THE RELATIONSHIP BETWEEN HYDROLOGIC AND MACROINVERTEBRATE METRICS ALONG AN URBANIZATION GRADIENT IN PIEDMONT HEADWATER STREAMS

by

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ABSTRACT

REBECCA NICOLE BLACK. The Relationship between Hydrologic and Macroinvertebrate Metrics along an Urbanization Gradient in Piedmont Headwater Streams (Under the direction of DR. SANDRA CLINTON)

Urban streams are characterized by altered hydrographs, increased nutrient concentrations, altered geomorphology, and decreased biodiversity. This study asked how the hydrologic flow regime impacts stream macroinvertebrates in Piedmont headwater streams by quantifying bed mobility using tractive force and threshold discharge to integrate flow impacts on stream organisms. These hydrologic metrics are used to assess the impacts of grain size movement during peak flows based on the dimensions of the stream. Tractive force (τ) is the average shear stress, the amount of force required to move a specific area of water in the bed of the channel, that is required to move the size of the material at initial motion. Tractive force depends on 1) the depth of flow and 2) the slope of the water surface. Threshold discharge (Qc) is the flow value that results in the mobilization of a specific sediment size and depends on 1) the median grain size and 2) the two-year flood discharge value.

I sampled watersheds that ranged from 0.47 to 9.51 square kilometers and 4.84 to 41.7 % impervious cover in Mecklenburg County, North Carolina. Macroinvertebrates, water quality (dissolved oxygen, specific conductivity, pH, temperature, nutrients), and Wolman pebble counts were collected during fall 2018 and winter 2019. Nearby USGS gages were used to assess flow data for two years prior to sampling.

The background environmental parameters and water quality assessed for the study resulted in positive relationships with increasing impervious cover. The water quality concentrations studied yielded mixed results when compared to impervious cover. The distribution of grain sizes found for the study locations varied between sites and sampling dates due to past restoration efforts of varying magnitude, that included bank stabilization to full restoration of the study location. Macroinvertebrates diversity, species richness, and species evenness decreased along the impervious cover gradient. The collector functional feeding group was dominant throughout the study compared to the predator, shredder, and scraper functional feeding groups. The percentage of tolerant species were dominant compared to the percentage of intolerant species found throughout the study.

Q_c did not vary systematically with %IC due to local variability in streambed D_{50}. The D_{50} tractive force and the D_{50} threshold discharge relationships with the macroinvertebrate metrics yielded mixed positive and negative correlations that were not significant. Species richness, diversity and evenness had a significant moderate positive correlation with the D_{50} percent bed mobility. Threshold discharge and the percent of EPT and tolerant species positive correlation shows that the flow that moves the median grain size increases similarly as the number of tolerant species and sensitive species are found. By linking sediment mobilization and macroinvertebrate diversity, new insights into best practices for stream restoration design for controlling sediment transport and improving ecological health can be determined.

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1.1 Benthic Macroinvertebrates

1.1.1 Background Information

Macroinvertebrates are freshwater organisms, which do not have a backbone, are visible without the use of a microscope and include both insect and non-insect taxa. These organisms have important roles in stream food webs as both predators and prey and as consumers of particulate organic matter. Furthermore, stream macroinvertebrates link freshwater and terrestrial systems since emergent insects are food sources for bats, birds, and terrestrial insects (Nakano and Murakami, 2001). In-stream, fish feed on macroinvertebrate larvae and some larvae, such as dragonflies, are predators on other aquatic insects (Merritt et al., 2008). Many stream insect larvae feed on in-stream particulate organic matter, playing an important role in stream energy flow. Thus, macroinvertebrates are often classified by their functional feedings groups as collectors, shredders, scrapers, or predators, which emphasizes carbon source and feeding life history as opposed to individual species diversity (Cummins and Klug, 1979). Collectors feed on fine particulate organic matter, while shredders break down course particulate organic matter. Scrapers feed on benthic algae and predators feed on other macroinvertebrates or small fish.

Macroinvertebrates can be identified using dichotomous keys and then each macroinvertebrate species can be assigned a corresponding tolerance value based on NC state data (Appendix E, NCDEQ, 2016). The tolerance value and quantity of the species collected are used to infer stream water quality. The tolerance value is a number between zero and ten, where the higher the number indicates degraded water quality. The North

Carolina Biotic Index combines species abundance and tolerance values to create a water quality score that reflects the overall health and biodiversity of the ecosystem.

1.1.2 Sediment Grain Size Effects

Different sediment grain sizes can have different effects on individual macroinvertebrate species and there is an overall mean threshold level of fine sediment (< 0.25 mm) that leads to declines in macroinvertebrate community diversity (Kaller and Hartman, 2004). Furthermore, fine sediment impacts fish spawning habitat and benthic organisms that require gravel substrate (Castro and Reckendorf, 1995). The movement of grain sizes of sand, granule, pebble, cobble, and boulder can damage or even kill smaller macroinvertebrates such as dipterans, stoneflies, and mayflies. Silt, clay and smaller grain sizes can clog the gills of caddisflies, mayflies, and stoneflies. In addition to grain size, the duration that the sediment load is in contact with the macroinvertebrate will also adversely affect them (Castro and Reckendorf, 1995). Table 1 summarizes the density and diversity of macroinvertebrates in preferred habitats with specific bed types and bed movement (Castro and Reckendorf, 1995).

Table 1: Stream reach classification based on bed material

Bed type	Particle size (mm)	Relative frequency of bed movement	Typical benthic macroinvertebrates	
			Density	Diversity
Boulder--Cobble	>/=64	Rare	High	High
Cobble--Gravel	2-256	Rare to periodic	Moderate	Moderate
Sand	0.062-2	Continual	High	Low
Fine material	<0.062	Continual or rare	High	Low

(Castro and Reckendorf 1995)

The size of the grain that makes up the bed correlates with the density and diversity of macroinvertebrates within the system. Grain size influences movement of bed material and thus, the macroinvertebrate diversity and density. In general, sand beds with a particle size from 0.062 -2.0 mm can have continual bed movement that leads to high macroinvertebrate density and low macroinvertebrate diversity (Castro and Reckendorf, 1995). Cobble and gravel beds with a particle size from 2-56 mm have rare to periodic bed movement that leads to moderate macroinvertebrate density and moderate macroinvertebrate diversity (Castro and Reckendorf, 1995). The boulder and cobble beds with a particle size >=64 mm can have rare bed movement that leads to high macroinvertebrate density and high macroinvertebrate diversity (Castro and Reckendorf 1995).

1.1.3 Impact of Fine Sediment

The finer sediment grains harm the macroinvertebrates gills and/or disrupt their function. Invertebrates are vulnerable to damage from the waterborne transport of particles, during high flow events invertebrates can become dislodged and also be injured through collisions with moving sediment (Jones et al., 2011). Macroinvertebrates however, do not exhibit the same morphology, nor do they feed the same way, so different species will show different impacts.

The transport of fine particles, such as clays and silts, can result in an accumulation on the organs of invertebrates, disrupting the normal functioning of gills and filter feeding apparatus, making respiration and feeding difficult (Jones et al., 2011). The macroinvertebrates that may be impacted by this process most are various blackfly (Simuliidae) and caddisfly (Hydropsychidae) larvae, because many of these species are filter feeders. Both active and sedentary invertebrates are vulnerable to burial, especially when sedimentation is high (Jones et al., 2011). When the stream bed is unstable, it is more vulnerable to high flows events and that could cause more displacement of macroinvertebrates in their habitats. Increased loading of fine sediment alters river ecosystems, changing substrate particle size and the macrophyte community (Jones et al., 2011). The oxygen concentration decreases when sediment enters the macroinvertebrate habitats, negatively affecting the biota as a result of decreasing pore space between sediment grains.

High loadings of fine organic matter can also benefit filter-feeding invertebrates that rely on particulate organic matter as a food source (Jones et al., 2011). If the non-organic fine sediment stays suspended in the water column for an extended duration, then the population will begin to decline significantly. Macroinvertebrates are greatly affected by fine sediment, but it can also harm other aquatic biota such as fish. Invertebrates are a main food resource of many species of fish; as a result, invertebrates are often released from predation where fish populations decline as a consequence of increased fine sediment loading (Jones et al., 2011).

Various aquatic systems may function with high background levels of fine sediment but the changing sedimentation rates can hurt the system, whether the change is natural or human induced (Castro and Reckendorf, 1995). Defining the primary sources of sediment input into a system is vital when trying to restore a stream or when trying to stabilize the banks of a creek that are eroding into the stream. Once the source of sediment pollution is located, the effects can be mitigated in order to transform the stream back into a more natural condition.

Fine sediment buildup can cause a loss of abundance and diversity in macroinvertebrate communities such as taxa from the Ephemeroptera, Plecoptera, and

Trichoptera orders (EPT) (Harrison et al., 2007). Table 1 (Section 1.1.2), shows that the finer sediment grain sizes <+ 0.062 mm led to continual or rare bed movement, which can be associated with a high density of macroinvertebrates, but low macroinvertebrate diversity.

"To improve our understanding of the impact of fine sediment on macroinvertebrate communities, research is required on the responses of individual taxa to fine sediment accumulation, the influence of different flow habitats, disentangling its impact from other associated land-uses, and the relationship between fine sediment accumulation and macroinvertebrates at a regional scale (Harrison et al., 2007)." Studies have been conducted at the reach scale such as Kaller and Hartman (2004), that attempt to look fine sediment accumulation. Guidelines for managing the ecological impact of fine sediment accumulation would aid the managers in implementing appropriate mitigation measures to protect areas from fine sediment accumulation and allow degraded rivers to recover (Harrison et al., 2007). On local or regional scales, the source of fine sediment into these impacted systems should be mitigated and the effect on each species should be evaluated. Fine sediment accumulation in streams is due to the changes in environmental conditions that altered the inherent hydrology and dynamics of sediment input and transport within the streams (Kaller and Hartman, 2004).

1.1.4 Relationship of Drift and Sediment Substrate

The most immediate response to an increase in the concentration of suspended fine sediment is an increase in the number of invertebrates entering the drift (Jones et al., 2011). Drifting of macroinvertebrates occurs first, because the organisms are trying to remove themselves from the impacted part of the system. During the drifting period, it can create opportunities for fish or other macroinvertebrates to prey upon them.

Surges of fine sediment can change the suitability of the substrate for some taxa, leading to an increase in macroinvertebrate drift and affect respiration and feeding activities (Harrison et al., 2007). The drifting of macroinvertebrates from dawn to dusk, to avoid predation or to find food sources is acceptable, but drift caused by fine sediment input into the system can cause the macroinvertebrate to become damaged or killed in the process.

Macroinvertebrates drift downstream for multiple reasons including flooding, changes in temperature, and disturbance of habitat due to sedimentation. Drift from floods impacts the community by moving organisms through the system and reducing fitness in survivors and increasing mortality (Gibbins et al., 2007). Drift naturally occurs from dawn to dusk when macroinvertebrates move around in the stream, but catastrophic drift can be caused by human disturbance, flooding, or sediment input into the system. By studying river channels during high flow events, the processes that lead to catastrophic drift from sediment transport can be determined (Gibbins et al., 2007).

When sediment is mobilized during high flows in unstable stream beds, invertebrates are lost through drift, due to their lower density (Gibbins et al., 2007). High flows can weaken unstable bed material and cause them to move, displacing the macroinvertebrates that are present on the substrate. The high flow event causes bed movement and sediment loads to become mobile.

Holomuzki and Biggs (2003) found that drift was highest from a moderately sorted cobble streambed, when a large number of snails were dislodged. Different macroinvertebrates are more vulnerable depending on their location in the stream.

Caddisflies had the highest tendency to drift, but their dislodgement was due to increased water velocity rather than sediment erosion (Holomuzki and Biggs, 2003). Many macroinvertebrates are not living on rock or sediment substrate, but on woody debris or root wads within the body of water. The flow event may move sediment into their habitat, but they may not drift as much as the macroinvertebrates living on the substrate itself. The substrate they are living on may not move until very high flow events, but the suspended sediment may still affect them.

1.2 Urban Streams

1.2.1 Urban Stream Syndrome

Urban streams are significantly impacted by impervious cover stormwater runoff. These impacts have been summarized as the urban stream syndrome and include altered hydrographs, increased nutrient and contaminant concentrations, altered channel morphology, and decreased biodiversity, with increased dominance of tolerant species (Walsh et al., 2007). Precipitation droplets collect to form sheets of water that flow into streams quickly creating flashy floods. This increase in discharge causes stream banks to down-cut and the channel to incise. The scour of the channel can cause influxes of sediment to enter the system. Urban streams have often been channelized, reducing the natural meanders of the stream; therefore, the flow does not slow down around the curves but moves downstream quickly. The flashiness of the system causes the macroinvertebrates and other aquatic life to become disrupted (Walsh et al., 2007).

1.2.2 Restoration

Stream restoration is one way in which increased sedimentation of urban systems can be addressed. Stream restoration, as defined by the Stream Restoration Design

National Engineering Handbook (2011), is the process of returning an ecosystem as closely as possible to predisturbance conditions and functions. Stream restoration is conducted in urban systems in response to increased frequency and magnitude of erosive overland flow, increased concentrations of nutrients, altered channel morphology, sedimentation, and increases in tolerant macroinvertebrates (Walsh et al., 2007).

1.3 Hydrologic Metrics

The hydrologic metrics: tractive force (τ) and threshold discharge (Q_c); are used to assess the impacts of grain size movement during peak flows based on stream dimensions (Table 2). Tractive force is the average shear stress, the amount of force required to move a specific area of water in the bed of the channel, that is required to move the size of the material at initial motion (Newbury and Gaboury, 1994). Tractive force is equal to the incipient diameter of grain size in centimeters, meaning that the grain size distribution is directly proportional to the tractive force required to move the sediment grain.

Threshold discharge (Q_c) is the discharge value or the volume of water moving through a given area of flow per unit time, that results in the mobilization of a specific sediment size. Q_c can be calculated for the two-year annual probability exceedance of flow by using a regression equation that was developed with data from 195 sites in California and Kentucky (USA) and Victoria (Australia) to compare the 2-year peak flow and the bed median particle size (Hawley and Vietz, 2016).

Table 2: Comparison of Specific Hydrologic Metrics

Metric	Slope	Flow Depth	Grain Size	2-yr Peak Flow
Tractive Force	X	X	X	
Threshold Discharge			X	X

1.4 Objective and Research Questions

1.4.1 Objective

The overall objective of this study is to examine if there is a relationship between the hydrologic and macroinvertebrate metrics in headwater streams of Mecklenburg County along an urban gradient.

1.4.2 Research Questions

Q1. What is the distribution of macroinvertebrates in urban headwater streams along an impervious cover gradient?

H1.1: Macroinvertebrate diversity will decrease and tolerant species will increase along an impervious cover gradient; due to runoff from impervious surfaces impacting the system which alters the quality of the habitat of the macroinvertebrates.

H1.2: Macroinvertebrate diversity will not decrease and tolerant species will not increase along an impervious cover gradient.

Q2. How does the frequency of threshold discharge (Q_c) change along an impervious cover gradient?

