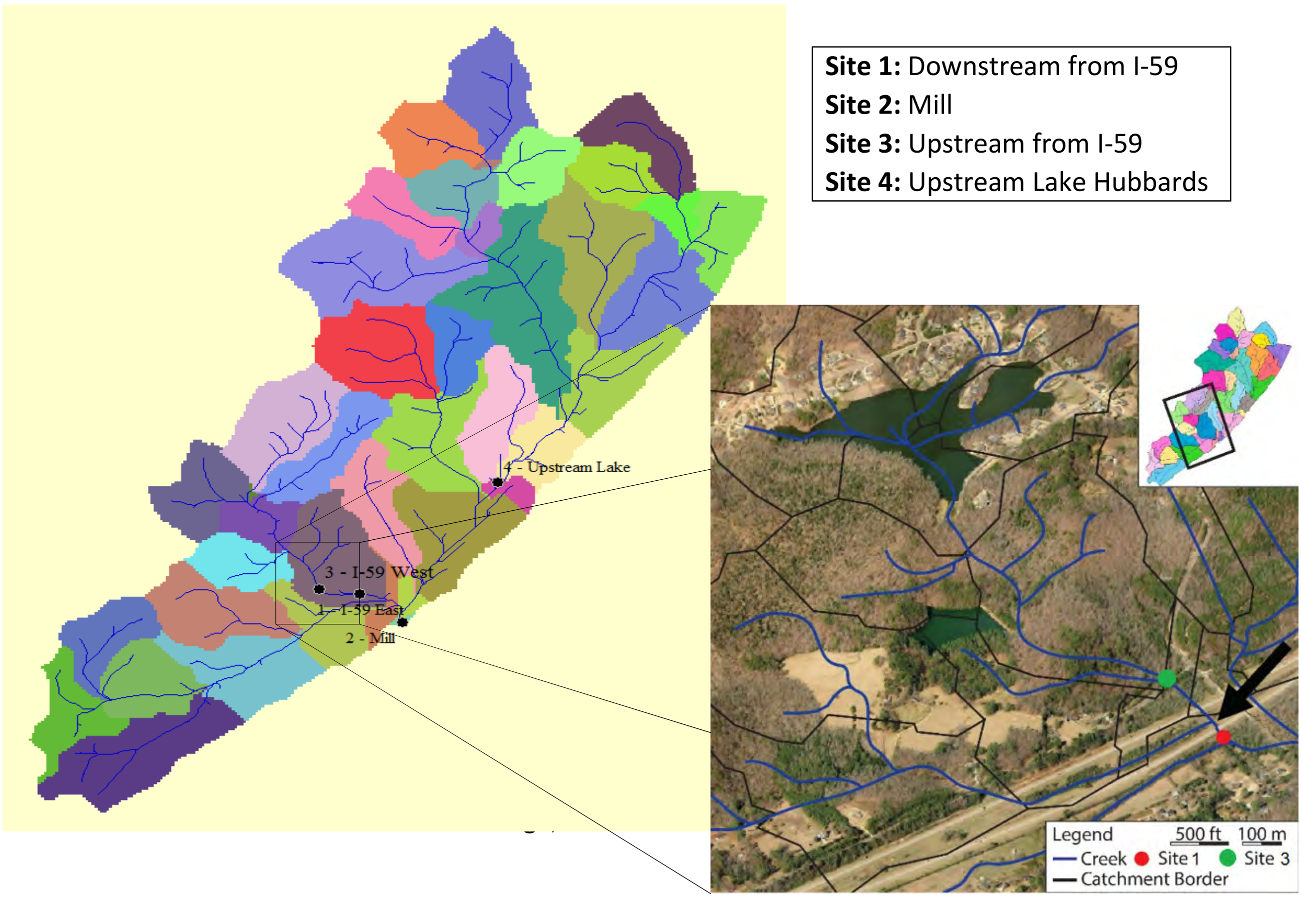



**Figure 4: LCC watershed divided into subcatchments, with the four research site locations identified, and close-up with sites 1 and 3 with respect to I-59**

Between Sites 3 and 1 there was a small, intermittent stream that joined the LCC tributary in the median of the road. A detailed watershed delineation indicated that the catchment area for this intermittent stream was in its vast majority farmland located upstream from I-59. In few rain events this tributary contributed toward LCC surface flows, and in these situations the contributions in terms of hydrology and water quality of the roadway runoff and the catchments upstream from this intermittent stream where combined.

There were some practical difficulties encountered in monitoring hydrological parameters (e.g. flash flows displacing and damaging level loggers) as well water quality parameters (e.g. probes must be submerged at all times to avoid damage) in this intermittent stream. The strategy that was later selected in this investigation was to use numerical modeling as a means to separate the contributions from the locations upstream from I-59 in the intermittent branch from the contributions that the intermittent branch receives from the roadway at times when it is flowing. Results from the simulation of the watershed obtained with EPA's Storm Water Management Model (SWMM 5.1) model is presented later in the report, with the quantification of the impacts of the added imperviousness created I-59, as well the lateral stream runoff.

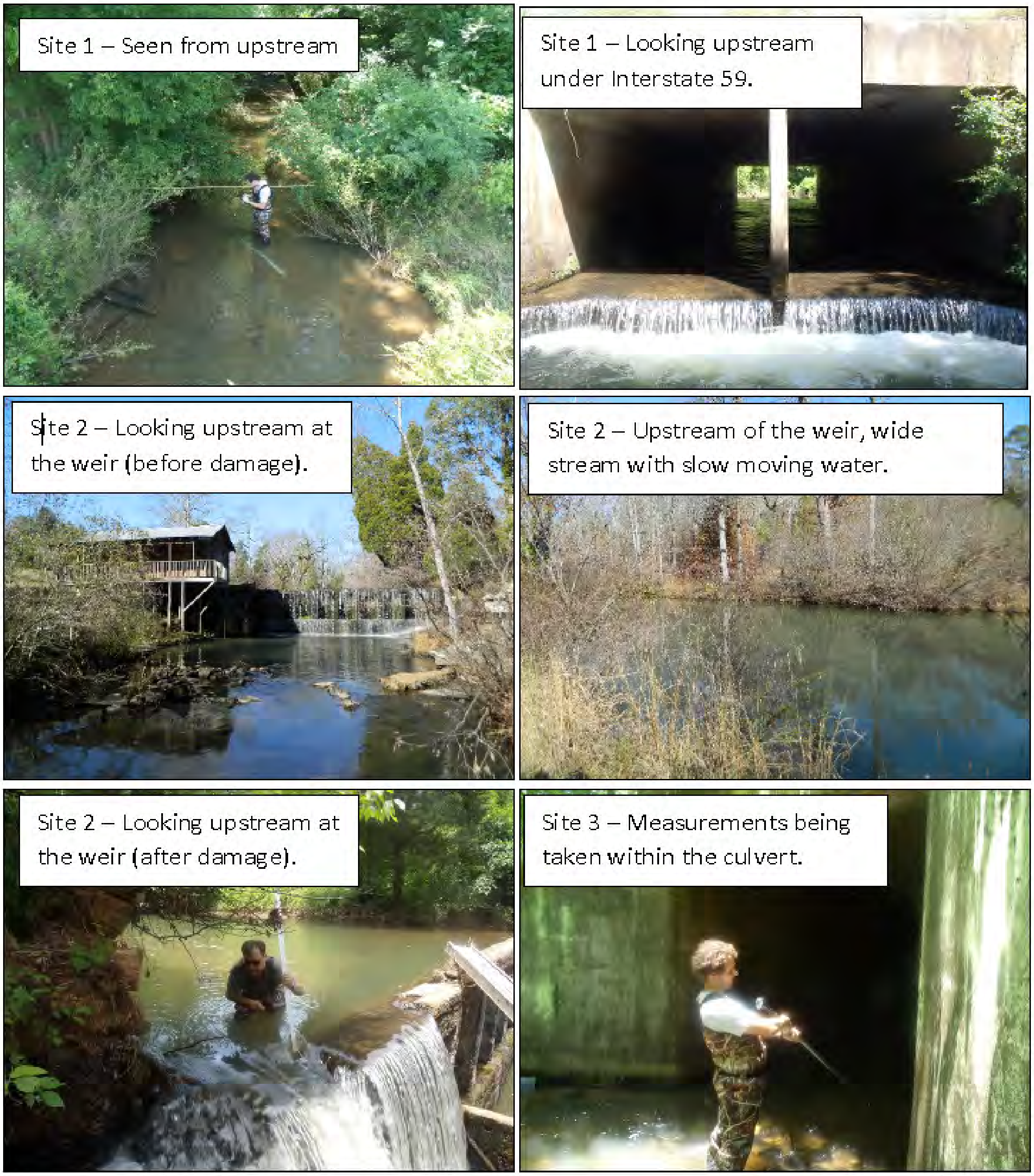



**Figure 5: Different locations within the LCC watershed – Sites 1 to 3**


**Figure 5 (continued): Different locations within the LCC watershed – Site 4**

## 1.3. Traffic characterization at I-59

I-59 crosses the LLC watershed in a SW-NE direction. Traffic on I-59 was initially characterized with a traffic sensor deployed by Auburn University, which indicated that a ratio of 20 to 25% of the traffic is comprised by larger vehicles (more than 2 axis).

As the research progressed, a continuous traffic meter (ATR-163) operated by ALDOT at a point 2 miles SW from the research site provided an hourly series of traffic flow during an entire week, which is presented in Figure 6. Measurements over the course of 3 months were used to derive an average traffic and standard deviations for the traffic at each hour. This in turn was used as a means to estimate the vehicle count between consecutive rainfalls, which is turn was used in correlations with water quality parameter changes.

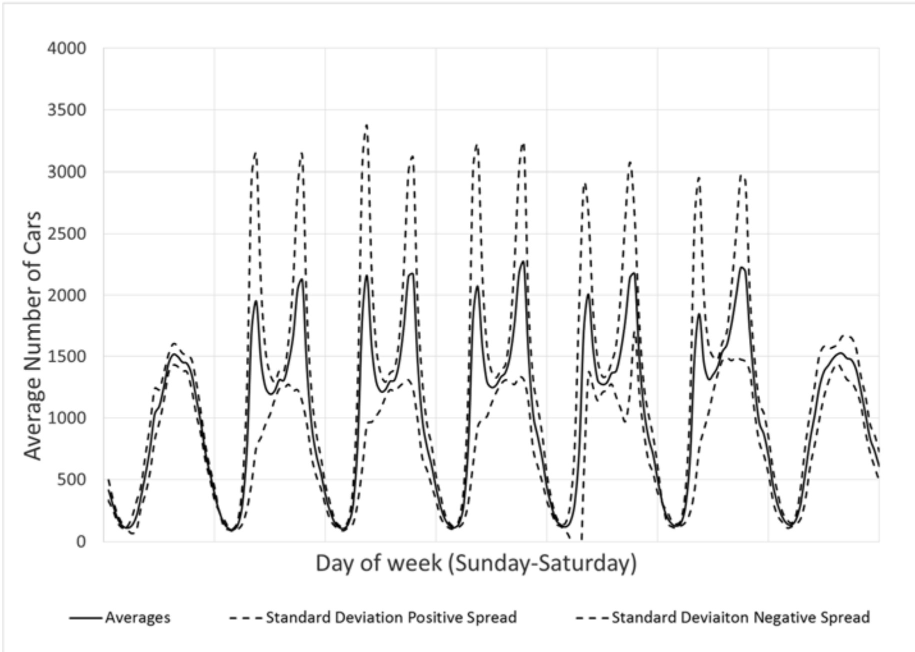



**Figure 6. Average daily traffic over a week on I-59 north of Birmingham, AL, mile post 140.2. Data was collected over a 3 month period.**

## 1.4. Stages of the research work

The proposed research was developed in eight tasks:

1. Literature review: presented in the discussion that follows in the chapters of this final report.
2. Hydraulic/Hydrologic characterization: presented in section 2 of this report, which presents results from the hydrologic characterization.
3. Water quality characterization: presented in section 3 of this report, which presents results from the water quality characterization.
4. Traffic characterization: presented in this introductory chapter.
5. Data analysis: presented in section 4 of this report, which discusses modeling results from LCC watershed.
6. Draft analysis framework to estimate post-construction runoff impacts: a simple modeling framework to estimate roadway runoff impacts was created using SWMM model, and is presented in section 5 of the report.
7. Elaboration of this final report.
8. Education, training and outreach activity: a training on the proposed draft framework was promoted in December 2015.

The following chapters detail the research efforts on the estimation of post-construction runoff impacts to the LLC and modeling efforts to predict these impacts for future rain events in that watershed.

## 2. HYDROLOGICAL CHARACTERIZATION OF LCC WATERSHED

One of the main goals of the proposed was to quantify the impacts of I-59 to LCC with respect to runoff quantity. Various hydrological parameters including temperatures, rainfall, water levels in streams and shallow wells, as well as stream flow were monitored continuously. Results from this monitoring is presented in the subsequent sections. Emphasis on these results are in Sites 1 and 3, since these represent more closely the impacts of the roadway crossing to the LLC.

### 2.1. Temperature

The relevance of measuring air temperature is linked with abstractions in the watershed caused by evapotranspiration processes. In this study, temperatures were obtained from HOBO® level loggers deployed 5 feet above ground level, with results presented in Figure 7. Additionally, daily maximum and minimum temperatures are given from the Birmingham municipal airport weather station, and are plotted as reference. The daily average temperatures have varied from a maximum of 88°F (31°C) down to 14°F (-10°C). For approximately four months in the year, the average temperature was at or above 80°F (27°C), corresponding to a period from May to September. The abstraction in these periods would be anticipated to be more significant than in the rest of the hydrological year.

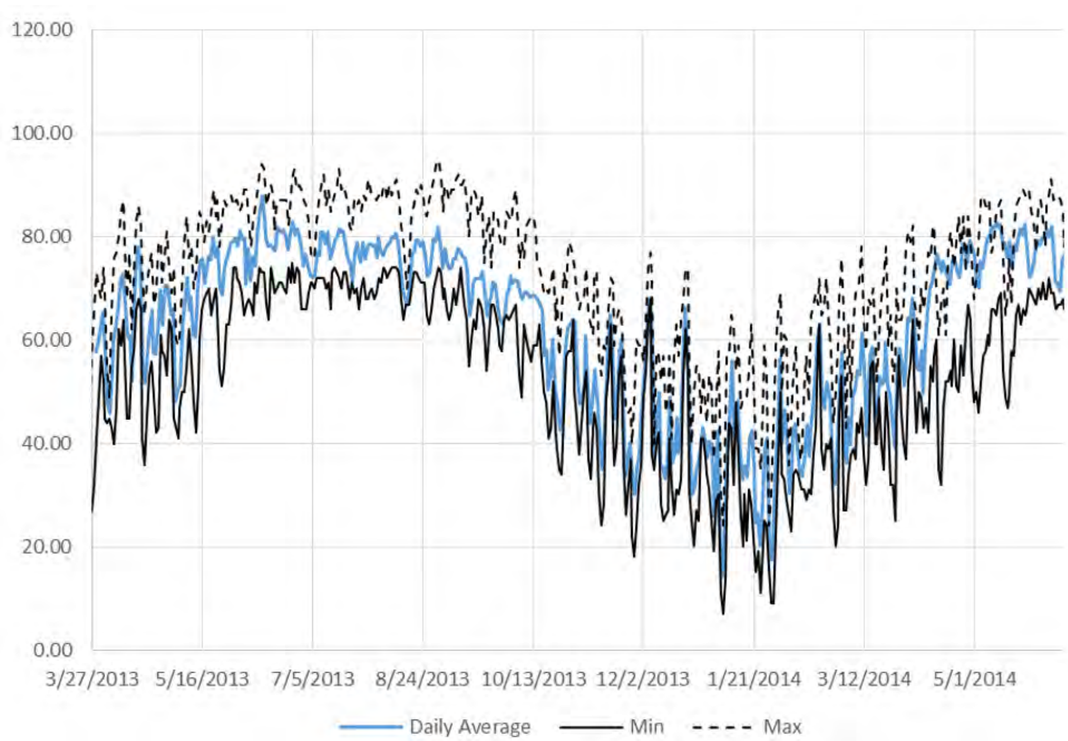



**Figure 7: Daily average air temperatures at LCC and corresponding maximum and minimum temperatures recorded at Birmingham Airport weather station.**

### 2.2. Rain events

As a key parameter for studying rainfall-runoff processes, rainfall has been measured since April of 2013, using two HOBO RG3 rain gauges at two locations within the watershed. One location was at the Gas Station Site is located at I-59 exit 148, close to the center of LCC watershed. The other location near to

Site 2, which is also close to Sites 1 and 3, and closer to where hydrological characterizations across I-59 were performed. Reporting in the Gas Station rain gauge was performed until July 2014, whereas the reporting in Mill location is ongoing as of December 2014. Results are presented in Figure 8.

In the period April 2013 to August 2014, there were approximately 47 significant rain events measured with more than 6 hours between rainfall events and with rainfall depth greater than 0.1 in/hr (2.54 mm/hr). Over the research period, the average rain depth was approximately 1.6 inches (40.6 mm), and rain events had a frequency of 2.8 days. Fourteen of these rain events occurred within two days of another significant rain event. This is an important factor since antecedent dry periods are important in the context of rainfall abstractions linked to groundwater infiltration. More intense rain events occurred in the summer, but elapsed time between rain events tended to be larger.

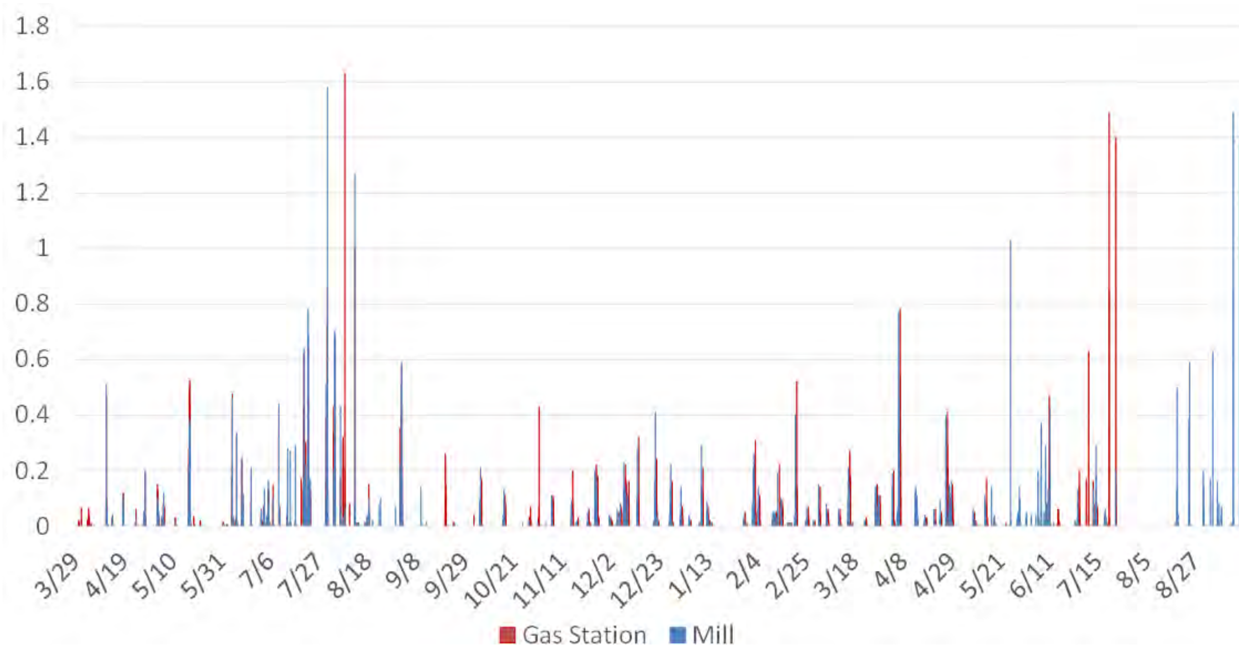



**Figure 8: Hyetograph (in inches) measured by two rain gauges set up in LCC watershed.**

## 2.3. Stream stages and flows

For the past 18 months, rainfall and stream level measurements have been collected continuously. Stream levels have been recorded with HOBO level loggers that have an estimated error of +/- 0.03 feet (+/- 9.1 m). Head-Discharge curves were developed by measuring stream heights and velocities at regular intervals for both sites along a cross section. Using this relationship, flows can be calculated at 30 minute intervals (the measurement interval for the HOBO level loggers). This approach works well with low flow events, but seemed to represent unlikely large numbers for higher flow events. A 13 month history of recorded stages at Sites 1 and 3 are presented in Figure 9.

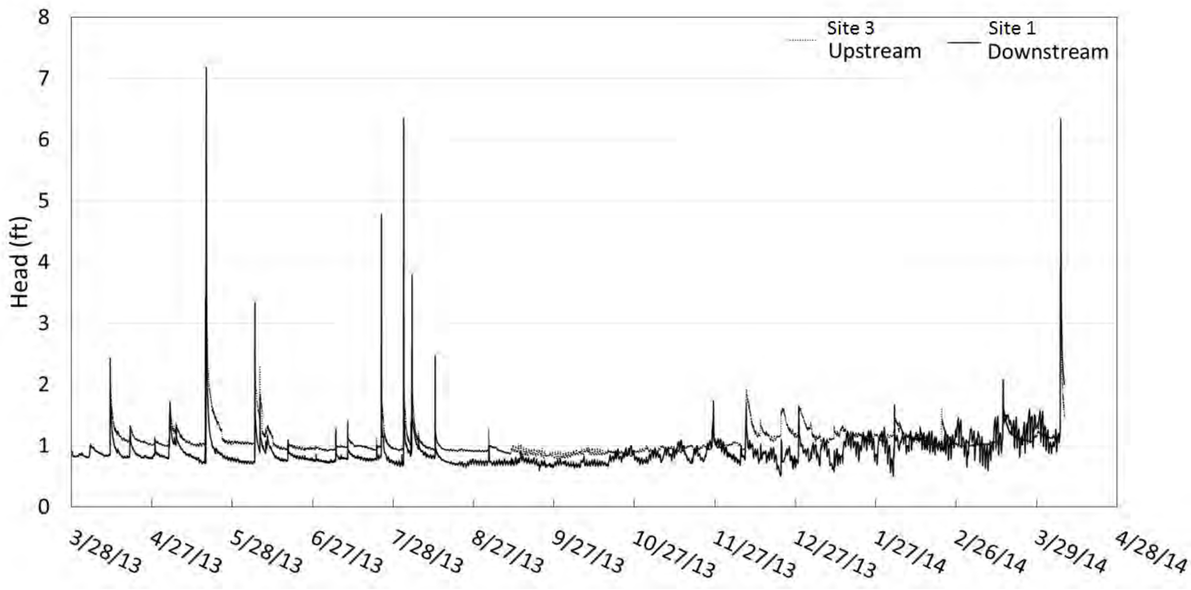



**Figure 9: Stage hydrographs measured at sites upstream and downstream from I-59 crossing with the Little Cahaba Creek over a 13 month period.**

Starting on 7/7/14, ISCO Area-Velocity (AV) sensors were installed at both sites to obtain more accurate flow measurements, especially those experiencing high flow rates and velocities. The 2150 AV flow module in are part of the ISCO 2100 Series. This device can hold approximately 79,000 readings (equivalent of nine months of data). The AV sensor records water level and velocity of open channel flow streams. These values are viewed in the separately purchased software Flowlink®.

The water level is measured by an internal differential pressure transducer which is a small "piezo-resistive chips that detects the difference of the pressures felt on the inner and outer face" (Teledyne 2012). The AV sensor must be calibrated with the reference cross-section at which the sensor is deployed. The stream level and zero level offset, if applicable, must also be entered into the program settings when first installing the sensor. If there is a build-up of silt around the sensor, that value will need to be accounted for as well. Since both of the AV sensors deployed at the upstream and downstream sites were installed above the streambed floor at the center of the channel, the offset distance the AV Sensor was entered into the Flowlink® program. These water level measurements were cross-referenced with the stream level measurements from the HOBO level loggers.

As mentioned previously, the AV sensor measures velocity by using ultrasonic sound waves and the Doppler Effect. As stated in the Teledyne Operation Guide, the Doppler Effect is "the frequency of a sound wave passed from one body to another is relative to both their motions". As two waves approach one another, the frequency increases; thus, as they move apart, the frequency decreases. The sound waves generated by the transducers bounce off the particles or air bubbles in the stream and reflect to the AV sensor.

The AV sensor uses the area velocity flow rate conversion method to calculate the flow rate in the stream. Since the AV sensor has the reference cross-sectional area that was measured for the program set up, the flow rate can simply be calculated by using the user defined cross-sectional area and the stream flow velocity measured by the sound wave frequencies.

The AV sensors indicate that baseline flows are about 0.6 CFS (0.016 $m^3/s$) and 2 CFS (0.056 $m^3/s$) for the sites upstream and downstream from I-59 crossing (Sites 1 and 3) respectively. Two events shown are from calculations using the HOBO level logger data. The rain event occurring on 9/12/14, captured with the AV sensor, resulted in large flows for LCC at sites 1 and 3, with the site downstream from I-59 having peak flows 8 times larger than values upstream from the road, as shown in Figure 10. Flow peaks very rapidly following the rain event, indicating the flashy character of this headwaters watershed. Finally, flows return to baseline levels after three days from the rain event.

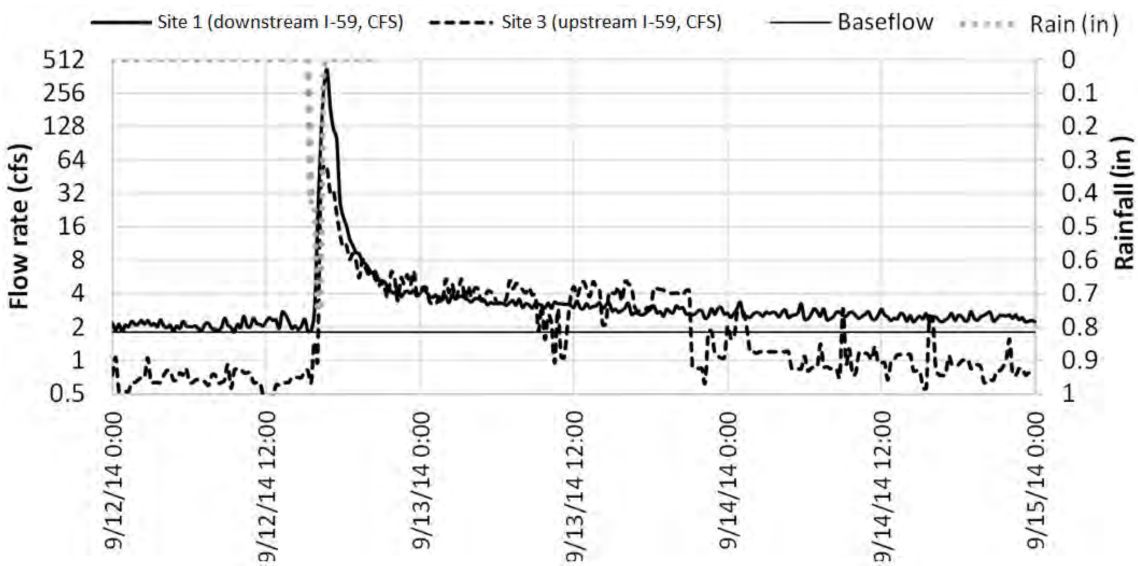



**Figure 10: Flow hydrographs upstream and downstream from LCC as it intercepts I-59 for an intense rain event that occurred on 9/12/14.**

The second rain event, also captured with the AV sensor, occurred on 8/4/14 has a smaller rain intensity and smaller stream flows, as shown in Figure 11. Also, the peak flow downstream from the road is less than twice as large as the value observed upstream from the road. These results point to one characteristic from LCC as it is intercepted by I-59. There are areas drained by intermittent streams between I-59 West and I-59 East stations that will not contribute runoff for low intensity rain events. Such characteristic creates significant variability runoff coefficients upstream and downstream of the roadway. For this small rain event, return to baseline flow conditions occurred within 6 hours from the peak flow.

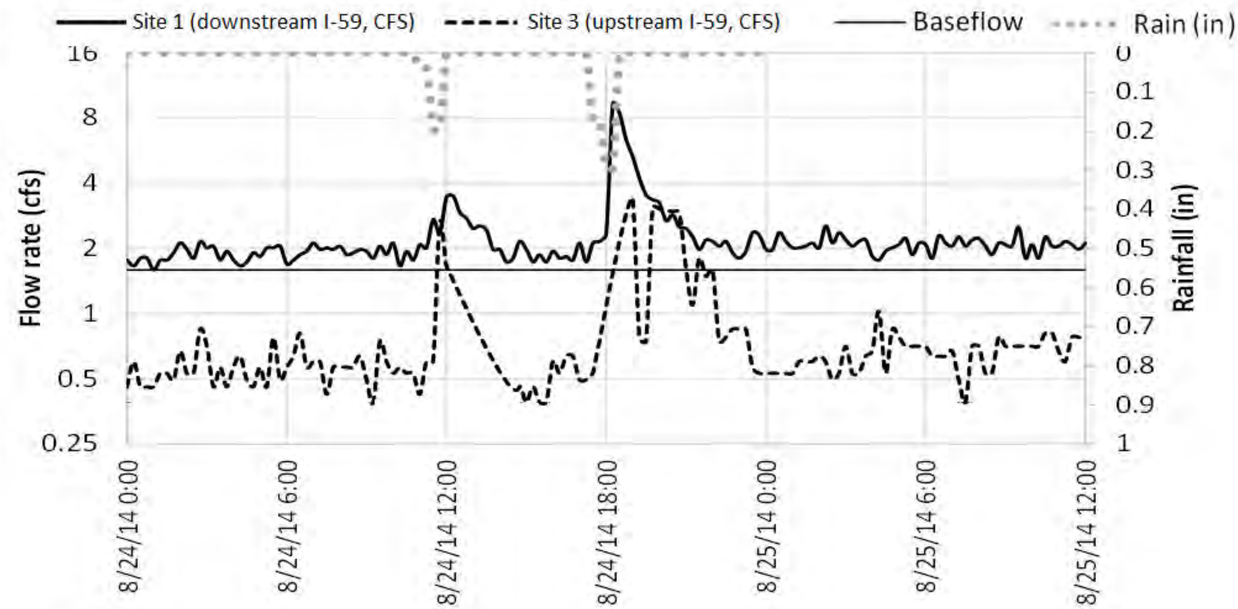



**Figure 11: Flow hydrographs upstream and downstream from LCC as it crosses I-59 for a weak event that occurred 8/24/14 with intensity smaller than the event presented on 9/12/14 in Figure 9.**

The deployment of the AV sensor has also been useful to derive an accurate head-discharge curve for LCC at the two stations. As it was hypothesized when the AV sensors were deployed, there is a strong non-linear relationship between head and discharge in these two stations, as shown in Figure 12. When flow depth exceeds 0.5 ft (0.15m) on Site 3 (upstream I-59), flow increase will occur with more significant increase in depth. This is also observed in Site 1, with the threshold depth at 0.7 ft (0.21m). This is explained by much larger flow resistance with increased depth, as is expected in natural streams.

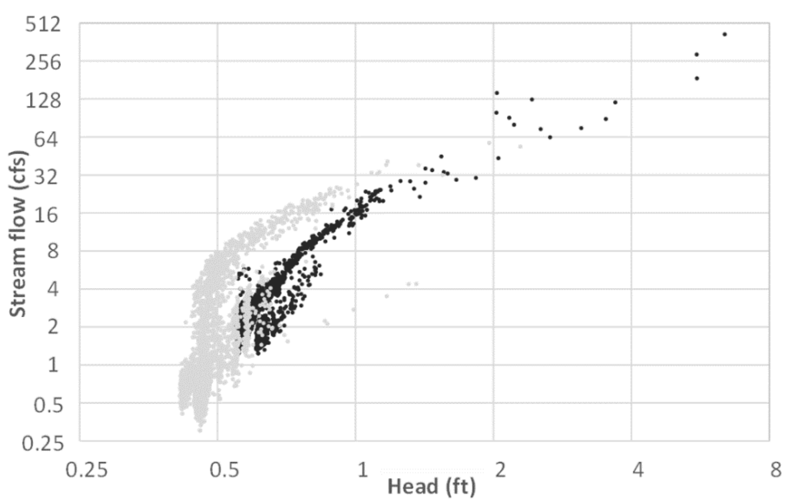



**Figure 12: Head discharge curves for Site 1 (downstream I-59, black dots) and Site 3 (upstream I-59, grey dots), obtained with data from the AV sensors**

The stream flow definitively increases as it receives additional runoff while crossing the interstate. A relevant question is how much of this runoff is caused by increased imperviousness of the interstate and its associated structures as compared with natural preconstruction contributions. One sequence of rain events observed in December 2014 helps highlight the impacts of the runoff from the I-59 into the LLC. It can be seen that the peak flows measured at Site 1 (downstream), presented in Figure 13, can be significantly larger than the peak flow observed in Site 3. This is likely related to the runoff contributions from impervious pavement and the quick drainage from the median regions. However, with the 2nd and 3rd rain events, the relative contribution from upstream (Site 3) increases, possibly due to decreased infiltration at the regions upstream from the interstate crossing.

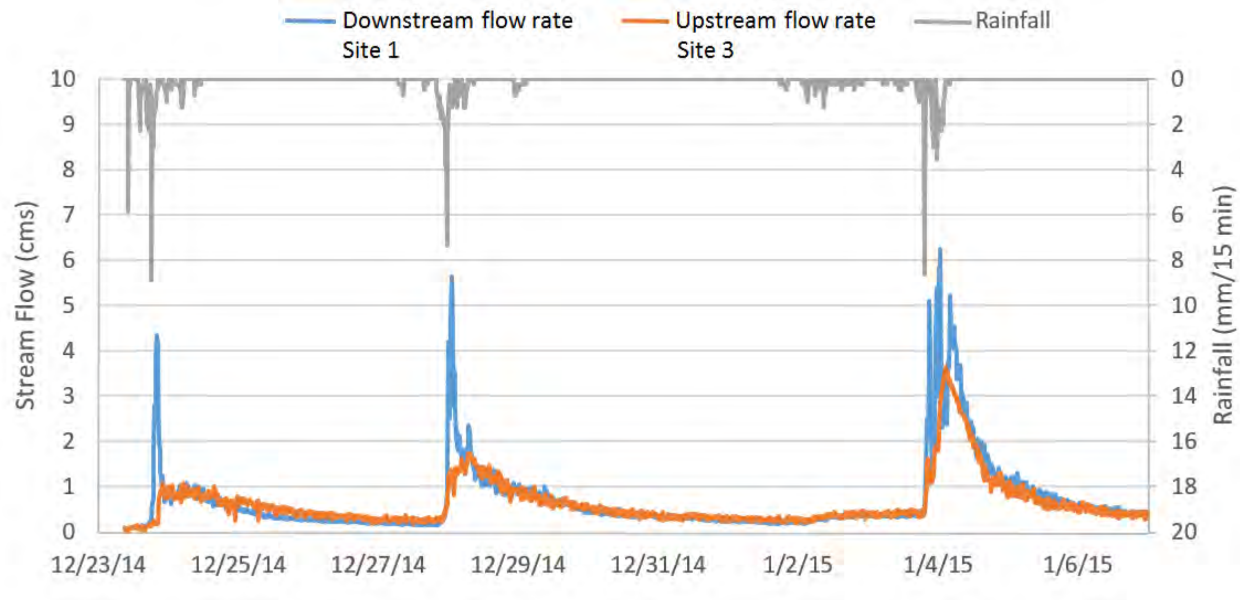



**Figure 13: Three rain events between 12/2014 and 01/2015, with measured flows at Sites 1 (downstream I-59) and 3 (upstream I-59).**

## 2.4. Surface water/groundwater interactions

There is an intrinsic relationship between groundwater and surface water in any natural watershed. Rainfall abstractions in the form of infiltration will create an increase in shallow water tables, which in turn will feed stream flows long after a rain event ended. The response of groundwater may be more or less dynamic depending on the conductivity of the surface layers of the soil.

Two shallow wells, approximately 20 ft (6.1 m) in depth, were installed next to the streams. The water level between the stream and the water in the well were measured with the aid of a total station. Two level loggers were deployed at each site, with one monitoring the water level in the stream while the other was monitoring the water level in the corresponding well. Results such as the one presented in Figure 14 were typical. Greater increases in stream depths were recorded downstream from the road when compared to Site 3 and compared to the groundwater rise. On the other hand, increase in groundwater levels were comparable between Sites 1 and 3. The recovery of groundwater elevation was much more gradual in Site 3 when compared to Site 1.

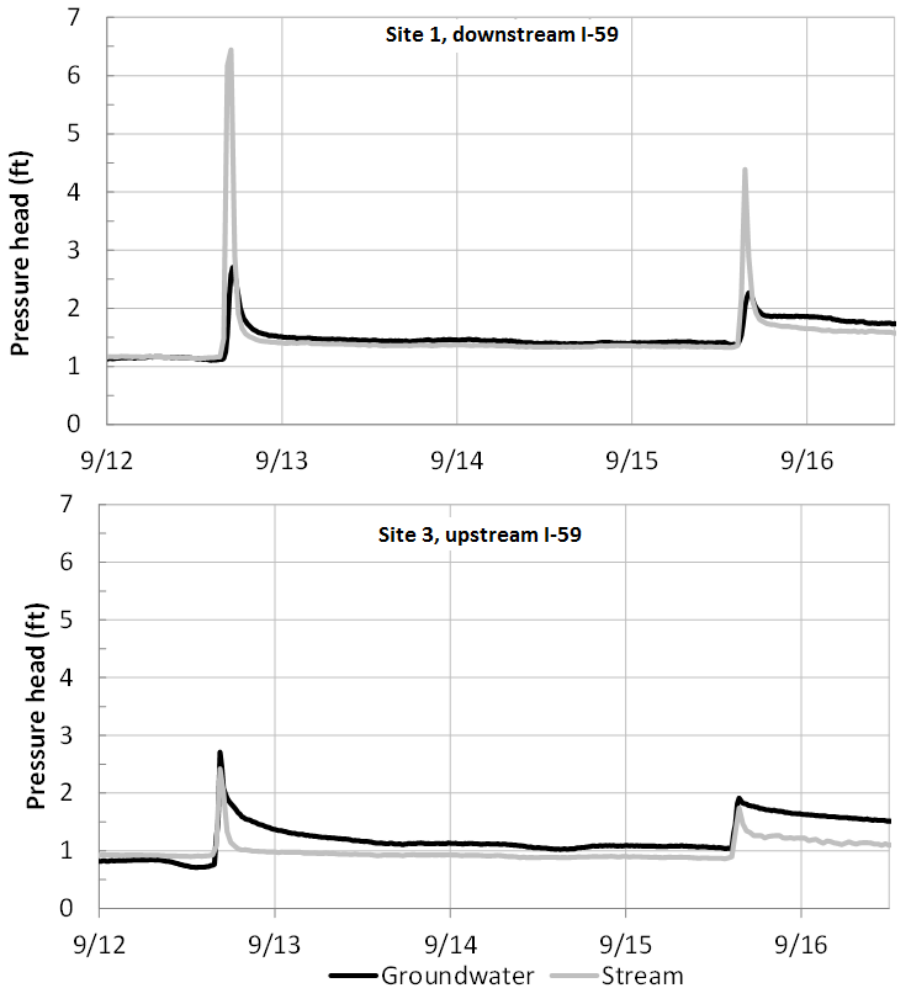



**Figure 14: Pressure hydrograph for two rain events on Sep/14, with level logger changes upstream from the I-59 (site 3) and downstream from I-59 (site 1) presented both for the well and the stream.**

## 2.5. Volumetric runoff coefficient evaluation

The runoff coefficient is commonly defined as a ratio between rainfall and runoff, but it can also be defined in terms of the volume of rainfall and the volume of runoff. Using the catchment areas calculated upstream from Sites 1 and 3, and the rainfall distribution measured with the HOBO rain gages, it is possible to calculate, at any given time during the rain event, the volume of rainfall that has reached the catchment. On the other hand, with the measurements obtained by the AV sensor it is possible to determine the stream flows draining the areas upstream from Sites 1 and 3. Integration of these stream flows provide a measurement of the surface runoff when the base flows are discounted. Finally, by dividing the volume of runoff by the volume of rainfall, and summing the incremental calculations, an instantaneous runoff coefficient can be calculated. Two events are shown in Figure 15, with the results calculated for the volumetric runoff coefficient (Cv) increasing over time during the rain event. The smaller rain event in August presents a smaller runoff coefficient than the 9/12/14 rain event, but there is still a rapid increase in the volumetric coefficient. The event on 9/12/14 on the other hand has increased more rapidly in the initial hours of the rain event, and then presented a much more gradual increase. In both cases, the runoff coefficient is larger downstream from the road crossing, possibly due to the added impervious areas between these two sites.