H2.1: The frequency of threshold discharge (Q_c) will increase as impervious cover increases, due to increased runoff from impervious surfaces impacting the system, altering the hydrology and geomorphology of the channel.

H2.2: The frequency of threshold discharge (Q_c) will not increase as impervious cover increases.

Q3. What is the relationship between bed mobility and the distribution of macroinvertebrates?

H3.1: As the bed mobility increases macroinvertebrate diversity will decrease; as a result of grain size movement affecting the quality of the macroinvertebrate habitats.

H3.2: There is not a relationship between bed mobility and the distribution of macroinvertebrates.

1.5 Study Locations

To answer these questions, eight study sites were selected in Mecklenburg County, North Carolina (Figure 1; Table 3). The watershed area of the study sites ranges from 0.47 square kilometers to 9.51 square kilometers. The percent impervious cover (%IC) ranges from 4.84 % to 41.7 % as of March 2018. Table 3 indicates the %IC and the change in impervious cover from 2011 to March of 2018. The %IC data were calculated using Google Earth Images from March 2018 and the NLCD 2011 data was provided in StreamStats.

Table 3: Mecklenburg County Study Site Characteristics

Sites	USGS Gage ID #	Drainage Area (km^2)	% Impervious Cover NLCD 2011	% Impervious Cover Google Earth March 2018	% IC Change from 2011 to March 2018
Reedy Creek	0212430293	6.55	4.23	4.84	0.61
McDowell Creek Trib.	0214265828	2.54	1.44	8.11	6.67
Beaverdam Creek	0214297160	9.51	4.61	10.8	6.23
Briar Creek Trib. at Runnymede Ln	0214645080	3.19	14.6	32.2	17.6
Briar Creek Trib. at Colony Rd	0214645075	2.90	13.2	32.5	19.3
McMullen Creek	02146700	4.43	23.2	33.0	9.79
Edwards Branch	0214643820	0.47	34.4	37.1	2.70
Little Hope Creek	02146470	6.73	33.3	41.7	8.38

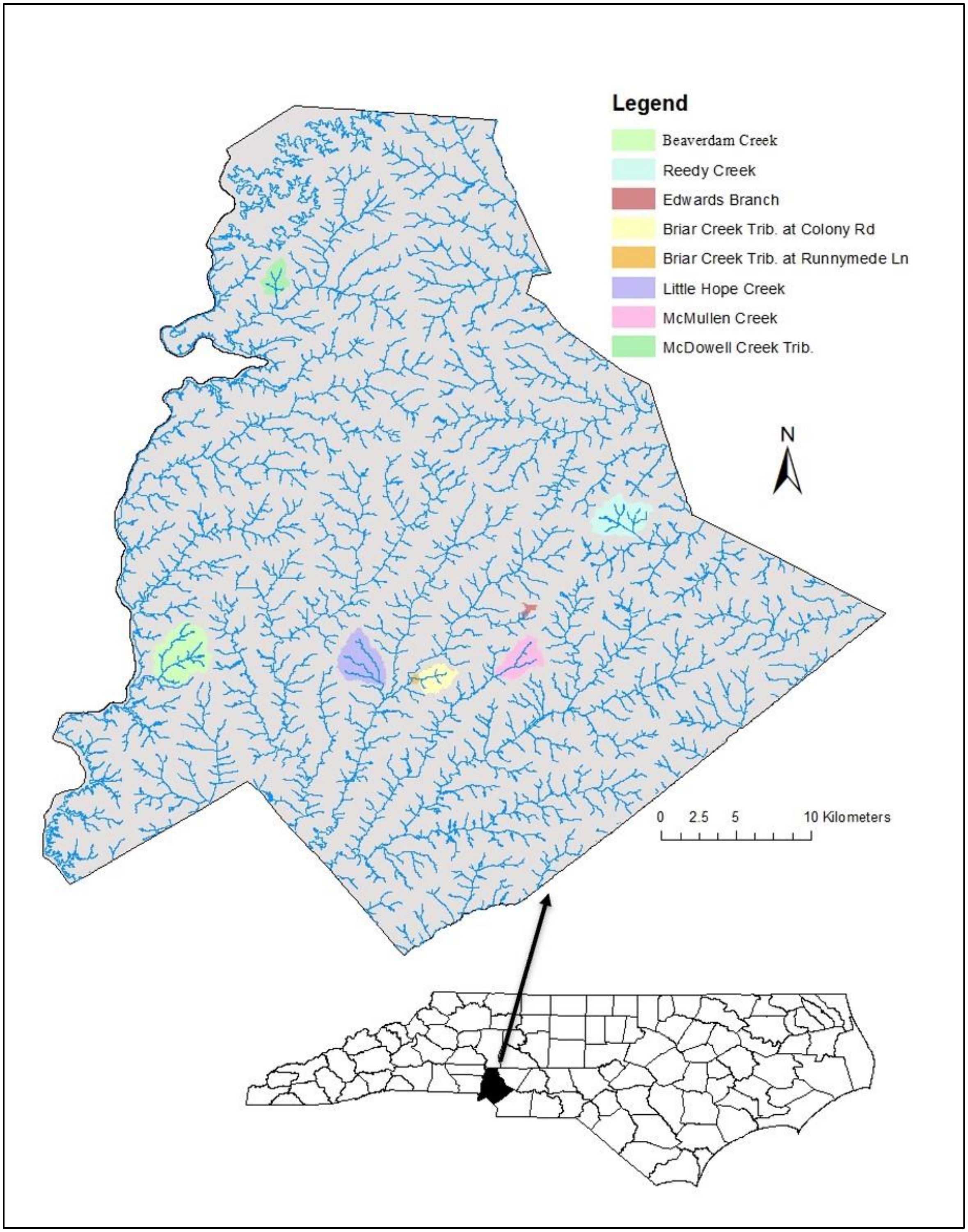

Figure 1: ArcMap of the eight study watersheds in Mecklenburg County, NC

Figure 2.1-2.8: ArcMaps of the eight individual watersheds in Mecklenburg County, NC

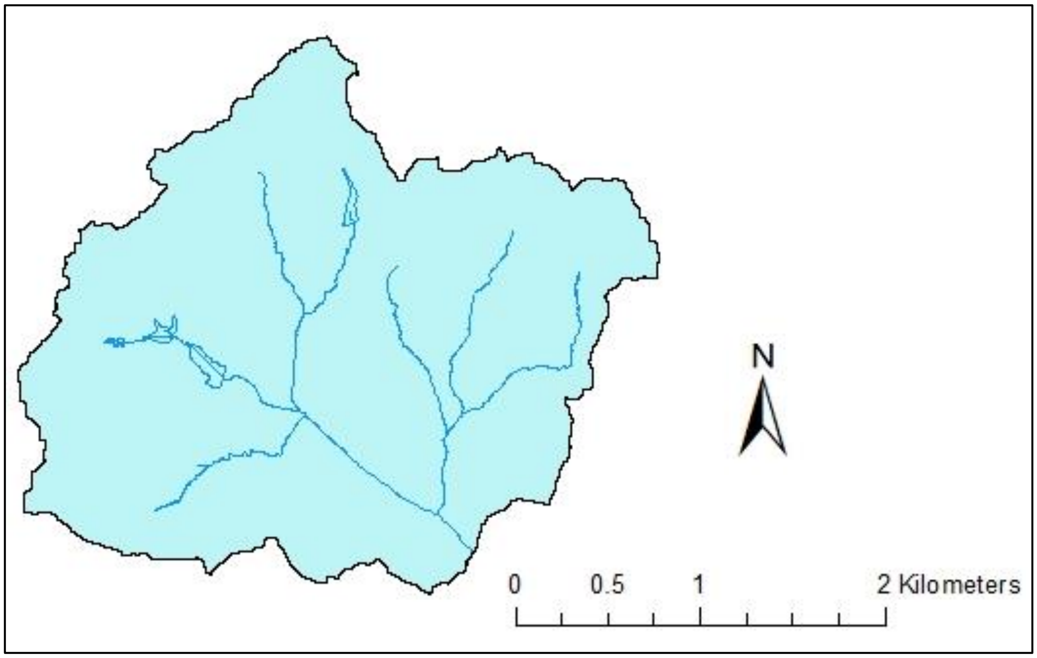

Figure 2.1: Reedy Creek (RC1)

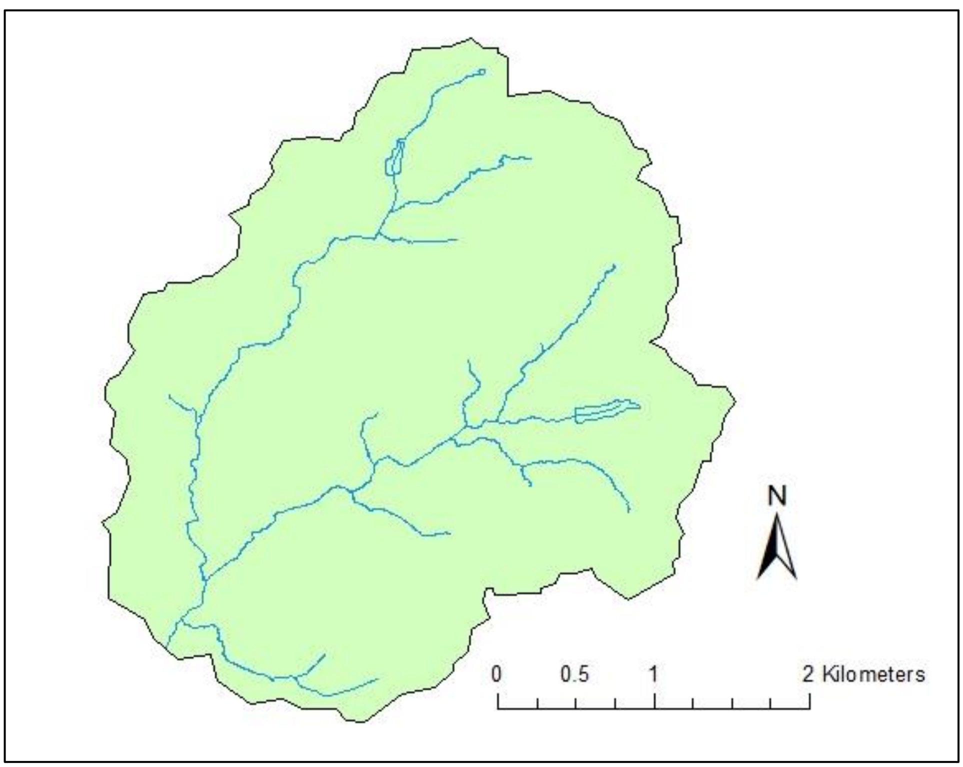

Figure 2.2: Beaverdam Creek (BD2)

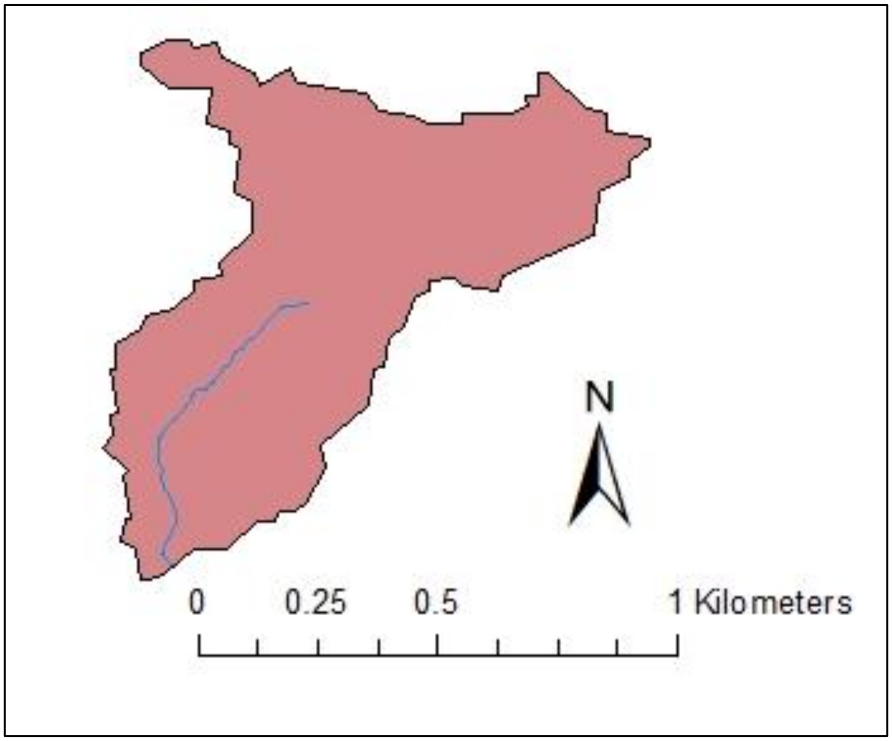

Figure 2.3: Edwards Branch (EB3)

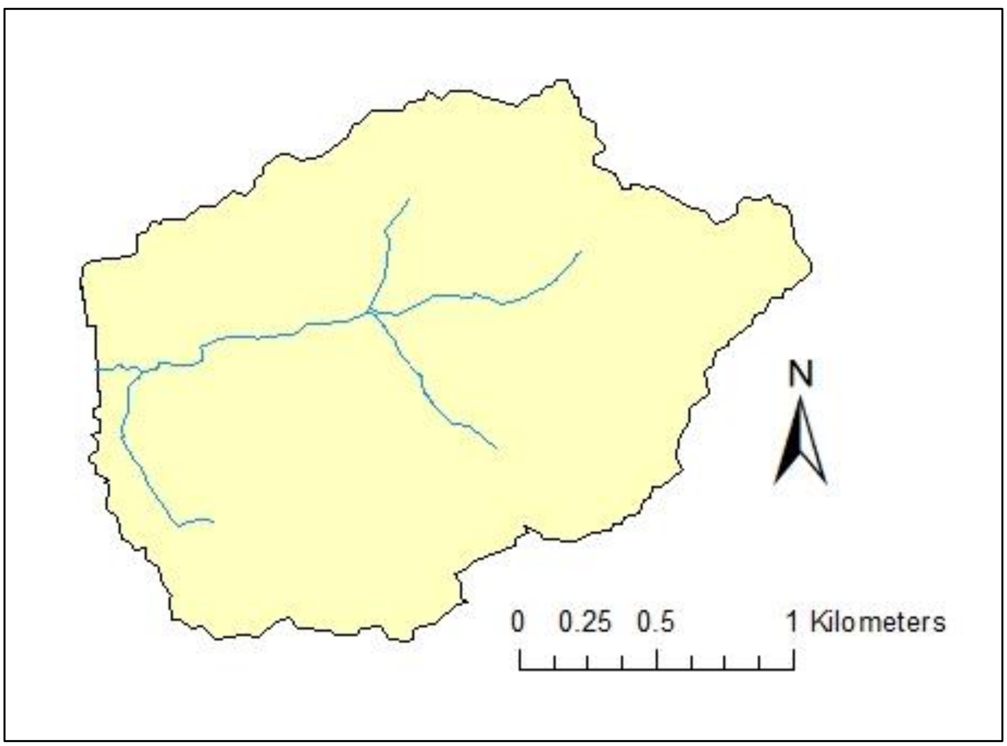

Figure 2.4: Briar Creek Tributary at Colony Rd (TBCCR4)