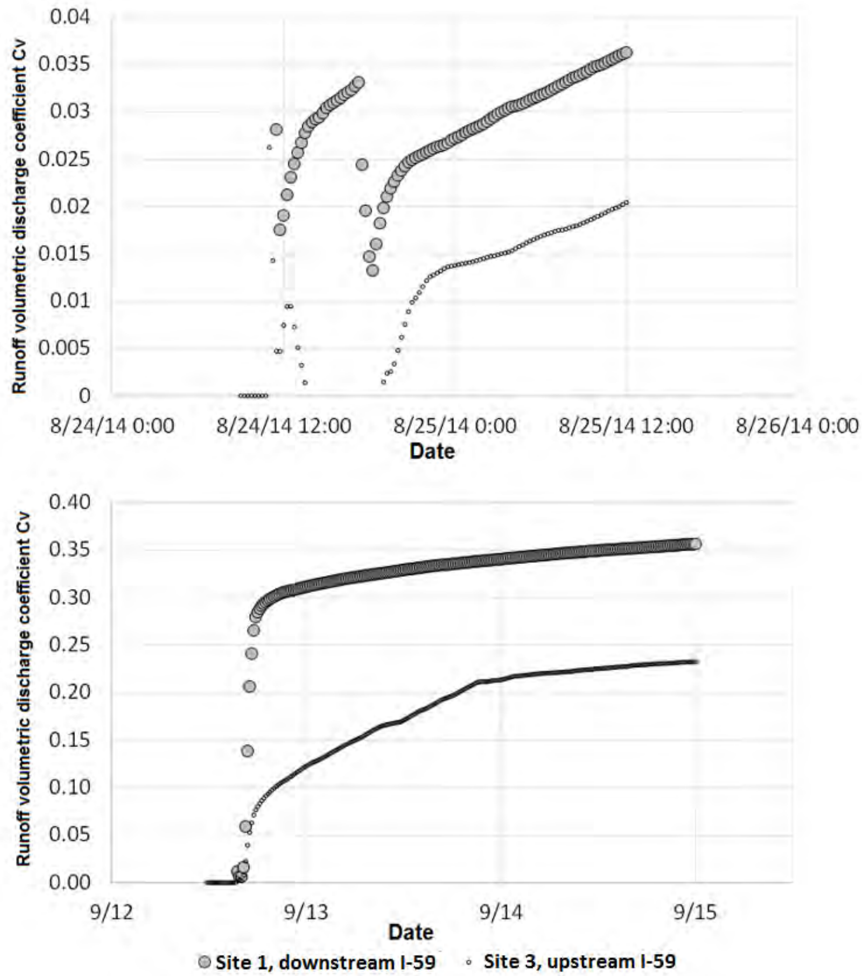



**Figure 15: Volumetric runoff coefficient across the intercept between I-59 and LCC for two rain events**

## 2.6. Summary of findings

The findings for the hydrological characterization of the LLC may be summarized as follows:

1. LCC stream is very flashy, with significant changes in flow rate during intense rain events, which are more rapid in site 1 (downstream from I-59) than what is observed in Site 3 (upstream of I-59)
2. Peak flows in LCC at Site 1 can reach the range of or 350 CFS (10 $m^3/s$), thus almost 200 times the base flow.
3. Peak flows at Site 3 are significant, but not as large in magnitude as in Site 1, as it would be expected. Peak flows tend to increase with a sequence of rain events at Site 3, possibly due to decrease in abstraction losses such as infiltration
4. Changes in groundwater level in Sites 1 and 3 are comparable, even though stage level changes in Site 1 were more pronounced

5. There is a great variability of calculated values for the volumetric runoff coefficient calculated at the crossing region between I-59 and LCC. This indicates that the abstractions in the watershed are extremely dependent on antecedent conditions prior to rain events.

Considering the complexity of flow conditions, interactions between surface and groundwater, and abstractions in the LCC watershed, it was decided to initiate a hydrological modeling strategy to represent the characteristics of this stream. The model chosen to perform this analysis was the EPA Storm Water Management Model – SWMM 5. The model aims to help in the analysis of the characteristics of the watershed, with the aim of applying modeling strategies to other smaller watersheds that are in the proposed alignment of BNB. Details of the modeling steps and results are presented in section 4 of this final report.

# 3. WATER QUALITY CHARACTERIZATION OF THE LCC WATERSHED

The water quality characterizations in LCC watershed has been performed through three approaches: (1) point sampling, (2) continuous monitoring with environmental probes, and (3) event-based characterization with auto-samplers. The first approach was performed in all for research sites to obtain baseline information on the water quality aspects of LCC watershed. As pointed earlier in this report, the location of these sites are:

- Site 1 – Downstream from the crossing of I-59 and the LCC tributary
- Site 2 – Mill creek, location that receives contributions from both Site 1 and Hubbards Lake
- Site 3 – Upstream from the crossing of I-59 and the LCC tributary
- Site 4 – Upstream from Hubbards Lake

The latter two approaches were performed only at Sites 1 (downstream from I-59) and 3 (upstream from I-59) to assess impacts of the roadway runoff to this stream. The initial three sections in this chapter are organized by these three characterization approaches. Within each section, water quality parameters (physical and chemistry) are presented and discussed.

In addition to the scope of the proposed research work in the LCC, by request from the research advisory committee of this research, two other types of environmental characterization were included in this investigation:

1. Macroinvertebrate count: a single data collection campaign was performed to measure the diversity of aquatic species at Sites 1 and 3
2. Metals/oil and grease: concentrations of four metals (Chromium, Cooper, Cadmium, Lead, Nickel and Zinc) and oil/grease were measured in samples collected in Sites 1 and 3, and in a ditch that discharge runoff into Site 1.

## 3.1. Point sampling at all research sites

Point sampling correspond to the characterization of water parameters made in laboratory from samples collected in the field by our research team. These characterizations included physical parameters (temperature, pH, turbidity, TSS, TS), and chemical parameters such as Nitrogen and Phosphorus species.

### 3.1.1. Temperature

Stream temperature measurements were taken every 2 weeks and results are presented in Figure 16. The temperatures at Site 2 were highest in the summer months and early fall, about 5.5 degrees above results in Sites 1, 3 and 4. The reason for this difference can be attributed to the Hubbards Lake and other ponds that influence results in Site 2. It is speculated that the relatively stagnant water is warmed by summer temperatures influencing temperature at Site 2. On the other hand, stream measurements on Sites 1, 3 and 4 would have less exposure to sunlight. Concerning the differences between Sites 1 and 3 (upstream/downstream from I-59 crossing) temperature differences were small, on average 1.0 degree over the entire collection period.

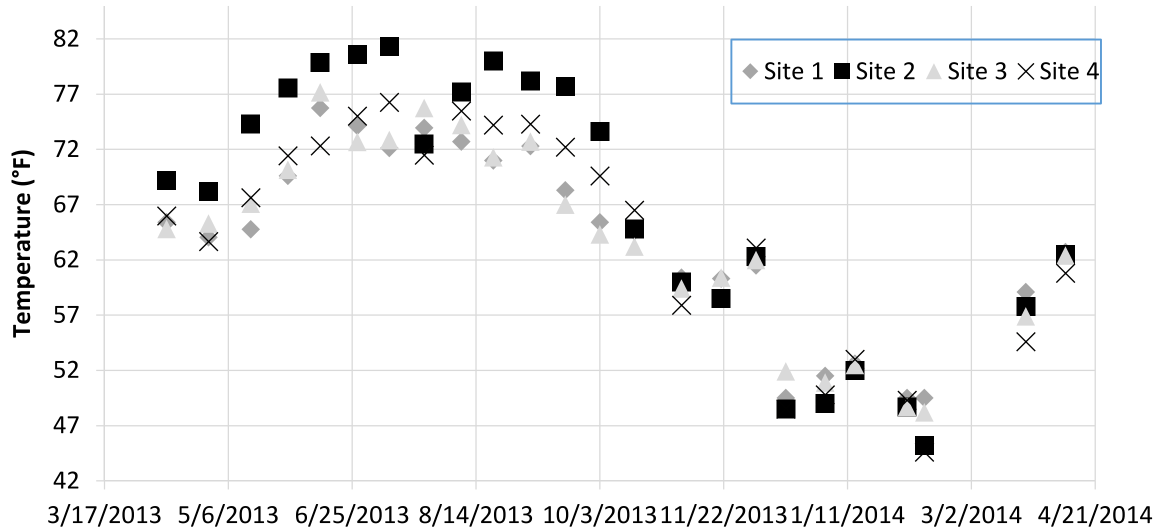



**Figure 16: Point sampling results for stream water temperature for all sites studied in LCC over a hydrological year.**

### 3.1.2. Other water quality physical parameters

The physical parameters collected in the point sample collections, showed no significant difference in pH levels between the 72 hours following a rain event and samples collected outside of the 72 hours following the rain event. The pH was within 1 unit between each of the four research sites. The total solids (TS) tended to be greater outside 72 hours after a rain event. Total suspended solids (TSS) at Site 3 (upstream of the interstate) tended to be greater within the 72 hours following a rain event while the TSS at Site 1 (downstream of the interstate) tended to be greater after 72 hours following the rain event. The average turbidity across all sites tended to be greater for the samples collected within 72 hours of a rain event. Physical parameter results are summarized in Table 4.

**Table 4: Summary of other water quality physical parameters from the LCC watershed monitoring program**

| | | | | Occurred within 72hrs of a Rain Event | | Occurred After 72hrs of a Rain Event | |
|---|---|---|---|---|---|---|---|
| **Physical Parameter** | **Site** | **Average** | **Standard Deviation, σ** | **Average** | **Standard Deviation, σ** | **Average** | **Standard Deviation, σ** |
| **TS (mg/L)** | 1 | 118.808 | 32.585 | 111.071 | 36.642 | 127.833 | 24.141 |
| | 2 | 118.160 | 29.803 | 108.000 | 33.308 | 131.091 | 17.552 |
| | 3 | 116.577 | 32.783 | 112.857 | 38.645 | 120.917 | 23.479 |
| | 4 | 155.769 | 88.853 | 148.643 | 80.424 | 164.083 | 97.114 |

| Table 4 (*Continued*) | | | | Occurred within 72hrs of a Rain Event | | Occurred After 72hrs of a Rain Event | |
|---|---|---|---|---|---|---|---|
| **Physical Parameter** | **Site** | **Average** | **Standard Deviation, σ** | **Average** | **Standard Deviation, σ** | **Average** | **Standard Deviation, σ** |
| **TSS (mg/L)** | 1 | 3.188 | 9.990 | 2.071 | 11.781 | 4.492 | 7.152 |
| | 2 | 4.911 | 3.778 | 4.906 | 4.145 | 4.917 | 3.299 |
| | 3 | 12.558 | 26.369 | 16.807 | 34.904 | 7.600 | 6.293 |
| | 4 | 4.108 | 3.206 | 4.364 | 3.551 | 3.808 | 2.720 |
| **Turbidity (NTU)** | 1 | 3.769 | 2.843 | 4.327 | 3.318 | 2.989 | 1.714 |
| | 2 | 5.311 | 6.347 | 7.316 | 7.684 | 2.504 | 0.702 |
| | 3 | 3.398 | 3.195 | 3.717 | 3.447 | 2.953 | 2.744 |
| | 4 | 8.393 | 11.428 | 11.350 | 14.220 | 4.254 | 0.986 |
| **pH** | 1 | 7.844 | 0.127 | 7.809 | 0.110 | 7.893 | 0.133 |
| | 2 | 7.848 | 0.254 | 7.758 | 0.184 | 7.974 | 0.284 |
| | 3 | 7.646 | 0.209 | 7.608 | 0.165 | 7.699 | 0.249 |
| | 4 | 7.577 | 0.222 | 7.552 | 0.186 | 7.616 | 0.265 |

### 3.1.3. Nitrogen and phosphorus species

Nitrogen and phosphorus species were measured from the grab samples that were collected every 2 weeks. Samples were collected, preserved and tested with a Hach DR/890 colorimeter, for a full year from March 2013 to March 2014. The samples were collected in accordance with the procedure outlined in Pitt (2007). The major nitrogen species collected included $NO_3$, $NO_2$, and $NH_3$. This work measured $NO_3$, $NO_2$, $NH_3$, and total nitrogen using Hach methods 8192, 8507, 8155 and 10071 respectively. Phosphorus species consisted of ortho-phosphate and poly-phosphate. Similar to our analysis of nitrogen, we measured ortho- and poly-phosphate, as well as total phosphate in our lab, according to Hach methods 8048, 8180 and 8190 respectively.

The Hach DR/890 colorimeter tests have the following accuracy associated with each of the corresponding parameters: $NO_3$-N +/- 0.3 mg/L, $NO_2$-N ±0.001mg/L, $NH_3$-N ±0.02 mg/L, TN +/- 0.5 mg/L, $PO_4^{-3}$ +/- 0.05 mg/L (both ortho-phosphate and poly-phosphate), and TP +/- 3.0 mg/L.

To guarantee quality control of nutrient concentration measurements, the samples tested for nitrogen and phosphorous species concentrations were analyzed in an ion-chromatograph (IC) column once every month. The point collection data was tested with an IC column from Dionex Products. The first full run of water samples and standards showed an average error of ~22%. The IC column was run with standards with the following concentration: 0.25 mg/L of $NO_3$, 1.0 mg/L of $NO_3$, 2.0 mg/L of $NO_3$ and 0.5 mg/L of $PO_4$, 1.5 mg/L of $PO_4$, and 3.0 mg/L of $PO_4$. All the standards had a $R^2$ coefficient in the range 0.9131 to 0.9999. As the investigation progressed, IC column and colorimeter results showed much increased consistency with an overall average $R^2$ value of 0.9858.

Module 3 of Pitt (2007) Water Sample Collection Methods was followed to handle and preserve the samples adequately, ensuring the best analytical results. High density polyethylene plastic containers with screw lids were used to hold the water samples. The amount of sample collected was dependent on how many tests that were being performed. 1500 mL was collected per sample at each site. There was also a duplicate sample collect for each site in case there was a non-point source of contamination.

To avoid increases, transformations, and/or losses in pollutants concentrations the nutrient samples were analyzed as soon as possible. TP, TN and NH3 could be preserved up to 28 days by adding sulfuric acid to reduce the pH to 2 (at least 2 mL). However, $NO_3$, $NO_2$, ortho-phosphate, and poly-phosphate need to be analyzed within 24 to 48 hours. All the samples had to be put on ice once they were collected (Pitt 2007). This was done on ice via a standard cooler cleaned with rubbing alcohol.

In preparation for each sample collection the sample bottles and glassware were cleaned using the ASTM (1996) standard D 5088-90. The equipment first has to be rinsed with water to remove any dirt or debris left behind. Then the bottle must be washed with a phosphate-free detergent solution using a scrub brush if necessary, followed by the rinse of “clean” water, e.g. tap water. This rinse is then followed by a rinse with 10% hydrochloric acid, which is followed by a rinse of deionized water. The bottles and glassware are washed with an additional rinse of deionized water to insure the laboratory equipment is ready for new sample water.

In addition to the cleaning of the laboratory equipment, the HACH DR/890 colorimeter tests were carried out following the Hach Data logging Handbook for the DR/890 colorimeter. The manual covered chemical analysis techniques such as temperature consideration- making sure the samples were analyzed at room temperature; sample dilution techniques – this was seldom an issue; operating the Hach TenSette Pipets – e.g. maintaining a slow constant pressure when pressing down and releasing pipettes; the use of graduated cylinder – reading at the meniscus; and mixing water samples – assuring the sample is thoroughly mixed either by inverting or swirling the sample. There was also a prescribed technique for opening the pillow packets that were used for each of the tests.

Standards were also implemented to further assess the quality of the results. The following standards were applied to the Hach DR/890 colorimeter tests: 1 mg/L as N, 2.0 $NO_3$-N, 100 mg/L as $NO_2$, 1 mg/L as $NH_3$-N and 25 mg/L as P. These standards were chosen because they fell within the specific range for each of the corresponding test.

**Table 5: Summary of Nitrogen and Phosphorus species measurements from LCC watershed monitoring program**

| Nutrient | Site | Results from all samples | | Water Sampled within 72hrs of a Rain Event | | Water sampled after 72hrs of a Rain Event | | Error, ± (mg/L) | Detection Limit (mg/L) |
|---|---|---|---|---|---|---|---|---|---|
| | | Average (mg/L) | Standard Deviation, σ (mg/L) | Average (mg/L) | Standard Deviation, σ (mg/L) | Average (mg/L) | Standard Deviation, σ (mg/L) | | |
| **$NO_3$** | 1 | 0.499 | 0.327 | 0.450 | 0.314 | 0.556 | 0.333 | 0.03 | 0.01 |
| | 2 | 0.324 | 0.234 | 0.399 | 0.279 | 0.236 | 0.119 | | |
| | 3 | 0.528 | 0.350 | 0.506 | 0.348 | 0.552 | 0.351 | | |
| | 4 | 0.314 | 0.243 | 0.394 | 0.278 | 0.221 | 0.150 | | |
| **TN** | 1 | 1.312 | 1.187 | 0.927 | 0.778 | 1.729 | 1.394 | 0.5 | 2 |
| | 2 | 0.954 | 1.280 | 0.854 | 1.258 | 1.063 | 1.294 | | |
| | 3 | 0.794 | 0.805 | 0.521 | 0.691 | 1.067 | 0.819 | | |
| | 4 | 0.764 | 0.917 | 0.654 | 0.803 | 0.883 | 1.012 | | |
| **$NH_3$** | 1 | 0.032 | 0.029 | 0.035 | 0.028 | 0.028 | 0.029 | 0.02 | 0.02 |
| | 2 | 0.036 | 0.023 | 0.042 | 0.025 | 0.030 | 0.018 | | |
| | 3 | 0.026 | 0.021 | 0.030 | 0.018 | 0.023 | 0.023 | | |
| | 4 | 0.061 | 0.112 | 0.091 | 0.148 | 0.029 | 0.021 | | |
| **$NO_2$-N** | 1 | 0.006 | 0.008 | 0.003 | 0.003 | 0.010 | 0.010 | 0.003 | 0.005 |
| | 2 | 0.006 | 0.005 | 0.005 | 0.003 | 0.008 | 0.007 | | |
| | 3 | 0.007 | 0.008 | 0.003 | 0.003 | 0.012 | 0.010 | | |
| | 4 | 0.006 | 0.006 | 0.006 | 0.006 | 0.008 | 0.005 | | |
| **TP** | 1 | 0.218 | 0.296 | 0.308 | 0.384 | 0.121 | 0.067 | 0.06 | 0.07 |
| | 2 | 0.161 | 0.225 | 0.239 | 0.288 | 0.076 | 0.044 | | |
| | 3 | 0.162 | 0.199 | 0.249 | 0.258 | 0.082 | 0.041 | | |
| | 4 | 0.192 | 0.264 | 0.277 | 0.337 | 0.101 | 0.073 | | |
| **$PO_4^{3-}$** | 1 | 0.583 | 0.474 | 0.770 | 0.565 | 0.379 | 0.208 | 0.05 | 0.05 |
| | 2 | 0.542 | 0.484 | 0.611 | 0.608 | 0.467 | 0.276 | | |
| | 3 | 0.484 | 0.445 | 0.522 | 0.545 | 0.443 | 0.295 | | |
| | 4 | 0.413 | 0.350 | 0.455 | 0.441 | 0.367 | 0.201 | | |
| **Poly-phosphate** | 1 | 0.499 | 0.303 | 0.490 | 0.330 | 0.510 | 0.269 | 0.05 | 0.05 |
| | 2 | 0.441 | 0.375 | 0.458 | 0.367 | 0.423 | 0.383 | | |
| | 3 | 0.445 | 0.337 | 0.458 | 0.296 | 0.431 | 0.376 | | |
| | 4 | 0.421 | 0.351 | 0.498 | 0.428 | 0.338 | 0.209 | | |

Over the collection period of point samples, the overall average and standard deviation was taken for each of the seven N and P species: $NO_3$, TN, $NH_3$, $NO_2$-N, TP, $PO_4^{3-}$, and Poly-phosphate. Average and standard deviation were calculated for all samples by grouping results with different methods. First, results from samples taken in LCC within 72 hours of a rain event were separated from results taken from samples obtained following a longer period without rainfall. In addition, results from all samples were characterized in terms of average and standard deviation, irrespective of how recent the rain events were.

In general, all samples contain relatively small concentrations of N and P species, and the values are consistent with the National Stormwater Quality Database version 1.1 (Pitt et al 2004). For nitrogen species, results from all sites were in general larger for samples taken after 72 hours following a rain event. Site 2 and Site 4 had comparatively larger values of $NH_3$ and $NO_3$ within the 72 hours after a rain event; however, both of these sites are downstream of farmland.

For phosphorous species, Site 1, 2, 3, and 4 were found to have greater values on average within 72 hours of a rain event. Many possible factors can contribute to this presence of phosphorous species during rain events such as weathering phosphorous materials in streambeds or organic or inorganic material from nearby land.

## 3.2. Continuous monitoring

Continuous water quality monitoring was implemented through the use of two HYDROLAB DS5 Water Quality Sondes, deployed at the sites upstream and downstream of the perennial branch of the LCC crossing I-59 (Sites 1 and 3). There was additional probe deployed in the intermittent tributary that join the LCC tributary in the median, between Site 3 (upstream I-59) and Site 1 (downstream I-59), but it was lost in one event where the stream flow eroded the location where the sensor was installed.

The HYDROLAB sonde software allowed the selection of specific parameters. Temperature (F), pH, Specific Conductivity (µS/cm), Dissolved Oxygen (LDO) (mg/L), Salinity (PPT), TDS (g/L), and Turbidity (NTU) were measured at 30 minute intervals. These parameters were continuously recorded in the environmental probes that stayed out in the field for a maximum of three weeks. Although the probes were set to continuously monitor the stream's water quality, there were periods where there was no data for one or both of the probes. This was due to the probe suddenly turning off due to battery depletion or the nearby electrical lines sending a voltage through the ground and water causing the probe to suddenly turn off.

The Water Quality Sonde data was compared with the point collection and auto sampler date analyzed in the on campus lab for the site upstream from the interstate and the site downstream from the interstate. The Water Quality Sonde was able to catch dynamic changes in turbidity. Where the point collection data and the auto-sampler data could only captured part of the turbidity, the Sonde was able to capture a more detailed picture of the stream's turbidity levels during the investigation.

The deployment of the HYDROLAB Environmental Water Quality Sonde needed to be free of obstruction by branches and other stream debris that could become caught on the sensor, thus affecting the turbidity and possibly the specific conductivity, salinity and pH values. The sensor needed to be exposed to the water but also be deep enough to not catch any passing debris. Additionally, the sensor needed to be secured to the streambed in case of a storm with extreme flow conditions that moved the sensor. Therefore, the sensor was secured to the streambed using cement blocks that can be found in any landscaping store. These blocks were then braced with iron rods that were hammered one foot into the streambed.

Theft was another concern; therefore, a PVC pipe with holes drilled on either side was used to contain both Sondes. The ends of the PVC pipe were closed off with rubber lids that were tightened with a metal strap. The probes were only displaced once since being deployed. This was during a major storm event that carried large pieces of debris through the stream.

Every 2 to 3 weeks the probes were accessed for data gathering and calibrated for each of the following parameters: LDO, pH, Turbidity, temperature and pressure. The calibration and data gathering process were conducted within the Hydras 3 LT software provided with the probe. The calibrated parameters were selected within this program. The user could create and store a template file to make deploying the probe more efficient. This template file could contain any of the parameters available in the Sonde (e.g. battery voltage, Temperature, Total Dissolved Oxygen, Turbidity, etc.). Some of these parameters have a separate sensor, but all are calculated within the Sonde.

Each sensor has a specific set of calibration instructions. When calibrating the Sondes, the current readings display next to the newly calibrated value until the "Calibrated" option is selected. The Water Quality Sonde has the following errors associated with each of the corresponding parameters: LDO +/- 0.2 mg/L, pH ±0.2 pH units, Turbidity ± 1%, Atmospheric pressure ±0.05%, Conductivity± (0.5% of reading + 0.001 mS/cm), Temperature +/- 0.10 degrees C.

Furthermore, when downloading the measured parameters, all the data was downloaded at once. The measured data could only be downloaded when the Sonde was disconnected or no longer recording, unlike the area-velocity sensor, which downloaded data even while the sensor was still recording. Once the download was complete, the data was downloaded as a text file. From here, the file was converted to an Excel format which was the primary method of keeping track of data throughout the monitoring and analysis of the LCC.

### 3.2.1. Conductivity

The environmental probes recorded specific conductivity and through correlations calculated values for TDS and salinity. Therefore, TDS and salinity are represented through the specific conductivity. Results for conductivity are presented in Figure 17.

Low conductivity values were generally observed in the stream, indicating no influx of salts to the stream. The average value for specific conductivity in the upstream side of the interstate was 214.0 µS/cm while the downstream site had an average specific conductivity of 208.6 µS/cm. There was no consistency as to which site presented the highest conductivity values.

Rain events had the effect of dropping the conductivity in the stream since the runoff presented even lower conductivity values. For instance, on 6/11/2014 a total rainfall of 0.42 inches caused a drop in specific conductivity of 148 µS/cm.  Few other rain events are presented in Figure 17 showing the drop in conductivity in stream water during rain events.

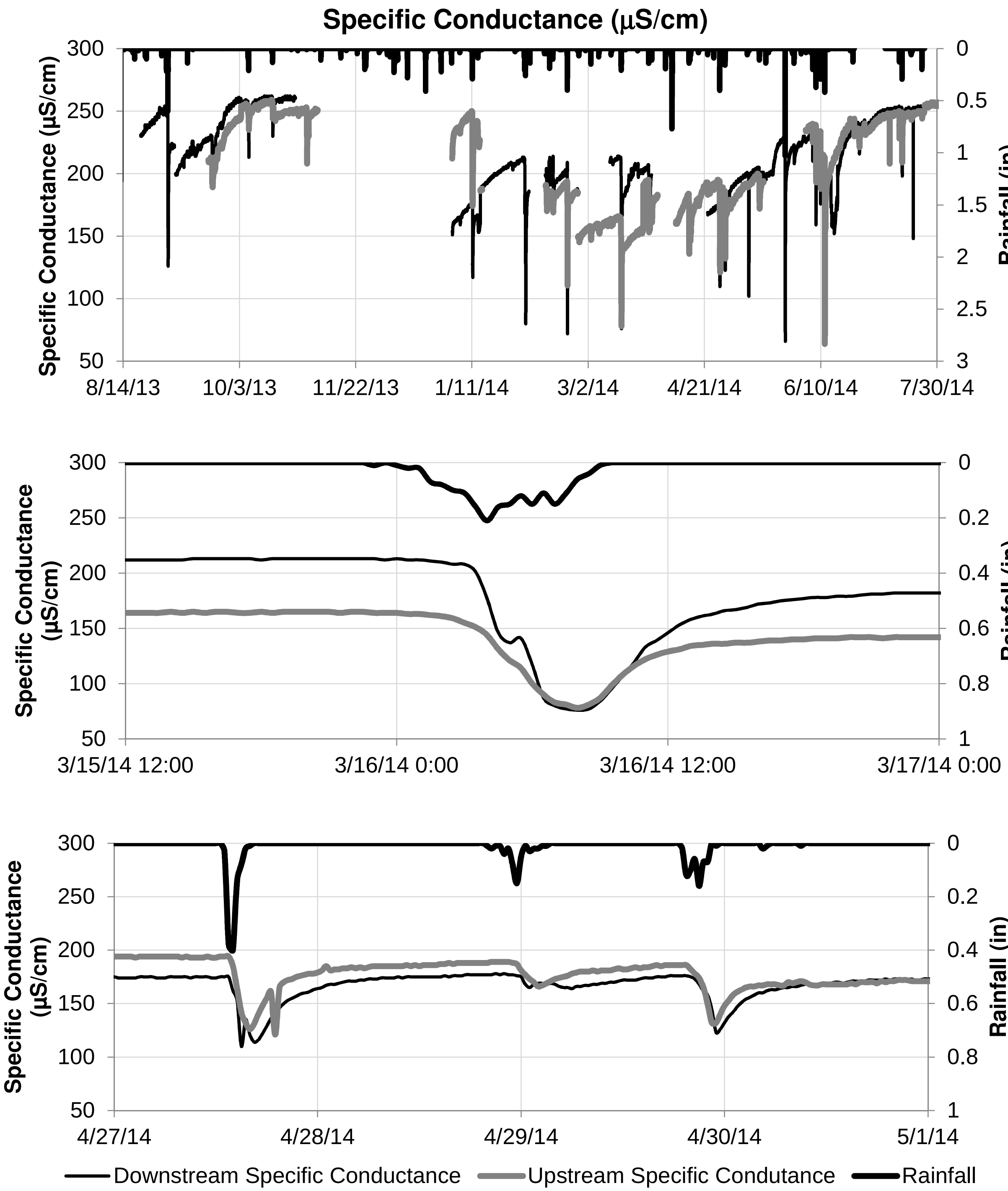



**Figure 17: Conductivity values measured in LCC for Site 1 (downstream from I-59) and Site 3 (upstream from I-59), and corresponding rainfall.**

### 3.2.2. Turbidity

The continuous measurements of turbidity revealed that the turbidity upstream and downstream of the interstate indicated that LCC flows have low turbidity; on average were less than 10 NTU in the absence of recent rain events. Turbidity results for three separate rain events are shown in Figure 18.

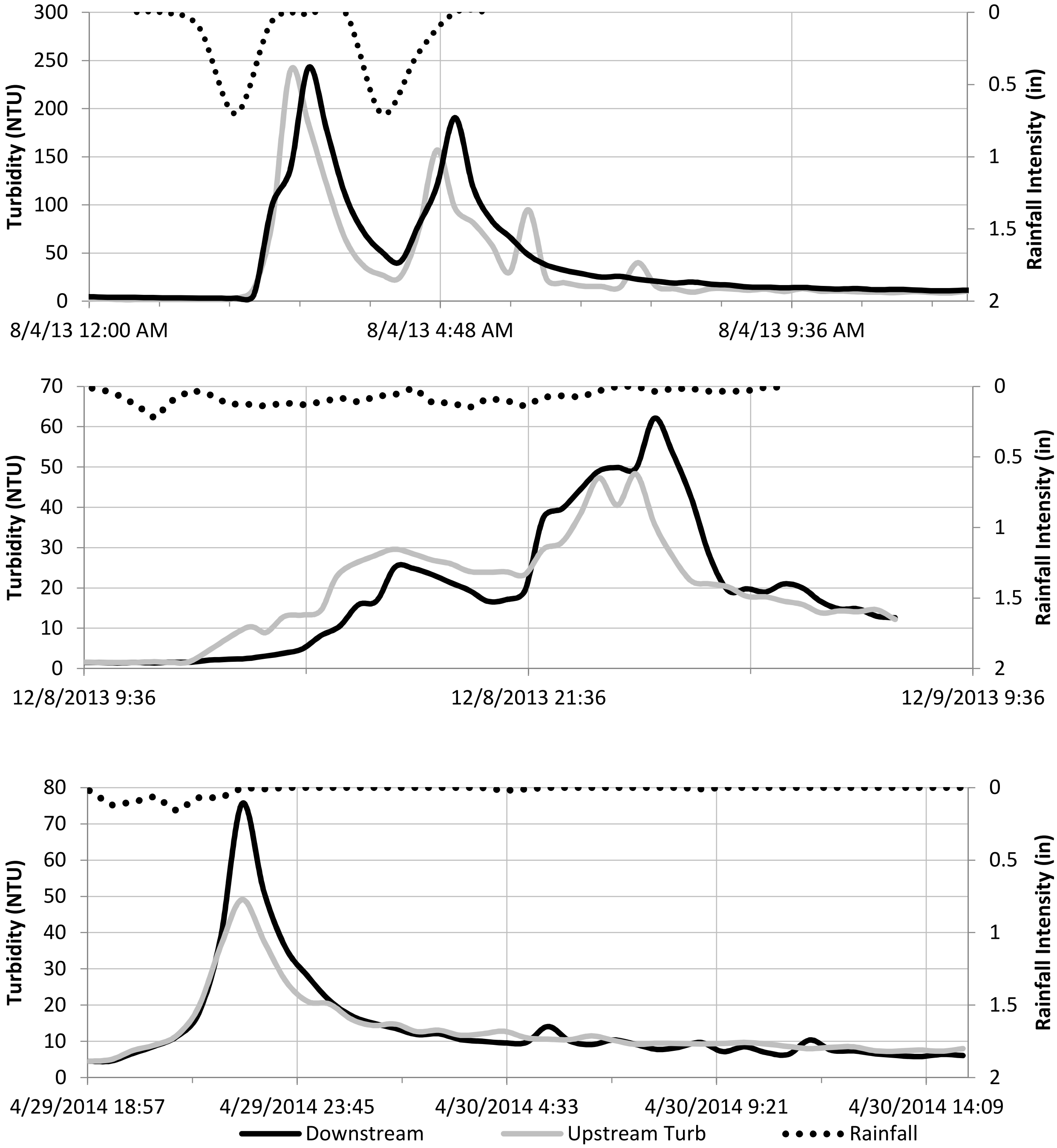



**Figure 18: Turbidity results measured in LCC for Site 1 (downstream from I-59) and Site 3 (upstream from I-59), and corresponding rainfall**.

The environmental sonde turbidity results for the rain events 8/4/2013, 12/8/2013 and 4/29/2014 exemplify that in general during rain events the turbidity increase downstream from the road was more pronounced, with peaks up to 40% larger than the peak turbidity upstream. It can be assumed that contributing factors in the interstate (pavement, median) would be causing the turbidity to increase at the downstream end. This contribution may be from the interstate, the median, the tributary that connects to the LCC at the median or some other unidentified factor. However, this relative turbidity increase across the interstate is not major in absolute terms, and in most cases is under 50 NTUs.

### 3.2.3. Temperature

The water temperature recorded by the sonde showed a predictable trend during winter months, with stream temperatures around 50-60 °F, increasing to around 65-70 °F during summer months, consistent with point sampling results. In general, the temperature downstream from the crossing between the LCC and I-59 is higher by 1-2 °F when compared to results upstream, but this is changed during rain events. Examples of the impact of two rain events (one in the fall and one in the summer) to the stream temperature is shown in Figure 19.

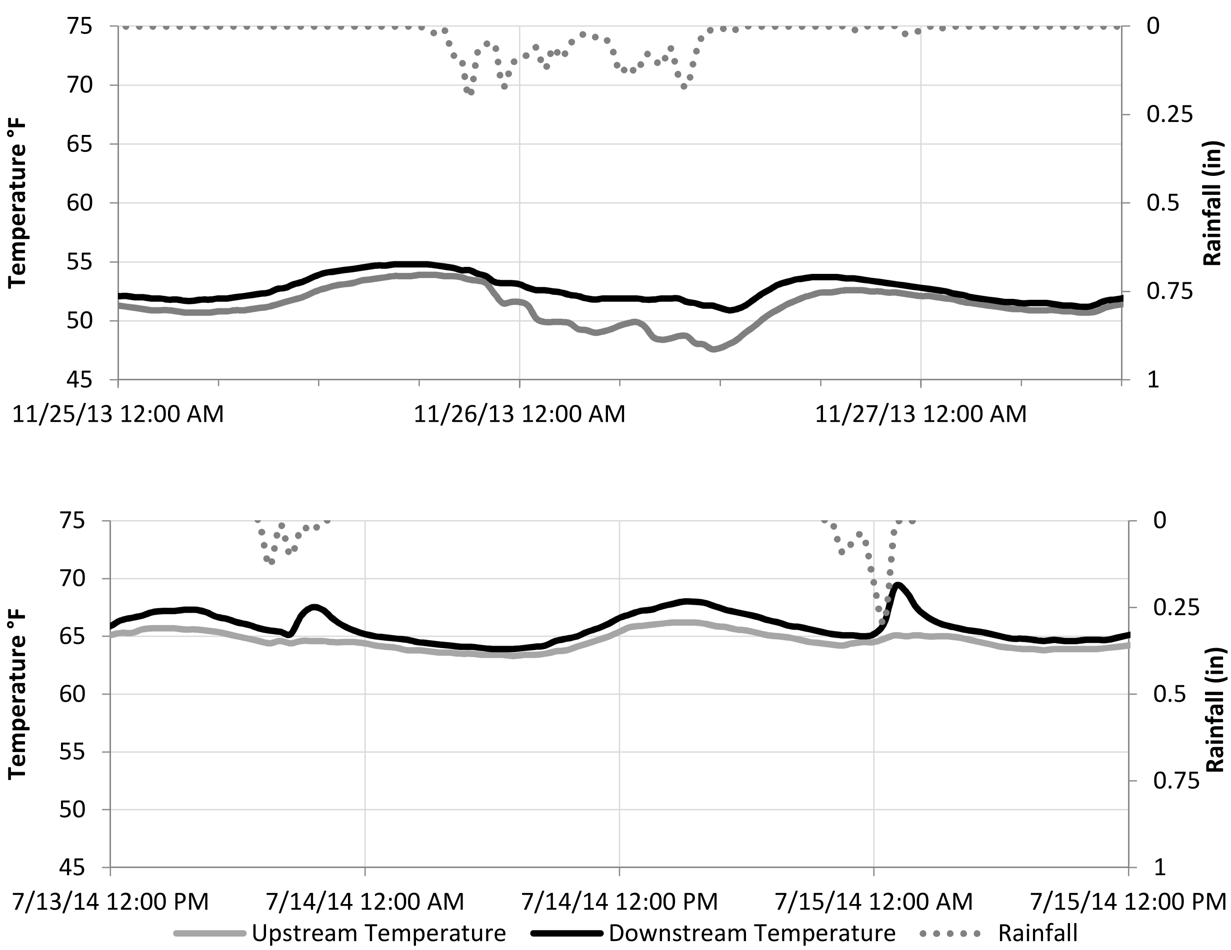



**Figure 19: Temperature results measured in LCC for Site 1 (downstream from I-59) and Site 3 (upstream from I-59), and corresponding rainfall.**

The effect of rainfall on temperature was taken into consideration for the following dates: 11/25/2013, and 7/13/2014. Over the year, daily temperature changes in the stream is between 3 to 5°F(-16 to -15°C). As shown in Figure 19, stream temperatures were not affected by runoff downstream from the I-59 crossing for late fall rain events. However, summer rain events with higher-temperature runoff have shown to increase the temperature downstream.