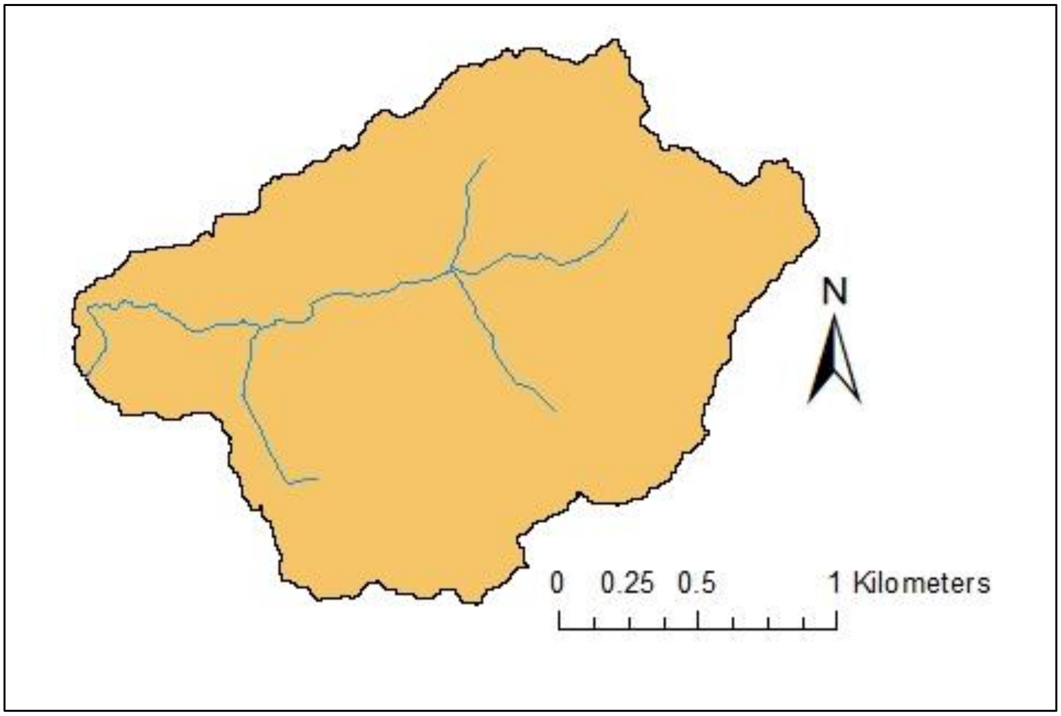

Figure 2.5: Briar Creek Tributary at Runnymede Ln (TBCRL5)

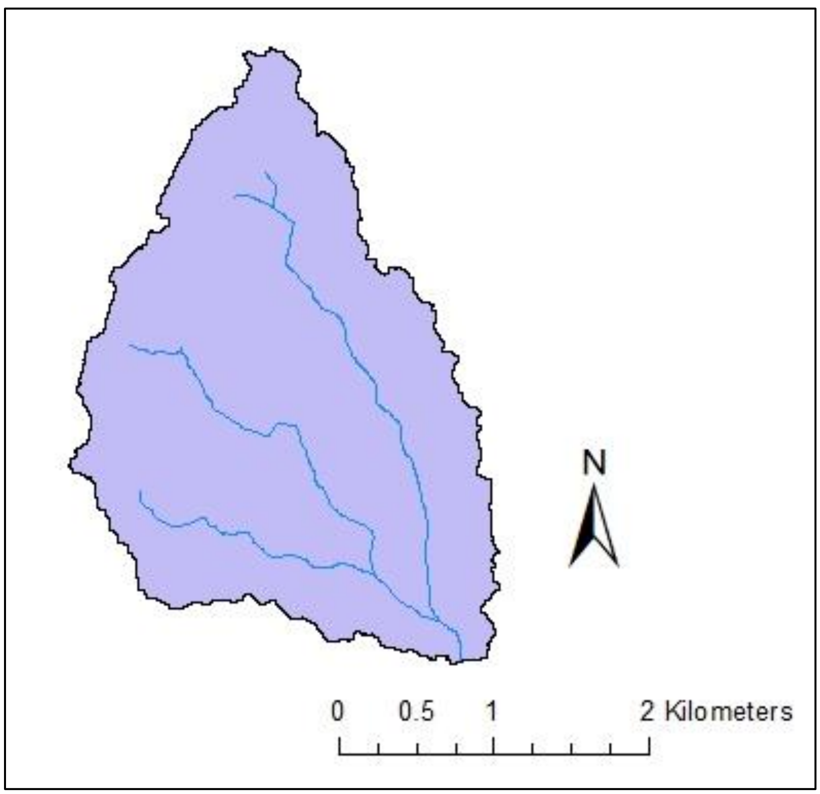

Figure 2.6: Little Hope Creek (LHC6)

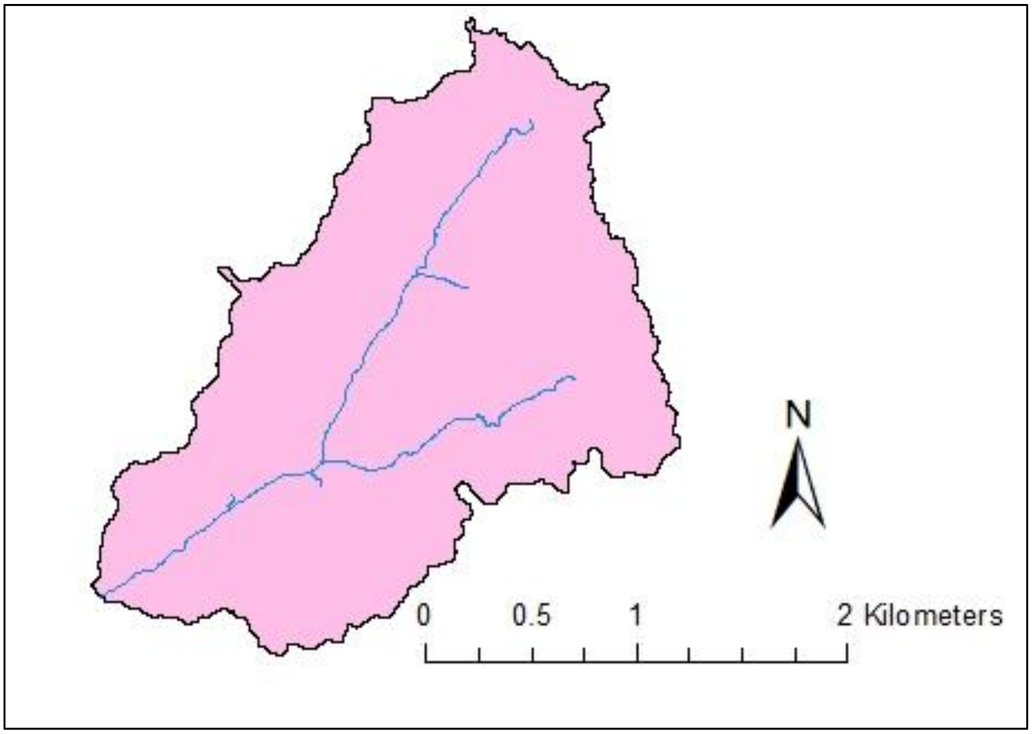

Figure 2.7: McMullen Creek (MC7)

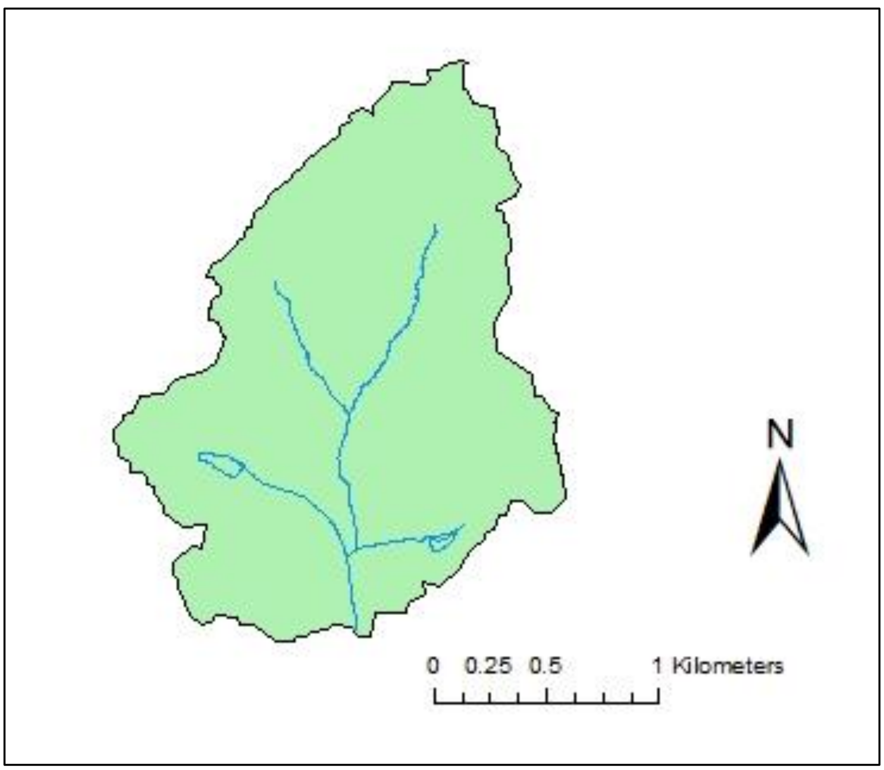

Figure 2.8: McDowell Creek Tributary (MDCT8)

2. METHODS

2.1 Site Determination

The study sites were selected based on the drainage area size and the presence of a USGS stream gage. The drainage area was determined by delineating each watershed in StreamStats. The USGS gage identification number listed in Table 3 (Section 1.5), indicates the gage used for each study site. The McMullen Creek and Edwards Branch drainage areas are based on the drainage area of study site and not that of the USGS gage location. The McMullen Creek sampling site was given a drainage area ratio of 0.24. The Edwards Branch sampling site was given a drainage area ratio of 0.18. All of the other sampling locations utilized the USGS gage that was located on site.

The USGS stream gage discharge data was extracted for two years previous to the fall 2018 sampling and the winter 2019 sampling. The data was then used to produce flow duration curves for each study site for the two sampling dates.

2.2 Field methods

2.2.1 Surface Water Sample Collection

Baseflow surface water sampling occurred at each of the 8 site locations for each date of sampling, in the fall of 2018 and the winter of 2019. Stormflow surface water samples were collected during two storms, on February 16, 2019 and February 25, 2019. Grab sampling was used to collect both the baseflow and stormflow surface water samples. Stormflow samples were collected at 3 of the sampling sites using a multi-stage passive sampler, 2 were collected on February 16, 2019 and 1 was collected on February 25, 2019. Multi-stage passive samplers were installed at every location prior to the two stormflow sampling dates, nonetheless the samplers were either damaged or did not collect a sample (see Appendix A for the multi-stage passive sampler schematic).

2.2.2 Background Environmental Parameters

A YSI multi-parameter probe will be used to collect specific conductivity, pH, temperature, and dissolved oxygen data at each site on a given sampling day. The percent of oxygen saturation was determined by dividing the observed dissolved oxygen concentration (mg/L) by the dissolved oxygen concentration based on local temperature and multiplying it by 100. A densiometer was used to measure canopy cover at each transect 0, 20, 40, 60, 80, and 100 meters. Readings of the closed canopy were averaged at each transect at North, East, South, and West. The values were then divided by 1.04 and then all transect values were averaged to determine the covered tree canopy for each study site.

2.2.3 Benthic Macroinvertebrate Sampling and Metrics

Sampling:

At each site a 100 m reach was sampled for macroinvertebrates according to the NC Qualitative Four Method (NCDEQ, 2016). Each sample collection involved one kick net sample, one sweep net sample, one leaf pack sample, and a ten-minute visual search. The kick net sample is collected by disturbing a riffle within the reach; rubbing and moving the rocks and debris, and then a rectangular-framed 500 micrometers net is swept over the water to collect the macroinvertebrates drifting downstream. The 500 micrometers sweep net was also used to sample the various habitats of the macroinvertebrates within the creek. The net was vigorously swept under root wads, undercut banks, and across a debris run once disturbed approximately six feet upstream.

A leaf pack that was slimy and decomposing was removed from the creek and colonizing macroinvertebrates collected. The visual search was conducted for ten minutes, where walked the reach looking under/on rocks, woody debris, and other structures in the creek for macroinvertebrates.

The kick net sample and sweep net samples were placed in a bucket, strained through a sieve, and the contents placed in Whirlpaks filled with ninety percent ethanol. The visual and leaf pack samples were placed in separate Whirlpaks filled with 90% ethanol. The samples were transported in the Whirlpaks back to the lab. The samples were then be placed into jars filled with 70% ethanol, until sorted and identified.

The ethanol will be drained out of the samples and the samples were placed in a tub filled with water. The macroinvertebrates tend to float to the top of the tub, and were removed, and a final visual inspection of the contents was conducted before discarding the debris and leaves. The macroinvertebrates were identified using (Merritt et al., 2008) and (Morse et al., 2016) taxonomic keys. The macroinvertebrates were identified down to the species level or to the lowest level of identification.

The North Carolina Biotic Index was calculated for each the study sites using equation 1 (NCDEQ, 2016). The small stream criteria NCBI is calculated by giving the quantity of each of the macroinvertebrate species an abundance number of one, three, and ten and summed for each site. The abundance is then multiplied by the tolerance value of the species and summed for each site. The sum of the abundance multiplied by the tolerance values is then divided by the sum of the abundance to get the NCBI score. The NCBI score calculation can be classified on the bioclassification scale outlined in Table 4.

NCBI Rating:

Equation 1: $$NCBI = \frac{\Sigma(T_i)(n_i)}{N}$$

NCBI = the North Carolina Biotic Index (NCBI)

T_i = the Tolerance Value (TV) for the i^{th} taxon

n_i = the abundance category value (1, 3, or 10) for the i^{th} taxon

N = sum of all abundance category values

Table 4: Thresholds for determining NCBI Scores

Bioclassification	Piedmont Biotic Index Values
Excellent	< 4.31
Good	4.31– 5.18
Good – Fair	5.19–5.85
Fair	5.86–6.91
Poor	> 6.91

EPT Richness:

The metric of EPT richness is a measure of the proportion of the Ephemeroptera, Plecoptera, and Trichoptera, the taxa that are sensitive to pollution, compared to the total the taxa found (Haney et al., 2013).

Equation 2: $$EPT\ Richness = \frac{Total\ EPT\ Taxa}{Total\ Taxa\ Found} \times 100\%$$

Species Diversity:

The Shannon’s Diversity Index calculates the sum of the number of a certain species found compared to the total number of individuals (Doherty et al., 2011).

Equation 3: $$H = \sum_{i=1}^{S} -(p_i \times \ln(p_i))$$

H = the Shannon's Diversity Index

p_i = the fraction of the species compared to total number of individuals

S = the number of species encountered

$\sum$ = the sum from species 1 to species S

Species Richness:

The metric of species richness calculates the number of different species found compared to the total number of individual organisms in the sample (Colby College, 2009).

Equation 4: $$D = \frac{s}{\sqrt{N}}$$

D = the species richness

s = the number of different species in the sample

N = the total number of individual organisms in the sample

Species Evenness:

Species evenness describes how evenly the species are distributed at each sampling location (Pielou, 1967).

Equation 5: $$J' = \frac{H'}{H'_{max}}$$

J' = the Pielou Evenness Index

H' = the number derived from Shannon's Diversity Index

H'_{max} = the maximum possible value of H' if all species found across all sites were present

Functional Feeding Groups:

The functional feeding group that is associated with a specific taxon indicates the way in which the organism consumes particulate matter or another organism. The data for the taxa found during both sampling dates were compiled in Table 5 (Barbour, 1999, W.V. EPA, 2019).

Table 5: Functional Feeding Groups for Collected Taxa

Order	Family	Genus/ Species	FFG
Ephemeroptera	*Baetidae*	*Baetis intercalaris*	Collector
Ephemeroptera	*Heptageniidae*	*Maccaffertium modestum*	Scraper
Ephemeroptera	*Ephemerellidae*	*Ephemerella dorothea*	Collector
Plecoptera	*Perlidae*	*Isoperla spp.*	Predator
Trichoptera	*Hydropsychidae*	*Cheumatopsyche spp.*	Collector
Trichoptera	*Hydropsychidae*	*Diplectrona modesta*	Collector
Trichoptera	*Hydropsychidae*	*Hydropsyche betteni*	Collector
Coleoptera	*Elmidae*	*Dubiraphia spp.*	Scraper
Coleoptera	*Dytiscidae*	*Neoclypeodytes spp.*	Predator
Diptera	*Chironomidae*		Collector
Diptera	*Simuliidae*	*Cnephia ornithophila*	Collector
Diptera	*Tabanidae*	*Tabanus spp.*	Predator
Diptera	*Tipulidae*	*Tipula spp.*	Shredder
Odonata	*Coenagrionidae*	*Argia spp.*	Predator
Odonata	*Coenagrionidae*	*Enallagma spp.*	Predator
Odonata	*Cordulegastridae*	*Cordulegaster spp.*	Predator
Odonata	*Gomphidae*	*Progomphus obscurus*	Predator
Oligochaeta	*Haplotaxidae*	*Haplotaxis gordioides*	Collector
Hirudinea	*Erpobdellidae*	*Erpobdella/Mooreobdella*	Predator
Gastropoda	*Physidae*	*Physa spp.*	Scraper
Gastropoda	*Planorbidae*	*Helisoma anceps*	Scraper
Bivalvia	*Corbiculidae*	*Corbicula fluminea*	Collector

2.2.4 Wolman Pebble Count

At each study site a Wolman pebble count was conducted to establish the median particle size (Kline et al. 2009). The Wolman Pebble Count is conducted by collecting one hundred sediment grains along a zigzag transect that extends up the bank to the bankfull elevation. At equal paces along the transect, an individual grain was randomly chosen by reaching down into the creek without looking down. The size of the grain was measured in millimeters using a gravelometer and recorded, until one hundred pebbles are collected. The median grain size of the pebbles collected was designated as D_{50}. In pool-riffle systems, the pebble count is a representation of bed stability and D_{50} is used as the controlling particle for bed stability in order to conservatively approach the mobility of sediment grains (Vietz and Hawley, 2016).

2.2.5 Hydrologic metrics

Tractive Force:

Tractive force is the average shear stress, the amount of force required to move a specific area of water in the bed of the channel, that is required to move the size of the material at initial motion (Newbury and Gaboury, 1994). Tractive force is equal to the incipient diameter of grain size in centimeters, meaning that the grain size distribution is directly proportional to the tractive force required to move the sediment grain. The tractive force values for each sediment grain can be divided by 1000 and the slope of the water surface to determine the gage height at which the grain is moving. Using the elevation profile tool on StreamStats, the channel slope was calculated by the change in elevation divided by the one-hundred-meter length of the study location. Gage height data from a corresponding gage can be examined to determine the percentage gage height exceedance over a specific time period. The percentage of bed mobility for the grain size distribution can be graphed to understand how often each grain was mobile over the specific time period.

Equation 6: $\tau = 1000 \times d \times s$

$$Tractive\ Force\ (kg/m^2) = incipient\ diameter\ (cm)$$

τ = tractive force (kg/m^2)

d= depth of flow (m)

s= slope of the water surface (m/m)

Threshold Discharge:

The threshold discharge for streambed mobilization (Q_c) calculated for the two-year annual probability exceedance of flow (AEP). The 2-year AEP was determined using the U.S. Geological Survey (USGS) StreamStats online application procedure. The StreamStats program uses USGS stream gage location annual peak flow data, calculated from log-Pearson Type III analysis and the flow estimate for the site calculated from the regional regression equations that compare the drainage area and the annual probability exceedance of flow (Feaster et al., 2014). The annual probability exceedance of flow is the probability of a flood event occurring in any year, which for this study the 0.5-percent or 2-year AEP was utilized.

Equation 7: $Q_c = 0.00071{D_{50}}^{1.50} \cdot\ Q_2$

Q_c = mean threshold discharge estimate (m^3/s)

Q_2 = pre-development 2-year peak flow (m^3/s)

D_{50} = median particle size of the bed material (mm)

2.2.6 Statistical Analysis

During the statistical analysis in JMP, the Pearson correlation coefficient and correlation probability between the variables measured were exported. The correlation coefficient between two variables varies between negative one and positive one, and indicates the direction of correlation (positive or negative) and the strength of the relationship (closer to -1 or 1). The correlation probability indicates the significance of the relationship between two variables. For this study, $p < 0.15$ was determined as a significant relationship between the two variables.

2.3 Laboratory Methods

2.3.1 Total Suspended Solids

Total Suspended Solids (TSS) are particles suspended in the water column. The surface water samples were filtered through a 0.45-micron filter. The initial weight of the filter was recorded in grams and then the filter was weighed again after the sample had passed through the filter. The volume of the water that passed through the filter was recorded in milliliters. The difference in weight between the two pre and post filtration divided by the volume of the water filtered resulted in the TSS concentration in mg/L.

Equation 8:

$$TSS\,\frac{mg}{L} = \frac{post - filtration\ weight\ (mg) - pre - filtration\ weight\ (mg)}{volume\ filtered\ (L)}$$

2.3.2 Ammonium, Nitrate, Orthophosphate

Baseflow surface water samples were filtered through Whatman (GF/F; 0.7 µm) glass microfiber filters. After filtering was completed, samples were stored in 50mL centrifuge tubes and placed in the freezer until analysis. Baseflow surface water samples were analyzed for dissolved nutrients (ammonia, nitrate, and orthophosphate). Ammonia was analyzed using the QuikChem® Method 10-107-06-1-C and had a detection limit of 0.004 mg/N. Nitrate/Nitrite concentrations were determined using the QuikChem® Method 10-107-04-1-A, which has a detention limit of 0.01 mg N/L. To complete the analysis for orthophosphate, the QuikChem® Method 10-115-01-1-A was used and had a detention limit of 0.3 µg P/L. Concentrations that yielded negative values were corrected to equal zero; while values below the detection limits for each analysis, but greater than zero were halved (EPA, 1990).

2.3.3 Total Phosphorus

Total Phosphorus (TP) was analyzed in accordance with the U.S. EPA 1978 method number 365.3; the method used was specific to the orthophosphate ion.   The unfiltered samples were collected and stored in the freezer until analysis. The detection limit of the method is 0.01 to 1.2 mg P/L. Concentrations that yielded values below the detection limit, were halved in order to be used in data analysis (EPA, 1990). TP was measured by direct colorimetric analysis procedure using a spectrophotometer. The color of the sample is proportional to the total phosphorus concentration in mg/L, as determined from a standard curve developed from known phosphorus concentrations.

2.3.4 Dissolved Organic Carbon

Dissolved Organic Carbon (DOC) concentrations of the baseflow surface water samples were measured on a Shimadzu TOC carbon analyzer, according to the standard TOC-TN Analyzer Operational Procedure. In order to calibrate the data, two known standards of 10 mg/L and 20 mg/L, were inserted throughout the analysis. DOC concentrations were reported in mg/L.

3. RESULTS

3.1 Background Environmental Parameters

3.1.1 pH

The pH varied across the sites and sampling dates (Figure 3). The pH range for the fall sampling date was 5.44-6.95. The highest pH value was from TBCRL5 and the lowest pH value was MDCT8 (Appendix C). The pH range for the winter sampling date was 5.03-7.67. The highest pH value was from TBCCR4 and the lowest pH value was MDCT8 (Appendix C). There was no relationship between pH and %IC across sites (Table 7).

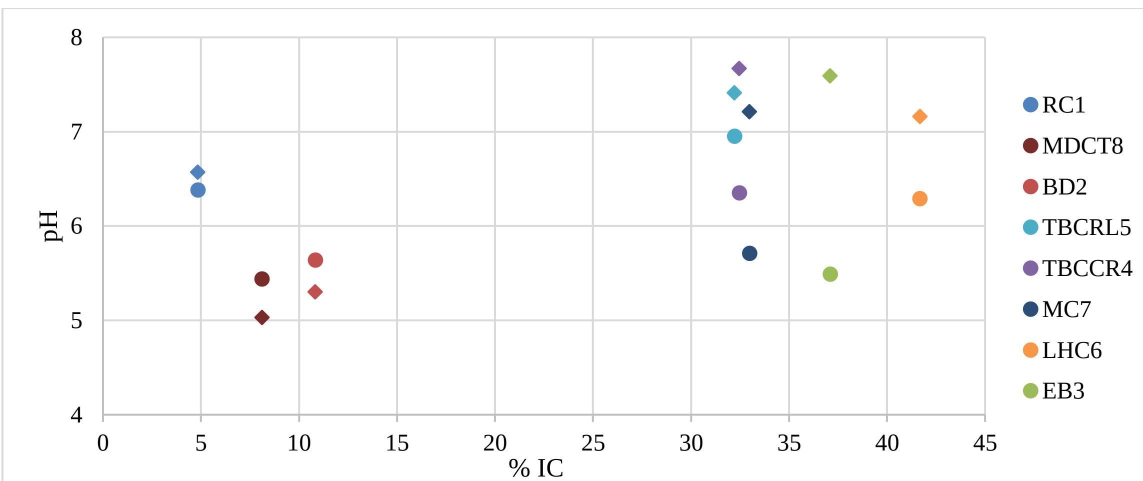

Figure 3: pH values for all of the sites over the course of the study compared to percent impervious cover. Dots represent the fall sampling and the diamonds represent the winter sampling.

3.1.2 Dissolved Oxygen

The Dissolved Oxygen (DO) concentrations varied across all sites and both sampling dates (Figure 4). The DO range for the fall sampling date was 3.56-10.15 mg/L. The highest concentration was at RC1 and the lowest DO was at BD2 (Appendix C). The DO range for the winter sampling date was 8.11-18.20 mg/L, where the highest DO value was from TBCCR4 and the lowest DO value was RC1 (Appendix C). There was no relationship between DO concentration and %IC (Table 7).

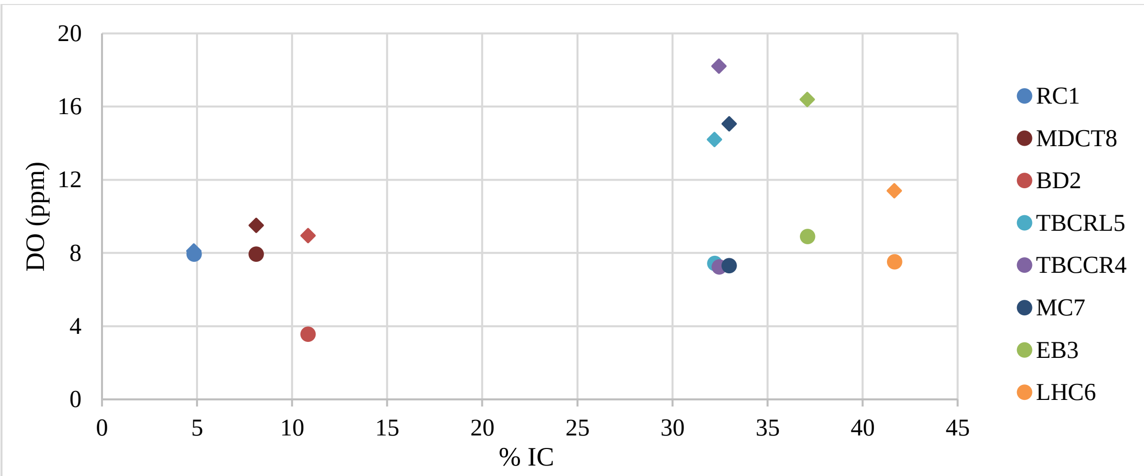

Figure 4: Dissolved Oxygen values for all of the sites over the course of the study compared to percent impervious cover. Dots represent the fall sampling and the diamonds represent the winter sampling.

3.1.3 DO Saturation

The percent of dissolved oxygen saturation, or the amount of oxygen in the stream compared to the water temperature, indicates the amount of oxygen available in the water column. The percentages varied among the sites and season, with greater DO saturation for all sites in the winter sampling except for RC1. Values exceeding 100% can be attributed to the excess amount of photosynthetically- active species such as plants or algae, that were present at the study sites (YSI, 2005).

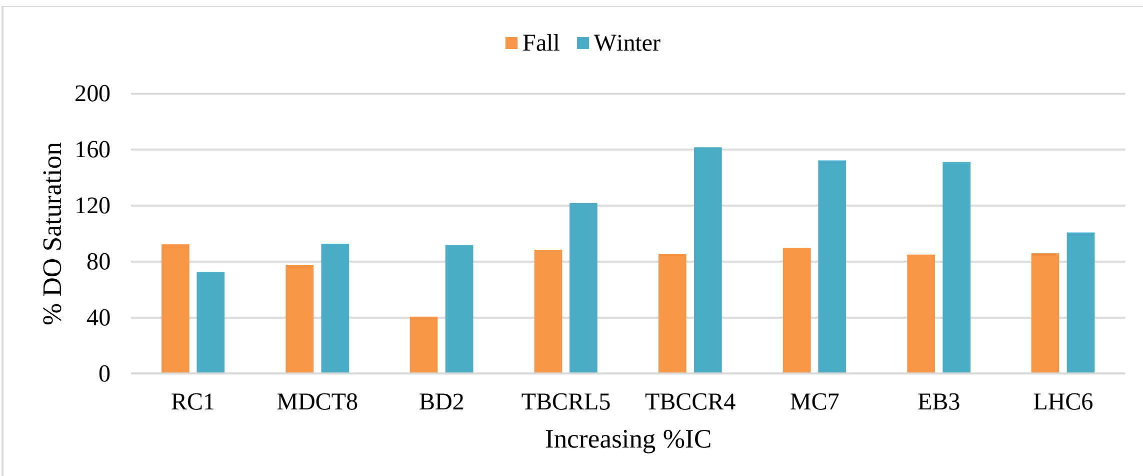

Figure 5: DO Saturation (%) values for all of the sites over the course of the study compared to percent impervious cover.