### 3.2.4. Dissolved oxygen

Dissolved oxygen measured in the stream were in the range of 8 to 12 mg/L over the entire monitoring period. As expected, this parameter is very much dependent on water temperature, as is indicated in the results from Figure 14 from Sites 1 and 3.

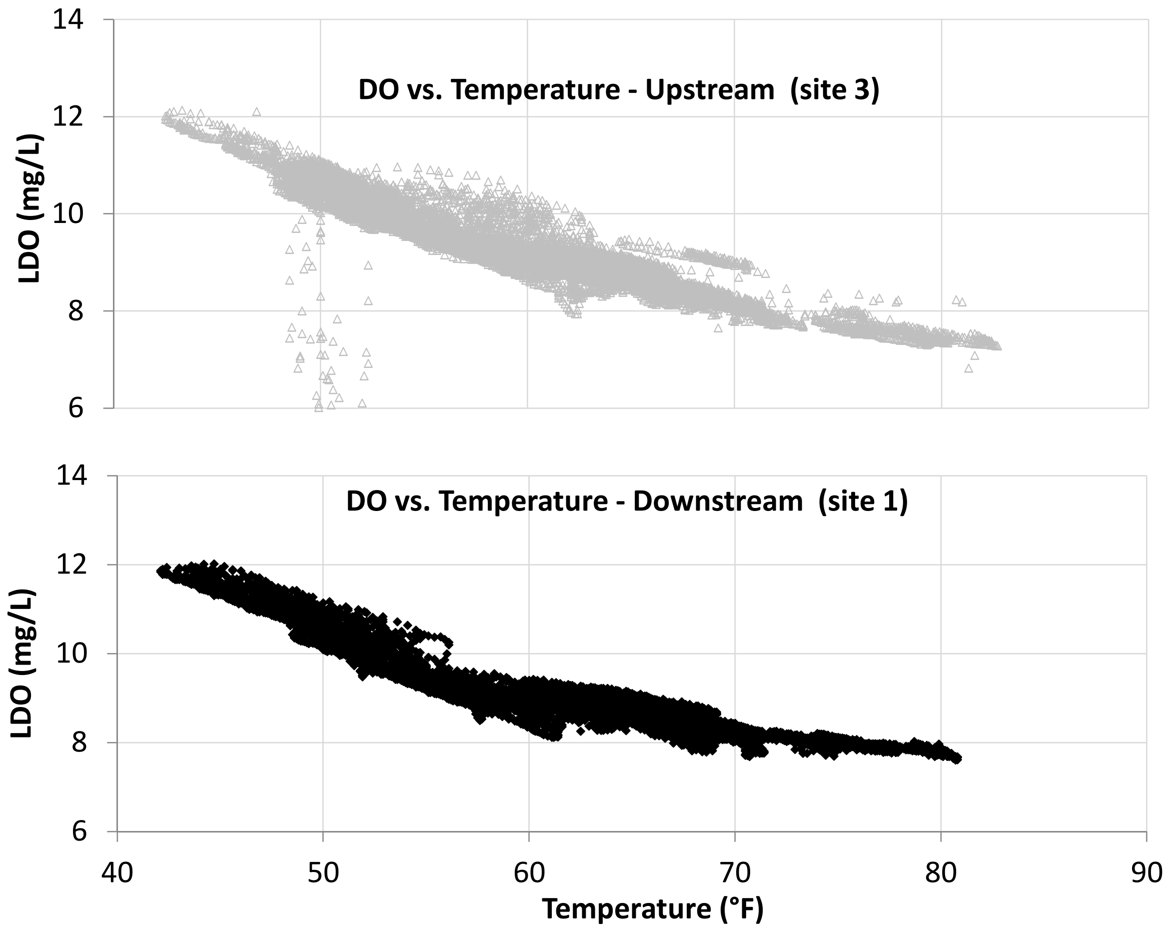



**Figure 20: Relationship between temperature and dissolved oxygen measured in LCC for Site 1 (downstream from I-59), and Site 3 (upstream from I-59).**

As a result, from this strong relationship between temperature and DO, changes in the stream temperature caused by daily temperature cycles and by rain events will affect DO values. As shown in Figure 15, the fall rain event of 11/25/14 caused a drop in the stream temperature upstream from I-59 crossing (Site 3), causing an increase in DO value, while DO measurements in Site 1 were not as significantly affected. On the other hand, the late spring rain events of 7/13/14 caused an increase in Site 1 temperature, and a drop in DO values.

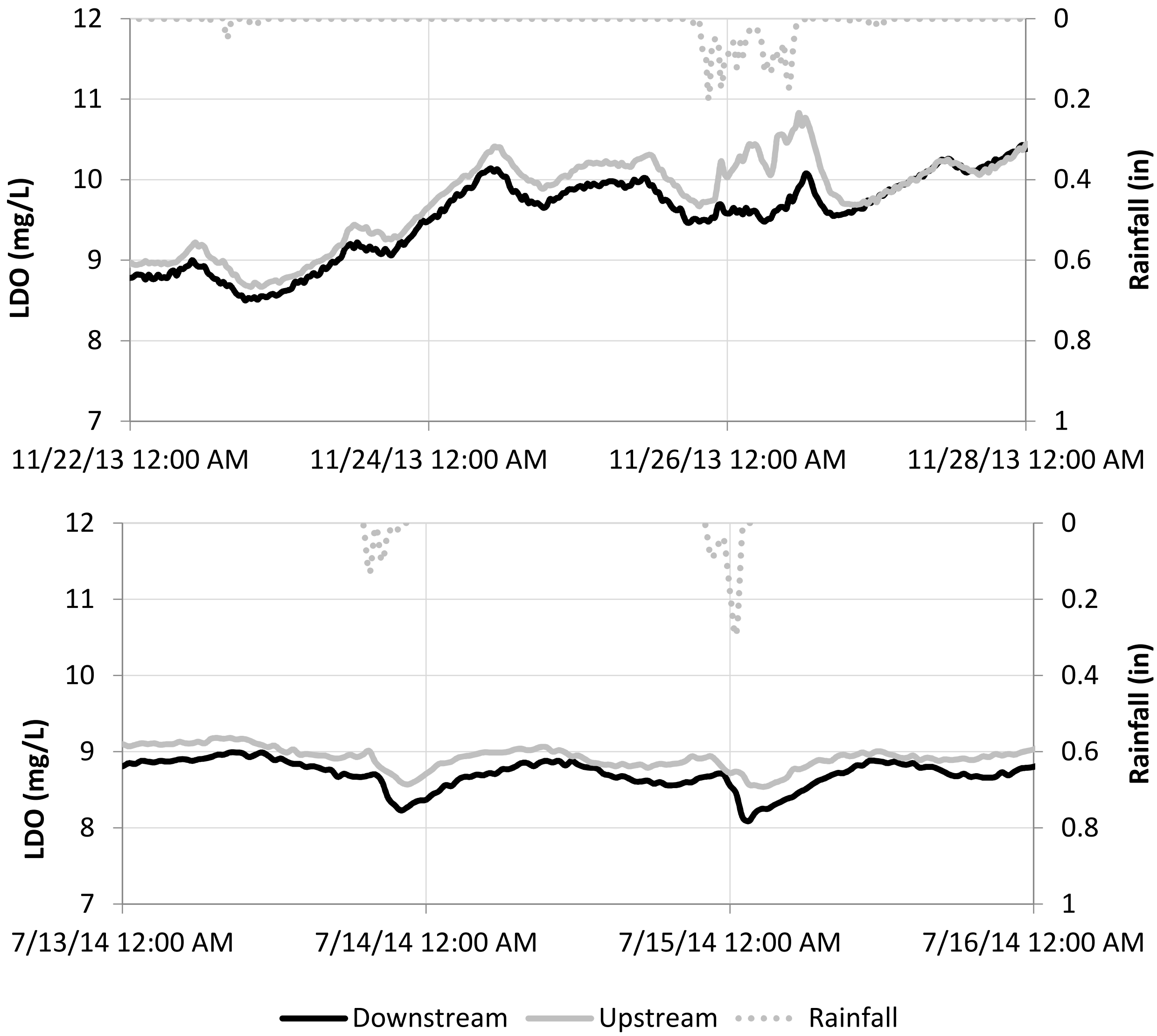



**Figure 21: Dissolved oxygen results measured in LCC for Site 1 (downstream from I-59) and Site 3 (upstream from I-59), and how this parameter was impacted by rain events, and more specifically by changes in water temperature shown in Figure 19.**

## 3.3. Event-based water quality characterization with auto sampler

The auto-samplers were deployed to help in event-based characterizations of the stream water, particularly how stream turbidity and TSS would vary during rain events. These results are presented in Figure 22.

Samples were collected between 10/1/2013 and 8/26/2014 and used to derive a relationship between the TSS and turbidity measured from these samples. The results indicate that for the low TSS values (under 8 mg/L), the turbidity across the crossing between LCC and I-59 (between Sites 3 and 1) are comparable; however, the turbidity is slightly higher downstream from the road. For higher TSS values, there is a steady increase of turbidity for samples collected in Site 3, up to the range of 18 NTUs. The results of turbidity for a large range of TSS in Site 1 also increased, but is the data points are much more scatter. Turbidity values reached 110 NTUs during one rain for a TSS value of 30.8 mg/L. In another rain event, for the same range of TSS (32.6 mg/L) a much smaller turbidity value (3.4 NTU) was recorded. This indicated that contributions from roadway runoff have a complex impact on the stream turbidity. Some events carry significant solids and increasing turbidity, while in other cases only minimally impact turbidity. This is possibly correlated to the antecedent dry period, and correlations between EMC values for turbidity and antecedent dry days are currently being developed.

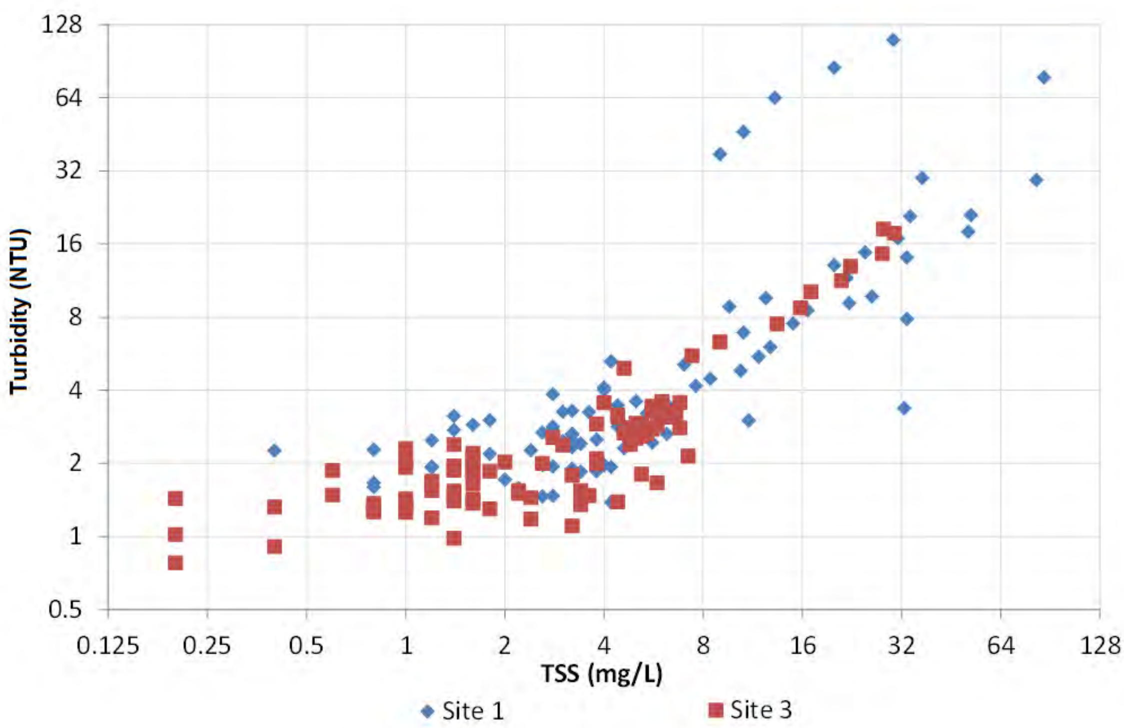



**Figure 22: Total suspended solids and turbidity from samples obtained with the use of auto samplers for Site 1 (I-59 East, downstream from I-59) and Site 3 (upstream from I-59).**

During typical rain events, as anticipated, turbidity and TSS were impacted by surface runoff. Some events, as the rain event occurred 10/6/13, indicated that this impact could be more pronounced at Site 1, downstream from I-59. As shown in Figure 23, good correlation was observed in TSS and turbidity values either upstream or downstream from I-59.

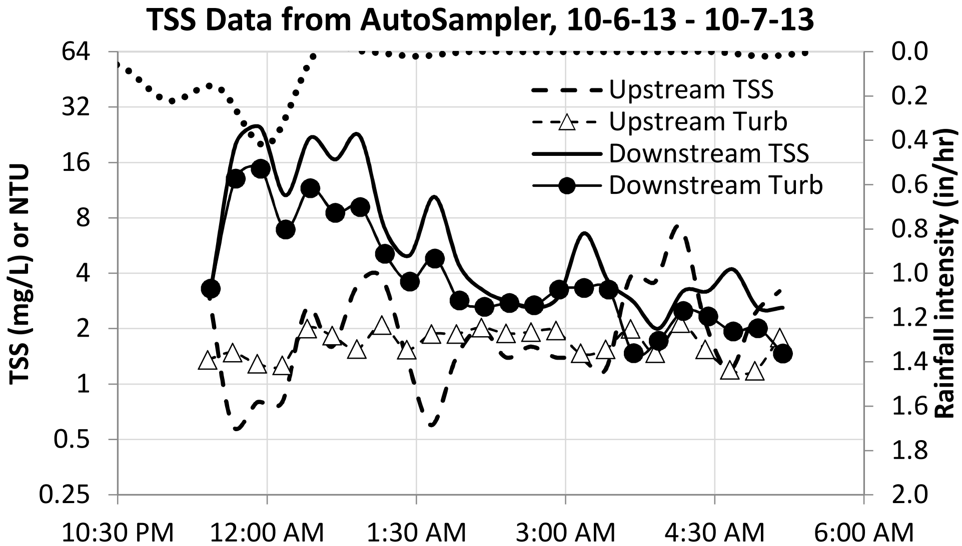



**Figure 23: TSS and turbidity results from samples collected with ISCO auto samplers during the rain event on 10-7-13, both for Site 3 (upstream from I-59) and Site 1 (downstream from I-59).**

It was attempted to develop a correlation between turbidity results obtained with the auto samplers and the results obtained with the environmental probe. This relationship is better developed for Site 1, and is presented in Figure 24. As shown, there is good correlation between the two approaches to measure turbidity. Results with the environmental probe tend to yield large turbidity values when these values exceed 16 NTU, whereas auto sampler results were larger for turbidity values under 4 NTU.

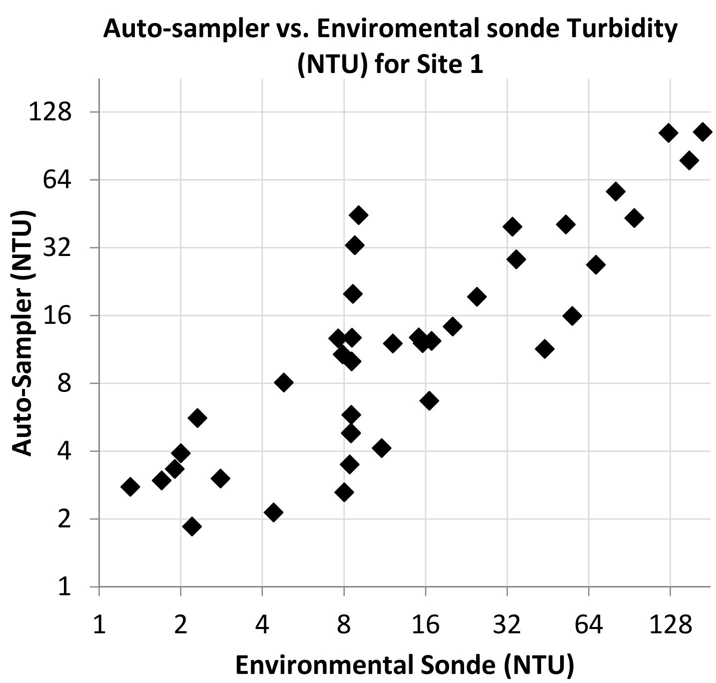



**Figure 24: Relation between turbidity values from the auto sampler and environmental probe measurements at Site 1.**

## 3.4. Macro-invertebrate characterization

As an addition to the initial scope of this research, a stream biomonitoring event was implemented in order to classify the condition of the LCC at Sites 1 (downstream from I-59) and 3 (upstream from I-59), and with this assess the impact of I-59 to the stream macro-invertebrate diversity. This assessment of living organisms in the stream was conducted in accordance with the Alabama Water Watch (AWW) Stream Biomonitoring Manual. The techniques used to collect and analyze the different types of organism focused on benthic macroinvertebrates. These organisms live in different physical habitats called microhabitats which are classified as the following: riffles, pools, runs, cracks and spaces, boundary layer, surface film, water column, and banks and overhangs. Macroinvertebrates are divided into three main Taxa groups, 1, 2 and 3. Group 1 has the least amount of tolerance for water quality pollution and group 3 is the most tolerant organism.

The following equipment were used for the collection of these macroinvertebrates:

- Two dip nets (one per site)
- Six pans (white or light colored)
- Two picture keys
- Waders and water proof boots
- Two bucket
- Four forceps
- Four observation cups or magnifying glasses, and
- Two stream Biomonitoring forms.

With the use of this material, macroinvertebrates were collected on site in different microhabitats. These collections were done according to the following procedure:

- By taking approximately 3 quality samples from the different microhabitats, this provided a wide variety of organism taxa groups with different tolerance levels.
- These samples should include collected matter from riffle areas, on the bottom of rocks and an area with slower moving current.
- Finding 10 or more of a specific insect will be adequate in representing that organism. Thus, a minimum of 50-75 organisms should be collected. Collecting more organisms may be necessary.
- These organisms may be latched onto the net, so it was at times needed to examine the net before going to collect another sample. **Organism were only handled with forceps**.
- Clean the net by dipping it in the shallow water and move it from side-to-side.

Specific, step by step instructions for the collection of stream macroinvertebrates for a kick net are in page 56 of the AWW manual. AWW also covers how to make a kick net if you cannot locate D-net. **Most importantly there must be as little disturbance to the sampling area**. Downstream collections should be made first and that section of water should be approached downstream if possible. Either Site 1 or 3 was not approached from upstream because this disturbed sediments in the stream. When placing back rocks and stones used to examined for macroinvertebrates, set the rocks carefully back in the same place to not disturb the existing stream.

While team members were collecting the samples, others were looking through and dividing the collected debris and plant matter for the macroinvertebrates. This made easier to organize the debris collected. If there was a large amount of debris, it was placed in a holding container before it was divided into smaller sections to be analyzed and sorted. Water was added to the bucket or container that the contents collected in the stream can be further sorted. There should be separate containers or pans to sort through the collected debris. The organisms were occasionally hidden on back on leaves and along sticks, so a thorough inspection of the sample was needed with forceps.

The sorting of the macroinvertebrates is described on the AWW reference. Forceps were used to pick up the organisms and the organism picture key to accurately identify the organisms. In order to identify the macroinvertebrates correctly, following questions were addressed:

- Was it on the water surface, attached to rocks or sticks or was it swimming on its own?
- How big is the body?
- Is it in sections or one part?
- Long, slender, round, or curved body shape?
- Does it have a shell?
- Does it have a tail(s)? How many?
- Does it have legs? How many pairs?
- Are the gills along the sides of the abdomen, on top, bottom, or under the legs? (this is where a magnifying glass come in handy)
- Does it have a distinct head?
- Are there antennae?
- Does it have pinching jaws?

The number of each type of organism on the stream was recorded on biomonitoring forms, one for Site 1 and another for Site 3. The number of a specific type of macroinvertebrate will be counted and used for the total for the corresponding taxa group and cumulative index value. The number of a collected organism will be represented with a different letter code as well A, B or C. Once enough organism have been identified, the organisms were released in shallow water near the riffle in which they were collected, not in strong currents because they would be quickly swept downstream and exposed to predators.

Results are expressed in terms of a Cumulative Index Value (CIV), and four classifications are possible: less than 11 – poor; between 11 and 16 – Fair; between 17 and 22 – Good; above 22 – Excellent. Both sites presented excellent CIV values, with Site 1 (downstream from I-59) with CIV equal to 28, while Site 3 with CIV equal to 32. The biomonitoring forms used in this evaluation are in the appendix of this final report.

## 3.5. Metals and oil and grease evaluation

Another addition to the research was the evaluation of heavy metals, oils and greases in samples collected at Sites 1 (downstream from I-59) and 3 (upstream from I-59) during rain events, as well a one-time sample collection at the drainage ditch next to Site 1. The heavy metal elements selected were Chromium (Cr), Copper (Cu), Nickel (Ni), Cadmium (Ca), Lead (Pb) and Zinc (Zn). The elements concentration was analyzed by an inductively coupled plasma optical emission spectrophotometer (ICP-OES; Varian Inc., CA, USA) according to the USEPA method 200.8.

An aliquot of a well-mixed, homogeneous aqueous sample is accurately measured, and thermal digested in acid condition. After cooling, the sample is made up to volume, then filtered through 0.45 µm (pore size) membrane for analyzing the total heavy metal concentration. The water sample for dissolved heavy metals concentration analysis were treated by filtering through 0.45 µm membrane (without adding acid and thermal digestion), and adding concentrated $HNO_3$ before ICP test to avoid clogging the ICP system.

The detection limits of various heavy metals were calculated by the following equation through analyzing a standard sample for 11 times:

$$\text{Detection limits} = \frac{Standard\ concentration\ \times 3\ \times standard\ deviation}{Average\ measured\ concentration}$$

The detection limits of each heavy metal is listed in Table 6.

**Table 6: Detection limits (µg L$^{-1}$) of various heavy metal element in storm water by ICP-OES**

| Element | Cr | Pb | Cd | Cu | Ni | Zn |
|---|---|---|---|---|---|---|
| **Detection limit** | 1 | 5 | 1 | 5 | 1 | 2 |

The oil and grease concentration in stormwater were analyzed according to USEPA Method 1664. Briefly, the oil and grease were extracted by *n*-hexane, then filtered and dewatered by $Na_2SO_4$. The extracts were then concentrated and dried, finally the oil and grease components amount were determined by gravimetric method. In the analysis process, the hexadecane/steric acid (1:1) spiking solution was prepared in acetone at a concentration of 2000 mg/L, and applied to verify the extraction efficiency and control the quality of this method. According the USEPA Method 1664, the detection limit is 5 mg/L, however, all the tested samples from stream had less than 5 mg/L of oil and grease. Few samples collected in the ditch were slightly above the detection limit.

### 3.5.1. Statistical analysis of the heavy metal concentration in upstream I-59 and downstream I-59

Table 7 shows summary statistics for all the stormwater samples taken from the two site close to I-59 (upstream and downstream). For all samples, the Cd concentration is negligible, the Cr and Pb concentration are all less than 3 µg/L. White and Bernhard (2014) measured the total edge of pavement constituent concentration in stormwater runoff I-10, and found the mean Cd, Cr and Pb concentration are 20, 30, and 30 µg/L, respectively, which are higher than our analyzed data (<3 µg/L). They also measured Cu concentration much higher than in LCC (200 µg/L), but the Zn concentration is comparable.

**Table 7: Heavy metal element (µg L$^{-1}$) concentration in LCC at Site 3 (upstream I-59) and Site 1 (downstream I-59).**

| | Number of Samples | | Mean | | Standard Deviation | | Median | |
|---|---|---|---|---|---|---|---|---|
| | Site 3 | Site 1 | Site 3 | Site 1 | Site 3 | Site 1 | Site 3 | Site 1 |
| **Cd** | 24 | 18 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Cr** | 24 | 18 | 1.8 | 2.4 | 0.6 | 6.6 | 0 | 0 |
| **Cu** | 24 | 18 | 12.1 | 13.0 | 17.1 | 7.3 | 9.5 | 13.3 |
| **Ni** | 24 | 18 | 3.0 | 4.2 | 2.3 | 4.3 | 1.9 | 2.2 |
| **Pb** | 24 | 18 | 1.4 | 0 | 3.2 | 0 | 0 | 0 |
| **Zn** | 24 | 18 | 29.4 | 41.5 | 20.6 | 54.1 | 21.4 | 23.9 |

The heavy metals in the stormwater come from various sources, including vehicle traffic, emissions, dust fall, precipitation, etc., which can be affected by traffic density, local land use, weather (White and Bernhard, 2014). There are significant differences in annual average daily traffic (AADT) load is 89000 for I-10, and 21670 for I-59 from state traffic measurements, and lower traffic count in I-59 is expected to yield less pollutants in the rainwater. Meanwhile, the water samples in our study are taken from stream, the dilution of stormwater pollutants by stream water will be contribute to the low heavy metal concentration.

The heavy metals concentration in stormwater from the ditch are higher than in stream (shown in Figure 25), which confirmed that the stream diluted the pollutants from road. These values approached, but were still generally lower than the ones presented by White and Bernhard (2014), except by Zinc, which was slightly higher in concentration.

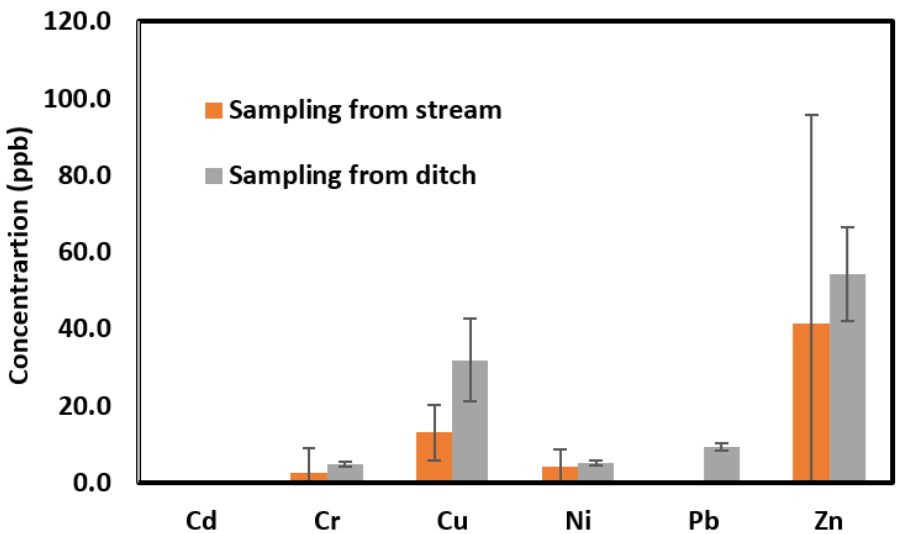
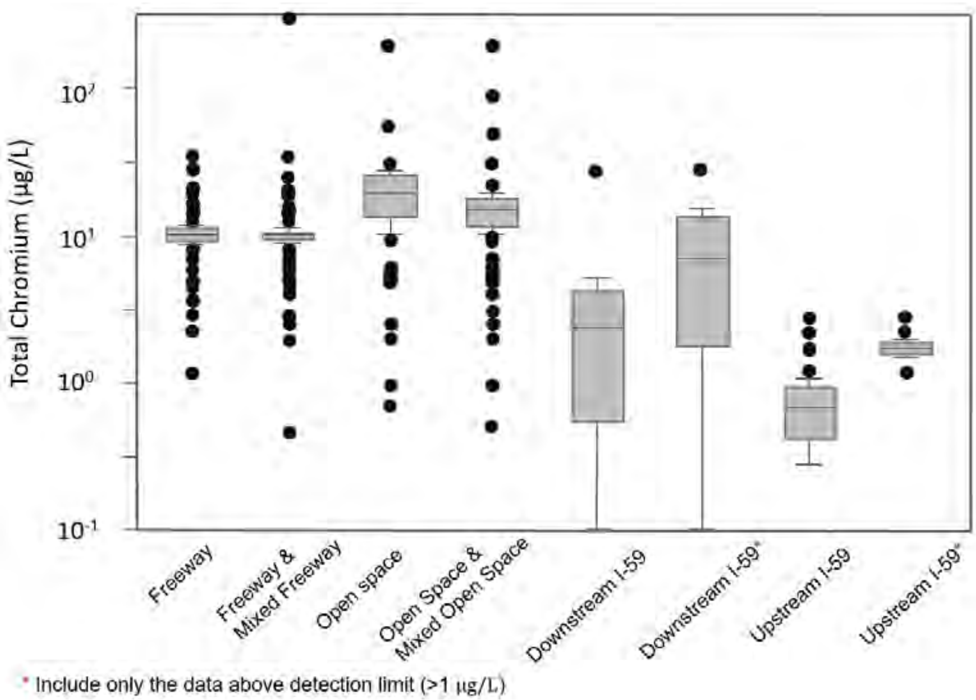



**Figure 25: Heavy metals concentration for stormwater samples taken from Site 3 (upstream I-59) and ditch next to I-59, which discharged into Site 1 (downstream from I-59).**

The heavy metal concentration for open space and freeway were compared with measurements presented in the National Stormwater Quality Database (Version 4.02_2015) accessed from the International Stormwater BMP Database and plotted in Figure 26a to 26d with the analyzed data. These figures present a whisker plot and compare results with the NSQD database for stormwater data for different land uses, and compared to LCC measured results for the upstream and downstream sites. In these plots, the top error bar represents the maximum value, while the bottom error bar represents the minimum value recorded. The top of the box represents the 3rd quartile value, the value in the middle of the box represents the average and the bottom of the box represents the 1st quartile value.

(a)




(b)

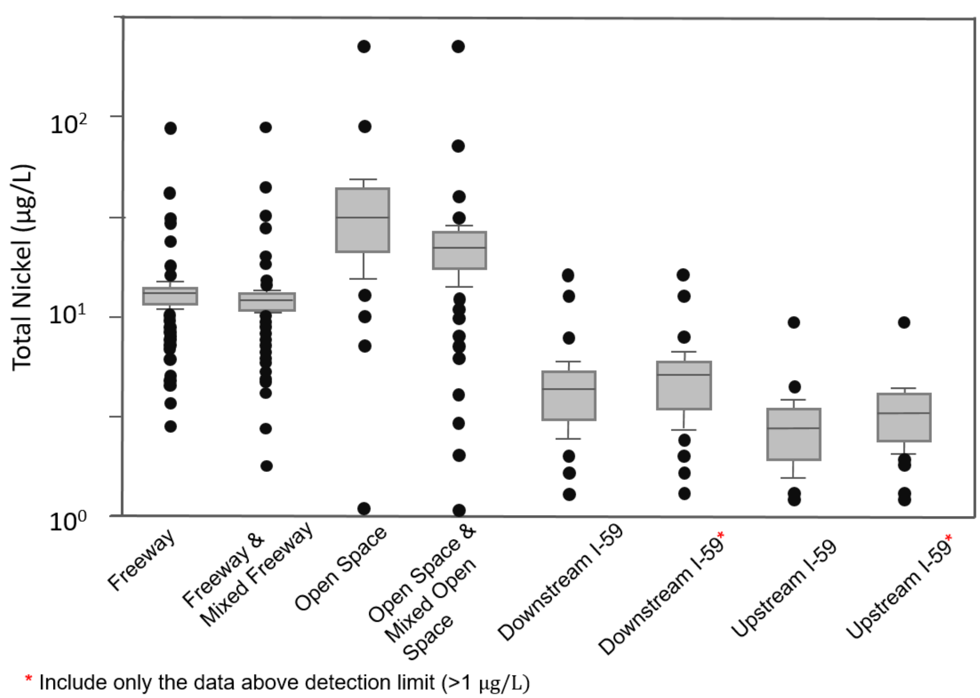
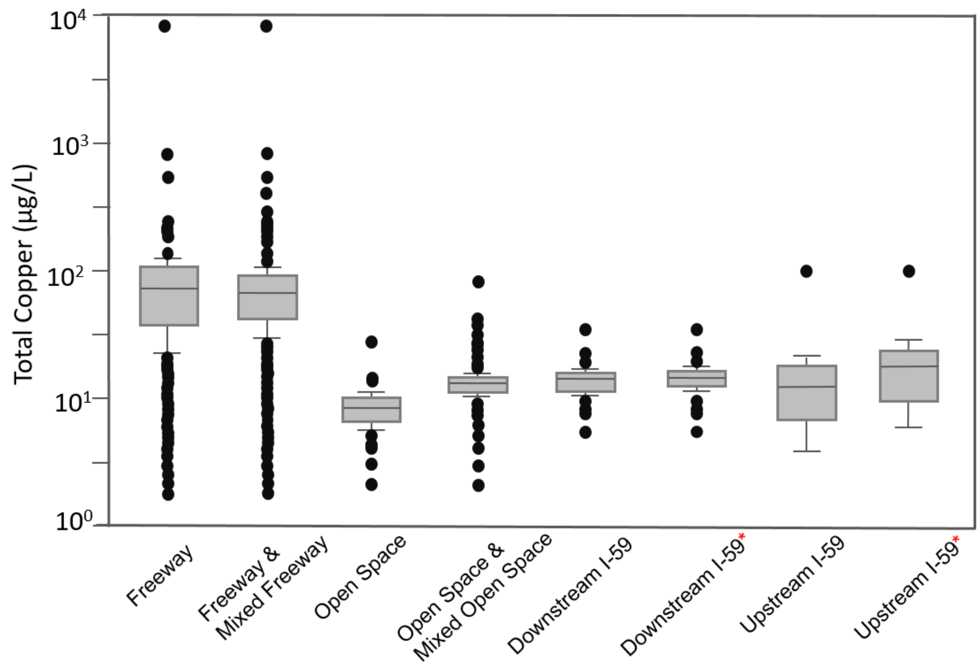



**Figure 26 a-b: Box and whiskers plots for heavy metals by land use. (a) Total chromium, (b) total nickel compared with results at Site 1 (downstream from I-59) and Site 3 (upstream from I-59). Data for freeway and open space are from the National Stormwater Quality Database, Version 4.02_2015.**

(c)




* Include only the data above detection limit (>5 µg/L)

(d)

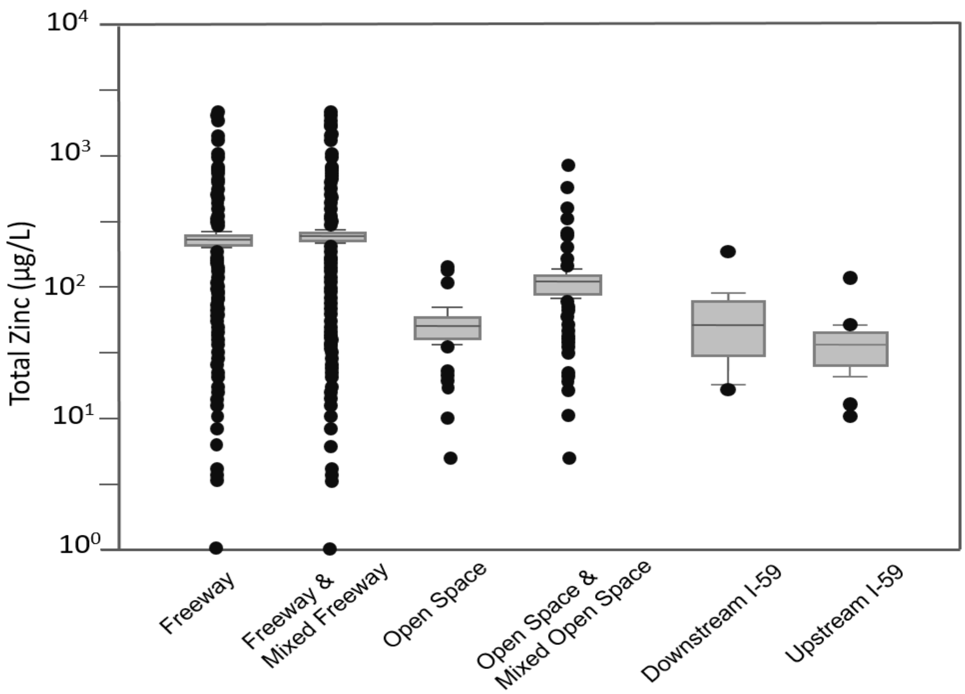



**Figure 26 c-d: Box and whiskers plots for heavy metals by land use. (c) total copper, (d) total zinc compared with results at Site 1 (downstream from I-59) and Site 3 (upstream from I-59). Data for freeway and open space are from the National Stormwater Quality Database, Version 4.02_2015.**

The samples in our studied sites have lower average Cr and Ni concentration than the samples in the National Stormwater Quality Database, but the samples in our studied sites showed comparable Cu and Zn concentration with open space sites in the National Stormwater Quality Database. The difference can be firstly due to the dilution of stormwater by streamwater. Also, the National Stormwater Quality Database does not include water samples from Alabama, the heavy metals concentration in rainwater may be varied at different location.

To evaluate the first flush, the average ratio of heavy metal concentration at each sampling time point were calculated by divided the value to average value. The changes of heavy metal amount vs time were plotted on the Figure 27 and 28. In the figures, the characters in x-axis, e.g. A, B, C…, indicate the samples time from 0, 15, 30… minutes after initial sample collection during the early stages of the rain event. The measurements of Cr and Ni concentration in Figure 27 indicate signs first flush for these constituents.