3.1.4 Temperature

Temperature varied across the sites and sampling dates (Figure 6). The temperature range for the fall sampling date was 11.2- 25.8 degrees Celsius. The highest temperature value was from MC7 and the lowest temperature value was RC1 (Appendix C). As expected, the temperature range during winter was cooler and ranged 9.7-16.7 degrees Celsius. The highest temperature value was from BD2 and the lowest temperature value was TBCRL5 (Appendix C). There was no relationship between temperature and %IC in either summer or winter (Table 7).

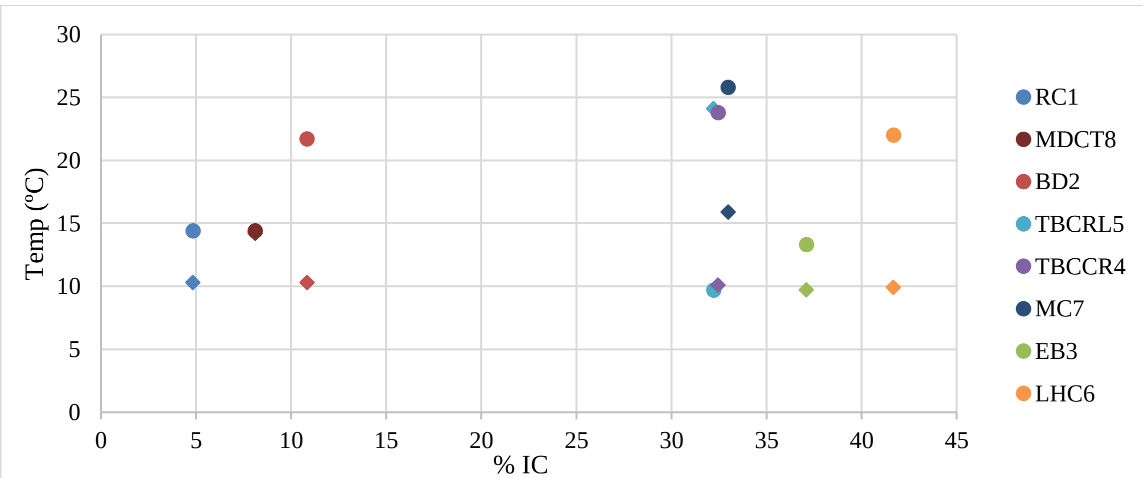

Figure 6: Temperature (ºC) values for all of the sites over the course of the study compared to percent impervious cover. Dots represent the fall sampling and the diamonds represent the winter sampling.

3.1.5 Specific Conductance

The specific conductance readings varied across the sites and sampling dates. The specific conductance range for the fall sampling date was 109.0-280.9 µS/cm. The highest specific conductance value was from TBCCR4 and the lowest specific conductance value was MC7 (Appendix C). The specific conductance range for the winter sampling date was 75.3-266.5 µS/cm. The highest specific conductance value was from TBCCR4 and the lowest specific conductance value was RC1 (Appendix C). There was a slight increase in specific conductance with increasing %IC although this was not statistically significant (Table 7).

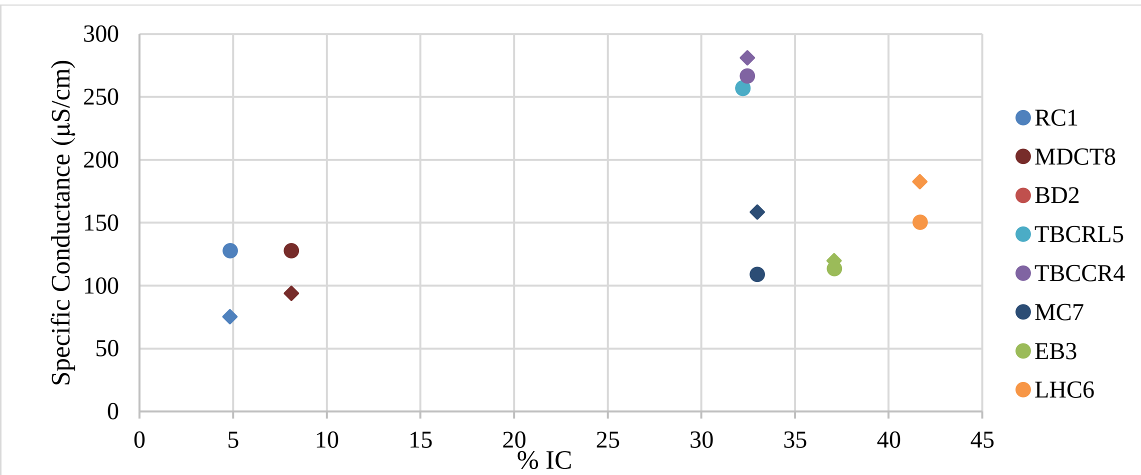

Figure 7: Specific Conductance values for all of the sites over the course of the study compared to percent impervious cover. Dots represent the fall sampling and the diamonds represent the winter sampling.

3.1.6 Tree Canopy Cover

As expected, tree canopy cover decreased between fall and winter sampling. The percent canopy cover in the fall ranged from 18.6-85.5%, while in the winter after leaf off the values were ranged from 10.6-31.8%.

Table 6: Tree Canopy Cover

Sites	Fall 2018	Winter 2019
	% Covered	
RC1	62.2	10.6
MDCT8	75.0	26.9
BD2	58.2	26.2
TBCRL5	82.6	26.6
TBCCR4	77.8	27.0
MC7	18.6	12.4
EB3	85.5	23.0
LHC6	73.8	31.8

3.1.7 Correlation Coefficients

Table 7 below indicates all of the correlation coefficients and probabilities for the pH, DO, temperature, specific conductance, and percent covered tree canopy. Dissolved oxygen, pH, and specific conductance had a moderate positive correlation between the parameter and increasing impervious cover for the entire study. The percent of air saturation had a moderate positive correlation with increasing impervious cover that was significant. Temperature and the percent covered tree canopy had slight positive correlation between the parameter and increasing impervious cover for the entire study. The background environmental parameters did not have statistical significance with increasing impervious cover.

Table 7: Correlation Coefficients for Background Environmental Parameters. Green shading indicates there is a positive association between the two parameters and red shading indicated there is a negative association. Bolded correlation probability values indicate statistical significance.

Percent Impervious Cover versus:	Correlation Coefficient	Correlation Probability
pH	0.5305	0.6440
Dissolved Oxygen	0.4117	0.7298
Air Saturation	**0.4634**	**0.0706**
Temperature	0.1598	0.8979
Specific Conductance	0.4231	0.7219
% Covered Tree Canopy	0.0841	0.7569

3.2 Water Quality

3.2.1 Total Suspended Solids

The baseflow TSS values ranged from 0.27-16.70 mg/L in the fall and from 0.20-13.27 mg/L in the winter (Figure 8). Baseflow TSS concentrations were highest in the fall at BD2 and in the winter at RC1. The lowest baseflow TSS concentrations were seen at LHC6 for both seasons. A slight decreasing trend with percent impervious cover and baseflow TSS was observed (Figure 9).

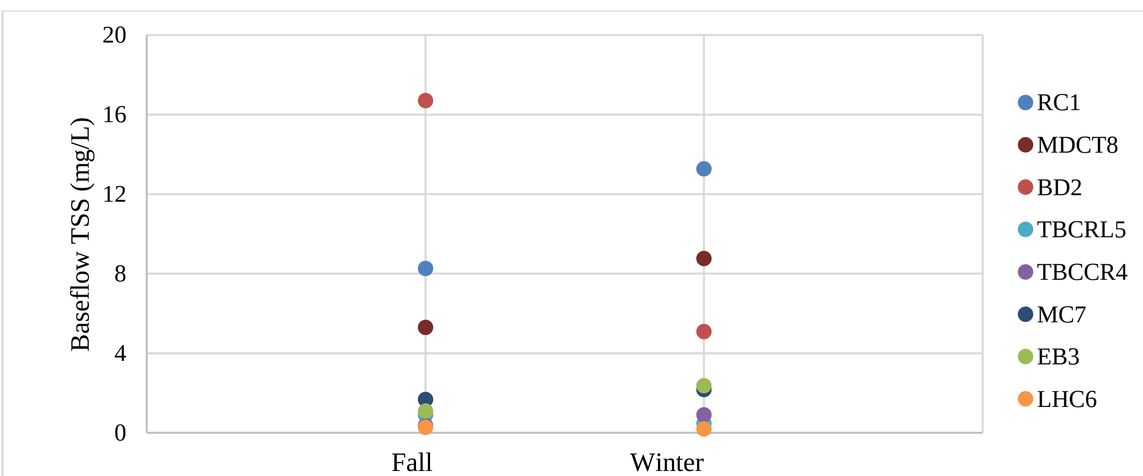

Figure 8: Baseflow TSS (mg/L) for all of the sites over the course of the study

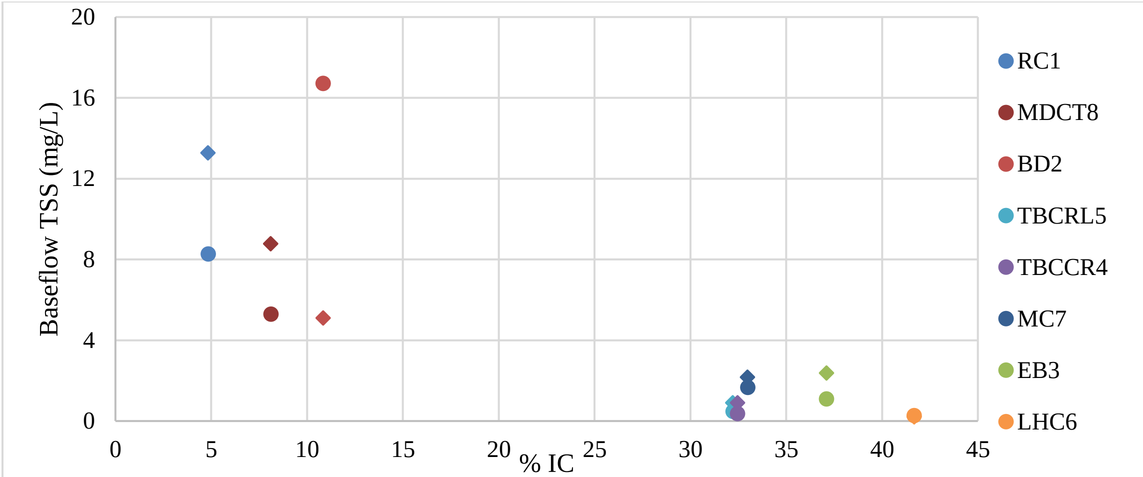

Figure 9: Baseflow TSS (mg/L) for all sites across percent impervious cover. Dots represent the fall sampling and the diamonds represent the winter sampling.

The stormflow TSS values ranged from 10.43-101.20 mg/L on 2/16/2019 and from 1.23-30.60 mg/L on 2/25/2019 (Figure 10). The highest stormflow TSS concentrations were seen at MDCT8 on 2/16/2019 and on 2/25/2019. The lowest stormflow TSS values were seen at LHC6 on 2/16/2019 and TBCRL5 on 2/25/2019. A distinct trend of percent impervious cover and stormflow TSS was not present (Figure 11).

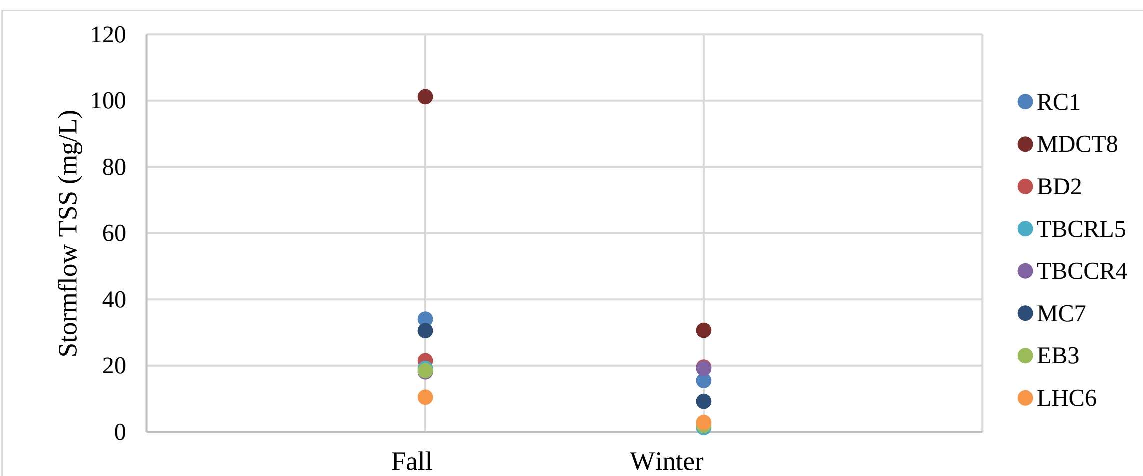

Figure 10: Stormflow TSS (mg/L) for all of the sites over the course of the study

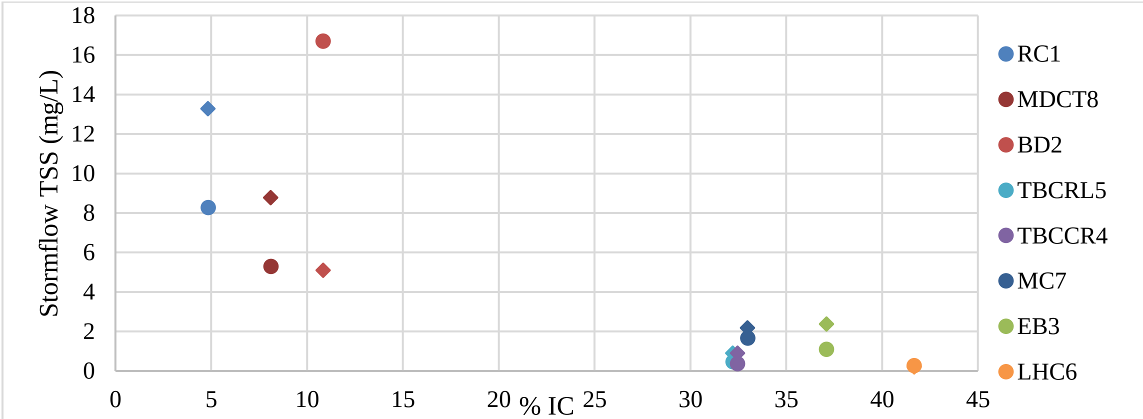

Figure 11: Stormflow TSS (mg/L) compared to percent impervious cover. Dots represent the fall sampling and the diamonds represent the winter sampling.

Multi-stage passive samplers were installed at every location prior to the two stormflow sampling dates, nonetheless the samplers were either damaged or did not collect a sample (Appendix A). The samplers collected pre-storm flow only at the lowest collection bottle for both 2/16/2019 and 2/25/2019. The sampler TSS values were 22.85 mg/L at EB3 and 36.75 mg/L on 2/16/2019 at TBCRL5 (fall, Figure 12). The sampler TSS value for 2/25/2019 was 71.30 mg/L at MDCT8 (winter, Figure 12). The Sampler TSS values decreased as impervious cover increased for 2/16/2019 (Figure 13).

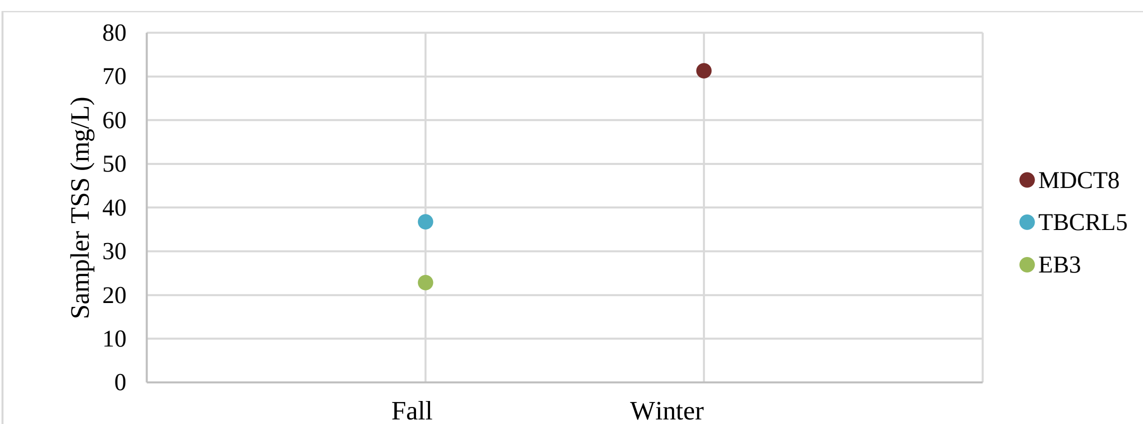

Figure 12: Multi-stage passive samplers TSS (mg/L) for three sites during stormflow sampling dates

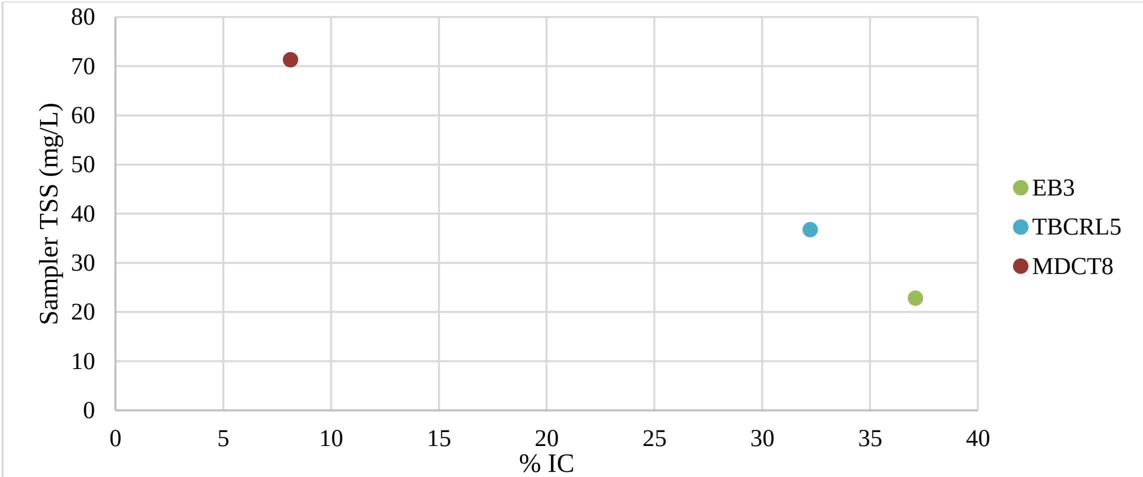

Figure 13: Multi-stage passive samplers TSS (mg/L) for three sites during stormflow sampling dates compare to percent impervious cover.

3.2.2 Ammonium, Nitrate, Orthophosphate

The concentrations of the ammonium, nitrate, and orthophosphate that were analyzed for both sampling dates are listed below in Table 8. Concentrations at several sites during both sampling dates were below the detection limit for the analytical methodology.

Table 8: Concentrations of Ammonium, Nitrate, and Orthophosphate

Site	Ammonium (mg/L)		Nitrate (mg/L)		Orthophosphate (mg/L)	
	Fall	Winter	Fall	Winter	Fall	Winter
RC1	0.02	0.05	0.05	0.18	0.00	0.00
MDCT8	0.00	0.01	0.03	0.00	0.00	0.00
BD2	0.51	0.12	0.02	0.04	0.00	0.00
TBCRL5	0.00	0.00	0.10	0.00	0.07	0.00
TBCCR4	0.00	0.00	0.02	0.10	0.05	0.00
MC7	0.02	0.00	0.05	0.03	0.01	0.00
EB3	0.01	0.00	0.33	0.32	0.02	0.00
LHC6	0.01	0.00	0.33	0.66	0.03	0.00

All ammonium concentrations are shown in Figure 14. The ammonium concentration range for the fall sampling date was 0.00-0.50 mg/L. The lowest ammonium concentration was found EB3, not including sites below the detection limit for the analytical methodology (Appendix B). The ammonium concentration range for the winter sampling date was 0.00-0.12 mg/L. The lowest ammonium concentrations value was LHC6 (Appendix B). BD2 had the highest ammonium concentrations during both seasons (Appendix B). Several sites during both sampling dates were too low to measure ammonium concentration (0.00 mg/L). Figure 14 presents the ammonium concentrations and percent impervious cover, with no apparent trend between the two variables.

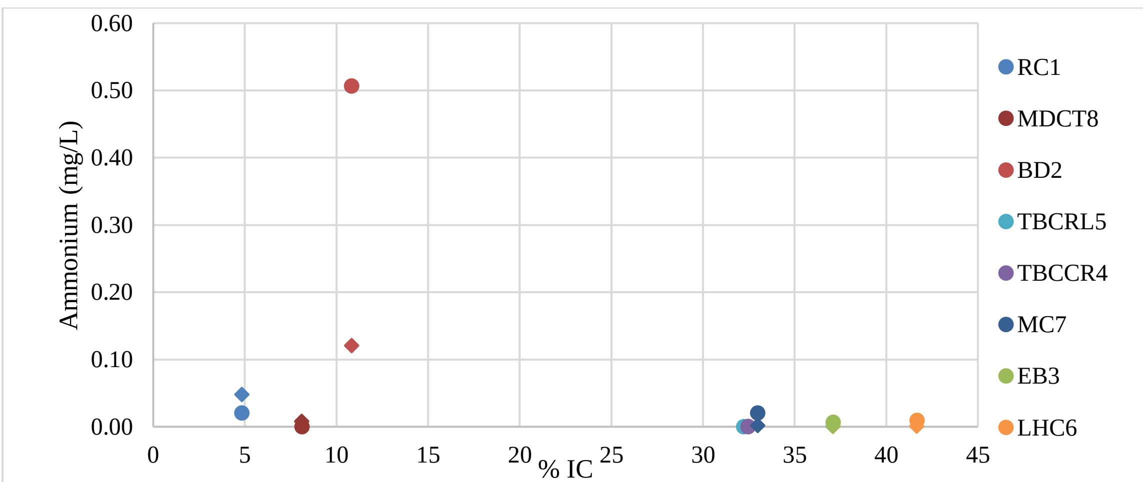

Figure 14: Ammonium concentrations (mg/L) for all sites compared to percent impervious cover. Dots represent the fall sampling and the diamonds represent the winter sampling.

All nitrate concentrations are shown in Figure 15. The nitrate concentrations range for the fall sampling date was 0.02-0.33 mg/L. EB3 had the highest nitrate concentration and the lowest nitrate concentration value was from BD2 (Appendix B). The nitrate concentrations range for the winter sampling date was 0.03-0.66 mg/L. The lowest nitrate concentrations value was MDCT8 and LHC6 had the highest nitrate concentration value for the winter sampling (Appendix B). Several sites during both sampling dates were too low to measure nitrate concentration (0.00 mg/L). Figure 15 presents the nitrate concentrations and percent impervious cover, with no apparent trend between the two variables. Study sites with a %IC greater than 35%, nitrate concentrations were reported 22% greater in the fall and 252% greater in the winter compared to the lowest concentration according to sampling season.

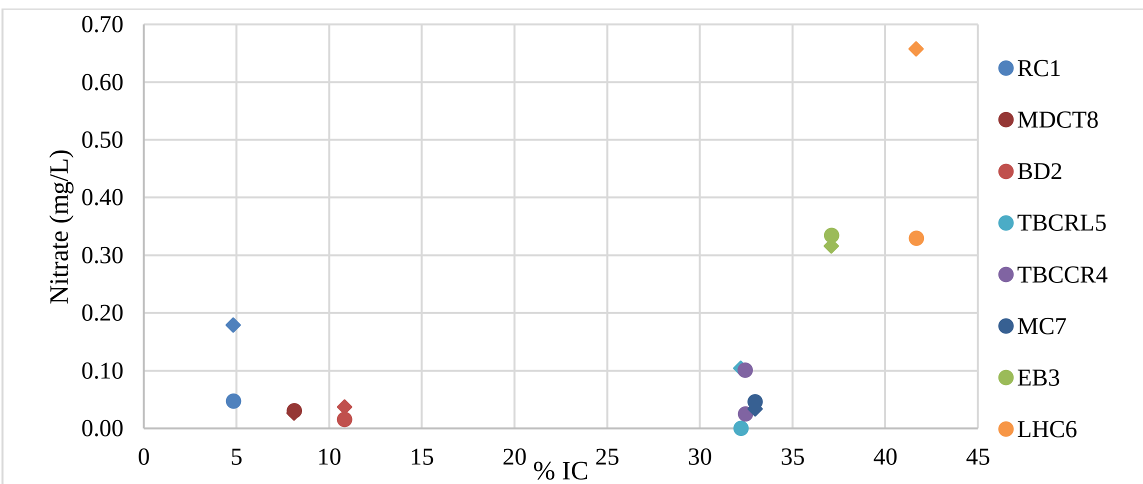

Figure 15: Nitrate concentrations (mg/L) for all sites compared to percent impervious cover. Dots represent the fall sampling and the diamonds represent the winter sampling.

All orthophosphate concentrations are shown in Figure 16. The orthophosphate concentrations range for the fall sampling date was 0.00-0.06 mg/L. The highest orthophosphate concentration was found at TBCRL6 and the lowest nitrate concentration value was from MDCT8 (Appendix B). Several sites during both sampling dates were too low to measure orthophosphate concentration (0.00 mg/L). Figure 16 presents the orthophosphate concentrations and percent impervious cover, with no apparent trend between the two variables. Study sites with a %IC greater than 33%, orthophosphate concentrations were reported 51% greater in the fall compared to the lowest concentration.

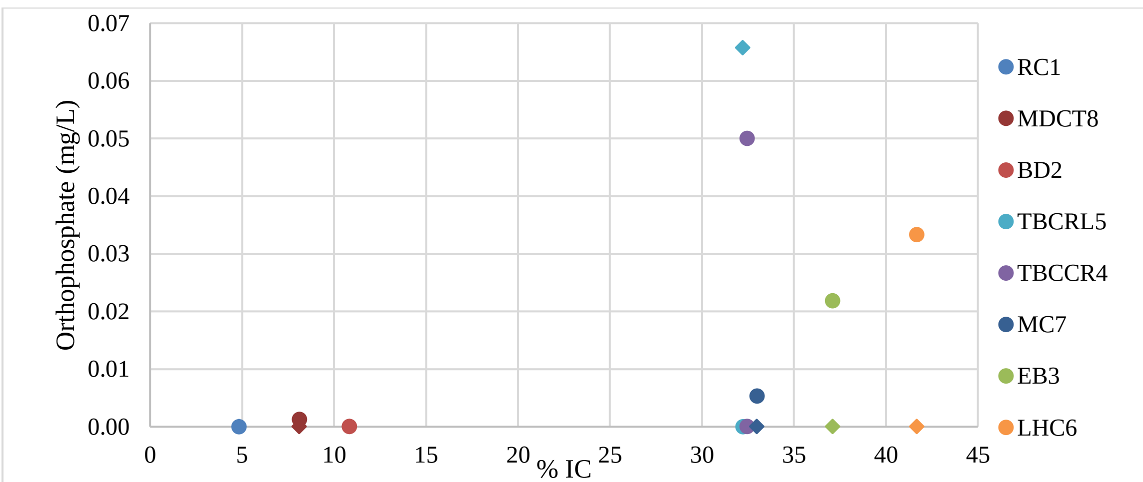

Figure 16: Orthophosphate concentrations (mg/L) for all sites compared to percent impervious cover. Dots represent the fall sampling and the diamonds represent the winter sampling.

3.2.3 Total Phosphorus

The concentrations of total phosphorus that were analyzed for both sampling dates are listed below in Table 9.

Table 9: Concentrations of Total Phosphorus

Site	Total Phosphorus (mg/L)	
	Fall	Winter
RC1	0.035	0.025
MDCT8	0.032	0.028
BD2	0.028	0.032
TBCRL5	0.074	0.025
TBCCR4	0.067	0.018
MC7	0.032	0.014
EB3	0.039	0.036
LHC6	0.049	0.036

All total phosphorus concentrations are shown in Figure 17. The total phosphorus concentrations range for the fall sampling date was 0.028-0.074 mg/L. TBCRL5 had the highest total phosphorus concentration and the lowest total phosphorus concentration value was from BD2 (Appendix B). The total phosphorus concentrations range for the winter sampling date was 0.014-0.036 mg/L. The lowest total phosphorus concentrations value was MC7. The highest total phosphorus concentration value for the winter sampling was present at both LHC6 and EB3 (Appendix B). Several sites during both sampling dates were too low to measure total phosphorus concentration (0.00 mg/L). Figure 17 presents the total phosphorus concentrations and percent impervious cover, with no apparent trend between the two variables.

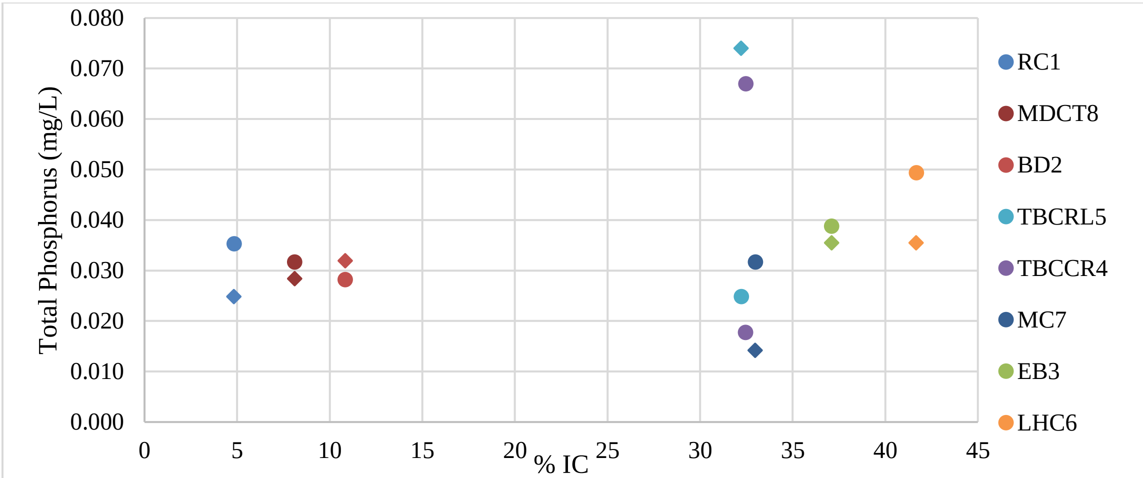

Figure 17: Total Phosphorus concentrations (mg/L) for all sites compared to percent impervious cover. Dots represent the fall sampling and the diamonds represent the winter sampling.