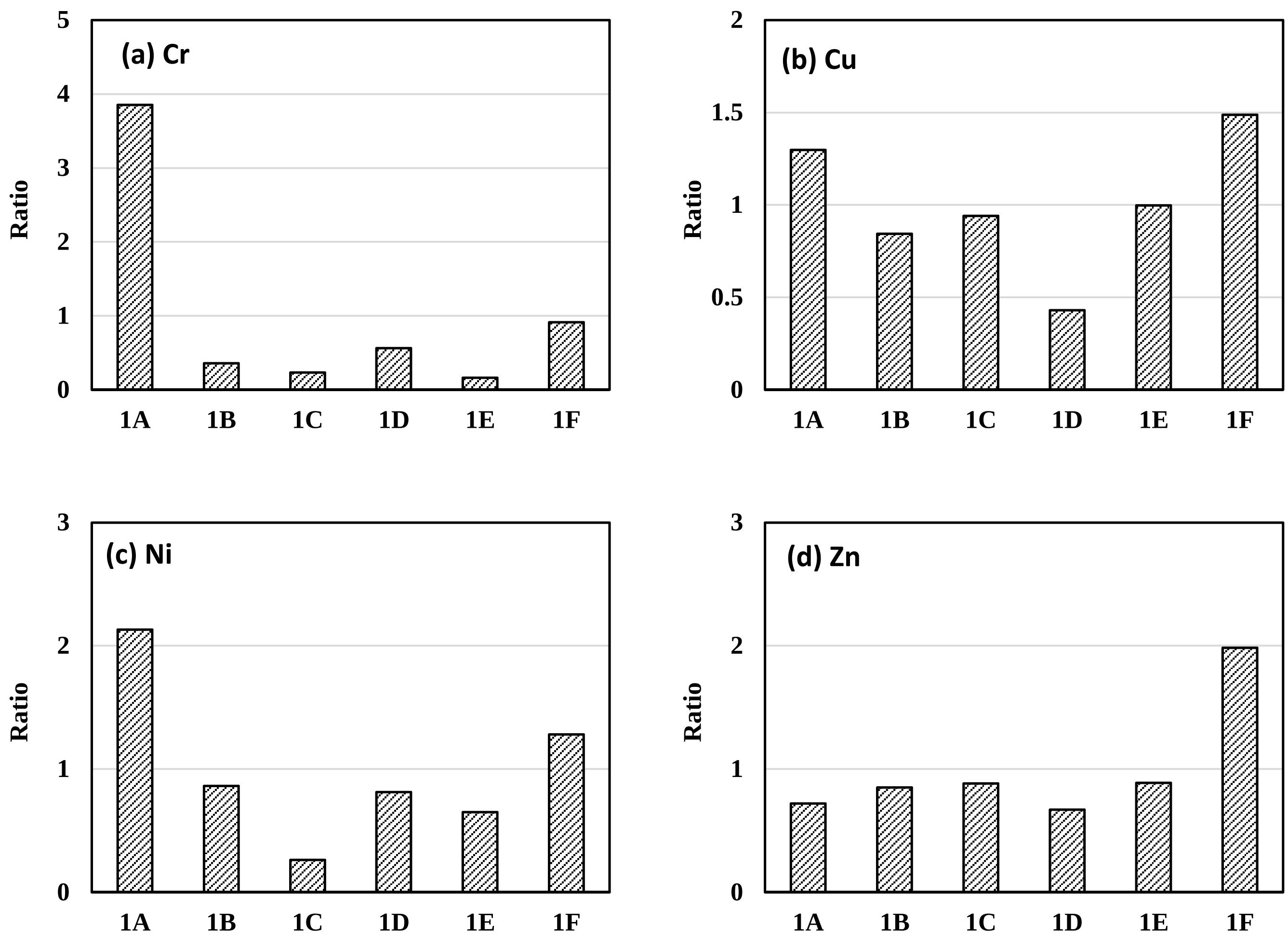



**Figure 27: Change of heavy metals at various time point for Site 1 (downstream I-59) samples.**

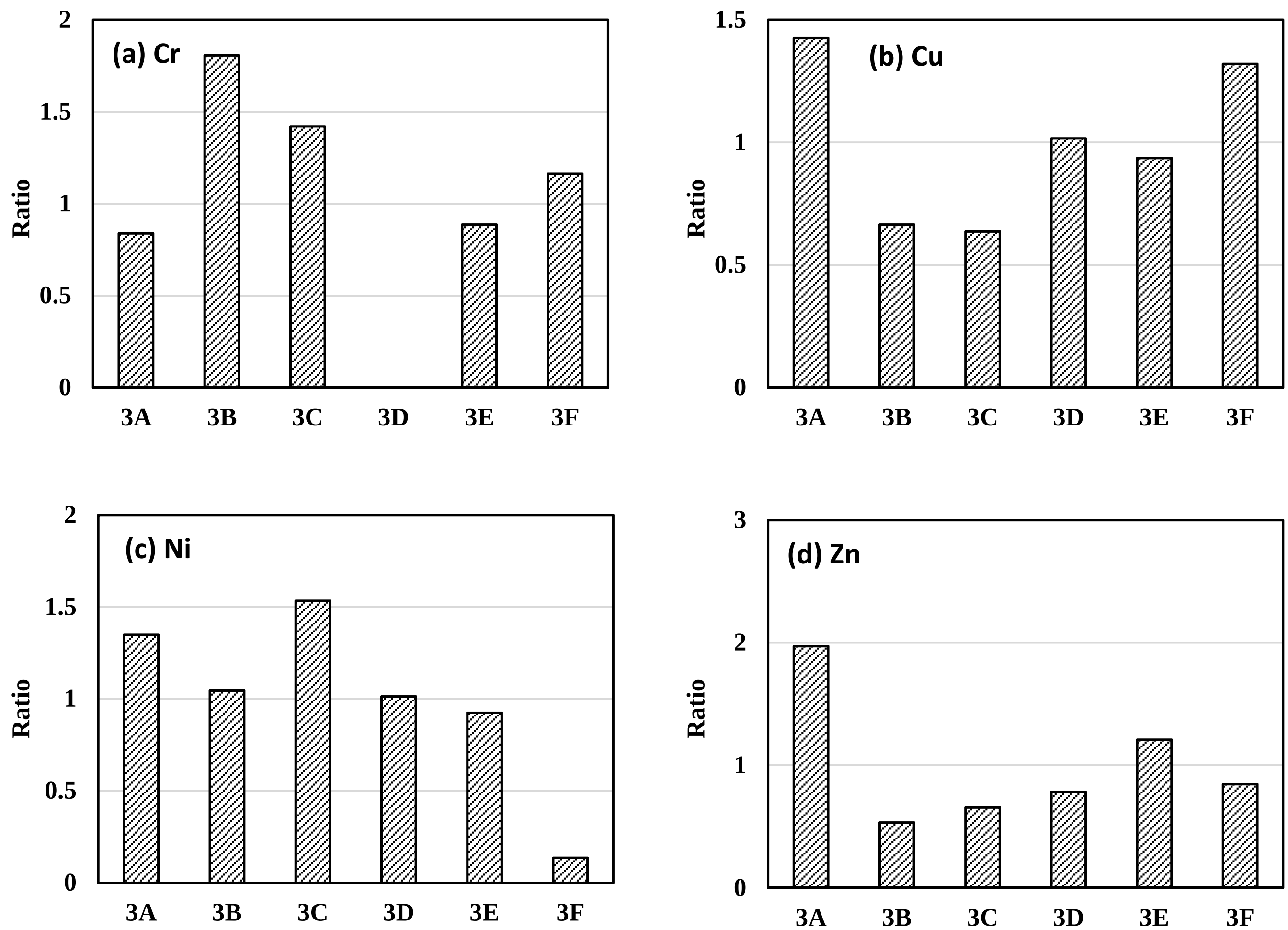



**Figure 28: Change of heavy metals at various time point for Site 3 (upstream I-59) samples.**

### 3.5.2. Oil and grease concentration in the stormwater from Site 3 (upstream I-59) and in the ditch next to I-59

Figure 29 indicates that the measured oil and grease concentration are lower than the minimum level of quantitation (5 mg/L) for all the samples taken from upstream I-59, however, 3 out of 6 samples in the ditch next to I-59 have the oil and grease concentration slightly higher than 5 mg/L. These data confirmed that the pollutants from road were diluted by the cleaner streamwater. For most sites in National Stormwater Quality Database (Version 4.02_2015), the oil and grease content are lower than their detection limits.

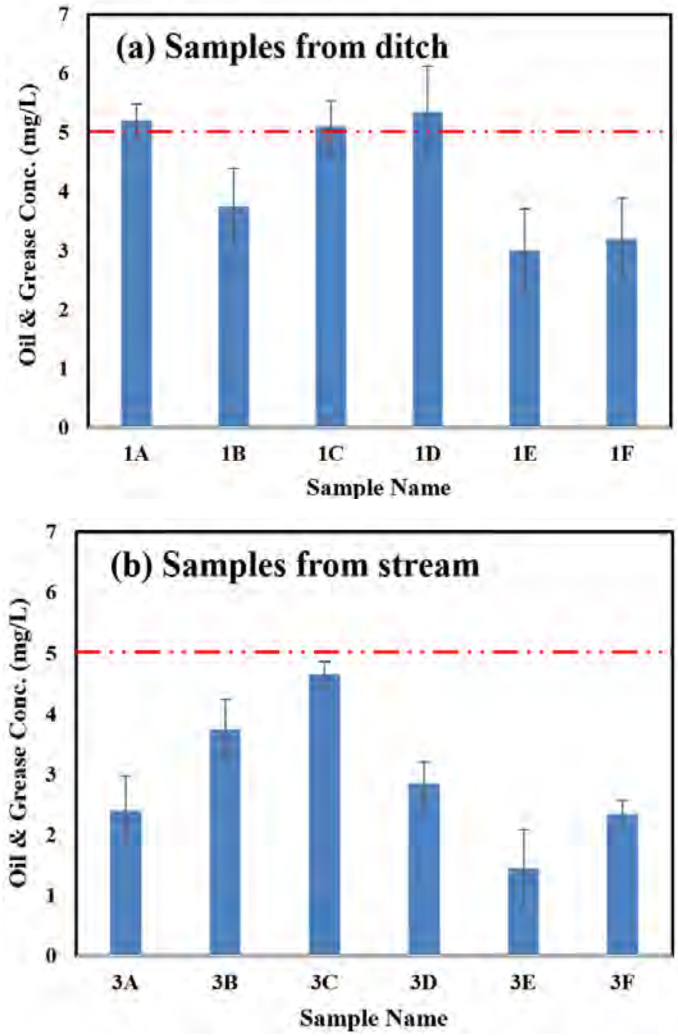



**Figure 29: Measured oil and grease concentration for stormwater samples (red line is the minimum level of quantitation).**

## 3.6. Final data analysis and summary of findings

While the hydrological measurements indicate that there is a measurable effect on the peak runoff measured in LCC downstream of the crossing with I-59, in general the impacts of the road to the stream are minor in terms of water quality, and in some cases the constituents levels were in levels below underdeveloped areas. In general, the selected water quality parameters of the stream indicate low levels of turbidity, solids, adequate pH, and low concentration of nitrogen and phosphorus species. Correlation of turbidity with traffic was in general poor. There was no clear correlation with the turbidity levels measured downstream from I-59 (Site 1) with the traffic count in between rain events. A slightly better correlation when the traffic count between rain events was associated with the rain depth. Following the approach by Cambez et al (2008), Figure 30 indicates that the levels of turbidity measured in Site 1 (both event-averaged levels and peak turbidity) increased with the product between traffic count and rainfall depth raised to the power of 1.5.

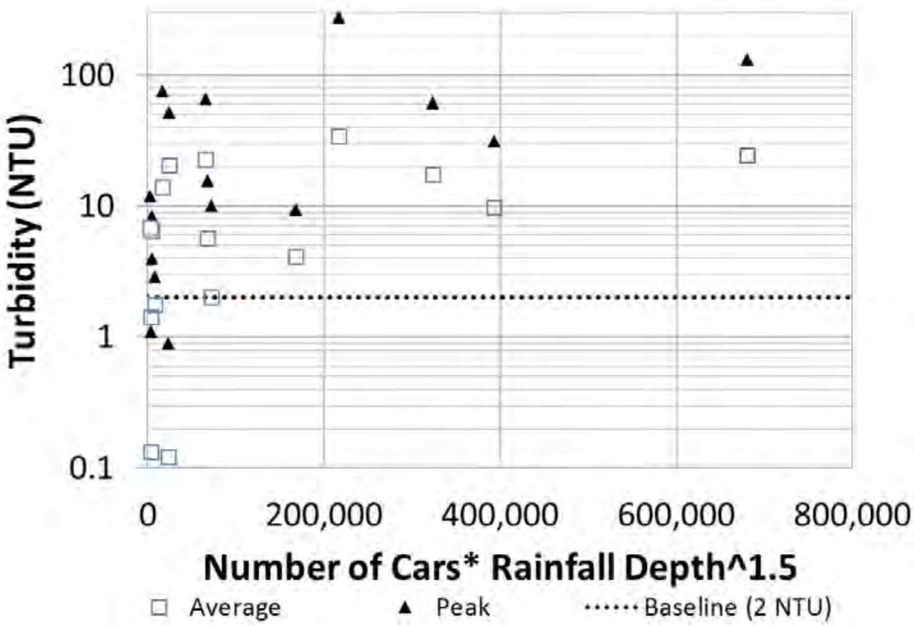



**Figure 30: Measured turbidity in Site 1 during rain events (average and peak) as a function of the traffic count times rainfall depth raised to the power of 1.5, following the approach by Cambez et al (2008).**

However, turbidity results were generally small downstream I-59 (baseline value was 2 NTU), which indicate low levels of solids, and associate contaminants, in water. Average concentration of heavy metals measured in the stream was generally smaller than any of the concentrations presented in the NSQD, except for copper. Concentration of metals in samples collected in the ditch was larger than the one measured in the stream, which may indicate that stream flow dilution decreased heavy metal concentration on the roadway runoff. Future investigation work should focus on metal concentration on the ditches next to roadways, particularly following resurfacing of pavements.

Figure 31 summarizes that the water quality of LCC indicate that water quality parameters from point samples for TSS, Total Phosphorus (TP) and $NO_3$+$NO_2$ are not significantly influenced by the roadway. The TSS levels are below the national average for land use, and seasonal the nutrient levels were also below the first Quartile of other land uses for both sites. The national standard deviation of Total Phosphorus (TP) for open space is significantly greater than the standard deviation for freeway land use. Although the TP levels coming from the specific land uses cannot be determined, the TP levels in the LCC are on average 0.13 mg/L with a maximum recording of 0.96 mg/L for the downstream site. The average and maximum levels of TP for the upstream site were 0.11 mg/L and 0.95 mg/L, respectively. The only land use where the LCC was above average for $NO_3$+$NO_2$ values was Freeway land use. The average $NO_3$+$NO_2$ for the upstream and downstream 0.5 and 0.46 mg/L, respectively, and the average $NO_3$+$NO_2$ for Freeways is 0.27 mg/L. However, the minimum $NO_3$+$NO_2$ value for the downstream were well below the minimum value for Freeway land use. These below average total phosphorous and nitrate plus nitrite levels of the both the upstream site (Site 3) and downstream site (Site 1) suggest that the surrounding open space/farmland does not have a significant impact on the immediate area.

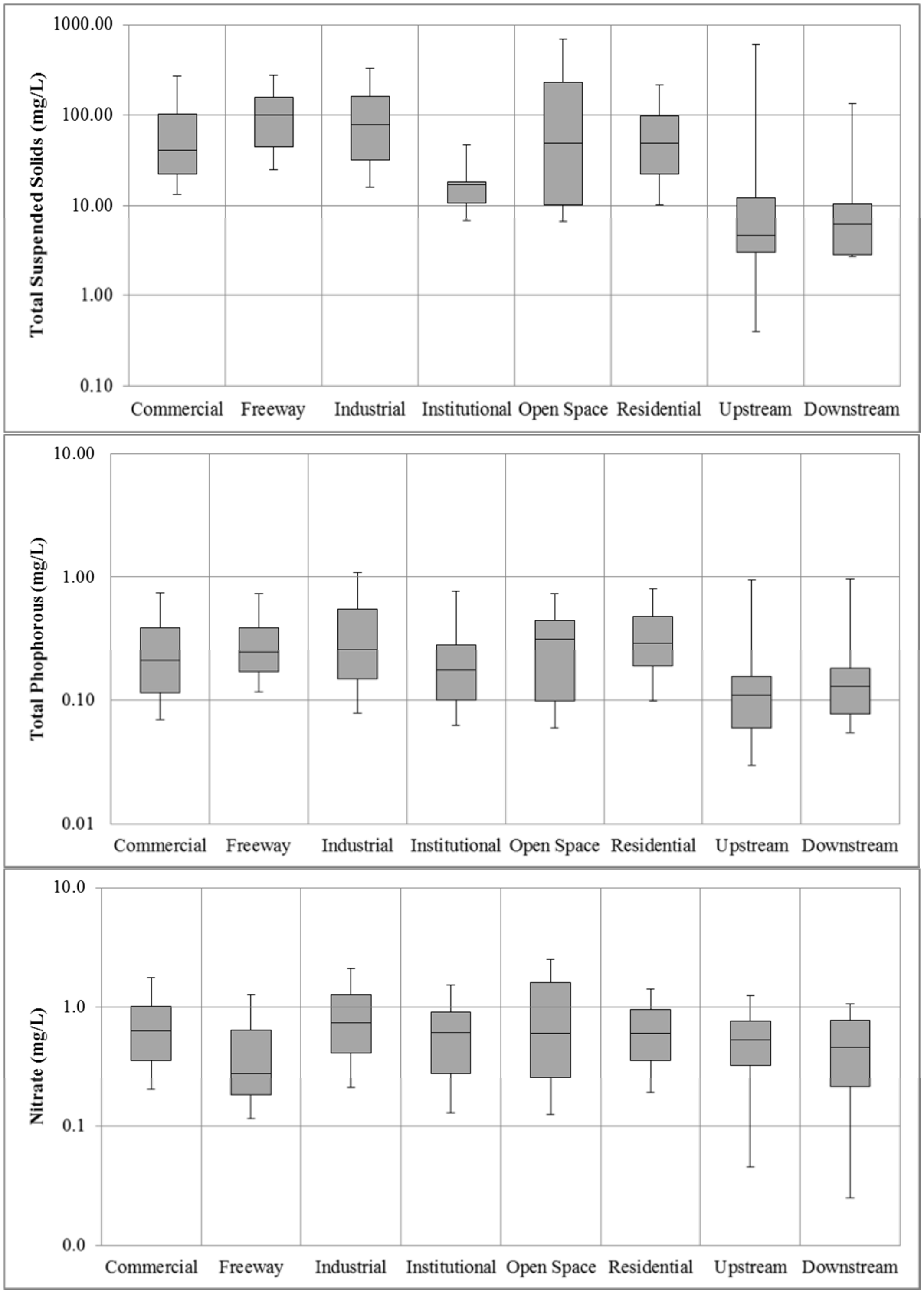



**Figure 31: TSS, TP and $NO_3$+$NO_2$ concentrations for Site 1 (downstream of I-59) and Site 3 (upstream of I-59) compared to other land uses concentrations present in the NSQD.**

# 4. Data analysis of LCC watershed

The large amount of data collected helps providing baseline information on the LLC watershed prior to future construction of the BNB in this watershed. However, the amount of data collected also allow for the development of a modeling study, enabling that impacts of rain events to be predicted in the watershed. Considering that a number of small streams will be intercepted by the BNB alignment, the approach used in this work, and possibly even some of the modeling parameters applied, could be used in other related studies on the post-construction impacts of the proposed road to other comparable streams.

Considering that only the LCC region upstream from Site 3 down to Site 1 is perennial, the focus of the modeling work was directed to this area, including all the catchments upstream from the roadway. The modeling study applies PCSWMM model, which applies the calculation engine of USEPA Storm Water Management Model (SWMM5.1). This model provides a great deal of functionality in terms of pre and post processing, including means to facilitate calibration work.

## 4.1. Modeling set-up and calibration

### 4.1.1. Data sources for modeling

The supporting data sources were used in SWMM and ArcGIS to georeferenced JPEG images as well as to spatially supported images to ensure the accuracy of the model. The images of the watershed were mainly used for visual reference and are not necessary for the development of the nodes, channels, storages, and outfalls.

The data used for the digital elevation model (DEM) was taken from the Tiger Products Database of the United States Census Bureau. The Tiger DEM files are provided by counties. Since the LCC watershed is located in both Jefferson and Saint Clair Counties. As the watershed is located in both of these counties, the DEM had to be joined to create one DEM. This DEM file was extracted and reduced in ArcGIS to focus on the area of the LCC. Once the DEM was corrected, contour lines were generated at 10 foot intervals and at 25 foot intervals in ArcMap. These contour lines would be used to define the subcatchment boundaries.

Another source of data that was utilized in the creation of the PCSWMM model was Global Mapper. A watershed was delineated in Global Mapper by first downloading the US Geological Survey Digital Elevation Data (NED) for a 30 m resolution from the USGS website. Once an elevation grid was provided, a watershed could be generated according to the following parameters: resolution (meters), stream threshold (drainage area), depression fill depth and digitizing tool operations. This Global Mapper generated watershed was used to validate and cross-reference the manually delineated watershed for PCSWMM. Finally, Google Earth was used to account for confirming natural drainage paths such as stormwater sewer systems and open channels carved from erosion, used in addition to the information gathered in scouting trips to the site.

### 4.1.2. Assumptions, formulations and parameters adopted for LCC modeling

The complexity of a model is determined by the amount of uncertainties of the input parameters. The complexity also depends on the level of discretization and the number of processes active (James 2005). Therefore, the assumptions applied to this model were given careful consideration as to how and when they would be implemented.

Subcatchment delineation was obtained with watershed generation tool in Global Mapper 13.0, a GIS software, from a DEM data obtained with the USGS for the catchment. The natural flow characteristics, the topography, land use, and the soil characteristics were also used to determine boundaries of subcatchments from the initial result obtained with GIS. Once the general outlines of the subcatchments were defined, natural runoff patterns were adjusted for each of the boundaries. Land use was considered in further dividing the subcatchments, as well obstacles to natural flow paths. Lastly, soil site characteristics from soil survey data (using ESDA SSURGO database) were used in subcatchment delineation. Figure 32 indicates that all subcatchments (total of 32) that were formed through the land and flow characteristics listed above. These subcatchments ranged from undeveloped forested areas to residential and roadway area. A majority of the subcatchments contain residential area and are also a mix of pastured land and undeveloped forested area. Therefore the soil characteristics did not vary significantly among the different subcatchments.

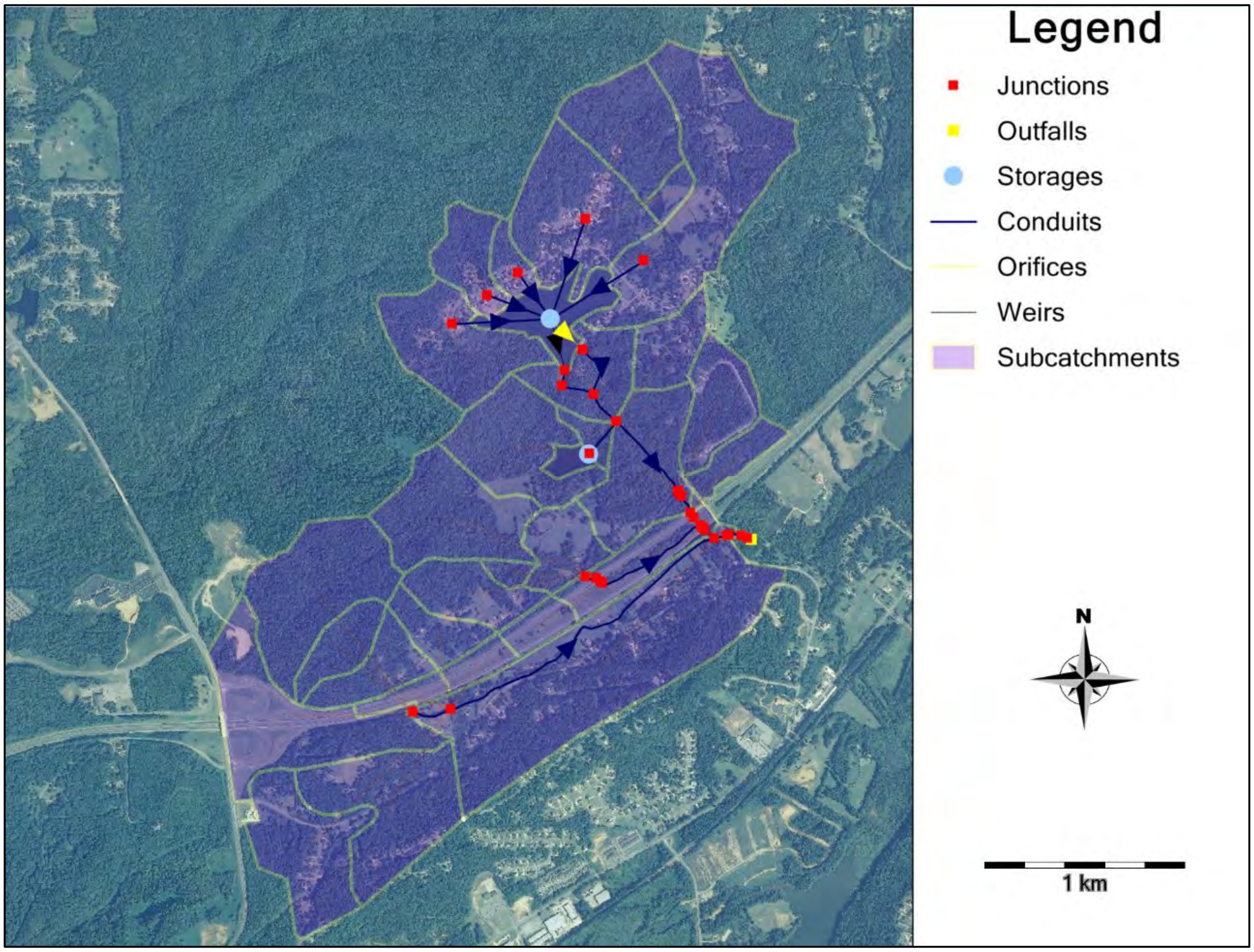



**Figure 32: LCC watershed generated in SWMM5 showing the structural elements used for the simulations runs.**

The characteristics of the soil played a part in the delineation of the watershed. Many soils in the LCC watershed had moderately high infiltration rates such as 1.98 to 5.95 in/hr (60.3 to 151.1 mm/hr); however, there were many areas which possessed a low infiltration rate such as 0.04 to 0.57 in/hr (1.01 to 14.5 mm/hr) (NRCS 2011). These areas of low infiltration rates would need to be separated from the areas of high infiltration rates to adequately model the abstraction characteristics of each subcatchment. The subcatchments were also combined if they possessed similar soil characteristic, natural drainage paths, land use, and slopes. Since there is such a large degree of uncertainty within the delineation of the LCC watershed, a 'relatively simple [model] may be selected in situations where field data are lacking,' as suggested by James (2005).

The recording of the amount of precipitation in the area was limited to the rain gauge located in the nearby farmland. Although this rain gauge was not located directly between Site 1 (downstream from I-59) and Site 3 (upstream from I-59), the rain gauge was within 0.43 miles (0.69 km) of both sites, which was considered an adequate distance representative for both sites. By using one rain gauge, the storm cells were assumed uniform for the entire area. However, through the use of rain gauges as triggering mechanism for the auto-sampler, the rain over that area was discovered to vary in intensity and duration over a fraction of a mile. Using two or three rain gauges would have created a better situation for applying to the calibration of the PCSWMM model (James 2005).

Sun et al. (2014b) produced SWMM results that suggest the modeling program is limited when simulating small rain events. This limitation can be an issue when modeling small rain events (<0.076 in/hr (1.94 mm/hr). With this in mind, individual rain events that produced less than 0.1 inches/hr (2.54 mm/hr) were not considered. In order to be considered an individual rain event, there had to be an inter-event time of six hours.

SWMM and PCSWMM can simulate of a number of pollutants present in the watershed and displaced by rain events. The following is required information for each pollutant: pollutant name, concentration units, concentration in rainfall concentration in groundwater, concentration in dry weather flow and first-order decay coefficient. Additionally, pollutants can be reliant or dependent on one another. For example the runoff concentration of phosphorous or nitrogen can be a fixed fraction of the runoff concentration of suspended solids. In this model study, suspended solids were tracked through the LCC watershed. Suspended solids were measured via grab samples and auto-sampler samples. Through measuring turbidity and total suspended solids for each auto-sampler sample, a distinct relationship was formed for the LCC watershed.

There are many features and elements to identify when creating a hydrological model of a watershed in PCSWMM, and these are characterized either through a field site inspection or using an updated virtual map with geographical information. According to Rossman and Supply (2005), these elements include dams, ponds, storage tanks, pump wells and pump stations, the largest diameter conveyances, tributaries, diversions, outfalls, weirs, and gates.

The simplest elements to assign were the conduits and their junctions. A centerline shapefile was created using ArcMap. This allowed for the use of the "snap-to-function" tool in PCSWMM when uploaded as a layer. The existing channelized sections and junctions of the LCC were clearly defined in the ArcMap program, which allowed for an accurate representation of the actual stream. The channel geometry was defined using the surveying data obtained from the total station. The channel geometry varied once the model was run. These variations are discussed in the section on Range of Variability.

There is only one outfall in the LCC watershed model. This outfall is located upstream of the Mill Creek dam just on the upstream of a property owner's pond. This pond at the outfall sometimes causes a backwater effect upstream at the downstream site of the interstate. Initially, there were only two weirs as the exit flow for both of the storage elements. Since the flow at the outfall needed to be restricted, another weir and orifice were placed, leading to the outfall. The additional weir and orifice restricted the flow in order to mimic the stream flow of the LCC.

The LCC watershed area of interest (AOI) contained two storage elements. The first was a large residential lake that covers 35.4 acres (14.3 hectares). The second storage element was a smaller pond, called J.M. Roberts Pond, which covers 6.8 acres (2.75 hectares). The storage curves for these tanks were calculated through the use of ArcMap. Contour lines were developed in ArcMap at 10 ft (3.04 m) intervals. The original depth of the storage unit could then be estimated. The calculated storage curves are provided below in Table 8. The storage units had the largest impact on the calibration of the surface water flow.

**Table 8: Storage curves for residential lake and JM Roberts Pond created in ArcMap 10**

| Residential Lake | | | JM Roberts Pond | | |
|---|---|---|---|---|---|
| **Elevation (ft)** | **Depth (ft)** | **Area($ft^2$)** | **Elevation (ft)** | **Depth (ft)** | **Area($ft^2$)** |
| **860** | 0 | 1,543,405 | 800 | 0 | 295,271 |
| **850** | 10 | 1,041,057 | 795 | 5 | 221,453 |
| **840** | 20 | 580,181 | 790 | 10 | 166,090 |

Another characteristic that needed to be specified were the subcatchment widths. This was done by creating a layer shapefile that represented the subcatchments overland flow path. Within the subcatchment boundaries, 1-3 flow path lines were drawn to represent the average area weighted values (Schmidt 2005). Once these paths were created, the file was applied to the flow length/width calculation tool to be generated and implemented into the subcatchment layer.

To model the surface water of the LCC, the dynamic wave routing was chosen. The reason the dynamic wave model was chosen over the kinematic wave routing was the lack of the kinematic wave method's ability to account for backwater effects, entrance/exit losses, flow reversal, or pressurized flow (Rossman and Supply 2005). A backwater situation was detected at the downstream site of the interstate. When large flows occurred, a constraint downstream caused a backwater effect to travel up to the upstream observation location. This occurrence could not be tracked using the Kinematic wave. Another advantage of using the dynamic wave routing method over the kinematic method is that the dynamic wave method produces the most theoretically accurate results by solving the complete one-dimensional Saint Venant flow equations, Equations 1 and 2:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0 \qquad (1)$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) + gA\frac{\partial H}{\partial x} + gA\left(S_f - H_L\right) = 0 \qquad (2)$$

Where:

$Q$ = flow rate through the conduit (CFS)
$H$ = hydraulic head of water in the conduit (ft)
$A$ = cross sectional conduit area ($ft^2$)
$S_f$ = friction slope
$h_L$ = local energy loss per unit length of conduit (ft)
$g$ = acceleration of gravity ($ft/s^2$)

The groundwater interrelation was established in the aquifer editor. This relationship was not determined until once all of the other parameters were adjusted. SWMM computes the groundwater flow as a function of groundwater and surface water levels through the use of Equation 3:

$$Q = A1(H_{GW} - H^*)^{B1} - A2(H_{SW} - H^*)^{B2} + A3(H_{GW}H_{SW}) \qquad (3)$$

Where:

$Q_{GW}$ = groundwater flow (CFS per acre)
$H_{GW}$ = height of saturated zone above bottom of aquifer (ft)
$H_{SW}$ = height of surface water at receiving node above aquifer bottom (ft)
$H^*$ = threshold groundwater height (ft)

A1 = groundwater flow coefficient
B1 = groundwater flow exponent
A2 = surface water flow coefficient
B2 = surface water flow exponent
A3 = surface-GW interaction coefficient

The groundwater component of this model was quite complex to implement. The site upstream of the interstate shows characteristics of a receiving stream, while the downstream site shows characteristics of a giving stream. One single aquifer that fed the LCC watershed was initially assumed. Furthermore, an assumption that the water table was 20 to 30 feet (6.1 to 9.1 m) below the dam located further downstream from the downstream observation site was applied. The assumption that the bedrock is at a higher elevation in this area was applied as well due to the region's less permeable soil, compared to a region such as the lower coastal plains of the southeastern United States (Moynihan 2013). Thus the aquifer is shallower due to the high bed flow.

Later, a second aquifer was assigned to specific subcatchments. The use of multiple aquifers proved to have a more accurate representation of the surface and groundwater flows (Moynihan 2013). The peak flows were reduced as well as correcting the recession curve. Each of the parameters used for the aquifers is listed in Table 9. All of the existing parameters for the aquifers were not changed from the default parameters. These values were validated with the soil properties of various soil types listed in Table 10 (Rossman and Supply 2005).

**Table 9: Groundwater properties of the two aquifers in the PCSWMM model.**

| Aquifers | AQ1 | AQ2 | AQ3 | AQ4 |
|---|---|---|---|---|
| **Porosity** | 0.43 | 0.43 | 0.43 | 0.43 |
| **Wilting Point** | 0.15 | 0.15 | 0.15 | 0.15 |
| **Conductivity (in/hr)** | 1 | 1 | 1 | 1 |
| **Bottom Elevation (ft)** | 674.79 | 684.79 | 735 | 750 |
| **Water Table Elevation (ft)** | 720 | 732 | 785.866 | 770.5 |

Other than the USDA soil survey data, there was no other soil survey data provided for this project. Therefore, altering these aquifer parameters would have only been speculation. However, the water table was best estimated by the geographical information provided by the Tiger/Line® shapefiles of the United States Census Bureau. The digital elevation model was downloaded for both Jefferson and Saint Clair County since parts of LCC watershed lie in both counties.

The Jefferson and Saint Clair County region is comprised mainly of limestone, chert, and sandstone from the Knox Group, Sequatchie Formation and Chickamauga Limestone, and Red Mountain Formation. This allows for a significant conveyance of groundwater through the region, which supports the perennial nature of the LCC.

**Table 10: Aquifer properties for various soil types, taken from Rossman and Supply (2005).**

| Soil Texture Class | Hydraulic Conductivity, K (in/hr) | Porosity, φ (fraction) | Field Capacity (fraction) | Wilting Point (fraction) | Suction Head, Ψ (in) |
|---|---|---|---|---|---|
| **Sand** | 4.74 | 0.437 | 0.062 | 0.024 | 1.93 |
| **Loamy sand** | 1.18 | 0.437 | 0.105 | 0.047 | 2.4 |
| **Sandy Loam** | 0.43 | 0.453 | 0.19 | 0.085 | 4.33 |
| **Loam** | 0.13 | 0.463 | 0.232 | 0.116 | 3.5 |
| **Silt Loam** | 0.26 | 0.501 | 0.284 | 0.135 | 6.69 |
| **Sandy Clay Loam** | 0.06 | 0.398 | 0.244 | 0.136 | 8.66 |
| **Clay Loam** | 0.04 | 0.464 | 0.31 | 0.187 | 8.27 |
| **Silty Clay Loam** | 0.04 | 0.471 | 0.342 | 0.21 | 10.63 |
| **Sandy Clay** | 0.02 | 0.43 | 0.321 | 0.221 | 9.45 |
| **Silty Clay** | 0.02 | 0.479 | 0.371 | 0.251 | 11.42 |
| **Clay** | 0.01 | 0.475 | 0.378 | 0.265 | 12.6 |

### 4.1.3. PCSWMM calibration process

The PCSWMM calibration processes varied parameters such as surface roughness, percent impervious and junction invert elevations (ft) during this process. Other parameters such as the saturated hydraulic conductivity, $K_{sat}$ (in/hr), minimum infiltration rate (in/hr), decay constant (1/hr), and drying time (days) were not varied with the calibration process. The calibration of the PCSWMM model was carried out using the Sensitivity-based Ratio Tuning Calibration (SRTC) tool offered in the PCSWMM packet. The SRTC tool helped detect the sensitive and insensitive parameters of the LCC watershed model. The method to determine each parameter is described in the following sections.

To run the model, an initial set of input parameters was defined. The initial parameter selection was based on the SWMM 5.0 Manual (Rossman and Supply 2005) and the NRCS soil characteristic survey for the Jefferson and Saint Clair county area. The saturated hydraulic conductivity was determined by defining the soils types for each subcatchment. This was done by overlaying the georeferenced NRCS soil map (**Error! Reference source not found.**) in ArcMap with the delineated subcatchments, the different soil types were assigned to each subcatchment. For subcatchments with multiple soil types that were evenly distributed across the plan, the saturated hydraulic conductivities were averaged across the area to represent the minimum infiltration rate (in/hr). Most subcatchments were composed of 2 to 3 different soil types. If the soil type covered more than 50% of the subcatchment, then that soil type was chosen as the predominant soil type and that infiltration rate represented the minimum infiltration for the subcatchment.