3.2.4 Dissolved Organic Carbon

The concentrations of the dissolved organic carbon (DOC) that were analyzed for both sampling dates are listed below in Table 10.

Table 10: Concentrations of Dissolved Organic Carbon

Site	DOC (mg/L)	
	Fall	Winter
RC1	6.46	3.12
MDCT8	2.51	2.05
BD2	3.70	2.07
TBCRL5	3.39	2.54
TBCCR4	3.08	2.26
MC7	3.48	3.13
EB3	1.40	1.01
LHC6	2.07	1.21

All DOC concentrations are shown in Figure 18. The DOC concentrations range for the fall sampling date was 1.40-6.46 mg/L. RC1 had the highest DOC concentration for the fall sampling date. The DOC concentrations range for the winter sampling date was 1.01-3.13 mg/L. MC7 had the highest nitrate concentration value for the winter sampling (Appendix C). Figure 18 presents the DOC concentrations and percent impervious cover, with a trend of decreasing DOC concentration as impervious cover increases.

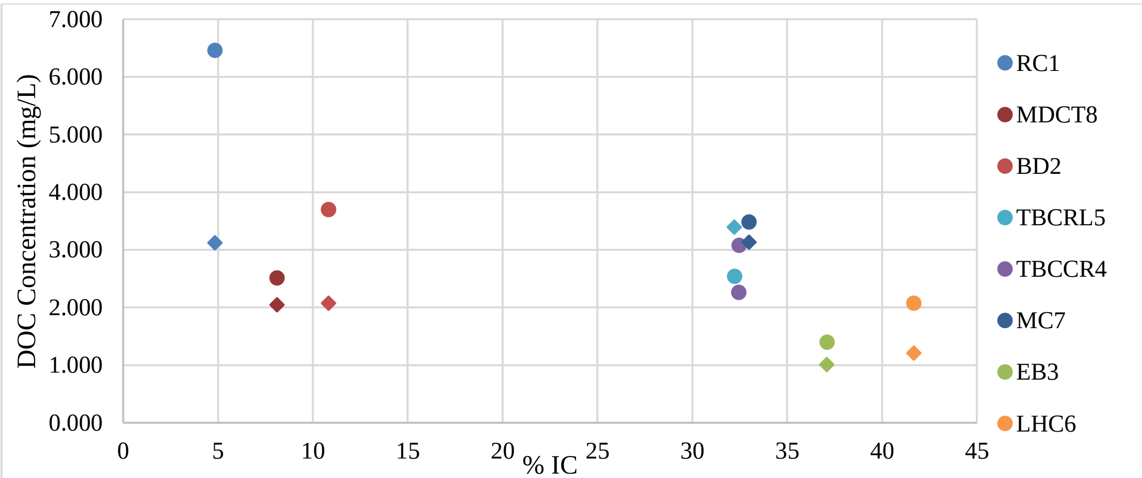

Figure 18: DOC concentrations (mg/L) for all sites compared to percent impervious cover. Dots represent the fall sampling and the diamonds represent the winter sampling.

3.2.5 Correlation Coefficients

Table 11 below indicates all of the correlation coefficients and probabilities for Baseflow TSS, Stormflow TSS, Sampler TSS, ammonium, nitrate, orthophosphate, total phosphorus and dissolved organic carbon. All of the TSS measurements, ammonium, and DOC had a strong negative correlation between the parameter and increasing impervious cover for the entire study. Nitrate, orthophosphate, and total phosphorus had weak positive correlations between the parameter and increasing impervious cover for the entire study. The sampler TSS strong negative correlation with increasing impervious cover was significant, however the samples were not collected from all sites for both sampling dates and the sampler samples were not representative of the pre-stormflow due to continuous stormflow cycling into the bottle altering the TSS concentration detected.

Table 11: Correlation Coefficients for Water Quality. Green shading indicates there is a positive association between the two parameters and red shading indicated there is a negative association. Bolded correlation probability values indicate statistical significance.

Percent Impervious Cover versus:	Correlation Coefficient	Correlation Probability
Baseflow TSS	-0.8264	0.3808
Stormflow TSS	-0.5286	0.6455
Sampler TSS	**-0.9923**	**0.0792**
Ammonium	-0.3732	0.7565
Nitrate	0.5326	0.6424
Orthophosphate	0.3836	0.7494
Total Phosphorus	0.2761	0.8219
Dissolved Organic Carbon	-0.4910	0.6733

3.3 Benthic Macroinvertebrates

3.3.1 NCBI Rating

The NCBI scores and ratings ranged from poor to good-fair and varies for each of the sites among the two sampling seasons, while others remained the same (Table 12). MDCT8, RC1, TBCCR4, and MC7 NCBI scores changed slightly with the change of season, but their overall bioclassification rating remained the same. BD2 and LHC6 bioclassifications decreased between the sampling dates, while EB3 increased from poor to good-fair. The bioclassification of the study sites provided insight into the biological condition of urban headwater systems. Figure 19 depicts the relationship of the NCBI score and increasing impervious cover and even sites with low %IC had high NCBI scores so that there was no evident decreasing trend between the two variables as might be expected.

Table 12: NCBI Ratings

Sites	Fall NCBI Score	Fall Rating	Winter NBCI Score	Winter Rating
MDCT8	6.32	FAIR	6.59	FAIR
RC1	7.60	POOR	6.46	POOR
BD2	5.76	GOOD-FAIR	6.24	FAIR
TBCCR4	7.81	POOR	7.11	POOR
TBCRL5	7.28	POOR	6.24	FAIR
MC7	6.61	FAIR	6.47	FAIR
EB3	7.69	POOR	5.78	GOOD-FAIR
LHC6	5.74	GOOD-FAIR	7.36	POOR

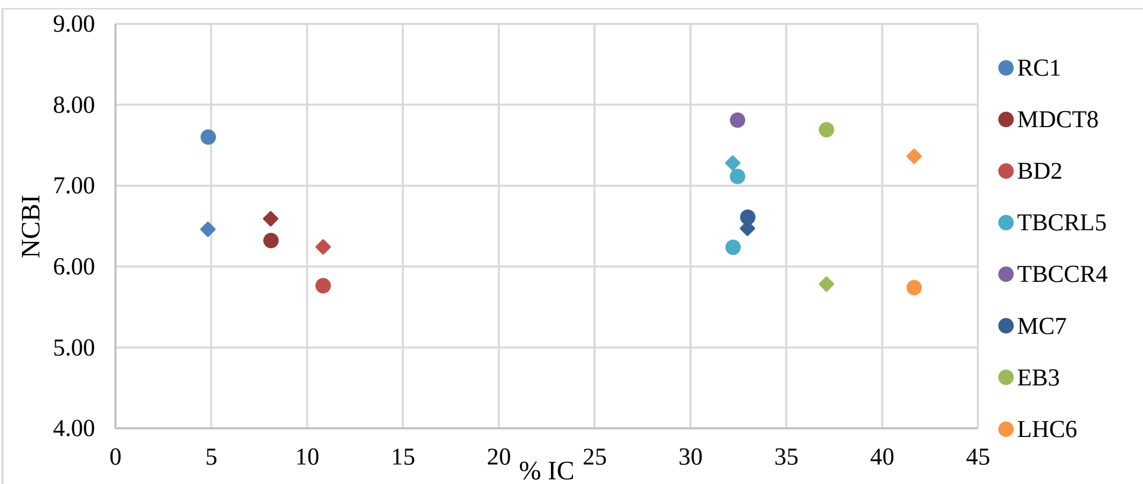

Figure 19: NCBI scores for all sites compared to percent impervious cover. Dots represent the fall sampling and the diamonds represent the winter sampling.

3.3.2 EPT Richness

The Ephemeroptera, Plecoptera, and Trichoptera (EPT) are the taxa that are most sensitive to pollution (Merritt et al., 2008). Figure 20 shows the relationship of percent EPT compared to percent impervious cover for all sites for both sampling dates. RC1 saw a decrease in EPT from fall to winter (from 50 to 0 percent respectively), due to the impacts from recent restoration of the study site. EB3, TBCCR4, TBCRL5, LHC6, and MDCT8 percent EPT decreased from fall to winter, while MC7 increased from one sampling date to the next. BD2 remained constant in the percentage of EPT found during both samplings.

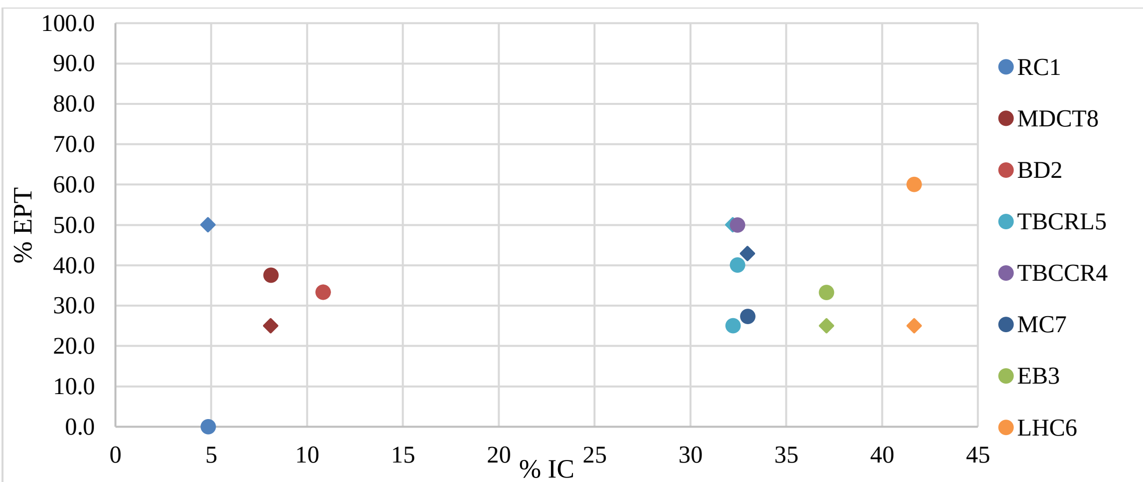

Figure 20: Percent EPT for all sites compared to percent impervious cover. Dots represent the fall sampling and the diamonds represent the winter sampling.

3.3.3 Species Richness

Species Richness indicates the number of taxa that are found compared to the total number of individuals. Values that are higher indicate a more diverse number of taxa at a sampling site. The following sites increased from fall to winter: BD2, MDCT8, TBCRL5, LHC6 and TBCCR4. EB3, MC7, and RC1 decreased between the sampling dates. BD2 saw the greatest increase in Species Richness, while MC7 saw a slight decrease in Species Richness. The Species Richness decreased as impervious cover increased during both sampling dates with the exception of BC2 and EB3.

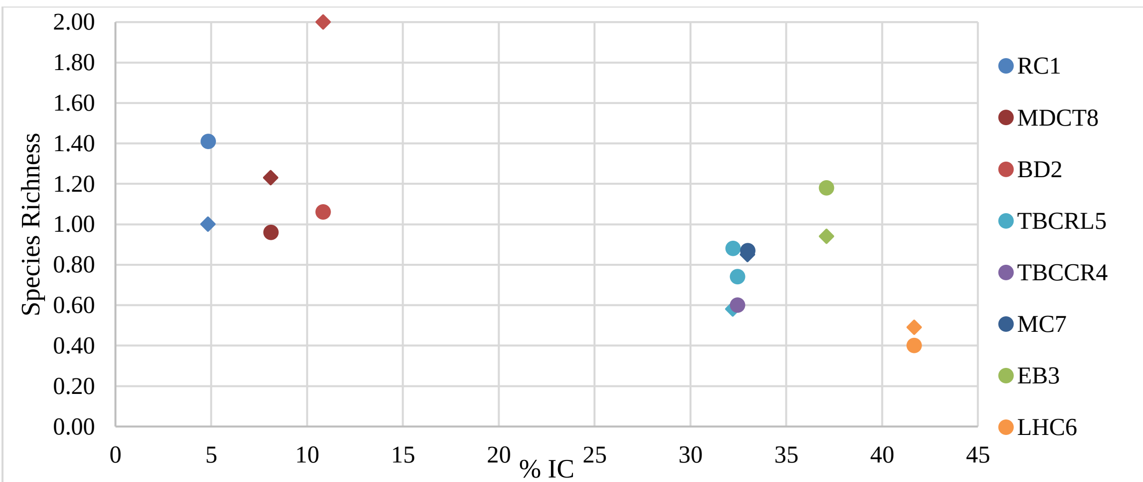

Figure 21: Species Richness for all sites compared to percent impervious cover. Dots represent the fall sampling and the diamonds represent the winter sampling.

3.3.4 Species Diversity

Species diversity measures the number of species found compared to the number of species at the site. Species diversity increased from fall to winter for all of the sites except TBCCR4 and EB3. There was not a significant trend in percent impervious cover and species diversity among both of the sampling dates.

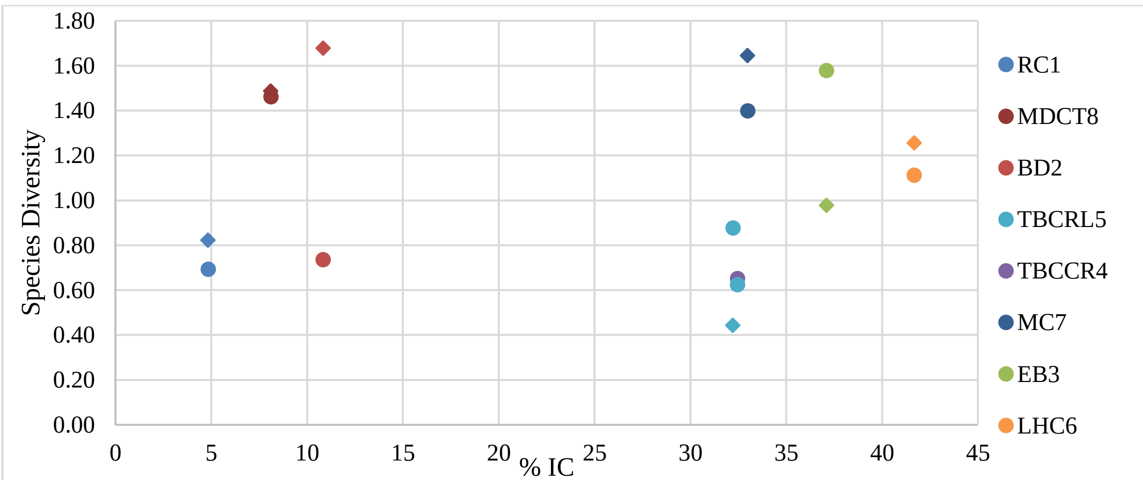

Figure 22: Species Diversity for all sites compared to percent impervious cover. Dots represent the fall sampling and the diamonds represent the winter sampling.