$K_{sat}$ was determined through the application of the maximum infiltration rate on the Horton curve definition, since the Horton infiltration method was selected as the infiltration model in PCSWMM. Horton's equations were used to calculate the potential infiltration rate as a function of time and the potential cumulative infiltration as a function of time in Equations 4 and 5, respectively.

$$f = f_c + (f_0 - f_c)e^{-kt} \qquad 4$$

$$F = \int_0^t f dt = f_c t + \frac{f_o - f_c}{k}(1 - e^{-kt}) \quad 5$$

Where:

$F$ = cumulative infiltration at time t

$f_p$= the infiltration capacity (depth/time) at time t

$k$= a constant representing the rate of decrease in $f$ capacity

$f_C$= a final or equilibrium capacity

$f_O$ = the initial infiltration capacity

Most of the soils in the LCC watershed are considered to be dry soils with dense vegetation. Therefore the soils in the NRCS group A were multiplied by 2 to calculate the maximum infiltration rate. Table 11 represents the selected $K_{sat}$ and minimum infiltration values as determined from the NRCS web soil survey tool. In addition to $K_{sat}$, the Horton's infiltration rate decay constant, k, the drying time and the depression storage values did not vary during the duration of the model (Rossman and Supply 2005). The default values assigned by SWMM were 2 $^{1}$/hr and 7 days, for the decay constant and the drying time, respectively. Typical values for the decay constant ranged between 2 and 7 $^{1}$/hr, and typical values for the drying time ranged from 2 to 14 days. The default value for both impervious and pervious depression storage was 0.05. Overall, these parameters were determined during the calibration stage to be insensitive parameters; therefore, the initial default values were maintained.

Another parameter that was not altered once applied were the storage curves for the residential lake and the JM Roberts pond. As mentioned earlier, the storage had a large impact on the stream flow, and the storage curves are represented in Table 8. The surface elevations of the subcatchments also did not vary throughout the calibration process. Since the average invert elevation for the junctions was 726.8 feet (221.5 m), the surface elevations were initially approximated to be 60 feet (18.3 m) above the receiving node invert elevation. Both the observed flow and stream flow level were kept constant during the calibration process. The stream flow rate was the primary parameter used to calibrate the model. As mentioned previously, the flow rate measurements came from the AV sensors, which are located upstream and downstream of I-59 (Sites 3 and 1 respectively). The AV sensor exports Excel files through the Flow Link software. These Excel files were converted into data files, and, eventually, time series files, in order to be accessed in PCSWMM. Once these files were uploaded for both sites, the simulated stream flow rate could be compared and calibrated to this observed flow. The stream level was another method of calibrating the hydrological elements of the LCC model. The stream level was also measured by the AV sensor and converted to time series files in order to be used in the calibration of the model.

**Table 11: Adopted saturated hydraulic conductivity also known as the minimum infiltration rate as well as the maximum infiltration rate used in PCSWMM.**

| Subcatchment | Maximum Infiltration Rate (in/hr) | Minimum Infiltration Rate (in/hr) |
|---|---|---|
| **S_1** | 5.24 | 2.62 |
| **S_2** | 1.58 | 0.79 |
| **S_4** | 3.00 | 1.285 |
| **S_5** | 1.58 | 0.79 |
| **S_6** | 5.24 | 2.62 |

| | | |
|---|---|---|
| **S_7** | 5.24 | 2.62 |
| **S_8** | 5.24 | 2.62 |
| **S_9** | 5.24 | 2.62 |
| **S_10** | 2.55 | 1.28 |
| **S_11** | 5.24 | 2.62 |
| **S_12** | 3.54 | 1.77 |
| **S_13** | 2.55 | 1.28 |
| **S_14** | 4.04 | 2.02 |
| **S_15** | 4.04 | 2.02 |
| **S_16** | 4.04 | 2.02 |
| **S_17** | 3.54 | 1.77 |
| **S_18** | 2.55 | 1.28 |
| **S_19** | 5.24 | 2.62 |
| **S_20** | 2.55 | 1.28 |
| **S_21** | 4.04 | 2.02 |
| **S_22** | 5.24 | 2.62 |
| **S_23** | 3.00 | 0.65 |
| **S_24** | 4.04 | 2.02 |
| **S_25** | 5.24 | 2.62 |
| **S_26** | 4.04 | 2.02 |
| **S_27** | 4.04 | 2.02 |
| **S_28** | 3.00 | 1.28 |
| **S_29** | 4.04 | 2.02 |
| **S_30** | 2.55 | 1.28 |
| **S_31** | 3.00 | 1.28 |
| **S_32** | 2.55 | 1.28 |
| **S_33** | 4.04 | 2.02 |

In addition to the hydrological parameters, the pollutant parameters were also modeled. Once the continuous Sonde turbidity was converted into TSS (mg/L) using the relationship discussed in the Results section of this paper, the time series files were uploaded into the PCSWMM time series manager. The initial pollutant parameters were taken from the SWMM5 Applications Manual (Gironàs et al. 2009). While these values were suggestions, this was a good starting point for the calibration of pollutants within the LCC.

The SWMM applications manual used the exponential buildup function (EXP). The buildup function is represented below in Equation 6. The initial values for the maximum buildup rate and the buildup rate constant are listed in Table 12:

$$\boldsymbol{B = C_1(1 - e^{-C_2 t})} \qquad 6$$

Where:

B = pollutant buildup remaining on the surface at time t (lbs);

$C_1$ = maximum buildup possible (lb/area-ft);

$C_2$ = buildup rate constant at a time t (1/day).

For the washoff process in SWMM5, the exponential function (EXP) was chosen over the event-mean concentration function due to the continuous data provided by the Water Quality Sonde (Gironàs et al. 2009). Without the continuous Sonde data for an estimation and calibration of the exponential function washoff variables, the event-mean concentration would have provided a more sufficient approach to the calibration of TSS in the LCC water quality model. The initial values for the washoff coefficient and the washoff exponent are listed in Table 13, and the exponential washoff function is shown in Equation 7.

$$W = C_1 \cdot q^{C_2} \cdot B \qquad 7$$

Where:

W = rate of pollutant load washed off at time t in (lbs/hr);

$C_1$ = washoff coefficient in units of (in/hr)-C2(hr)-1;

$C_2$ = washoff exponent;

q = runoff rate per unit area at time t (in/hr);

B = pollutant buildup remaining on the surface at time t (lbs).

**Table 12: Initial values for the exponential buildup function in SWMM.**

| Land Use | $C_1$ (lbs/area-ft) | $C_2$ (1/day) |
|---|---|---|
| **Interstate** | 100 | 0.2 |
| **Residential** | 45 | 0.5 |
| **Undeveloped** | 20 | 1.0 |

**Table 13: Initial values for the exponential washoff function in SWMM.**

| Land Use | $C_1$ (in/hr)$^{-C_2}$(hr)$^{-1}$ | $C_2$ |
|---|---|---|
| **Interstate** | 60 | 2.2 |
| **Residential** | 50 | 1.8 |
| **Undeveloped** | 45 | 1.1 |

Based on the literature by Chow (1973), the Manning coefficient of roughness (n) for the streams and overland flow depended on the land use and function of the surface (e.g., interstate, residential, etc.). Chow (1973) conducted a survey to thoroughly define n values by matching the channel bed slope and floodplain area to the best description of the surface condition and thus to determine n value. The default value for a smooth channel roughness was 0.01. The roughness was a sensitive parameter in the LCC model. Therefore, the SRTC tool was applied to obtain the optimum values of channel roughness.

The pervious and impervious roughness values for subcatchments were also calibrated in the SRTC tool. All of the roughness values for the watershed were optimized through a period of SWMM runs. The default values for n pervious and impervious subcatchment areas were 0.1 and 0.01, respectively. Eventually the n impervious values were changed to 0.005. This value better represented the characteristics of the watershed. Similarly, the value for pervious areas was changed to 0.2 across all subcatchments, and this corresponded to the majority of the areas in the LCC watershed.

Along with the coefficient of roughness, the percent impervious for the subcatchment area was also varied over the duration of the model. The default parameter given by SWMM was 25% impervious for all subcatchments. The subcatchments containing the right-of-way for the interstate were eventually assigned a value of 85% for percent impervious. The subcatchments containing only forested or wooded area were assigned a percent impervious of 10 to 13%. Lastly, the subcatchments containing residential and business lots were assigned a value of 13 to 25% (Rossman and Supply 2005). The range of variability for percent imperious is 0 to 100%; however, with little impervious area in the LCC watershed, the percent impervious range for the LCC area was only 0 to 85%.

The junction invert elevations were varied, depending on the elevations from the surveying data as well elevation points created in ArcMap. The elevation points in ArcMap were based on the USGS DEM, which had a coarse accuracy. Therefore, there are uncertainties present in the invert elevation values. In order to avoid adverse slopes from occurring in the channel, each of the junctions invert elevations were closely examined to determine the best value. The channel slopes were checked over to avoid supercritical flow conditions in areas that were experiencing subcritical flow. The range of invert elevations was from 718 ft (218.8 m) (outlet junction) to 850 ft (259.1 m) (subcatchments upstream of the residential lake).

During the calibration process, the need to control the outflow at the residential lake and pond as well as the outflow at the outfall became crucial. Since there are many cross-sections throughout the LCC acting as control structures, weirs and orifices were implemented to adjust this flow. Although the storage curves for the residential lake and JM Robert Pond were not varied, the flow control structures were, such as the weir and orifices.

The trapezoidal weir height at the residential pond was changed to 2 feet (0.61 m) (from the measured 1.5 feet (0.46 m)) and the length was changed to 45 ft (13.7 m) (from the measured 3 ft (0.91 m)) -to account for the wide, low flood plan surrounding the weir channel- with a side slope of 3.3%. The additional exit flow structure from the residential pond was an orifice with a width of 0.06 ft (0.02 m) and a height of 0.06 ft (0.02 m). The weir at J.M. Roberts Pond was approximated to be 20 ft (6.1 m) in length and 2 ft (0.61 m) in height. The weir at the J.M. Roberts Pond acts like a dam. In addition to these structures, a weir and an orifice were implemented just upstream of the outfall. These structures were added to slow the flow through the southern channels of the LCC watershed. The weir height is 10 ft (3.0 m) and the length is 30 ft (9.1 m). The reason for the large length is due to the nature of the floodplain area. This area is characterized mainly as a wetland area with a main channel flowing through the area. The orifice height is 2 ft (0.61 m) and the width is set as 10 ft (3.0 m).

Lastly, the pollutant buildup and washoff values were determined using the specified range of variability from Rossman and Supply (2005) and Vanoni (1975) as well as Cambez et al. (2008). The range of maximum buildup for the LCC was initially determined from the nationwide study by Manning et al. (1977), where dust and dirt buildup rates were examined for different land uses. The land uses included residential, commercial and industrial. The difference between these land uses and those of the LCC were taken into consideration upon calibration. Furthermore, in conjunction with the sediment transport theory, the washoff exponent, C2, should range from 1.1 to 2.6, with most values near 2. High density residential or commercial areas tend to release pollutants faster than areas with individual lots (Vanoni 1975).

### 4.1.4. Calibration data range/validation data range

Calibration for the developed SWMM model was carried out by focusing on a series of rain events between 6/12/2014 and 12/31/2014. There was a large variety of rain events within this time period. During the summer months or dry season, there were several smaller rain events that produced peak flows of less than 10 CFS (0.28 cms). There were multiple rain events in November and December, the wet season, which exhibited large groundwater flow that sustained the base flow over a period of days.

Due to the lack of observed data, the hydrological validation range was from 1/1/2015 to 3/26/2015. Since these wet conditions in the LCC support high water tables levels, this time period was mainly composed of groundwater-influenced events. The groundwater levels were still high at this time; therefore, only wet season events could be validated from the existing data. The lack of summer validation data did not ease the challenge of calibrating summer events for the LCC.

The calibration period for the calibration of TSS is also between 6/12/2014 and 12/31/2014. However, the validation period for TSS differs from the hydrological validation period due to the available data. Nevertheless, since the Environmental Probe was deployed since April 2013, the pollutant validation period was selected from 6/1/2013 to 6/11/2014. Even with this larger range of rain events, there were still only a few rain events in which the Water Quality Sonde was functioning properly and the downstream and upstream site data over-lapped. Nonetheless, there were only a handful of events to calibrate the upstream sensor site and even fewer to calibrate the downstream site. Consequently, the calibration and verification results for the TSS are not as satisfactory for the downstream site as the results were for the upstream site.

As mentioned previously, when calibrating the SWMM model for the best fit range of parameter, the range of variability for each parameter was considered by the SWMM 5.0 Manual. Initial calibration was conducted without the use of the SRTC tool of PCSWMM. Once more precise calibration was needed; the SRTC tool was applied to detect the sensitive parameters. The SRTC tool can be used to verify results as well. The verification process in PCSWMM takes the changes made to the parameters through the radio-tuning tool and runs them once more through SWMM to validate the predicted results. This verification process is to analyze whether or not the parameter changes made through the SRTC tool had the desired effects on the model.

## 4.2. Modeling results

### 4.2.1. Surface water flows modeling results

Modeling tools are useful in estimating the effects of rain events in watershed in terms of flow rate hydrographs and water quality changes, among others. Once the temporal characteristics of the hydrograph peak and recession are determined through field measurements, modeling parameters can be better adjusted to fit the observed data. Figures 33 to 38 are the result of several calibration and sensitivity radio tuning calibration tool (SRTC) in PCSWMM. These periods include both dry and wet weather situations in the hydrological calibration period (6/12/2014- 12/31/2014) and the validation period (1/1/2015-3/26/2015).

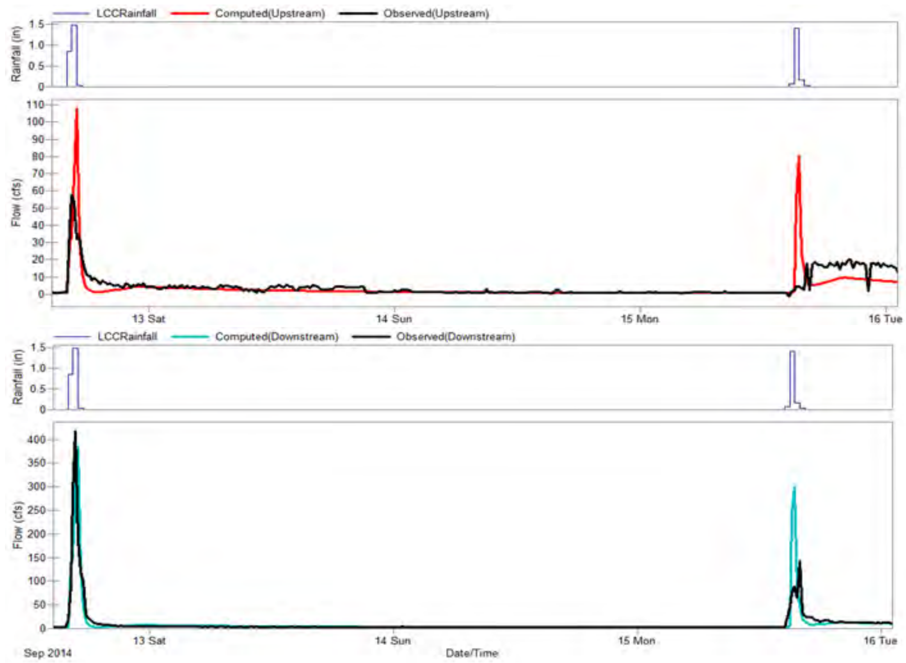



**Figure 33: Flow hydrograph comparison for upstream (top) and downstream (bottom) simulated and respective measurements (9/12/2014).**

Overall, the simulated flow matched fairly well with the observed hydrographs. Some smaller summer rain events were more difficult to represent (rainfall < 0.1in/hr). These small summer events eventually improved through the calibration process. For the larger summer events, such as in Figure 33, the simulated peaks were larger than the observed data for upstream. The downstream observation site produces more runoff and the peaks measured downstream were more sufficiently matched than those upstream. For the most part, the timing of the peak flows for the simulated results agreed with the observed peak flows for both summer and winter events.

During the winter season or the wet season, measured groundwater levels were higher, resulting in a more gradual recession curve for the stream. The simulation was able to replicate this gradual decent in water levels in the stream. However, in some cases in the model there is a gap among the simulated and observed recession curves for Figures 34, 35 and 36. This noticeable difference between water levels suggests that there are additional sources, possibly aquifers that are not properly represented by the PCSWMM modeling of LCC.

Additionally, the slow decay of flow observed in Figures 34, 35 and 36 is not produced by the median or interstate since the slow release is also observed upstream. This slow recession of stream water suggests that the LCC has a very slow return of groundwater to base levels, which may be reflection of the perennial characteristics of the stream.

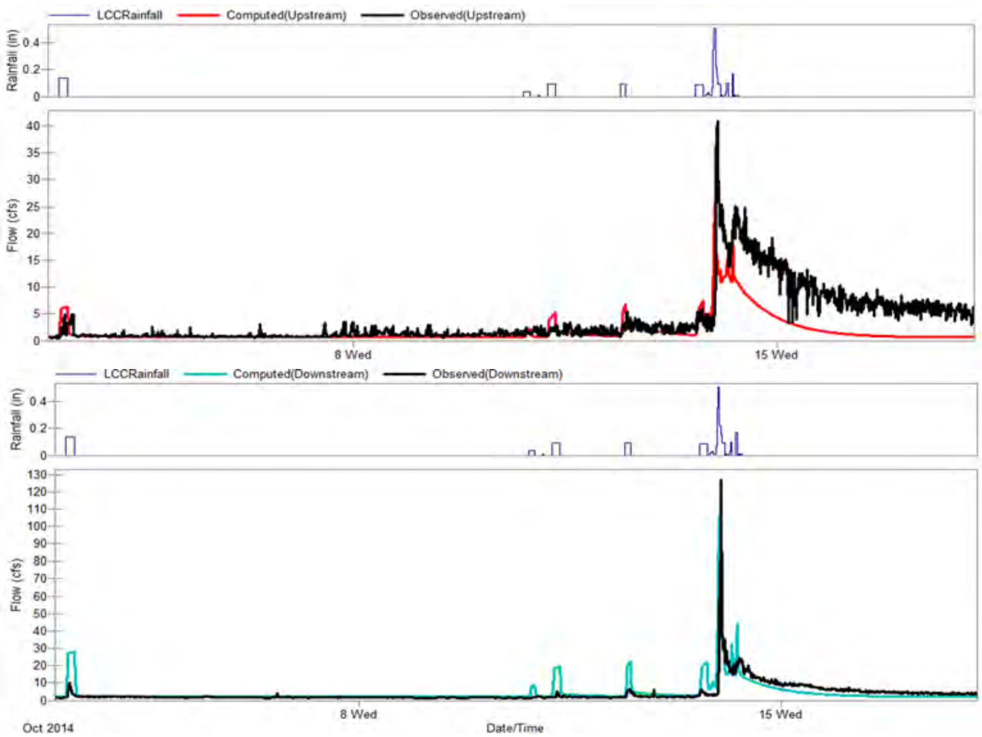



**Figure 34: Hydrograph comparison of upstream (top) and downstream (bottom) for simulated and observed stream flow data (10/14/2014).**

Another difference in rainfall events was observed through the comparison of Figures 35 and 36. In Figure 36, January rain events were different than the events represented in December, even though the first two rain events in December produced the same amount (or more) of rainfall. There is a significantly greater peak flow observed from the event in January than the previous events, both upstream site (Site 3) and downstream site (Site 1). Since the difference in flow is observed at both sites, this missing flow could originate further upstream. There was no surveying data available from the two waterbodies further upstream of I-59, and a lack of precise representation of these large physical structures of the LCC watershed could be influencing this discrepancy in observed and modeled flows.

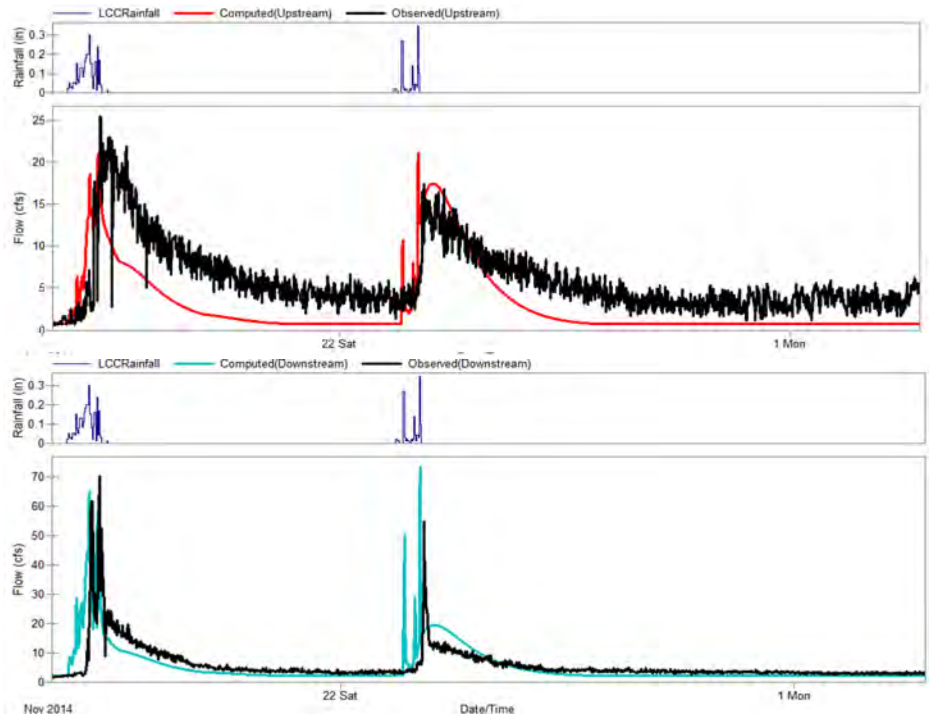



**Figure 35: Hydrograph comparison of upstream site (Site 3, top) and downstream site (Site 1, bottom) for simulated and observed stream flow data (11/17/2014).**

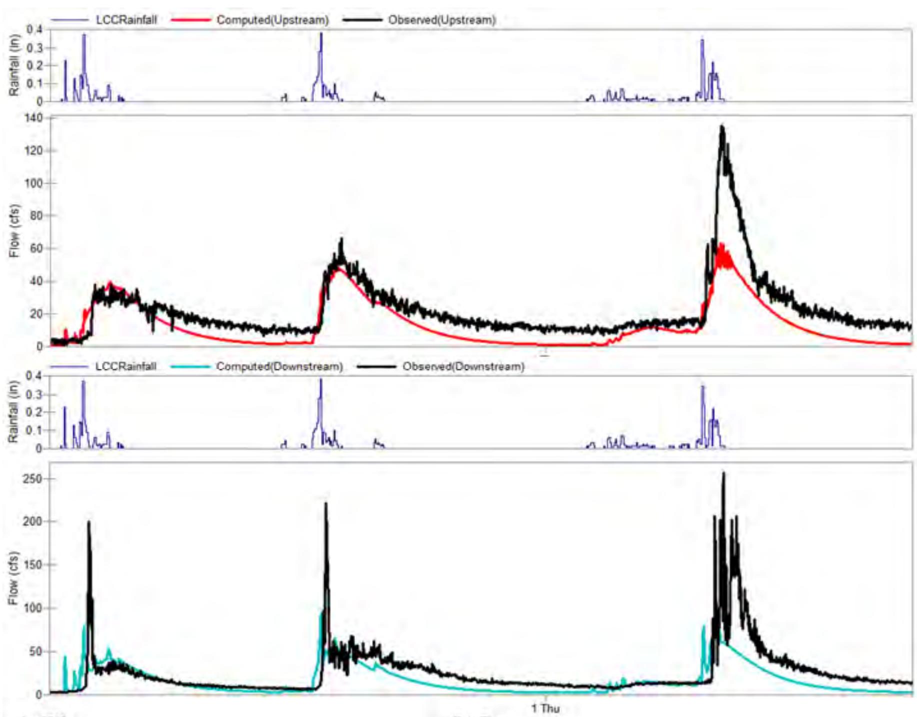



**Figure 36: Hydrograph comparison of upstream site (Site 3, top) and downstream site (Site 1, bottom) for simulated and observed stream flow data (12/14-1/15).**

The results for the validation period were sufficient for the modeling task. A key objective behind the calibration period was to represent the observed peak flows. While not all the flows matched up perfectly with the peak flows, the overall results were considered satisfactory to good according to the criteria by Moriasi et al. (2007). In Figures 37 and 38 the peaks were replicated, except the higher initial peak at the downstream site on the 3/22/2015 rain event.

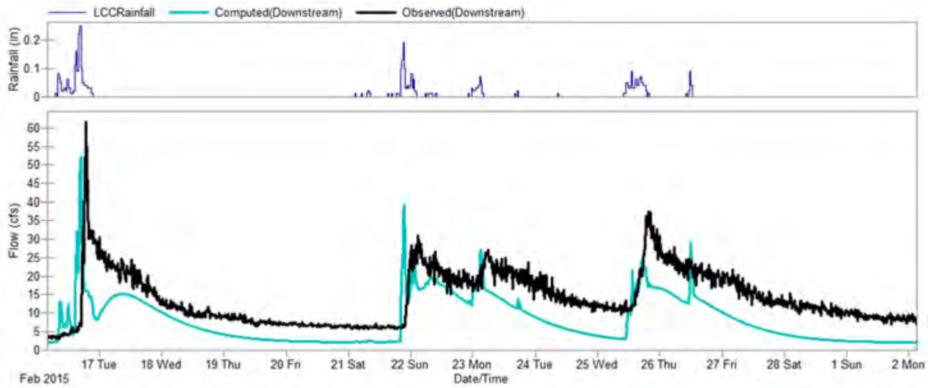



**Figure 37: Hydrograph comparison of downstream site (Site 1) for simulated and observed stream flow data (2/17/2015) (No data available at upstream location).**

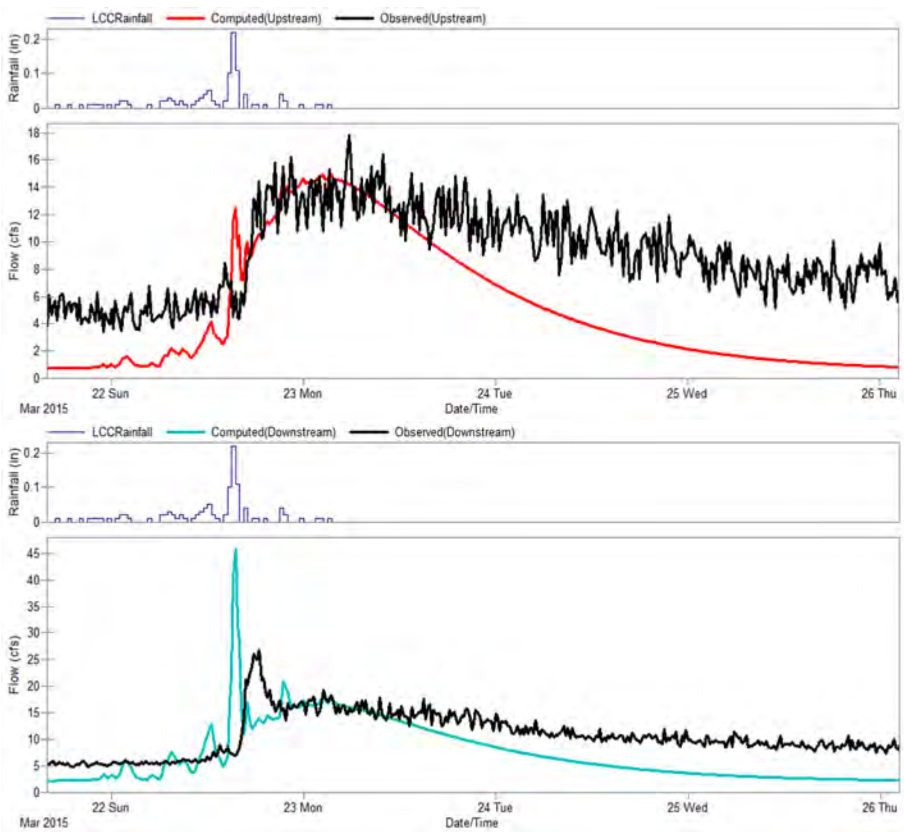



**Figure 38: Hydrograph comparison of upstream site (Site 3, top) and downstream site (Site 1, bottom) for simulated and observed stream flow data (3/22/2015) (validation period).**

Table 14 presents a comparison of the AV sensor observed peak flows for the same events between the upstream and downstream. The percent difference was calculated between 23 peak flow events for both the upstream and downstream sites. Those events were then categorized by: less than 0%, between 0% and 25%, between 25% and 50%, and greater than 50% difference. 78% of the downstream peak flows were 50% or greater than the peak flow values at the upstream site. This increase in peak flow downstream during storm events could possibly be from the impervious area from the surrounding area. The peak flow downstream was on average 1.7 times greater than the peak flows at the upstream site. However, there is approximately a 30% increase in subcatchment area for the downstream site. This increase in area along with the difference in land use influences this increase in peak flows downstream.

**Table 14: Percent difference between the AV sensor observed peak flows for both the downstream and upstream sites (Sites 1 and 3 respectively).**

| | |
|---|---|
| **Diff in Flows ≤ 0%** | 9% |
| **0% < Diff in Flows ≤ 25%** | 9% |
| **25% < Diff in Flows ≤ 50%** | 4% |
| **Diff in Flows > 50%** | 78% |

To compare the post-development conditions of the existing I-59, a second version of the LCC model was created to account for the pre-development conditions. This new pre-development model included changing the land use, imperviousness, channel bed roughness, and the channel bed geometry. With these changes the post-development stream flow was compared to the pre-development flow. The percent difference was calculated between 23 post- and pre-development peak flow events for both the upstream and downstream sites (Sites 3 and 1 respectively) and presented in tables 15 and 16. When the percent difference in flows were less than zero, the value from the pre-development was greater than the post-development model. Those events were then categorized by: less than 0%, between 0% and 2%, between 2% and 5%, and greater than 5% difference. Therefore, the percent shown in the right-hand column are the percentage of peak flow levels that fell into the specified category.

The most common difference in flows for the upstream site ranged between 0 and 2 %. The same was true for the downstream site. However, only 13 % of the upstream flows for pre-development were larger than the post-development, while for the downstream site, 39% of pre-development flows were larger than the post-development. The conduits may have been acting as a control structure, lowering the flow downstream of the interstate.

**Table 15: Percent difference between the peak flows of the post- and pre-development LCC models at the upstream site (Site 3).**

| | |
|---|---|
| **Diff in Flows ≤ 0%** | 13% |
| **0% < Diff in Flows ≤ 2%** | 48% |
| **2% < Diff in Flows ≤ 5%** | 22% |
| **Diff in Flows > 5%** | 17% |

**Table 16: Percent difference between the peak flows of the post- and pre-development LCC models at the downstream site.**

| | |
|---|---|
| **Diff in Flows ≤ 0%** | 39% |
| **0% < Diff in Flows ≤ 2%** | 43% |
| **2% < Diff in Flows ≤ 5%** | 4% |
| **Diff in Flows > 5%** | 13% |

### 4.2.2. Ground water flows modeling results

The groundwater results from the SWMM5 model are compared to the groundwater levels from the HOBO level loggers deployed at both downstream and upstream locations. Four events were chosen to display the similarities and differences between the groundwater levels: 9/12/2014, 10/17/2014, 12/24/2014, and 2/22/2015 (from the hydrological validation period). The HOBO level logger data is represented in pressure head (ft) with respect to a reference point at the bottom of the well, and the simulated results are represented by elevation (ft) with respect to sea level. The pressure hydrographs by both the level logger and SWMM5 are in general consistent as further elaborated in a later section.

Figures 39 to 42 present different seasonal patterns and ground water characteristics. For late summer events, such as in Figure 39, SWMM5 tends to overestimate the groundwater levels. During the winter events in October, December, and even late February (presented in figures 40, 41 and 42 respectively), the spikes in groundwater are more adequately represented by the SWMM5 model. There is speculation that the differences in groundwater levels between the model and measurements may be linked to the choice of modeling parameters defining soil and infiltration characteristics in the PCSWMM model.

Another reason for the difference in groundwater results could originate from the approach SWMM5 uses to calculate groundwater elevation. The groundwater elevation of a subcatchment represents the average groundwater level that subcatchment is experiencing and not at a specific point. The process implemented by SWMM of the infiltration and percolation of stream water to groundwater through the interaction with nodes, could be a limited representation of a specific point within that subcatchment, since lateral infiltration from stream into the nearby banks is not represented.

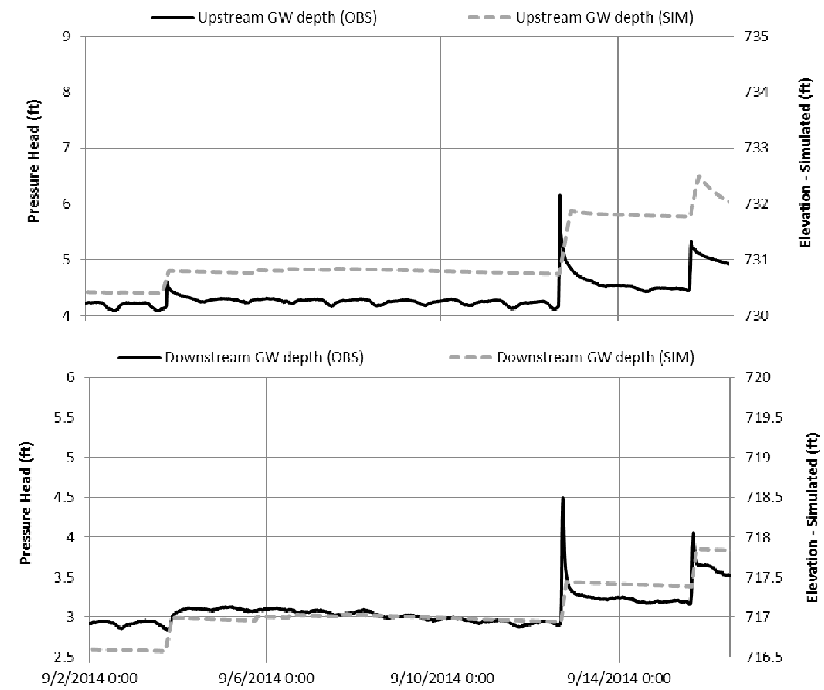



**Figure 39: Groundwater level comparison of level logger and PCSWMM results for 9/12/14-9/15/14.**

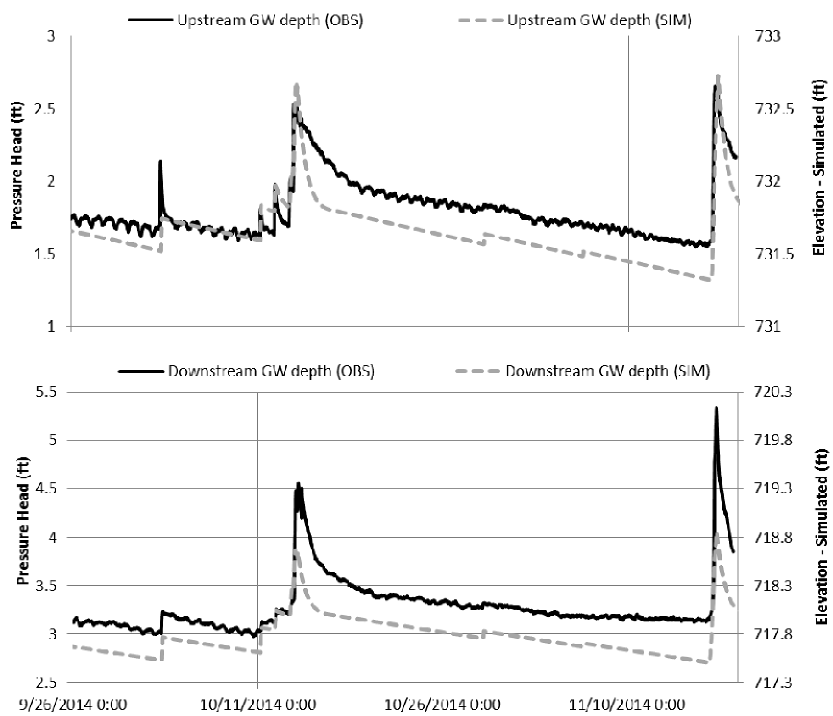



**Figure 40: Groundwater level comparison of level logger and PCSWMM results for 10/17/2014.**

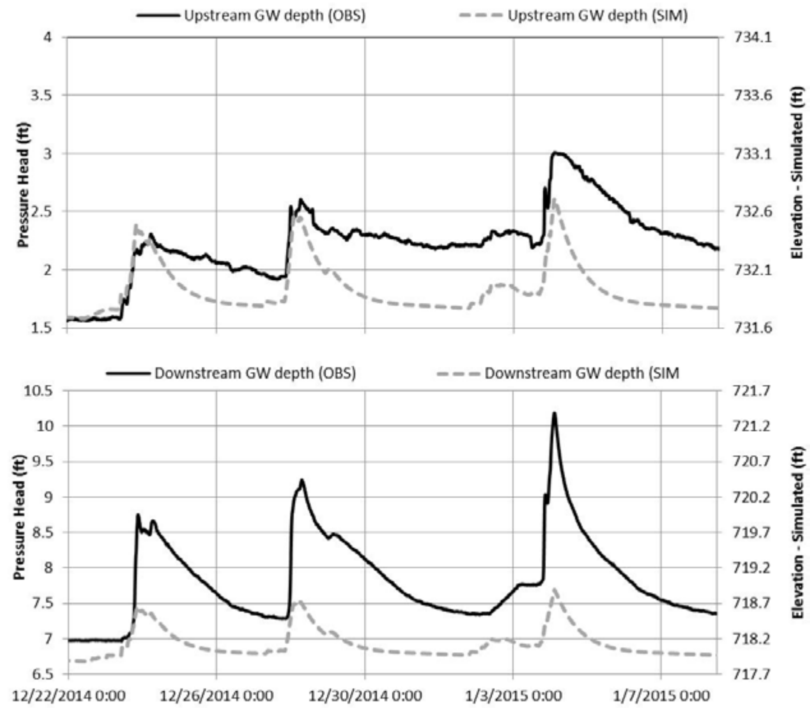



**Figure 41: Groundwater level comparison of level logger and PCSWMM results for 12/24/14-1/8/15.**

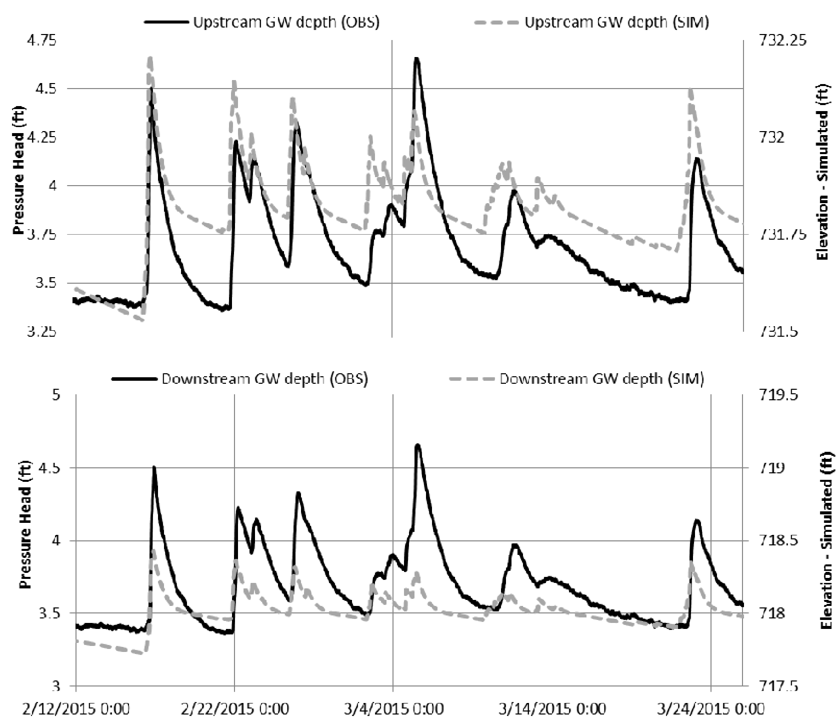



**Figure 42: Groundwater level comparison of hobo level logger and PCSWMM results for February 2015 rain events (hydrological validation period).**

### 4.2.3. Water quality modeling of total suspended solids

Figures 43 to 47 present the pollutographs used to calibrate the Total Suspended Solids (TSS) in the LCC watershed. The simulated pollutographs are plotted in comparison to how well each event represents the observed TSS flow (mg/L). Due to issues with the Water Quality Sonde data collection, there were not as many dates available for comparison during the calibration period (6/12/2014-3/26/2015). The dates compared are rain events that occurred on 7/13/2014, 7/15/2014, 8/24/2014, 9/12/2014, 9/15/2014, and 12/27/2014. Only events on 7/13/2014, 7/15/2014, and 12/27/2014 had available data for the downstream site. Among the pollutant calibration dates, 7/13/2014, 7/15/2014 and 9/12/2014 provided the best results for calibration of the upstream site. The peaks for these dates came within approximately 10 CFS of the observed peaks. In some cases the observed flow was underestimated, though for the most part the observed TSS peaks were overestimated, such as on 9/15/2014 for the upstream site. Calibration was attempted for both the dry and wet seasons. However, this limited data posed significant difficulties for a thorough calibration of TSS simulated results.

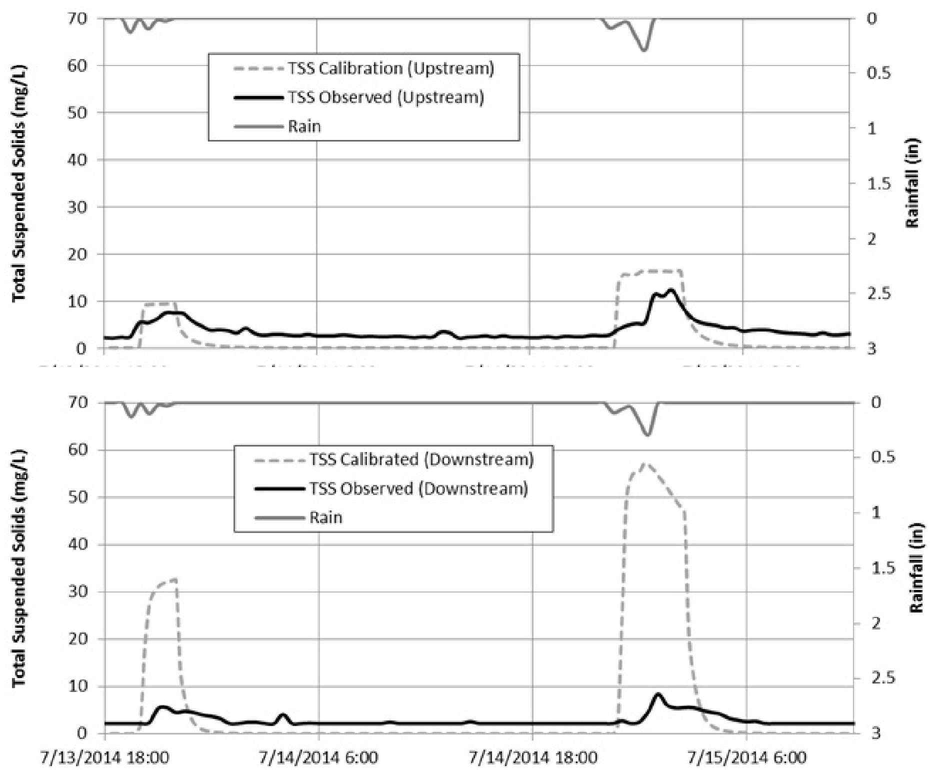



**Figure 43: Comparison of TSS measured and modeled results for rain event in 7/13/2014-7/15/2014.**

From the events provided in Figure 43 to 47 there is no simple relationship between the summer events and the winter events. The only winter date available, 12/27/2014, shows a significant underestimation of observed TSS. During the same winter events, the flow hydrograph sufficiently replicated the peak flows. Due to the preceding rain event, the TSS that should be available for washoff during the 12/27/2014 event may have been depleted from the previous event on 12/24/2014.

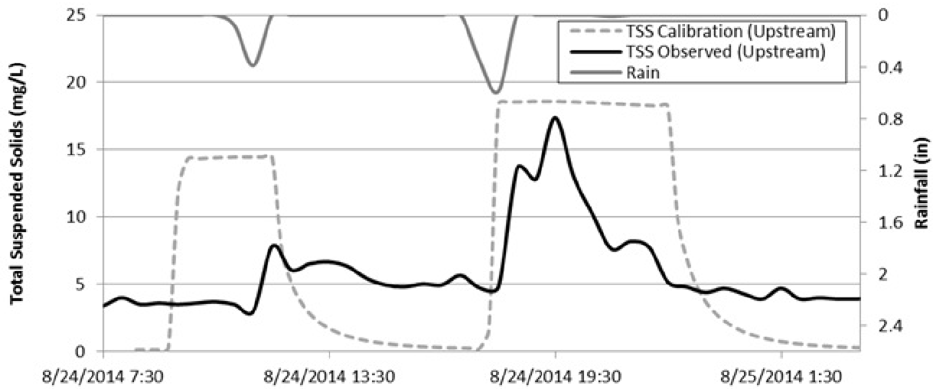



**Figure 44: Comparison of TSS measured and modeled results for rain on 8/24/2014.**

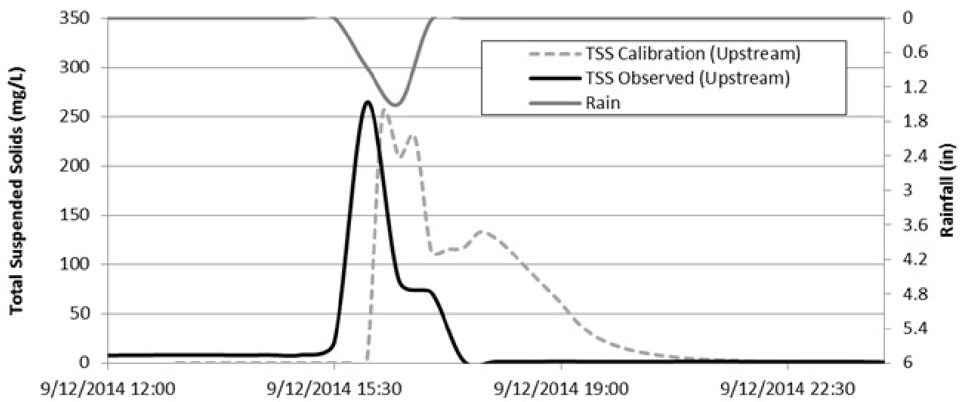



**Figure 45: Comparison of TSS calibration modeled results for rain on 9/12/2014.**

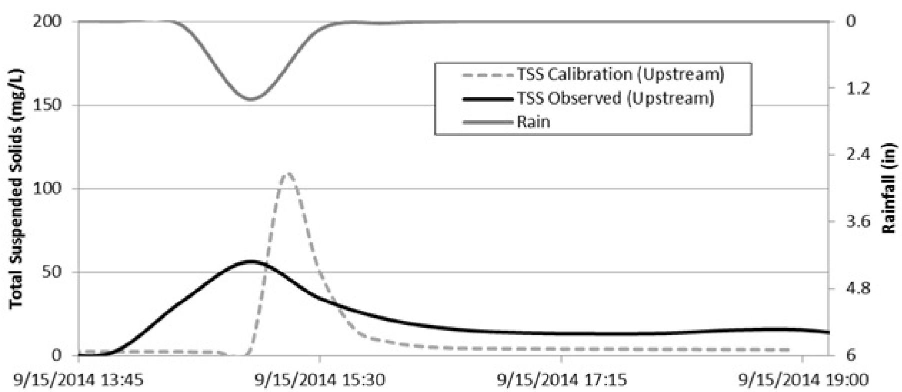



**Figure 46: Comparison of TSS measured and modeled results for rain on 9/15/2014.**

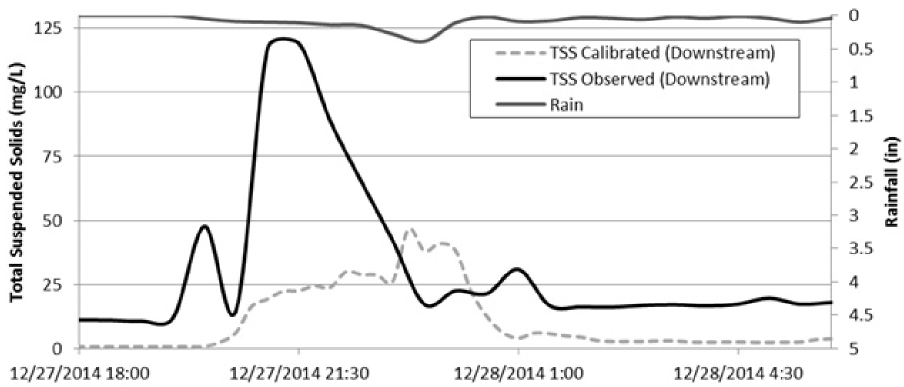



**Figure 47: Comparison of TSS measured and modeled results for rain on 12/27/2014.**

Figures 48 to 51 present validation results from the TSS simulation. This validation period is from 6/1/2013 to 6/11/2014. Compared to the accuracy of the calibration results for TSS, the modeling results from the validation period represented fairly well the observed TSS values. The simulated validation results were also more accurate for the upstream location when compared to the downstream. The reason for the less efficient calibration of TSS at the downstream site may be a result of the limited observed events available for the calibration of the downstream. The runoff characteristics downstream are very different from the upstream location in respects to the amount of impervious area directly surrounding the site.

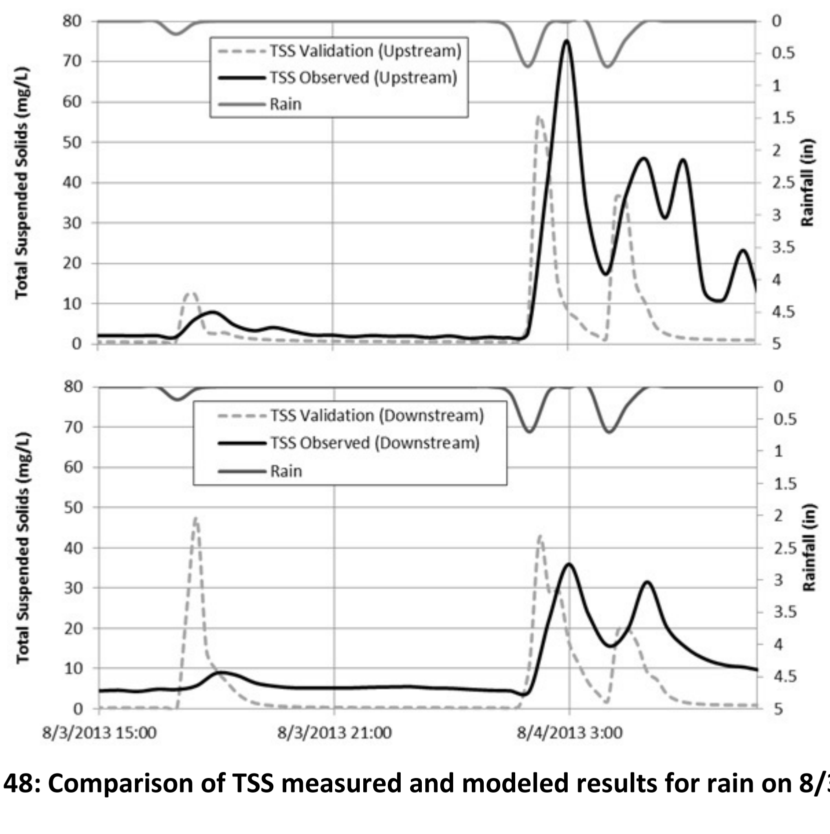



**Figure 48: Comparison of TSS measured and modeled results for rain on 8/3/2013.**

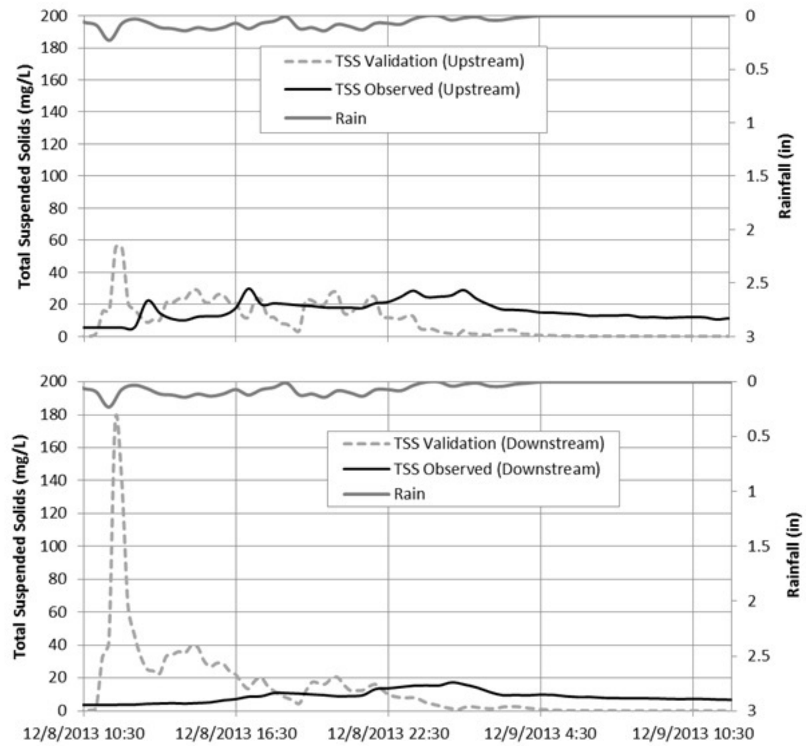



**Figure 49: Comparison of TSS measured and modeled results for rain on 12/8/2013.**

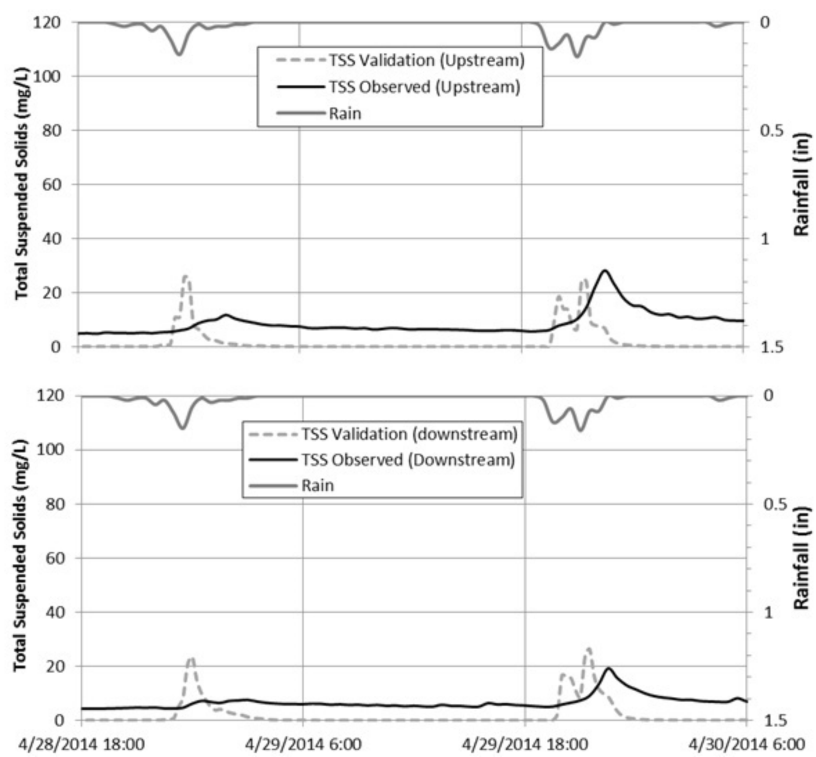



**Figure 50: Comparison of TSS measured and modeled results for rain on 4/28/2014.**

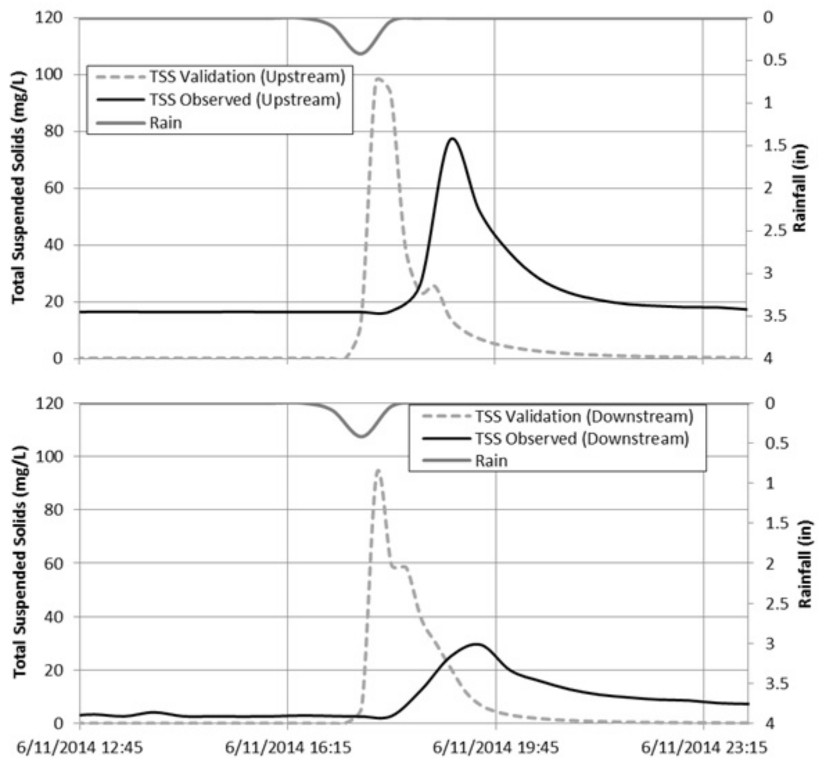



**Figure 51: Comparison of TSS measured and modeled results for rain on 6/11/2014.**

### 4.2.4. Estimation of I-59 effects to LCC tributary flows

A direct estimation of the impacts of I-59 to the LCC tributary that was selected in the investigation is not possible since pre-development data (i.e. prior to the road construction) is not available. Alternatively, a numerical model may be used to estimate the impacts of the added imperviousness created by the roadway. A hypothetical scenario needs to be developed, which introduces key assumptions.

- First, that the pre-construction soil characteristics in the area comprised by the median can be represented by the soil characteristics that were assumed at the subcatchments upstream from the roadway.
- Second, that the topography of terrain at the median has not been significantly affected by the roadway construction.
- Finally, that the rainfall series that have been measured in the duration of this research is representative of the conditions that were observed in pre-development conditions.

Figure 52 presents a comparison between the modeled scenario. In general, as is seen, the hydrological behavior of LCC is not severely impacted by the roadway construction in the hypothetical scenario that was created. In terms of total volumes over the 12-month simulation period, Table 17 indicates that only 1.8% of additional stream flow volume would have been generated by the added imperviousness from I-59 construction. There are, however, some discrepancies in the peak flows that are explored.

**Table 17 – Calculations of modeled flow volumes in LCC tributary in the post-development scenario and the hypothetical pre-development scenario**

| | With Road | Without Road |
|---|---|---|
| Total Volume (ft^3) | 1.73E+08 | 1.70E+08 |
| Total Volume (million gallons) | 1296.07 | 1272.65 |
| Absolute Difference (million gallons) | 23.42 | |
| Relative Difference (%) | 1.8% | |

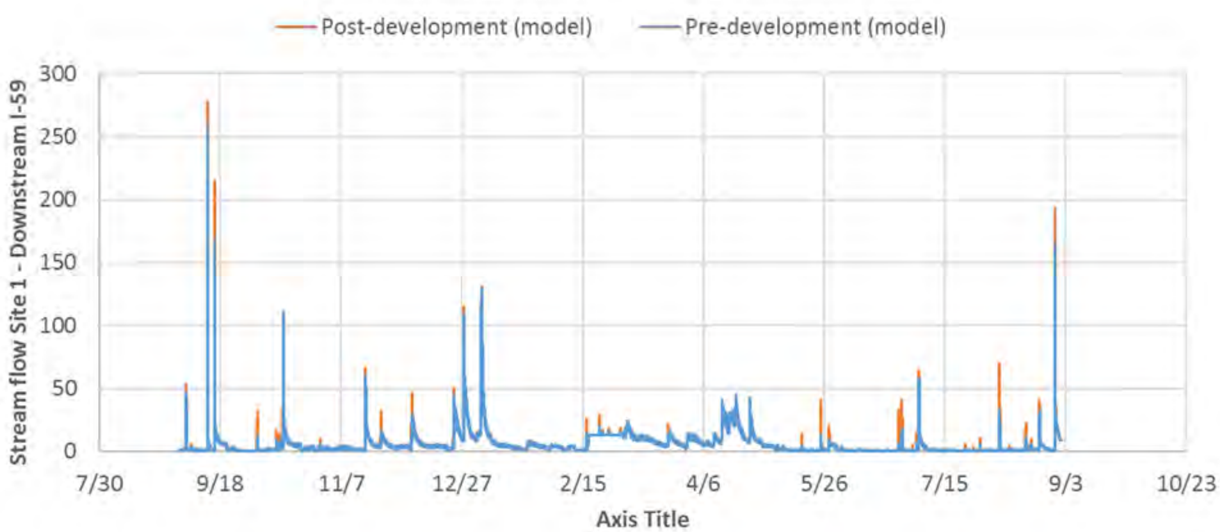



**Figure 52: Modeled flows measured downstream from I-59 and comparison with flows in the same location for a hypothetical pre-development scenario**

Table 18 presents in chronological order the peak stream flows observed in the hydrographs presented in Figure 52, with absolute and relative differences between the post and pre-development scenarios. In most cases (54%), the peak flow differences were under 28%. It was noticed that the larger discrepancies between the peak stream flows (up to 432%) have occurred predominantly in situations when where there were small peak stream flows. One also notices that for most of the larger rain events (leading to stream flow peaks exceeding 40 CFS) the added imperviousness added peak flows in average of 32%, with a median of 12%. Effects of smaller rain events (creating stream flow peaks under 33 CFS) were more pronounced.

This model representing the post-development scenario was also used to estimate the relative volume that the lateral stream contributes toward the flow at Site 1 (downstream from I-59). According to the modeling results, the total flow volume over 12 months of simulation was 43.4 million gallons. This value is only 3.3% of the flow volume that is flow through Site 1.

**Table 18 – Peak stream flows associated with each significant rain event in the 12-month simulation between modeled post-development and hypothetical pre development scenarios for LCC**

| Date | Peak Flow with Road [1] | Peak flow without Road [2] | Absolute difference=[1]-[2] | Relative Difference =([1]-[2]) / [2] |
|---|---|---|---|---|
| 9/3/2014 | 52.91 | 46.48 | 6.43 | 13.83% |
| 9/12/2014 | 277.79 | 258.04 | 19.75 | 7.65% |
| 9/15/2014 | 215.25 | 167.89 | 47.36 | 28.21% |
| 10/3/2014 | 32.18 | 12.35 | 19.83 | 160.57% |
| 10/14/2014 | 110.99 | 109.33 | 1.66 | 1.52% |
| 11/17/2014 | 66.17 | 59.22 | 6.95 | 11.74% |
| 11/23/2014 | 31.77 | 15.82 | 15.95 | 100.82% |
| 12/6/2014 | 46.15 | 28.79 | 17.36 | 60.30% |
| 12/23/2014 | 50.41 | 44.27 | 6.14 | 13.87% |
| 12/28/2014 | 114.82 | 108.63 | 6.19 | 5.70% |
| 1/4/2015 | 131.06 | 128.94 | 2.12 | 1.64% |
| 2/16/2015 | 25.82 | 14.63 | 11.19 | 76.49% |
| 2/21/2015 | 28.53 | 20.24 | 8.29 | 40.96% |
| 3/23/2015 | 21.92 | 12.78 | 9.14 | 71.52% |
| 4/13/2015 | 40.29 | 40.2 | 0.09 | 0.22% |
| 4/19/2015 | 42.86 | 42.81 | 0.05 | 0.12% |
| 5/16/2015 | 11.07 | 3.88 | 7.19 | 185.31% |
| 5/24/2015 | 40.33 | 12.66 | 27.67 | 218.56% |
| 6/25/2015 | 32.49 | 6.1 | 26.39 | 432.62% |
| 7/4/2015 | 59.79 | 57.37 | 2.42 | 4.22% |
| 8/6/2015 | 69.81 | 33.57 | 36.24 | 107.95% |
| 8/17/2015 | 22.72 | 11.27 | 11.45 | 101.60% |
| 8/23/2015 | 40.43 | 31.51 | 8.92 | 28.31% |
| 8/29/2015 | 193.21 | 165.4 | 27.81 | 16.81% |

# 5. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

The investigation on the LCC watershed completed its tasks, and reached the main objectives of providing baseline information on the hydrological and water quality characteristics of selected points in the watershed. This information will be useful in the future, once BNB is linked to I-59 in this watershed. In a post-development scenario, the hydrological and water quality parameters measured in this investigation will serve to provide a standard for the assessment of whether or not the operation of BNB is adding to the impacts of roadways to the LCC watershed.

In terms of physical water quality parameters, the main observations from the investigation on the LCC watershed are the following

1. All selected measurement sites indicate generally good water quality. Physical parameters such as pH, turbidity, and temperature were in the anticipated range for natural streams. Levels of turbidity and TSS were low, with peak turbidity levels usually under 50-60 NTUs and not exceeding 120 NTUs even during rain events
2. Levels of total phosphorus and $NO_3$+$NO_2$ were consistently below levels reported in previous measurements on runoff from the types of land use observed in LCC watershed.
3. Heavy metals and oil/grease levels measured in Sites 1 and 3 (downstream and upstream from I-59 crossing) were also consistently below levels reported in previous measurements on runoff from the types of land use observed in LCC watershed. However, these constituent concentration was significantly larger in samples taken from the ditches collecting runoff from the roadway.

These observations indicate that groundwater exfiltration into LCC is diluting the concentration of constituents in surface runoff, which attenuates impacts of roadway runoff to streams. It is also considered that vegetated strips and ditches have a role in filtering contaminants in the runoff. The same hypothesis is drawn to other constituents considered in this investigation, such as heavy metals, oil and grease. If this is the case, then intermittent and ephemeral streams can possibly be more impacted by roadway runoff, in which case the application of BMPs to aid in stormwater management of runoff is even more fundamental.

This investigation also attempted to assess whether I-59 is currently impacting LCC watershed, which is a question that is complex and can be evaluated within each of the studied areas of this research. Regarding hydrological impacts, the following observations are made:

1. Site 1 presented a base flow rate higher than Site 3, which could be caused by groundwater flow contributions between these locations.
2. During rain events, peak flows in Site 1 are higher than Site 3, as anticipated. However, this increase was not uniform even between comparable rain events, since antecedent dry days play a role in increasing abstractions due to infiltration.
3. Also, the flows increase is much faster in site 1, which could be attributed to some extent to the quick drainage from the pavement to draining ditches and into LCC. However, the duration of these peak flows was in general short, and it may indicate that appropriate BMP deployment (increasing infiltration or retaining runoff) could possibly neutralize these flow spikes.

4. Groundwater table levels near to the stream are very dynamic, responding rapidly to increase in stream stage and to rain events, which can reduce infiltration abstraction during more intense rain events.

In terms of water quality aspects related to I-59 and LCC, the field measurements indicated that:

1. Dilution of runoff in the stream have attenuated concentration of constituents in general. However, levels of TSS and turbidity were increased in Site 1 (downstream I-59), particularly in the peak stages of rain events, though such increase was not uniform among all observed rain events, and in most cases not significant. Such impacts can be attenuated with the deployment of BMPs in this roadway.
2. From the selected heavy metal constituents, Chromium and Nickel presented concentrations in Site 1 that were above values measured in Site 3 (upstream I-59). Concentration of Copper and Zinc were comparable between the sites. However, the concentrations were in general much below the levels measured in runoff from the typical land uses present in LCC watershed. The concentration of the heavy metals in the drainage ditch that discharges into Site 1 was significantly larger, which may be an indication of the effectiveness of the vegetated roadside ditches in reducing concentration of contaminants in the roadway runoff.
3. The macroinvertebrate count performed in Sites 1 and 3 following Alabama Water Watch guidelines indicate that the I-59 is not currently impacting the diversity of the selected organisms, and that the diversity in both sites yields an excellent stream quality.

The application of modeling tools, in the present case PCSWMM, demonstrated that the general trend of the hydrology of the LCC watershed can be reasonably well captured. With adequate calibration, TSS and other water quality parameters can potentially be well described. It is thus hoped that SWMM and other distributed hydrological models can be used in predicting impacts of design storms to similar watersheds. Such models could thus predict what types and sizes of BMPs can be deployed to attenuate the impact of new roadway construction to small/headwater streams. The idea of the draft framework developed in this study is to give one step in this direction, and support a widespread use of such hydrological models as drainage design tools and as well quantitative support for stormwater management in roadways.

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# APPENDIX 1: BIOMONITORING FORMS FROM LCC RESEARCH

## Alabama Water Watch
### STREAM BIOMONITORING DATA FORM

☐ online

Group Name: ______

Collector(s): Cat, Mitchell, Di V, Douglas  Address: ______

City: ______ State: ______ Zip: ______ Phone #: ______

Sample Date: 3/23/15  Sample Time: ______ ~~AWW~~ Site Code: 3-I-59 Wes-

Watershed: ______ Waterbody: ______ County & State: ______

Sampling site location: ______
(Notify the AWW office about any changes in sampling site location.)

Waterbody condition: ☐ Adequate Depth ☐ Inadequate Depth ☐ Dry ☐ No Access

Tidally influenced streams and rivers: ☐ Rising Tide ☐ Falling Tide ☐ Uncertain

Max of 10 ≥ identify

| Group I Taxa | Letter Code * | Group II Taxa | Letter Code * | Group III Taxa | Letter Code * |
|---|---|---|---|---|---|
| Stonefly | 19 A | Dragonfly | 4 C | Midge | 5 C |
| Mayfly | 18 A | Damselfly | 4 C | Aquatic Worm | 5 C |
| Caddisfly | 10+ A | Cranefly | 1 R | Leech | ∅ |
| Riffle Beetle | 4 C | Blackfly | — | Pouch Snail*** | ∅ |
| Water Penny Beetle | 2 R | Filtering Caddisfly** | 10+ A | | |
| Snail | 100+ A | Hellgramite | ∅ | | |
| | | Scud | 1 R | | |
| | | Sowbug | 10+ A | | |
| | | Crayfish | ∅ | | |
| | | Asiatic Clam | ∅ | | |
| | | | | | |
| | | | | | |
| | | | | | |
| Number of Taxa= 6<br>Multiply by 3 = 18<br>(Index Value) | | Number of Taxa= 6<br>Multiply by 2 = 12<br>(Index Value) | | Number of Taxa= 2<br>Multiply by 1 = 2<br>(Index Value) | |

* **Letter Code: R = 1 to 3 (Rare); C = 4 to 9 (Common); A = 10 or more (Abundant)**

** Filtering Caddisflies are in the Family Hydropsychidae (gills on abdomen; common caddisfly)
*** Pouch snails are in the Family Physidae (shell opens to the left; air-breathing snail)

| STREAM BIOTIC INDICES | | STREAM QUALITY ASSESSMENT (*Check box corresponding to Cumulative Index Value*) | | | |
|---|---|---|---|---|---|
| Total Number of Taxa (*Sum of Number of Taxa in each group*) | 13 | POOR <11 | ☐ | FAIR 11-16 | ☐ |
| Cumulative Index Value (*Sum of Index Values for each group*) | 32 | GOOD 17-22 | ☐ | EXCELLENT >22 | ✓ |

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# Alabama Water Watch
## STREAM BIOMONITORING DATA FORM

☐ online

Group Name:

Collector(s): Cat - Mitchell, Dr V., Douglas Address:

City: Trussville State: Zip: Phone #:

Sample Date: Sample Time: ~~AWW~~ Site Code: 1-I-59 E

Watershed: Waterbody: County & State:

Sampling site location:

(Notify the AWW office about any changes in sampling site location.)

Waterbody condition: ☑ Adequate Depth ☐ Inadequate Depth ☐ Dry ☐ No Access

Tidally influenced streams and rivers: ☐ Rising Tide ☐ Falling Tide ☐ Uncertain

| Group I Taxa | Letter Code * | Group II Taxa | Letter Code * | Group III Taxa | Letter Code * |
|---|---|---|---|---|---|
| Stonefly | 10 A | Dragonfly | 3R | Midge | 2R |
| Mayfly | 6 C | Damselfly | 2 R | Aquatic Worm | 3R |
| Caddisfly | 3R | Cranefly | 0 | Leech | |
| Riffle Beetle | 3R | Blackfly | 0 | Pouch Snail*** | |
| Water Penny Beetle | Ø | Filtering Caddisfly** | 3R | | |
| Snail (right opening) | 10 A | Hellgramite | 4C | | |
| Cased Caddisfly | 5C | Scud | 4C | | |
| | | Sowbug | 0 | | |
| | | Crayfish | 2R | | |
| | | Asiatic Clam | 2R | | |
| | | | | | |
| | | | | | |
| | | | | | |
| Number of Taxa= 6<br>Multiply by 3 = 12<br>(Index Value) | | Number of Taxa= 7<br>Multiply by 2 = 14<br>(Index Value) | | Number of Taxa= 2<br>Multiply by 1 = 2<br>(Index Value) | |

* **Letter Code: R** = 1 to 3 (Rare); **C** = 4 to 9 (Common); **A** = 10 or more (Abundant)

** Filtering Caddisflies are in the Family Hydropsychidae (gills on abdomen; common caddisfly)
*** Pouch snails are in the Family Physidae (shell opens to the left; air-breathing snail)

| STREAM BIOTIC INDICES | | STREAM QUALITY ASSESSMENT (*Check box corresponding to Cumulative Index Value*) | | | |
|---|---|---|---|---|---|
| **Total Number of Taxa** (*Sum of Number of Taxa in each group*) | 15 | **POOR** <11 | ☐ | **FAIR** 11-16 | ☐ |
| **Cumulative Index Value** (*Sum of Index Values for each group*) | 28 | **GOOD** 17-22 | ☐ | **EXCELLENT** >22 | ☑ |

**Page 1 of 2**

# APPENDIX 2: DRAFT ANALYSIS FRAMEWORK TO ESTIMATE POST-CONSTRUCTION RUNOFF IMPACTS

## Contents

# 1. Introduction and Background

Post-construction stormwater management is one of the elements stipulated by the US Environmental Protection Agency in the context of National Pollutant Discharge Elimination Stormwater (NPDES) program. These elements, referred to as minimum control measures, intend to reduce discharge of pollutants to a “minimum extent practicable”, to protect water quality and satisfy the appropriate water quality requirements of the Clean Water Act.

Without proper management, stormwater runoff from roadways can potentially cause hydrological and water quality impacts to receiving water bodies. Response to these potential impacts generally involves the use of structural and non-structural BMPs, ordnances to address post-construction runoff as well adequate long-term operation and maintenance of BMPs. In the context of the roadways, which consist in a type of linear MS4, structural BMPs constitute a fundamental component toward the implementation of post-construction stormwater management. Estimates of runoff impacts are clearly relevant in a preliminary stages of a project, prior to detailed design of stormwater structures. These preliminary assessments can be useful in estimating characteristics of BMPs to be implemented in planned roadway projects so that hydrology and water quality criteria are met.

The current investigation on the hydrology and water quality changes in LLC watershed linked to the runoff from I-59 has been providing a valuable assessment of the impacts of that road to this headwater stream. In the context of Research Project 930-837R, the development of tasks 2 through 5 have provided some predictive ability of how and to what extent stormwater runoff from these roads changes the water quality and quantity in LLC. Field measurements entailed in these tasks are useful for two objectives. First, it will allow for a future comparison between pre-development and post-development characteristics of LLC both in terms of Hydrology and water quality.  Second, it supports the development of a draft framework to estimate post-construction runoff impacts, which is envisioned as a structured approach to combine field data that is necessary to perform these estimates of post-construction stormwater runoff impacts.

This document presents a draft analysis framework to estimate roadway impacts to small streams, with this initial focus on hydrological impacts. The document initially defines the objectives of the framework, and discusses alternative tools that could be used to attain these objectives. The second part presents the required data needed for the application of this framework. The third and last part presents an example of the application of this framework, using the case of the watershed considered in this investigation, the LLC.

## 2. Draft framework objectives

The proposed framework to estimate post-construction runoff impacts aims to provide a 1st approximation of rainfall-runoff processes in watersheds with roadways. It is attempted with this framework to obtain a preliminary estimate of hydrological impacts of roads to natural streams and approximately evaluate hydrology and water quality impacts to natural streams. To attain this objective, it is proposed that the framework will have the following characteristics:

- The framework will be constructed around a user-friendly modeling tool
- Modeling efforts to yield these estimates will use available data as much as possible
- Limited data field collection will be necessary to quantify some parameters (e.g. base flows)
- Characteristics of the stream network, watershed topography, soil characteristics and land use need to be accounted in the framework.

While the present version of this document is focused in rainfall-runoff processes and hydrological impacts, future versions will attempt to consider some impacts in terms of water quality parameters.

# 3. Description and implementation of framework

The first step in the development of the framework is to select a hydrology and water quality-modeling tool that can help achieving the aforementioned objectives. This decision affects the characteristics of estimates, the amount of required input data, as well the ability of upgrading the accuracy of assessment efforts. Considering the alternatives for modeling efforts, EPA SWMM5 model was selected as the numerical model that will support the draft framework. The reasons for this selection are:

- Has the ability to simulate complex, unsteady watershed scale rainfall-runoff processes, yielding detailed results both in terms of hydrology and water quality.
- It is an open-source model, freely available through the US Environmental Protection Agency website, which supports the development of the tool.
- Has a very long (~4 decades) development history, and a large user base including consultants, academia, and MS4 operators.
- Includes water quality simulations in model formulation.
- Has commercial implementations (e.g. PC-SWMM and XP-SWMM) that can integrate with GIS tools and sources for rainfall data (e.g. NEXRAD), facilitating more accurate modeling efforts to simulate watershed rainfall-runoff processes.
- Consider (albeit simplistically) interactions between aquifers and streams.

Other modeling alternatives were considered. However, these alternatives have shortcomings such as:

- Extensive data requirement, as in the case of 2D models such as US Army Corps GHSSA
- Time scales that are too coarse, such as in the case of USDA SWAT
- Water quality processes not included, such as the case of US Army Corps HEC-RAS/HEC-HMS

In summary, the US EPA SWMM5 model consists in a good balance between modeling complexity and accuracy for the purposes of this draft framework. The implementation steps of the framework are outlined in the following subsections of this document.

## 3.1. Required data

To perform this runoff impact estimation using SWMM5 as the modeling tool, the data collection will need to include the following parts:

### 3.1.1. Rainfall distribution

Runoff processes in watersheds result from rain events, thus hyetographs containing the rainfall intensity over time are necessary to calculate estimates of runoff impacts.

Hyetograph information is accessible through the NOAA National Climatic Data Center website, http://www.ncdc.noaa.gov/cdo-web/search. Among the different data sources, two options are adequate for SWMM5 modeling: 15-minute precipitation and hourly precipitation. These two data sources will provide the intensity of rainfall at a time frequency that is adequate for these estimates. The choice of station should clearly be as close as possible to the watershed of interest.

Considering the goals of the estimate, representative rainfall events should be selected for analysis. Data from these rain events will need to be edited to match the required structure to be imported into SWMM5. Details of this step can be found in the SWMM5 Application Manual (Gironas et al. 2009).

### 3.1.2. Watershed map and elevation data

In the proposed framework, the delineation of a watershed impacted by roadways is an important, albeit complex, task which depends on the characteristics of the impacted water body. There are some key differences in the setting of the SWMM model to calculate the estimates of runoff impacts from roadways. Stream sizes are important in defining the extent of watershed delineation/elevation map:

- Perennial rivers/streams: with catchment areas can span over several square miles, the flow regime in such streams is complex and dictated by rain events that may have occurred at locations that may be far upstream from the region of interest, next to the roadway and stream crossing. Thus, flow rates and changes in water quality parameters can be affected either by roadway contributions as well by other physical and chemical processes that have occurred far upstream. In this case, the watershed map and elevation data needs to include the roadway areas that contribute towards the runoff from the roadway, as well nearby median and ditches. In general, the larger the stream/river, the less relative importance the roadway will have toward changes in hydrology and water quality.
- Small/intermittent streams: In various cases, roadways are intercepting small streams that may be perennial or intermittent. Sometimes the interception location is at the headwaters of a watershed, which is the case of the example presented here for the LLC. In this case, the watershed delineation may incorporate all areas upstream from the point where the stream and the road intercept, as well the areas that generate roadway runoff to the stream. Available information on land use can be incorporated in the analysis, which in turn can help reduce the amount of field data collection for water quality parameters.

Ponds and lakes may also be recipient of flows from roadways, yet the approach to describe these impacts becomes very complex and drafting a generic framework to understand such impacts is unfeasible. Water quality changes in these water bodies can be affected by processes that are not linked with rainfall-runoff as well. If post construction stormwater management activities require that changes in hydrology and water quality in ponds be monitored, and specific modeling studies are warranted.

GIS software should be used in this stage to aid in the delineation of the watershed. Few tools are web-based and free cost, albeit with limited capabilities. One example is the US EPA platform WSPlanner, which is accessible in the URL http://java.epa.gov/wsplanner/ . As shown in Figure 1, this tool has the ability of delineating a watershed (LLC is exemplified). However, this tool will not delineate smaller tributaries within the watershed, such as intermittent streams that will flow as result of local rain events. As it can be anticipated, the accuracy of the delineation will depend on the quality of the elevation data available for the watershed, such as USGS elevation map repositories.

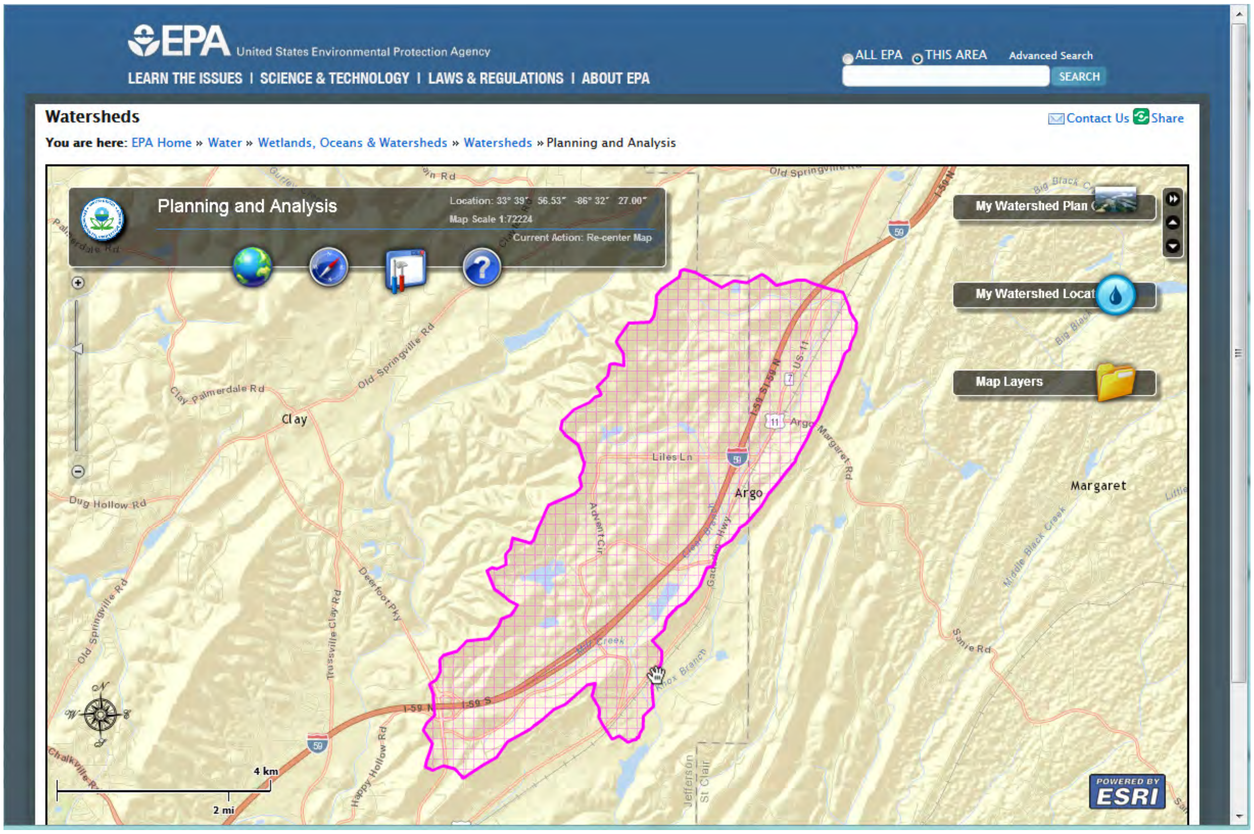


**Figure 53 - Example of watershed delineation obtained with US EPA WS Planner website**

Other GIS alternatives to US EPA WS Planner tool are also able to perform watershed delineation for watershed using USGS elevation data. One alternative that was used in the research in the LLC was the *Global Mapper*, a commercial GIS software by Blue Marble. Upon loading USGS topographical maps and layers with USGS hydrography one can obtain not only the delineation of the watershed but also the smaller streams that comprise the watershed. In this delineation, exemplified in Figure 2, there is no differentiation between permanent and intermittent streams. A USGS topographic map or access to the National Hydrography Dataset maps (http://viewer.nationalmap.gov/viewer/) is necessary to identify perennial streams. In addition, one may notice some incongruences between WS Planner and Global Mapper watershed delineation. Considering both approaches are based on USGS elevation maps, the cause of this discrepancy is not known.

In order to delineate a watershed such as the LLC watershed using Global Mapper, a digital elevation models (DEMs) data files are required. These may be downloaded from sources such as USGS digital map repositories. In Global Mapper, DEM data is also found on the list of available “Free Maps and Imagery from Online Sources”. For LCC, the United States Elevation Data (NED) at a 30 m resolution was used due to the lack of higher resolution map from USGS for this region. The view window of Global Mapper was set to the area of interest (AOI), which by default will yield a rectangular DEM. Once the AOI was chosen, the DEM file can be exported and used in commercial implementations of SWMM 5 models (such as PCSWMM and XP-SWMM) as a raster layer.

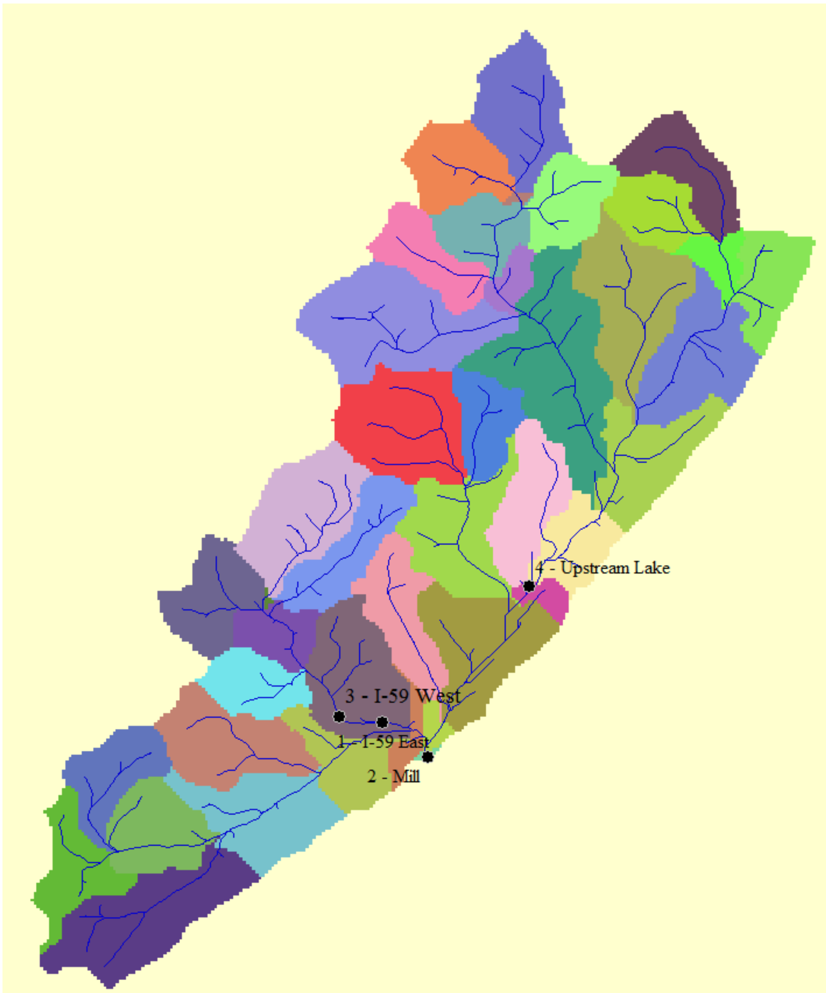

**Figure 54 - Little Cahaba Creek watershed delineation using Global**

The LCC watershed was delineated in Global mapper by using the “Generate Watershed” option in the File dropdown list. The ‘Watershed Generation Options’ allow the user to decide how detailed the watershed will be by choosing the arc degrees or meters as the resolution. The resolution for the LCC watershed was chosen as 20 meters for the x- and y- axis; the stream cell count was set as 400 cells as the number of cells the flow will accumulate from in order to be considered part of the stream; and the depression fill depth was set to 2.5 m. The smaller the numbers for the depression fill depth the more time Global Mapper will take to delineate watersheds. Once the watershed is created, the file can be exported with just the watershed shapefile. In the shapefile Export Options, the user can determine whether they want to export a line, area or point. The Generate Projection (PRJ) file was chosen to describe the ground reference system of the shapefiles.

Once exported as a shapefiles (.shp) and a geotiff (.tif) file for the watershed and DEM file, respectfully, the files may be opened in commercial SWMM implementations as layers, or in a single backdrop layer in the case of the freely available EPA SWMM5 program. The files will have to be referenced once opened in SWMM. Geo-referencing the files can be done by entering the lower left and upper right coordinates of the image. Below the map layer that was entered, there is an option to set the map coordinate system. The map in SWMM for LCC was set to the WGS 84 UTM zone 16N coordinate system. With this, any feature that is created to SWMM, whether a 1D feature such as a channel or a 2D feature such as a subcatchment, will transformed into that coordinate system and have values conveniently assigned for lengths and areas. This is further exemplified ahead in this document.

### 3.1.3. Streams and water bodies within watershed

The delineation of intermittent and perennial streams obtained with tools such as Global Mapper is very helpful in the hydrological calculations associated with rainfall-runoff processes. The delineation allows for the estimation of the length and the slope of these streams, as well the area associated with each subcatchment. As mentioned, SWMM5 has the ability of computing lengths and areas associated with the line and area features these are drawn over the referenced backdrop image in the model. Furthermore, commercial implementation of SWMM5 model such as PC-SWMM and XP-SWMM have integration with GIS tools, and the redraw step is not necessary. In both cases, it is key to verify and to adjust, as needed, the boundaries of the subcatchments in SWMM with aid of imagery. Figure 3 presents the subcatchments, junctions and channels in LCC created within SWMM.

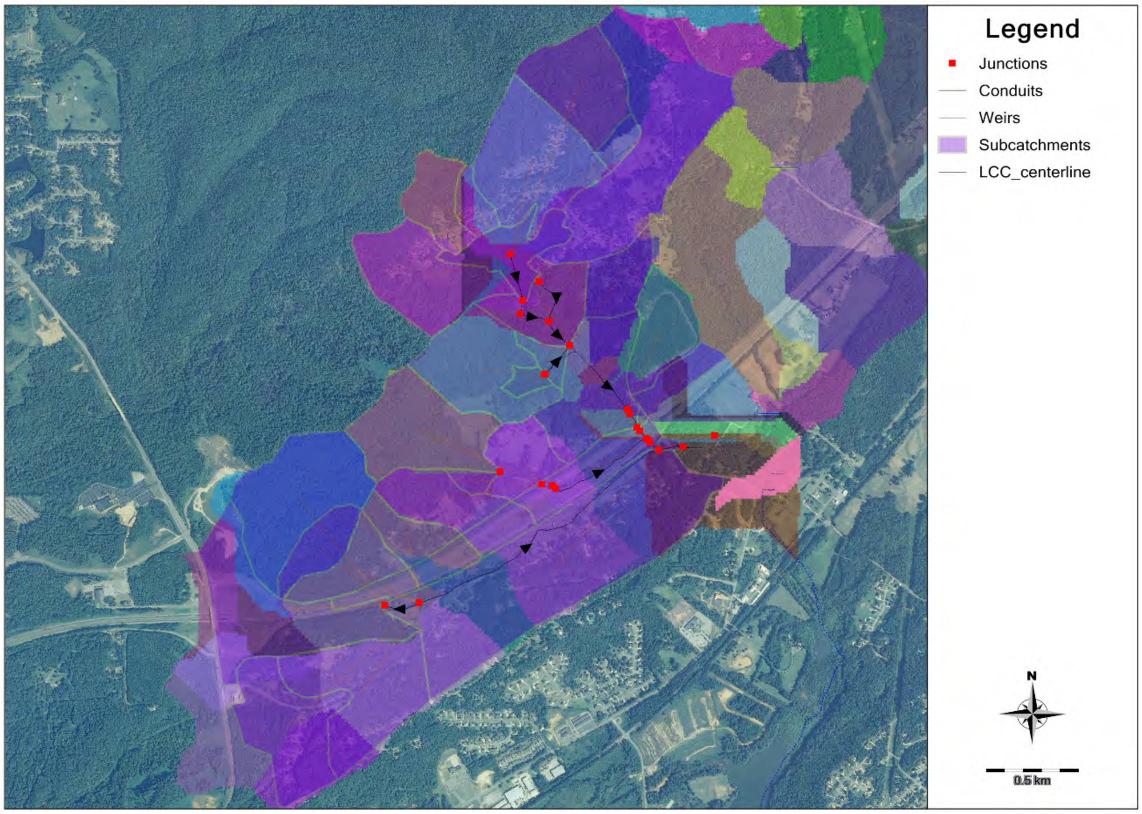


**Figure 55 - Subcatchments entered in a SWMM model of the lower Little Cahaba Creek**

An important modeling parameter for SWMM models, which is the catchment width, is related to the anticipated length of overland flow, and the estimation of these parameters becomes more accurate with the delineation of the subcatchments in the watershed and the associated streams. These overland flow contributions are admitted in the streams through junction nodes in the streams. SWMM assumes that abstraction processes such as groundwater infiltration takes place in subcatchments, and that groundwater exfiltration takes place at junctions. Yet, without field monitoring, SW-GW interactions cannot be estimated.

### 3.1.4. Land use characteristics

The National Land Cover Database, accessible at URL http://www.mrlc.gov/nlcd2011.php, as well high-quality aerial imagery facilitates the determination of human activities in the areas of interest. This type of information is very important to select modeling parameters such as infiltration in subcatchments, overland flow roughness, estimation of pollutant sources. These parameters should be supplied to the SWMM5 model in order to obtain estimates of overland flow volume, as well the timing of runoff peaks in the watershed. Further calibration of these parameters based on field measurements of flow stages and velocities have a tremendously positive impact in the accuracy of modeling estimates.

The method chosen in this framework to incorporate the impacts of land use to determine abstractions due to infiltration is the NRCS Runoff Curve Number presented in the TR55 report (USDA, 1986). This method considers land use and soil classification (to be covered in the next subsection) to estimate losses due to infiltration in the basin. Details on how to compute abstraction losses through the Runoff Curve Number Method are presented in TR55 report thus are not presented here.

### 3.1.5. Soil characteristics

Soil characteristics are very important to determine rainfall abstractions due to infiltration. A web-based tool to estimate these characteristics is the USDA Web Soil Survey, at URL http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx. Upon browsing the US map and finding the location where soil information is needed, an Area of Interest (AOI) polygon can be drawn. All available soil data, including available USDA SSURGO data, is then retrieved. Among the data made available from the Web Soil Survey tool is the USDA Hydrologic Soil Groups, useful to compute rainfall abstractions due to infiltration using the USDA TR-55 method.

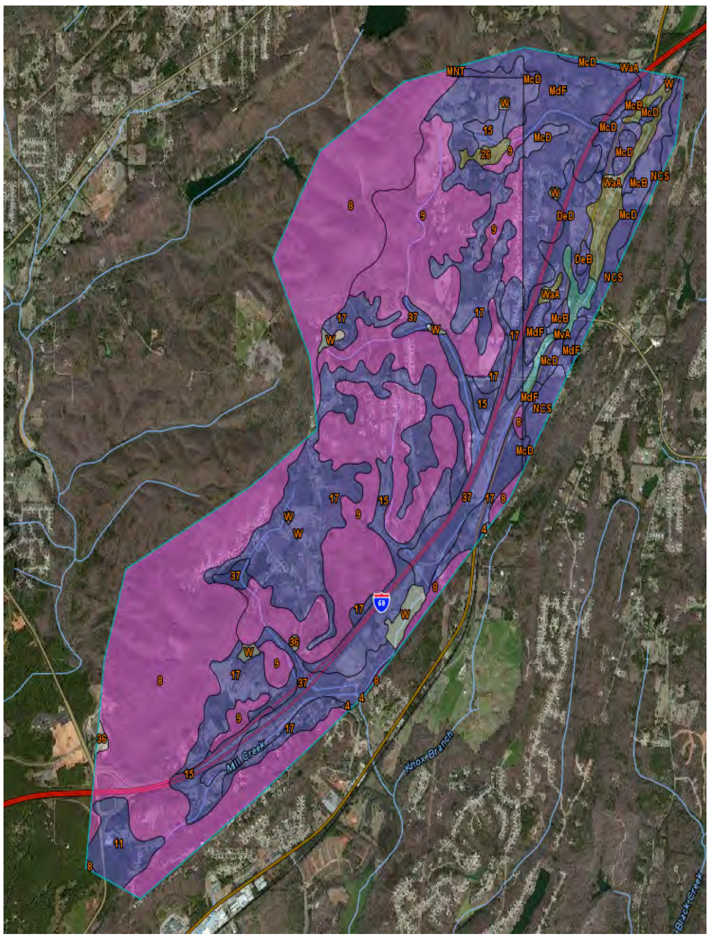

**Figure 56 - AOI polygon around Little Cahaba Creek and hydrologic soil group patches. Pink patches are A soils (high infiltration> 0.3 in./h), purple patches are B soils (moderate infiltration between 0.15 in/h and 0.3 in./h))**

The combination of land use (obtained by inspection of aerial imagery data) and hydrologic soil group characteristics provide a value for the soil curve number CN. This parameter values range from 30 to 100, with higher values linked to high runoff potential. Other model parameters dependent on CN value are the soil moisture retention parameter (after runoff begins) $S$, equal to $S = \frac{1000}{CN} - 10$. Another parameter is the initial abstraction *Ia* defined as $Ia = 0.20\, S$, though more recently the relation $Ia = 0.05\, S$ has been proposed. In order to create runoff, a rain event needs to have a depth *P* exceeding the initial abstraction. The runoff depth $Q$ from a subcatchment can be estimated through the expression $Q = \frac{(P-Ia)^2}{P-Ia+S}$, and the volume of runoff is obtainable by multiplying the runoff depth over the subcatchment area. SWMM5 incorporates this NRCS method to compute runoff volumes.

### 3.1.6. Base flows in perennial streams

Unlike traditional applications of SWMM5 model, frequently used to design engineered stormwater drainage systems, the proposed framework treats natural streams (intermittent and perennial) as main elements of the drainage network. This network is also comprised by engineered structures such as culverts, gutters, retention basins, etc., in case these are present in the watershed.

A practical modeling difficulty is that perennial streams within the watershed will maintain flow whether or not there are rain events, since flows will depend also in upstream inflow contributions that are not in the immediate vicinity of the roadway. While the determination of the streams base flow is important, the availability of data is very limited. USGS maintain a number of real-time streamflow gage stations (182 as of October 2014), and they are listed in http://waterdata.usgs.gov/al/nwis/current/?type=flow . In the context of the LLC, the closest station is Cahaba River at Trussville, and the data is available at http://waterdata.usgs.gov/al/nwis/uv/?site_no=02423110&PARAmeter_cd=00065,00060. The problem, however, is that this station is far too downstream from the LLC, and results from that station cannot be used to determine flows at the selected research site.

Thus, in the context of the proposed framework, it is important that base flows from perennial streams to be measured in the field. These measurements should be taken immediately upstream from the location where roadway runoff is discharged. Such measurements should also be taken after an extended dry period upstream from the stream-roadway interception point, in order to attenuate any effect from rain events upstream from the road. However, in the case of intermittent streams, this framework will assume initially dry bed conditions when runoff flows are generated in the watershed. The US Department of Interior – Bureau of Reclamation maintains a the Water Measurement Manual, access via http://www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/, which presents a compilation of various techniques to gage stream flows.

### 3.1.7. Water quality data

As in the case of flow monitoring for perennial streams, there are monitoring stations in streams that continuously report water quality parameters such as pH, specific conductivity, temperature, dissolved oxygen, among others. The availability of such stations is, however, significantly smaller than flow monitoring stations. There are only 17 stations that continuously monitor water quality parameters in Alabama streams, and they are listed at URL http://waterdata.usgs.gov/nwis/current/?type=quality.

Considering the limited data availability, field data collection for selected water quality parameters (e.g. turbidity, TSS) is necessary in order to provide baseline data to be used in a SWMM5 model to describe the impacts of roadway runoff to streams. As the present version of this analysis framework is not focused in predicting water quality impacts of roadway runoff to streams, details on obtaining baseline data for water quality characterization are omitted.

## 3.2. Example of draft framework implementation

A systematic implementation of the proposed framework is exemplified with the stream used in this investigation, the headwaters of the LLC, north of Trussville, AL.

### 3.2.1. Entering rainfall data

In the particular example, the only nearby source of high-frequency (e.g. within 1 hour) is the meteorological station at Birmingham-Shuttlesworth International Airport. Using the web provider by NOAA (http://www.ncdc.noaa.gov/cdo-web/datasets), and selecting the "Precipitation Hourly" database for weather station "COOP: 010831 - BIRMINGHAM AIRPORT, AL US", results of the Hourly Precipitation within 1/100th of an inch (HPCP) are provided. A sample of the table obtained is presented below:

| STATION | STATION_NAME | DATE | HPCP |
|---|---|---|---|
| COOP:010831 | BIRMINGHAM AIRPORT AL US | 20130101 01:00 | 0 |
| COOP:010831 | BIRMINGHAM AIRPORT AL US | 20130101 06:00 | 12 |
| COOP:010831 | BIRMINGHAM AIRPORT AL US | 20130101 07:00 | 7 |
| COOP:010831 | BIRMINGHAM AIRPORT AL US | 20130101 08:00 | 14 |
| COOP:010831 | BIRMINGHAM AIRPORT AL US | 20130101 09:00 | 23 |
| COOP:010831 | BIRMINGHAM AIRPORT AL US | 20130101 10:00 | 8 |
| COOP:010831 | BIRMINGHAM AIRPORT AL US | 20130101 11:00 | 10 |
| COOP:010831 | BIRMINGHAM AIRPORT AL US | 20130101 12:00 | 9 |

The table format above needs to be adjusted to match the data input format for SWMM 5 input data. Rainfall may be input in terms of intensity (in/hr or mm/hr), volume (in or mm), or cumulative volume within the recording interval. Rainfall in SWMM may entered as an external file, or entered as a time series within the SWMM input file. In the latter case, a time series needs to be defined, and the values in the time series constitutes a table with four columns:

- Time series name
- Date associated with the value in the time series
- Timestamp (hour: minute) associated with the value in the time series
- Value in the time series, in this case rainfall volume (in), within the recording interval

SWMM front end provides an interface to type this information, however for a larger input it may be more convenient to edit the input file directly with a text editor. An excerpt from the SWMM input file is presented below.

```
[TIMESERIES]
;;Name           Date       Time       Value
;;-------------- ---------- ---------- ----------
BrewsterRainGage 4/11/2013  15:30:00   0.055
BrewsterRainGage 4/11/2013  16:00:00   0
BrewsterRainGage 4/11/2013  16:30:00   0.01
BrewsterRainGage 4/11/2013  17:00:00   0.51
```

### 3.2.2. Entering watershed map and subcatchments

This stage is very important and requires information that should be collected with the aid of a GIS tool. It is assumed in this example that a GIS software has been used to create the map of the watershed that include the road and the adjacent subcatchments that will create runoff contributions to the stream.

In the case of the LCC example, a map such as the one presented in Figure 5 is necessary as a means to draw subcatchments. The basic steps are the following

1. Save the required image (formats BMP, JPG, JPEG, WMF, EMF) and load in SWMM as a backdrop image. Menu “View>Backdrop>Load”. Set image a watermark “View>Backdrop>Watermark” to facilitate the subsequent catchment drawing
2. With the aid of the GIS software, obtain the X-Y coordinates of the images (meters or feet) for the lower left corner of the map as well the top right corner.
3. Enter these two coordinates into SWMM. Menu “View> Dimensions”
4. Set SWMM to Auto-Length option to true by selecting this option in the SWMM model status bar (lower bar), left corner.
5. With this, all subcatchments will have areas calculated automatically. All channels and conduit lengths will also automatically be assigned by this scaling.

Further division of the subcatchments can also include characteristics of the soils obtained with the data from the survey. This would require that another backdrop map be generated and loaded in SWMM. The process, however, is the same as described above.

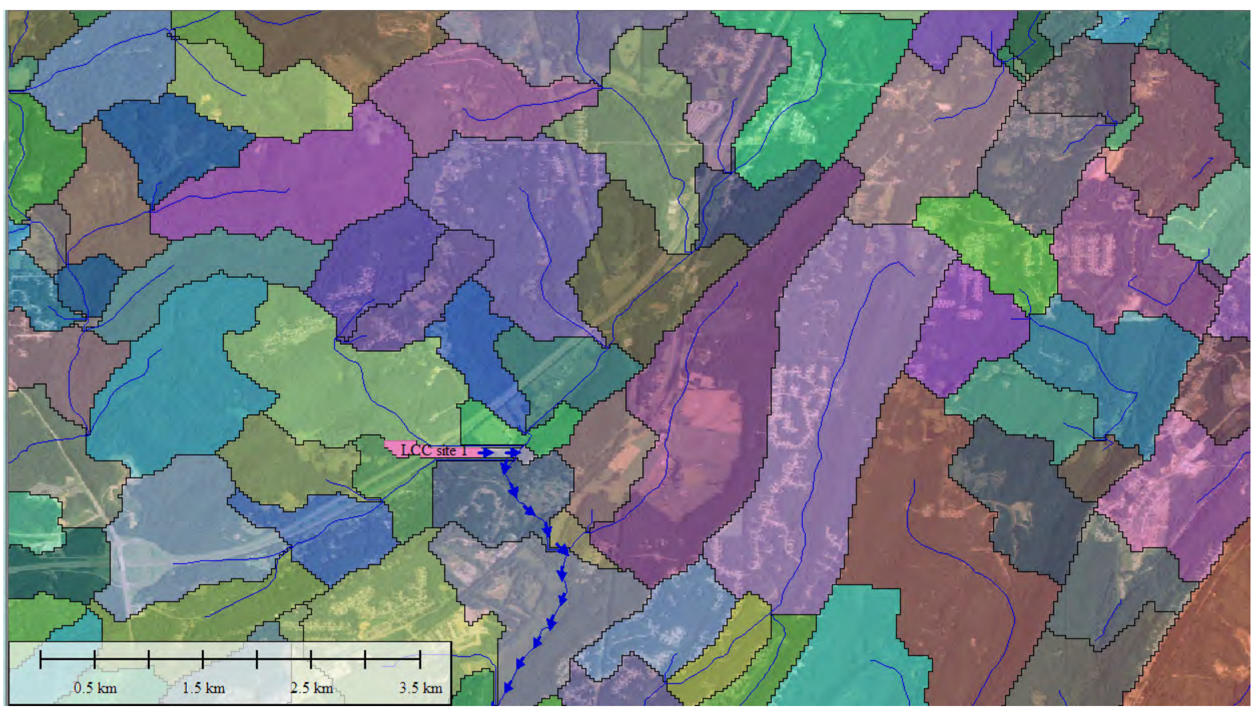


**Figure 57 – Map obtained with Global Mapper showing all subcatchments for the example watershed, the Little Cahaba Creek. Features such as the road, major land features, and streams are also visible. This map will serve as a backdrop to draw subcatchments using SWMM model.**

After following these steps, the screen with the SWMM map should resemble the result in Figure 6. At this stage, with the rainfall series and the backdrop image loaded, the subcatchments are ready to be input in the model

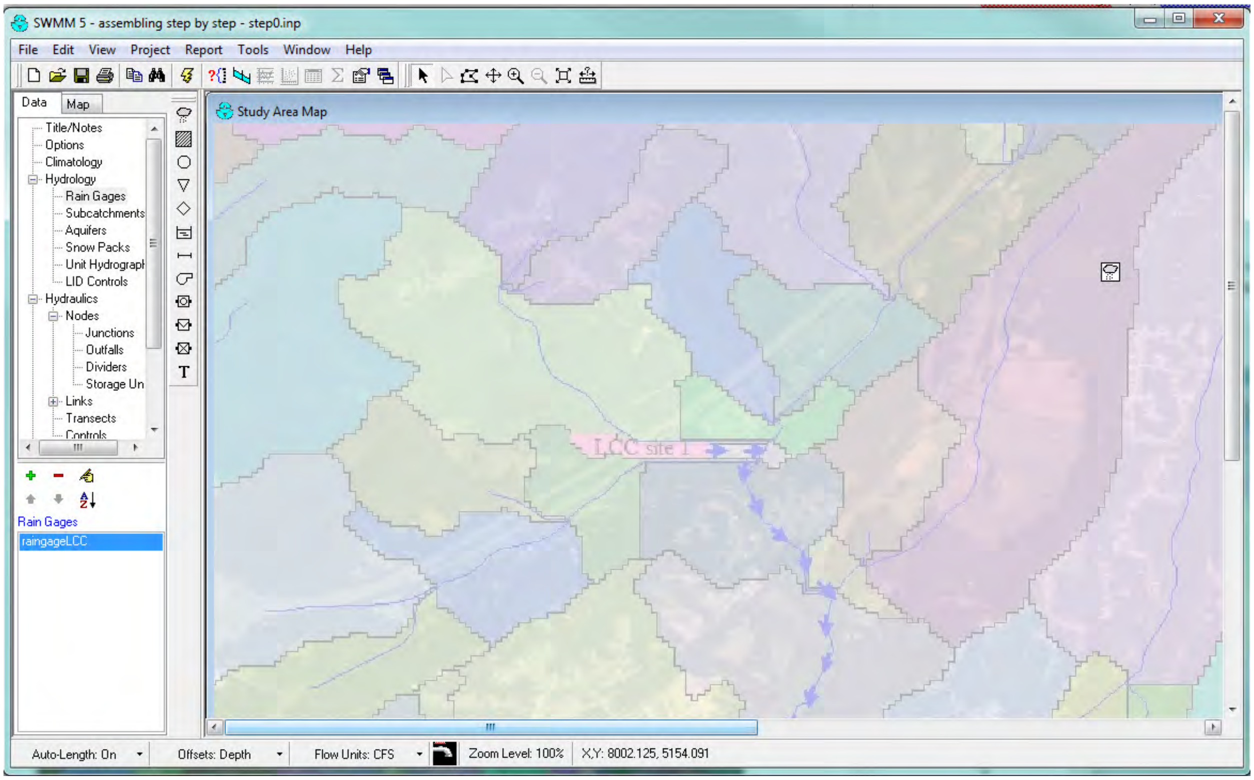


**Figure 58- Result of backdrop image loading into SWMM model. The user can draw subcatchments and channels/conduits on the top of this image.**

Using the symbol for subcatchments  in the SWMM toolbar that is left of the map, we can draw irregular-shaped subcatchments in SWMM. For instance, Figure 7 presents one of these subcatchments drawn with SWMM. Left clicking will allow creating the vertices of the subcatchment to conform to the backdrop map, and a last right click will finish the subcatchment drawing.

While the subcatchment area has been defined with the Auto-Length, many other properties in each subcatchment need to be defined for the model to work properly. Double clicking the subcatchment shows a "Property" dialog box with all the characteristics of the subcatchment, which will require editing. This dialog box is presented in Figure 8

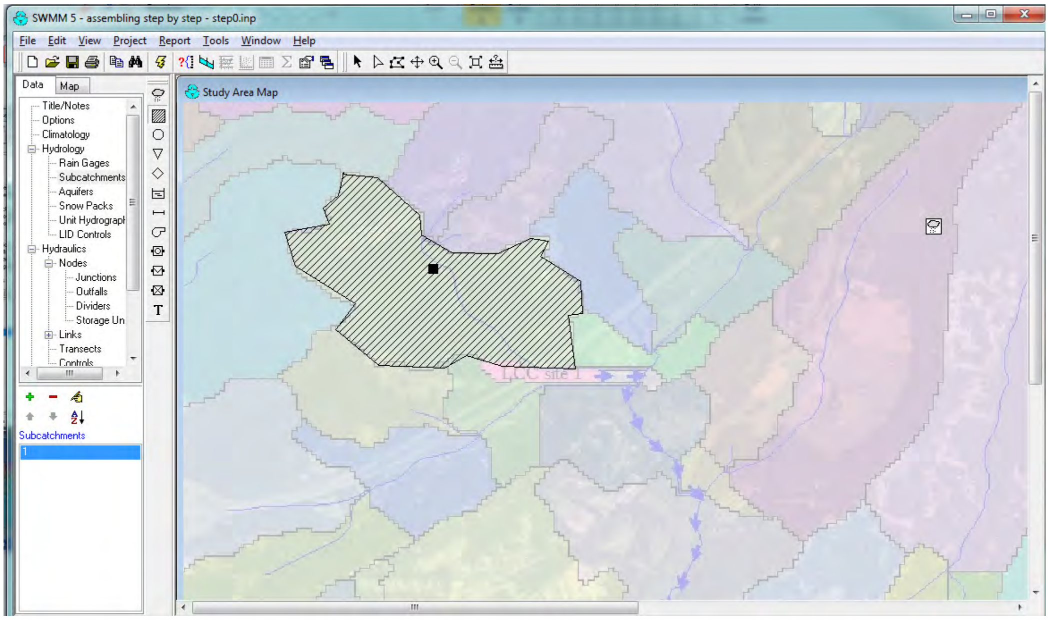


**Figure 59 – Drawing a 1st subcatchment using SWMM toolbar button for subcatchment**

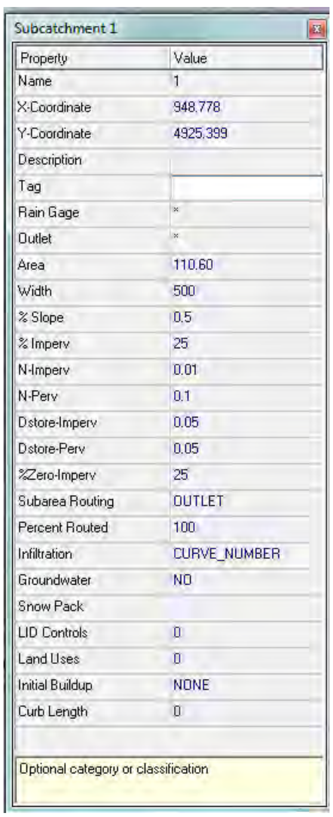


**Figure 60 - Double clicking the subcatchment presents the Properties of the newly created subcatchment**

At this stage, various properties to the subcatchments necessary to perform the analysis need to be input using the window presented in Figure 8. While this document does not intend to be a replacement to a SWMM manuals published by EPA (Rossman, 2010 or Gironás et al. 2009), some of the key subcatchment properties are presented below:

- Description: brief text description of the subcatchment .
- Rain gage: which rain gage has data on the rain events, and the rain gage as the object that has received the local area hyetograph(s).
- Outlet: The subcatchment runoff (overland flow) will be routed to a node that will be part of the drainage system. Nodes and conduits are explained ahead in this document.
- Area: obtained with aid of the auto length feature of SWMM.
- Width of the subcatchment: In order to prevent large times of concentration in subcatchments, this parameter is used to ensure that the overland flow length (between sheet flows and shallow concentrated flows) is not excessive. Details are presented in SWMM manuals.
- % slope: average slope of catchment, obtainable w/ GIS packages.
- % Imperviousness: percentage of subcatchment with impervious area.
- N-Impervious/N-Pervious: Roughness used in the Manning equation for open channel flow to be considered in impervious/pervious area. Hydraulic publications have tabulated values for various channel linings.
- D-storage impervious/pervious: Depression storage abstractions
- Infiltration: The framework adopts NRCS TR-55 approach to estimate infiltration abstraction. Each subcatchment require CN values along with estimates for drying time. Use NRCS TR 55 report for assigning CN values.

After the input of all subcatchments, the resulting map should resemble what is presented in Figure 9.

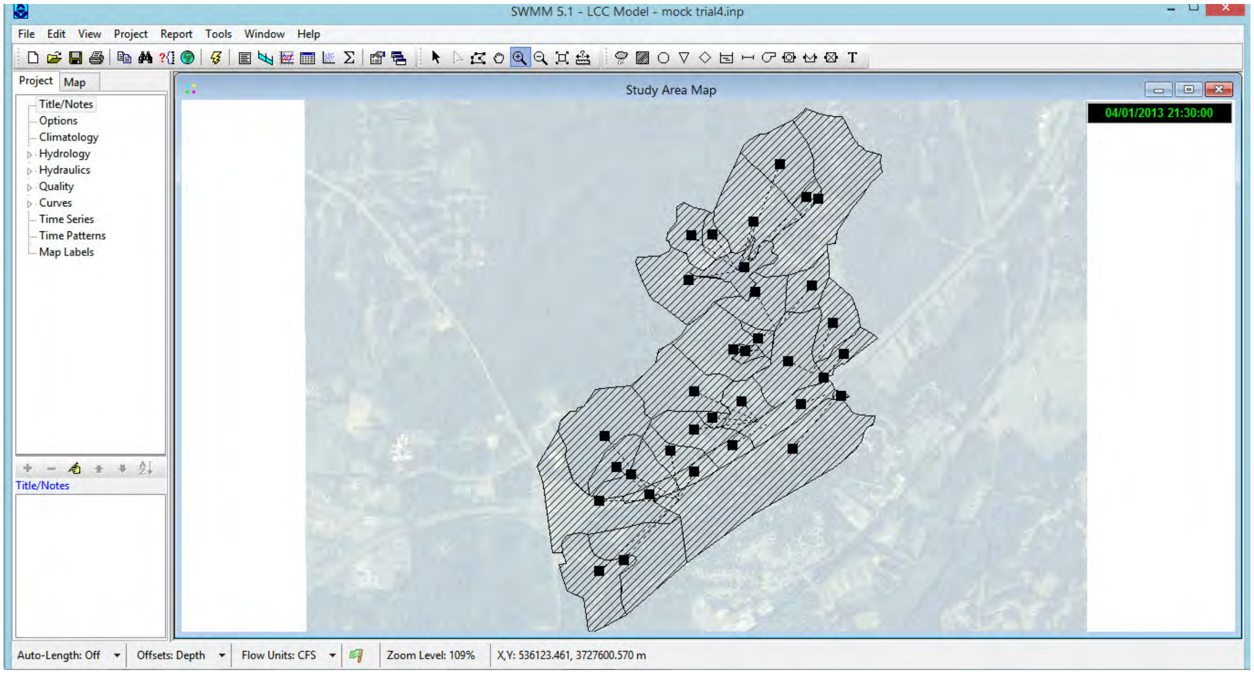


**Figure 61 – Map of LCC watershed with all subcatchments represented.**

### 3.2.3. Entering streams and drainage network

Following the input of subcatchments in the area of interest, natural and engineered components of the drainage system needs to be inserted in the SWMM model. While there are several elements in SWMM that constitute the drainage system, this framework adopts a simplified approach of considering only "nodes" and "links" as the parts representing the drainage network and stream-road interception points. Elements such as aquifers (groundwater flow), surface reservoirs, flow diversions, etc. are thus not included in the framework discussion, though an experienced SWMM user could add these and possibly improve the accuracy of estimates. Details on nodes and links are available in SWMM manuals.

As input data, the following information will be required

- Elevation map of the watershed (e.g. contour maps)
- Maps containing natural stream alignments (e.g. USGS Topo quadrangles maps, web sources such as http://viewer.nationalmap.gov/viewer/, maps created with GIS packages)
- Information on constructed drainage: culverts, artificial channels, etc.
- If possible, information (e.g. photographs) of channel lining and characteristics in the watershed

Every subcatchment will route its overland flows to nodes, which in turn will be linked via channels. More than one subcatchment can discharge its flows in a given node. The location of nodes should be selected downstream from the catchment, in an attempt to conform the selections of these points to the local drainage pattern. The only key information required for these points is the elevation. The X-Y coordinates are obtained with SWMM auto length feature. The map with the nodes is presented in Figure 10. Subcatchments are also present in the model file, but were omitted on the visualization. The node at downstream end is the outfall, to which stormwater runoff and stream base flows are routed. Finally, base flows (if known) may be entered in the inflow property in junctions.

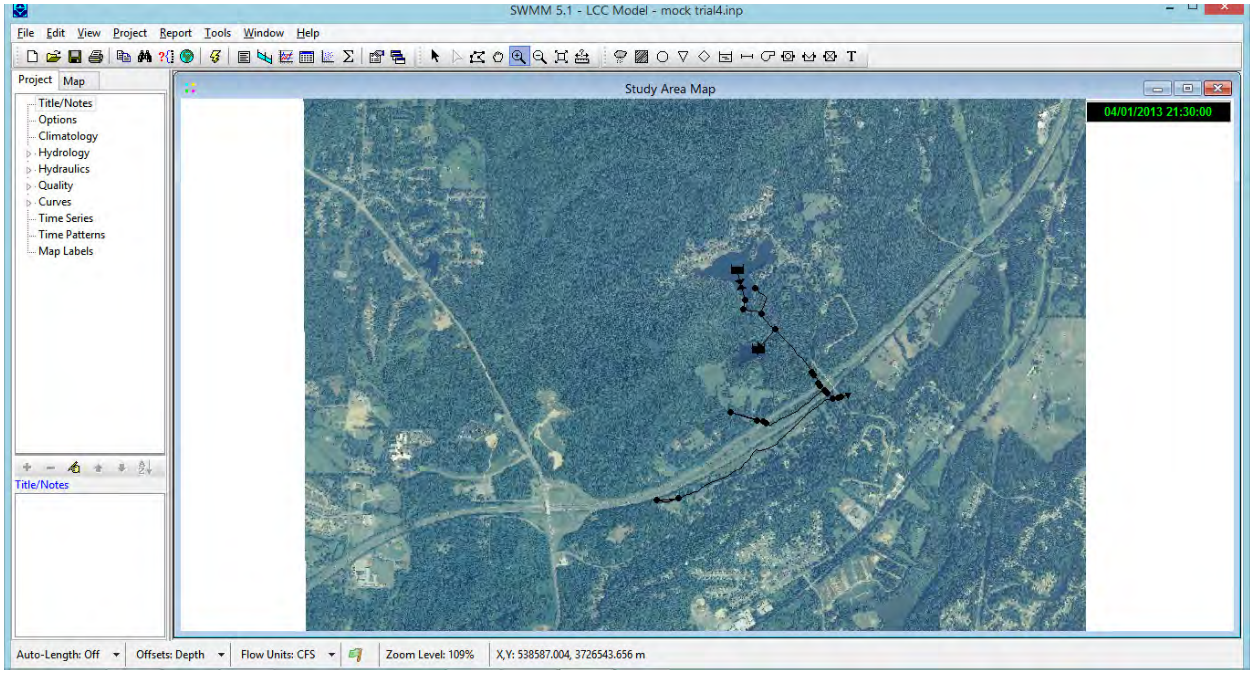


**Figure 62 - All nodes (points) and links entered in the Little Cahaba Creek watershed, as it intercepts I-**

With all nodes represented, links are drawn to connect the nodes based on local drainage pattern. Figure 11 presents the USGS National Hydrography Database, which helped draw the stream network, but this data was complemented with stream scouting. There are some discrepancies between the USGS map and the actual conformation of streams shown in Figure 10, particularly at the road median. This can be an indication that the I-59 construction has altered slightly the alignment of LCC tributaries.

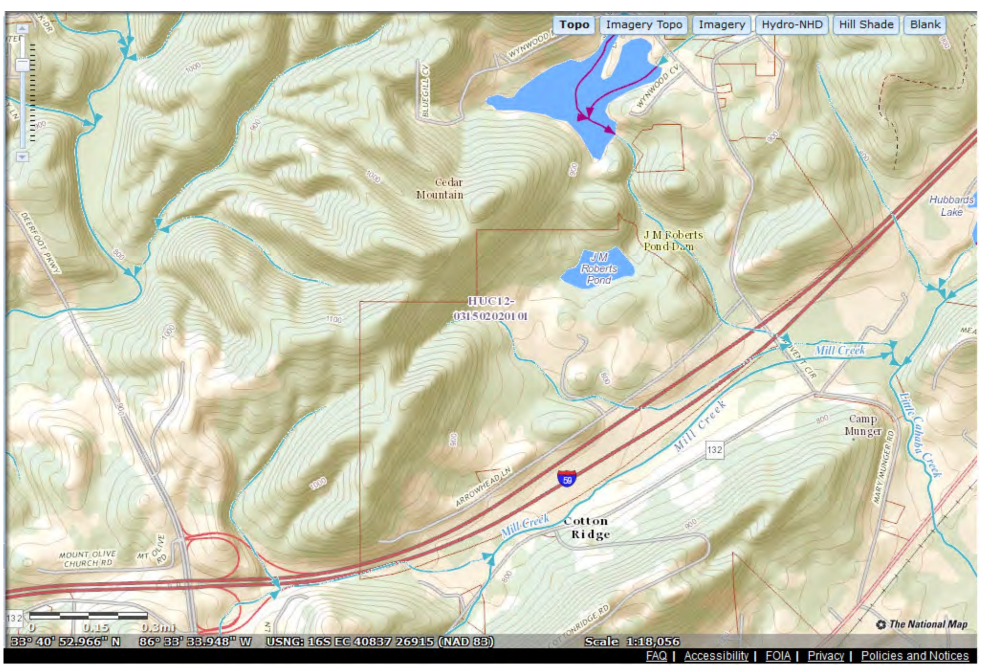


**Figure 63 – USGS NHD map of the region of the Little Cahaba Creek. Compare stream conformation on Figure 10, which reflects the construction of the I-59**

The natural stream network operate as open channels, and accurate modeling efforts would demand scouting the stream and obtaining of various cross sections. Aligned with a lower data requirement in this framework, it is assumed that natural streams have trapezoidal cross section. Channel side slopes as well Manning roughness have to be based on local observations. There is no offsets of natural channels with these nodes, so the elevation of these nodes and the length of the channels will determine the local channel slope. The channel length is determined with the auto length property of SWMM. Artificial channels share most characteristics of natural streams, except that the roughness should be significantly smaller. More details on how this information is input to SWMM is available in Rossman (2010).

Culverts are closed section elements, and may be represented in SWMM as a rectangular or circular cross section. Eventual invert offsets either upstream/downstream in culverts may be measured in the field and entered in SWMM. Another key variable to be entered is roughness, which also tends to be significantly smaller than natural streams.

The resulting SWMM with subcatchments, nodes, and links is presented in Figure 12

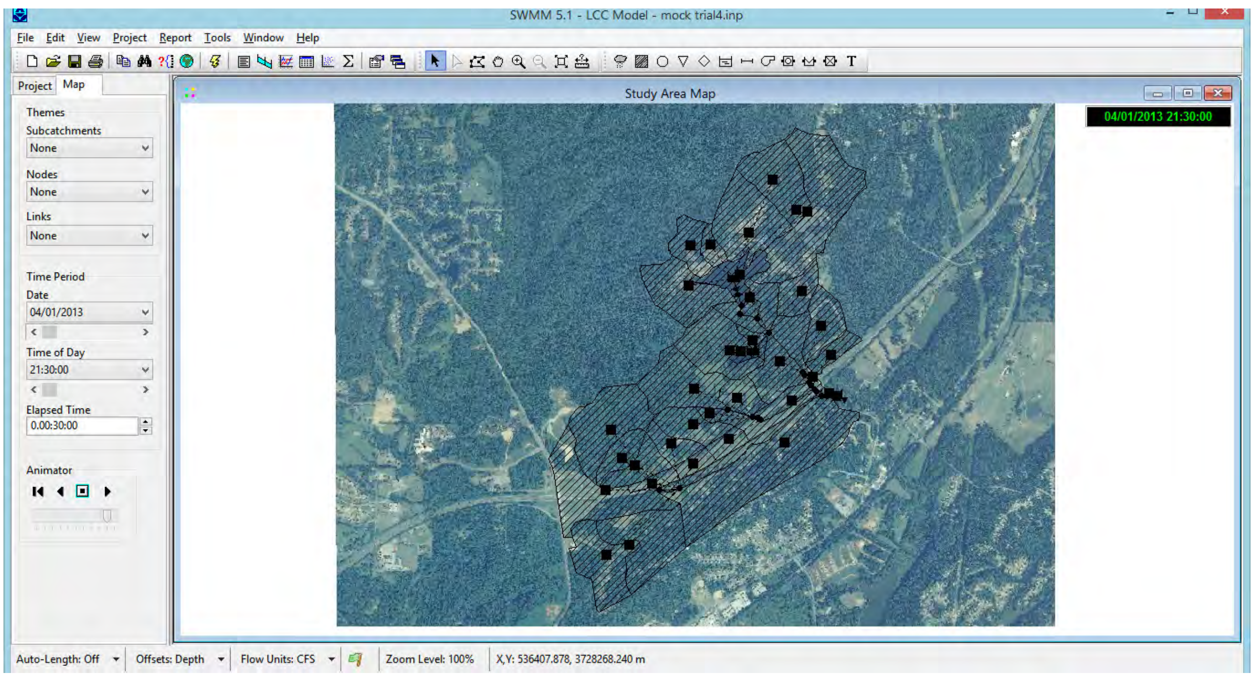


**Figure 64 - Completed SWMM project for the LCC watershed**

## 4. Results

A brief comparison of the modeling results is presented here, and is important to note that there has been no attempt to perform a systematic modeling calibration. The chart presented in Figure 13 presents measured results of the flow rate from June to October 2014, at the site downstream from the interception point between the LCC and I-59. The observed flows (square symbols) were measured with the aid of an area-velocity sensor deployed at a cross section which was previously surveyed. Flow rates were sampled every 30 minutes. In this 50-day interval there were 12 separate rain events.

Modeling results from the proposed framework are presented as a continuous red line. As it can be seen, modeled results tended in most times to be above observed flows. However, the order of magnitude of these flows is comparable, which was the initial objective of the proposed analysis framework to support post-construction stormwater analysis.

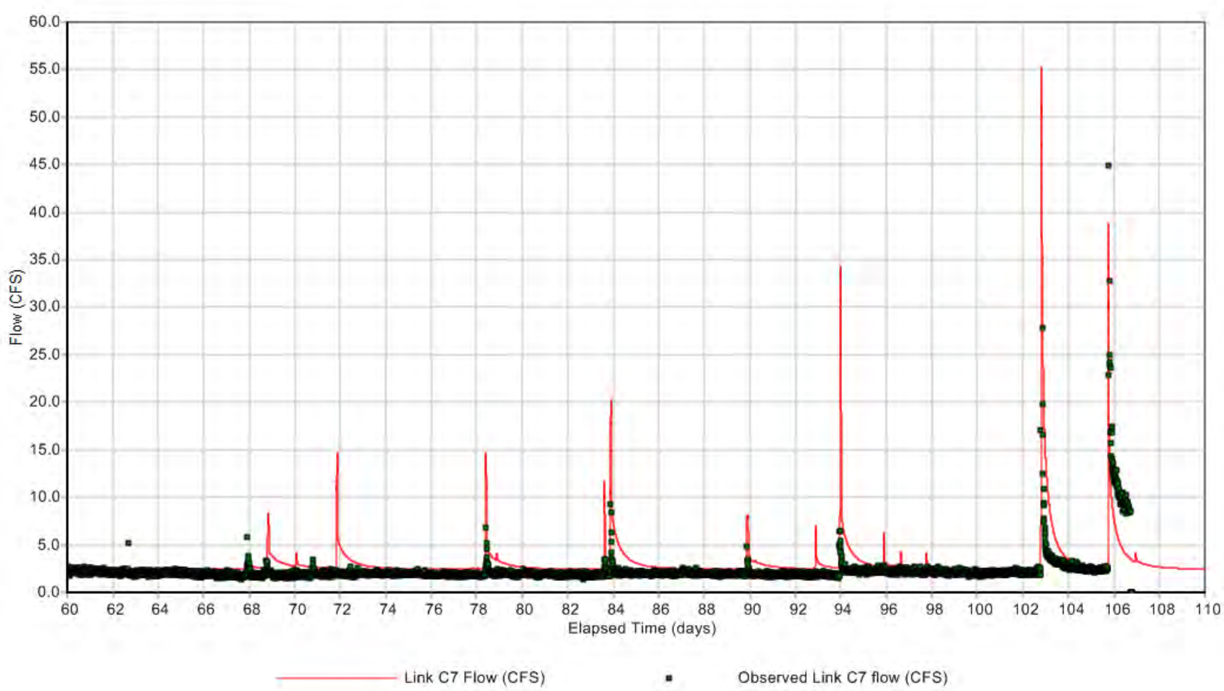


**Figure 65 – Comparison between observed flows in the Little Cahaba Creek and predicted flows using SWMM5 model, following the proposed framework.**

Despite of accuracy limitations from the framework, it is possible to use the simulation results to estimate the increase of runoff volume across the roadway interception. In the case of the LCC and I-59 crossing, the model results of runoff upstream and downstream from the crossing are presented in Figure 14. Field measurements have indicated that the baseline flows to be 1.2 and 2.4 CFS upstream and downstream of the crossing, respectively. When rainfall events occur, the stream level and flow rate increases, according to the magnitude of the rain and the antecedent dry period. Modeling results indicate that the flow rates upstream from I-59 are 25% to 60% of the flow rate observed downstream from the road. Subcatchments between these two points, including the road itself and the median contributes toward this increase in flows.

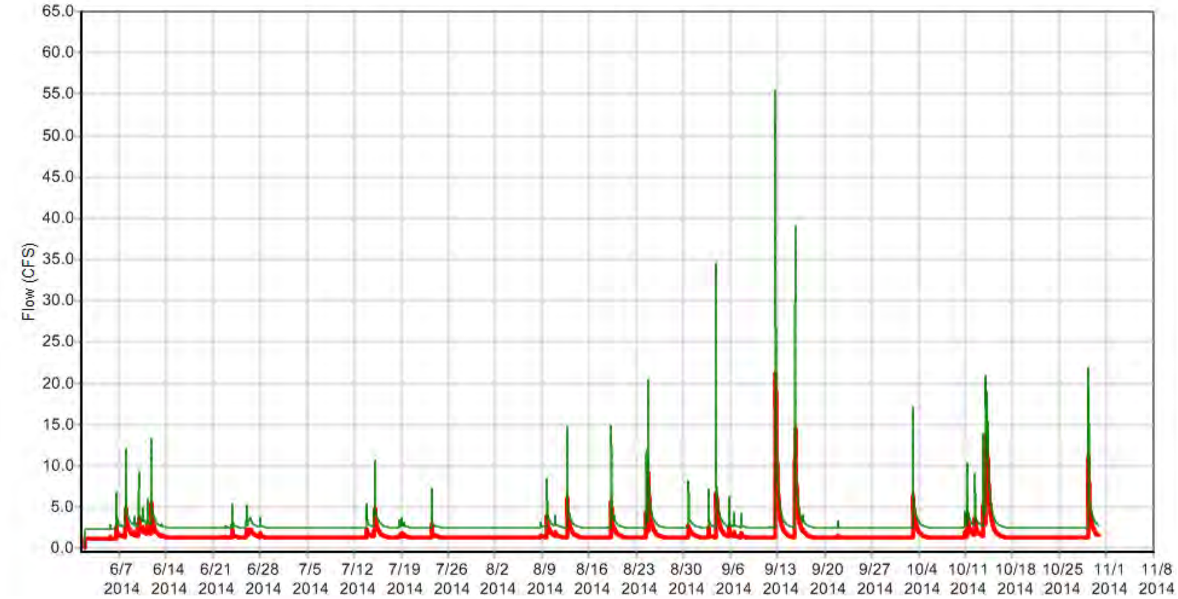


**Figure 66 – Model results of the Little Cahaba Creek flow rates upstream and downstream from I-59, using hyetograph results from June to October 2014.**

An interesting result that may also be obtained with SWMM is the ability of continuously relate flow rates from one location to flow rates in another location. Figure 15 presents the graph of modeled flows downstream of I-59 (x-axis) versus flows upstream of I-59 for the months of July and October 2014. July is a dry season, and it can be seen that flows do not increase beyond 11 CFS at the downstream station, with the flows measured upstream less than 50% of the downstream values. The wetter month of October presents much larger flows rates, with the flow rate upstream I-59 up to 67% of the flow rate downstream modeled with SWMM. Detailed output information on the modeling results is available in the appendix of this document, presented the SWMM 5 status report for the LCC simulation.

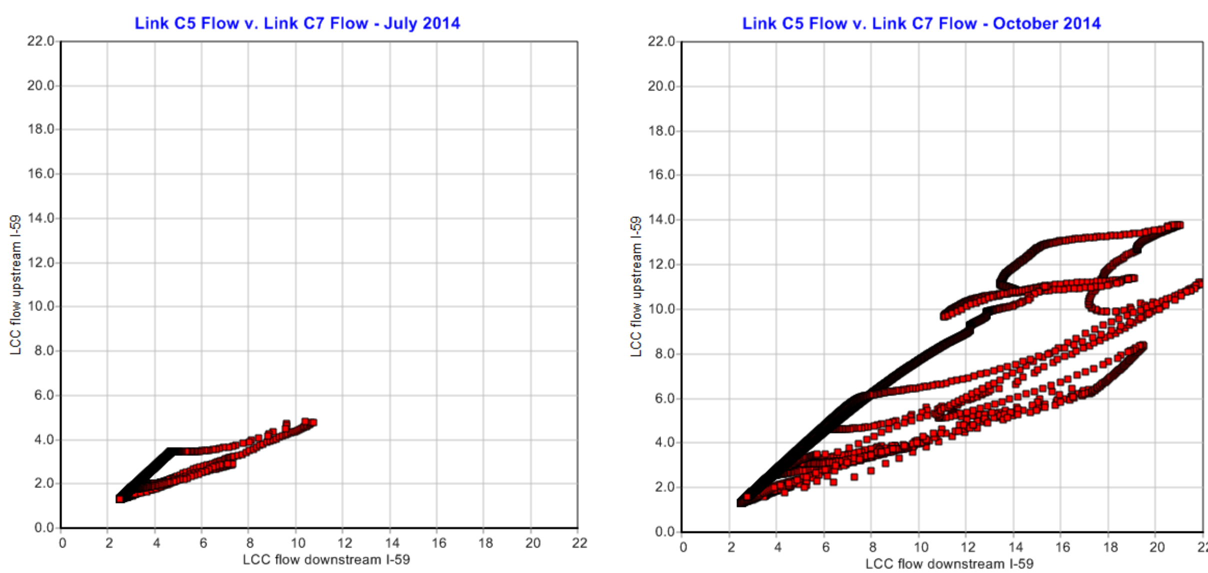


**Figure 67 – Comparison of flow rates obtained with SWMM model upstream and downstream from I-59 for a dry month (07/2014) and a wetter month (10/2014)**

# References

United States Department of Agriculture (1986). *Urban hydrology for small watersheds*. Technical Release 55 (TR-55) (2nd edition). Natural Resources Conservation Service, Conservation Engineering Division.

Gironas, J.; Roesner, L.; Davis, J. (2009) *SWMM 5 Application Manual*, Environmental Protection Agency Report EPA/600/R-09/077

Rossman, L . (2010) *Storm Water Management Model User's Manual, Version 5.0*, Environmental Protection Agency Report EPA/600/R-05/040

# Appendix – SWMM 5.1 status report for the LCC modeling using the approach outlined in this draft analysis framework

```
EPA STORM WATER MANAGEMENT MODEL - VERSION 5.1 (Build 5.1.007)
--------------------------------------------------------------


****************
Analysis Options
****************
Flow Units ............... CFS
Process Models:
  Rainfall/Runoff ........ YES
  RDII ................... NO
  Snowmelt ............... NO
  Groundwater ............ NO
  Flow Routing ........... YES
  Ponding Allowed ........ NO
  Water Quality .......... NO
Infiltration Method ...... CURVE_NUMBER
Flow Routing Method ...... DYNWAVE
Starting Date ............ JUN-01-2014 21:00:00
Ending Date .............. OCT-30-2014 21:00:00
Antecedent Dry Days ...... 1.0
Report Time Step ......... 00:01:00
Wet Time Step ............ 00:00:10
Dry Time Step ............ 00:00:10
Routing Time Step ........ 10.00 sec
Variable Time Step ....... YES
Maximum Trials ........... 8
Head Tolerance ........... 0.005000 ft


*************
Element Count
*************
Number of rain gages ...... 1
Number of subcatchments ... 34
Number of nodes ........... 27
Number of links ........... 27
Number of pollutants ...... 0
Number of land uses ....... 0


****************
Raingage Summary
****************
                                                     Data       Recording
Name                 Data Source                     Type       Interval 
-------------------------------------------------------------------------
BrewsterRainGage     BrewsterRainGage                VOLUME      30 min.


********************
Subcatchment Summary
********************
Name                       Area     Width   %Imperv    %Slope Rain Gage            Outlet
-----------------------------------------------------------------------------------------------
JM_Roberts_Pond            6.78    590.54      5.00    0.5000 BrewsterRainGage     JMRobertsPond
Lake                      35.43   3086.81      5.00    0.5000 BrewsterRainGage      ResLake
S_1                      223.97  19512.33      2.00    0.5000 BrewsterRainGage      J4
S_10                      30.13   2625.14      2.00   13.5000 BrewsterRainGage      J2
S_11                       9.60    836.62      2.00    0.5000 BrewsterRainGage      J2
S_12                      70.78   6166.60      2.00    0.5000 BrewsterRainGage     JMRobertsPond
S_13                     151.28  13179.11     10.00   13.5000 BrewsterRainGage      ResLake
S_14                      72.39   6307.02     10.00    0.5000 BrewsterRainGage      ResLake
```

| | | | | | | |
|---|---|---|---|---|---|---|
| S_15 | 32.34 | 2817.82 | 10.00 | 0.5000 | BrewsterRainGage | ResLake |
| S_16 | 13.91 | 1211.98 | 10.00 | 0.5000 | BrewsterRainGage | ResLake |
| S_17 | 89.79 | 7822.14 | 10.00 | 0.5000 | BrewsterRainGage | ResLake |
| S_18 | 9.63 | 838.55 | 1.00 | 13.5000 | BrewsterRainGage | ResLake |
| S_19 | 62.07 | 5407.55 | 1.00 | 0.5000 | BrewsterRainGage | ResLake |
| S_2 | 1.86 | 161.69 | 2.00 | 0.5000 | BrewsterRainGage | OF1 |
| S_20 | 32.35 | 2818.74 | 2.00 | 0.5000 | BrewsterRainGage | J18 |
| S_21 | 77.32 | 6736.18 | 2.00 | 0.5000 | BrewsterRainGage | J18 |
| S_22 | 38.29 | 3335.85 | 2.00 | 0.5000 | BrewsterRainGage | J18 |
| S_23 | 15.53 | 1352.63 | 10.00 | 0.5000 | BrewsterRainGage | J15 |
| S_24 | 101.86 | 8874.14 | 5.00 | 0.5000 | BrewsterRainGage | J9 |
| S_25 | 23.72 | 2066.46 | 2.00 | 0.5000 | BrewsterRainGage | J14 |
| S_26 | 26.97 | 2350.00 | 2.00 | 0.5000 | BrewsterRainGage | J9 |
| S_27 | 91.70 | 7989.06 | 2.00 | 0.5000 | BrewsterRainGage | J9 |
| S_28 | 13.50 | 1176.50 | 10.00 | 0.5000 | BrewsterRainGage | J14 |
| S_29 | 88.18 | 7682.48 | 2.00 | 0.5000 | BrewsterRainGage | J14 |
| S_30 | 73.18 | 6375.15 | 2.00 | 0.5000 | BrewsterRainGage | J14 |
| S_31 | 11.40 | 993.01 | 10.00 | 0.5000 | BrewsterRainGage | J14 |
| S_32 | 6.43 | 560.02 | 2.00 | 0.5000 | BrewsterRainGage | J18 |
| S_33 | 32.00 | 2787.96 | 2.00 | 0.5000 | BrewsterRainGage | J14 |
| S_4 | 38.79 | 3379.48 | 10.00 | 0.5000 | BrewsterRainGage | J3 |
| S_5 | 0.99 | 86.21 | 2.00 | 0.5000 | BrewsterRainGage | J8 |
| S_6 | 72.48 | 6314.54 | 2.00 | 0.5000 | BrewsterRainGage | J6 |
| S_7 | 18.81 | 1638.37 | 2.00 | 0.5000 | BrewsterRainGage | J8 |
| S_8 | 42.02 | 3660.36 | 2.00 | 0.5000 | BrewsterRainGage | J6 |
| S_9 | 43.03 | 3748.41 | 2.00 | 0.5000 | BrewsterRainGage | J2 |

************
Node Summary
************

| Name | Type | Invert Elev. | Max. Depth | Ponded Area | External Inflow |
|---|---|---|---|---|---|
| J1 | JUNCTION | 833.95 | 5.00 | 0.0 | |
| J10 | JUNCTION | 777.83 | 5.00 | 0.0 | |
| J11 | JUNCTION | 727.14 | 8.00 | 0.0 | |
| J12 | JUNCTION | 723.93 | 8.00 | 0.0 | |
| J13 | JUNCTION | 815.72 | 5.00 | 0.0 | |
| J14 | JUNCTION | 787.95 | 4.97 | 0.0 | |
| J15 | JUNCTION | 748.48 | 5.96 | 0.0 | |
| J16 | JUNCTION | 747.22 | 5.00 | 0.0 | |
| J17 | JUNCTION | 747.82 | 5.00 | 0.0 | |
| J18 | JUNCTION | 753.39 | 4.00 | 0.0 | |
| J19 | JUNCTION | 723.86 | 5.96 | 0.0 | |
| J2 | JUNCTION | 753.39 | 5.00 | 0.0 | |
| J20 | JUNCTION | 727.01 | 120.00 | 0.0 | |
| J21 | JUNCTION | 717.50 | 8.00 | 0.0 | |
| J22 | JUNCTION | 717.25 | 8.00 | 0.0 | |
| J3 | JUNCTION | 718.93 | 13.00 | 0.0 | Yes |
| J4 | JUNCTION | 718.58 | 8.10 | 0.0 | |
| J5 | JUNCTION | 700.00 | 100.00 | 0.0 | |
| J6 | JUNCTION | 731.51 | 8.00 | 0.0 | |
| J7 | JUNCTION | 730.27 | 8.00 | 0.0 | |
| J8 | JUNCTION | 727.14 | 8.00 | 0.0 | Yes |
| J9 | JUNCTION | 796.04 | 4.00 | 0.0 | |
| OF1 | JUNCTION | 717.00 | 14.00 | 0.0 | |
| 2 | JUNCTION | 716.50 | 8.00 | 0.0 | |
| 1 | OUTFALL | 716.00 | 8.00 | 0.0 | |
| JMRobertsPond | STORAGE | 700.00 | 95.00 | 0.0 | |
| ResLake | STORAGE | 728.00 | 125.00 | 0.0 | |

************
Link Summary
************

| Name | From Node | To Node | Type | Length | %Slope | Roughness |
|---|---|---|---|---|---|---|
| C1 | J1 | J10 | CONDUIT | 543.8 | 10.3761 | 0.0300 |
| C10 | J10 | J2 | CONDUIT | 587.7 | 4.1621 | 0.0300 |
| C11 | J8 | J11 | CONDUIT | 93.1 | 0.0011 | 0.0120 |
| C12 | J12 | J3 | CONDUIT | 64.3 | 0.0016 | 0.0120 |
| C13 | J13 | J10 | CONDUIT | 906.7 | 4.1824 | 0.0300 |
| C14 | J16 | J15 | CONDUIT | 40.1 | -3.1406 | 0.0300 |
| C15 | J9 | J14 | CONDUIT | 649.0 | 1.2467 | 0.0400 |
| C16 | J15 | J19 | CONDUIT | 1910.3 | 1.2893 | 0.0300 |
| C17 | J17 | J16 | CONDUIT | 89.9 | 0.6638 | 0.0120 |
| C18 | J18 | J17 | CONDUIT | 191.1 | 2.9155 | 0.0300 |
| C19 | J19 | J12 | CONDUIT | 37.0 | -0.1986 | 0.0100 |
| C2 | J5 | J2 | CONDUIT | 644.7 | 4.1310 | 0.0300 |
| C20 | J21 | J22 | CONDUIT | 38.4 | 0.6507 | 0.0120 |
| C21 | J22 | OF1 | CONDUIT | 224.1 | 0.1116 | 0.0351 |
| C3 | J2 | J6 | CONDUIT | 1577.7 | 1.3869 | 0.0300 |
| C4 | J6 | J7 | CONDUIT | 96.1 | 1.2916 | 0.0300 |
| C5 | J7 | J8 | CONDUIT | 279.2 | 1.1213 | 0.0100 |
| C6 | J11 | J19 | CONDUIT | 177.9 | 1.8455 | 0.0100 |
| C7 | J3 | J4 | CONDUIT | 207.4 | 0.1687 | 0.0100 |
| C9 | J14 | J4 | CONDUIT | 5292.4 | 1.3109 | 0.0350 |
| W1 | J20 | J1 | CONDUIT | 247.9 | 1.2338 | 0.0120 |
| 1 | J4 | J21 | CONDUIT | 202.5 | 0.5333 | 0.0350 |
| 4 | 2 | 1 | CONDUIT | 200.0 | 0.2500 | 0.0100 |
| 2 | OF1 | 2 | ORIFICE | | | |
| W2 | JMRobertsPond | J5 | WEIR | | | |
| W3 | ResLake | J20 | WEIR | | | |
| 3 | OF1 | 2 | WEIR | | | |

*********************
Cross Section Summary
*********************

| Conduit | Shape | Full Depth | Full Area | Hyd. Rad. | Max. Width | No. of Barrels | Full Flow |
|---|---|---|---|---|---|---|---|
| C1 | TRAPEZOIDAL | 4.00 | 56.00 | 2.34 | 22.00 | 1 | 1576.77 |
| C10 | TRAPEZOIDAL | 5.00 | 48.25 | 2.60 | 11.30 | 1 | 922.84 |
| C11 | RECT_CLOSED | 8.00 | 48.00 | 1.71 | 6.00 | 1 | 27.90 |
| C12 | RECT_CLOSED | 8.00 | 40.00 | 1.54 | 5.00 | 2 | 26.03 |
| C13 | TRAPEZOIDAL | 5.00 | 48.25 | 2.60 | 11.30 | 1 | 925.09 |
| C14 | Conduit14 | 3.95 | 35.45 | 0.30 | 25.30 | 1 | 139.33 |
| C15 | TRAPEZOIDAL | 4.00 | 56.00 | 2.34 | 22.00 | 1 | 409.92 |
| C16 | Conduit16 | 5.96 | 50.66 | 2.00 | 26.00 | 1 | 452.13 |
| C17 | RECT_CLOSED | 5.00 | 20.00 | 1.11 | 4.00 | 1 | 216.47 |
| C18 | TRAPEZOIDAL | 4.00 | 29.28 | 2.03 | 8.64 | 1 | 397.02 |
| C19 | Site1median | 2.86 | 27.43 | 1.75 | 14.00 | 1 | 263.51 |
| C2 | TRAPEZOIDAL | 3.00 | 20.97 | 1.70 | 7.98 | 1 | 300.99 |
| C20 | RECT_CLOSED | 8.00 | 48.00 | 1.71 | 6.00 | 1 | 686.80 |
| C21 | TRAPEZOIDAL | 8.00 | 69.12 | 3.03 | 11.28 | 1 | 204.30 |
| C3 | TRAPEZOIDAL | 5.00 | 48.25 | 2.60 | 11.30 | 1 | 532.71 |
| C4 | RECT_CLOSED | 8.00 | 64.00 | 2.00 | 8.00 | 1 | 571.91 |
| C5 | Site3UpSt | 4.50 | 49.84 | 2.62 | 14.00 | 1 | 1491.79 |
| C6 | Site1median | 2.86 | 27.43 | 1.75 | 14.00 | 1 | 803.27 |
| C7 | Site1 | 8.10 | 125.76 | 4.22 | 18.00 | 1 | 2003.60 |
| C9 | Conduit9 | 4.97 | 43.00 | 1.82 | 26.00 | 1 | 311.47 |
| W1 | TRAPEZOIDAL | 5.00 | 128.25 | 2.93 | 42.30 | 1 | 3612.19 |
| 1 | TRAPEZOIDAL | 7.00 | 58.17 | 2.80 | 10.62 | 1 | 358.68 |
| 4 | TRAPEZOIDAL | 8.00 | 181.12 | 4.92 | 25.28 | 1 | 3890.32 |

```
  **************************        Volume         Depth
  Runoff Quantity Continuity     acre-feet        inches
  **************************     ---------       -------
  Total Precipitation ......      2761.421        19.980
  Evaporation Loss .........         0.000         0.000
  Infiltration Loss ........      2576.529        18.642
  Surface Runoff ...........       178.166         1.289
  Final Surface Storage ....         6.730         0.049
  Continuity Error (%) .....        -0.000


  **************************        Volume        Volume
  Flow Routing Continuity        acre-feet      10^6 gal
  **************************     ---------     ---------
  Dry Weather Inflow .......         0.000         0.000
  Wet Weather Inflow .......       178.166        58.058
  Groundwater Inflow .......         0.000         0.000
  RDII Inflow ..............         0.000         0.000
  External Inflow ..........       718.784       234.226
  External Outflow .........       915.601       298.362
  Internal Outflow .........         0.000         0.000
  Evaporation Loss .........         0.000         0.000
  Exfiltration Loss ........         0.000         0.000
  Initial Stored Volume ....      2325.330       757.743
  Final Stored Volume ......      2326.628       758.167
  Continuity Error (%) .....        -0.619


  *************************
  Highest Continuity Errors
  *************************
  Node J22 (-11.65%)
  Node J21 (9.61%)
  Node J14 (-2.53%)


  ***************************
  Time-Step Critical Elements
  ***************************
  Link C12 (1.64%)


  ********************************
  Highest Flow Instability Indexes
  ********************************
  Link C20 (14)
  Link C21 (14)
  Link 2 (12)
  Link 4 (9)


  *************************
  Routing Time Step Summary
  *************************
  Minimum Time Step           :     1.80 sec
  Average Time Step           :     9.89 sec
  Maximum Time Step           :    10.00 sec
  Percent in Steady State     :    59.53
  Average Iterations per Step :     1.40
  Percent Not Converging      :     0.00
```