3.3.5 Species Evenness

The species evenness of each site determines how evenly distributed the different taxa are compared to the total number of taxa that was found across all of the sites during both sampling dates. BD2 and TBCCR4 species evenness remained constant from fall to winter, while EB3 decreased. All of the other sampling locations increased to a more evenly distributed sample from the fall to winter sampling.

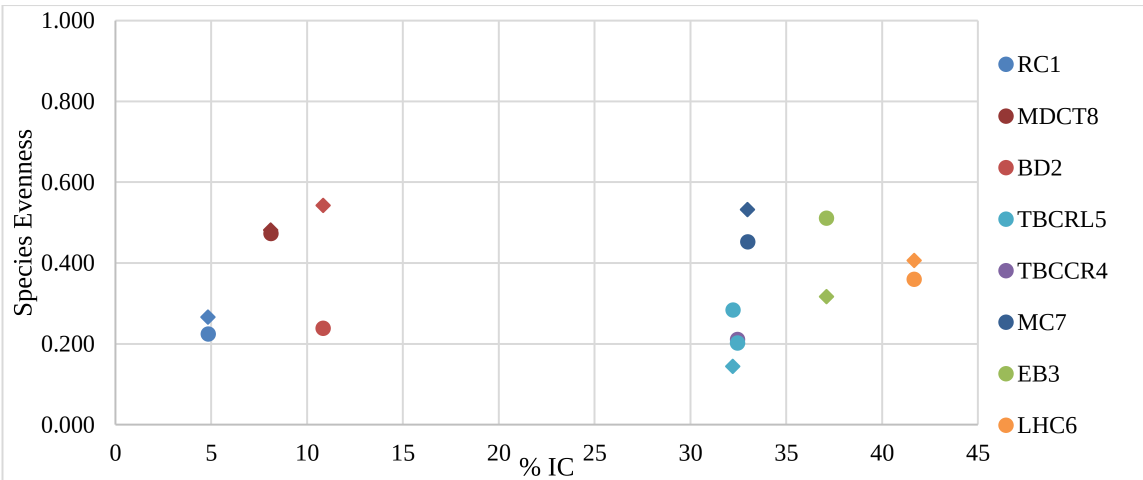

Figure 23: Species Evenness for all sites compared to percent impervious cover. Dots represent the fall sampling and the diamonds represent the winter sampling.

3.3.6 Functional Feeding Groups

The functional feeding groups (FFGs) of macroinvertebrates determines the role in which the individual species feeds on the particulate matter or other aquatic insects. The distribution across both sampling dates compared to impervious cover is depicted in Figure 24 and Figure 25. The dominant FFG for the fall and the winter were collectors, compared to the least prominent group were scrapers. BD2 winter FFGs distribution was made up of scrapers and predators. TBCCR4 fall FFGs distribution was predominantly scrapers while at the other sites it was collectors. Predators were seen at RC1 and EB3 in the fall sampling event. Shredders were not a leading FFG, but they were found MDCT8 and MC7 in the fall and MDCT8, TBCCR4, and MC7 in the winter.

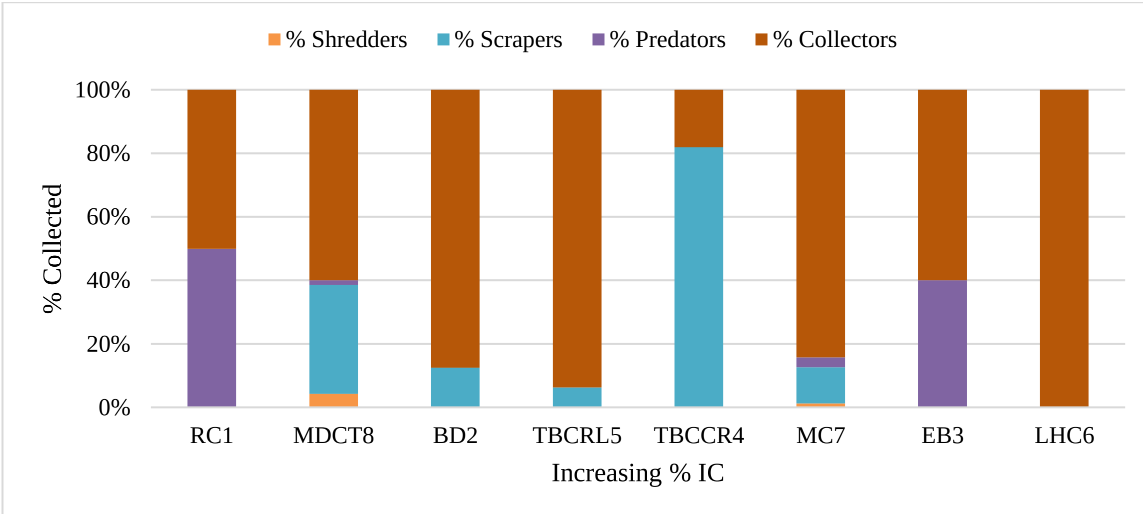

Figure 24: Functional Feeding Groups for all sites compared to percent impervious cover for the fall sampling date

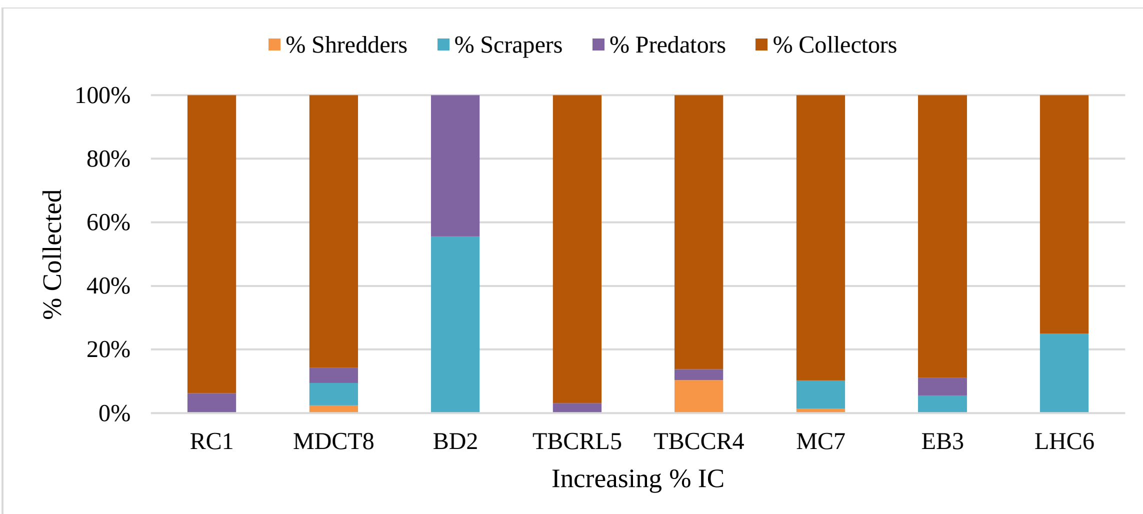

Figure 25: Functional Feeding Groups for all sites compared to percent impervious cover for the winter sampling date

3.3.7 Tolerant vs. Intolerant Species

The tolerant species are species that have a tolerance value greater than four and the intolerant species are species that have a tolerance value less than or equal to four. Figures 26 and 27 depict the trends for the fall and winter sampling, in which tolerant species were dominant and intolerant species were only found at a few sites during each sampling.

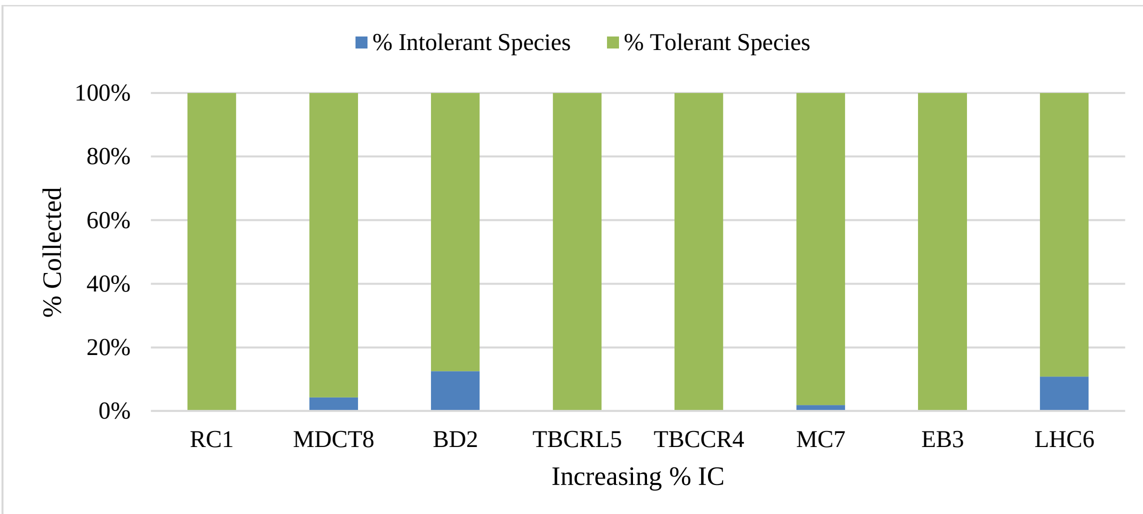

Figure 26: Tolerant vs. Intolerant species collected at fall sampling

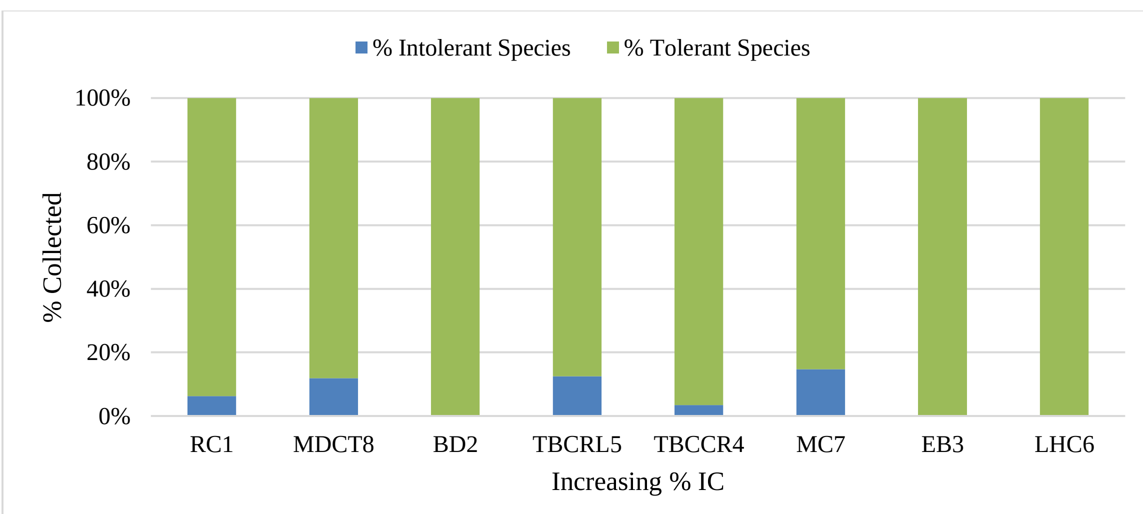

Figure 27: Tolerant vs. Intolerant species collected at winter sampling

3.3.8 Correlation Coefficients

Table 13 below indicates all of the correlation coefficients and probabilities for NCBI, percent EPT, species richness, species diversity, species evenness, the percent of the four functional feeding groups, and the percent tolerant and intolerant species. Species diversity, species evenness, percent shredders, percent scrapers, and percent tolerant species had a weak negative correlation between the parameter and increasing impervious cover for the entire study. Species richness had a moderate significant negative correlation with increasing impervious cover. NCBI, percent EPT, percent predators, percent collectors, and percent tolerant species had weak positive correlations between the parameter and increasing impervious cover for the entire study. The percent of collectors had a strong positive correlation with increasing impervious cover that was significant.

Table 13: Correlation Coefficients for Macroinvertebrate Metrics. Green shading indicates there is a positive association between the two parameters and red shading indicated there is a negative association. Bolded correlation probability values indicate statistical significance.

Percent Impervious Cover versus:	Correlation Coefficient	Correlation Probability
NCBI	0.1375	0.6115
% EPT	0.2882	0.2790
Species Richness	**-0.6598**	**0.0054**
Species Diversity	-0.0144	0.9578
Species Evenness	-0.0117	0.9657
% Shredders	-0.0936	0.7303
% Scrapers	-0.0074	0.9783
% Predators	0.0701	0.7963
% Collectors	**0.3817**	**0.1446**
% Intolerant Species	-0.1272	0.6387
% Tolerant Species	0.1255	0.6432

3.4 Wolman Pebble Count

3.4.1 Grain Size Distribution

The grain size distribution collected for both sampling dates and are shown in Figure 28 and Figure 29. The prominent grain size was gravel across all of the sites in the fall, but it varied in the winter. BD2 was mainly sand in the winter, while it was evenly distributed with sand and gravel in the fall.

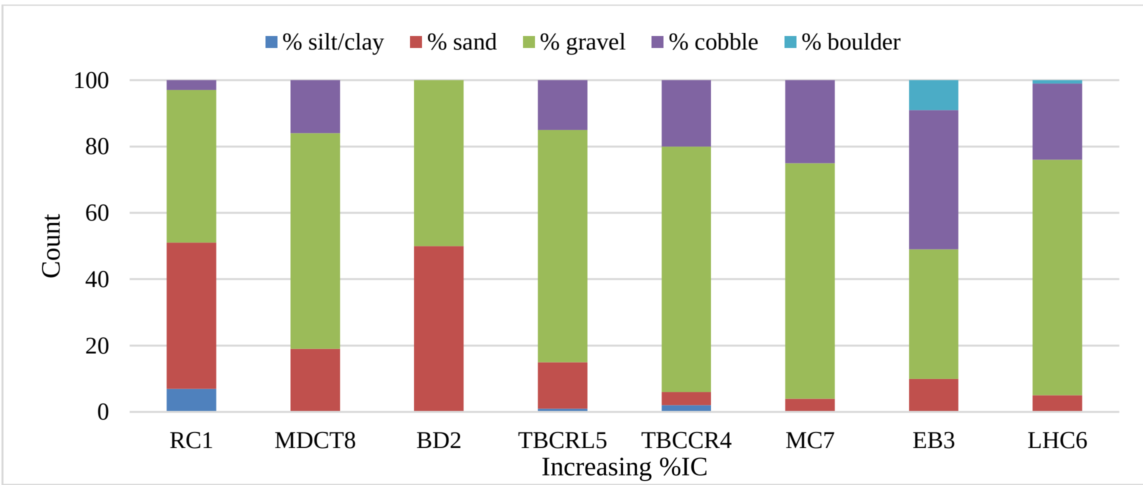

Figure 28: Grain size distribution for all sites compared to percent impervious cover for the fall sampling date

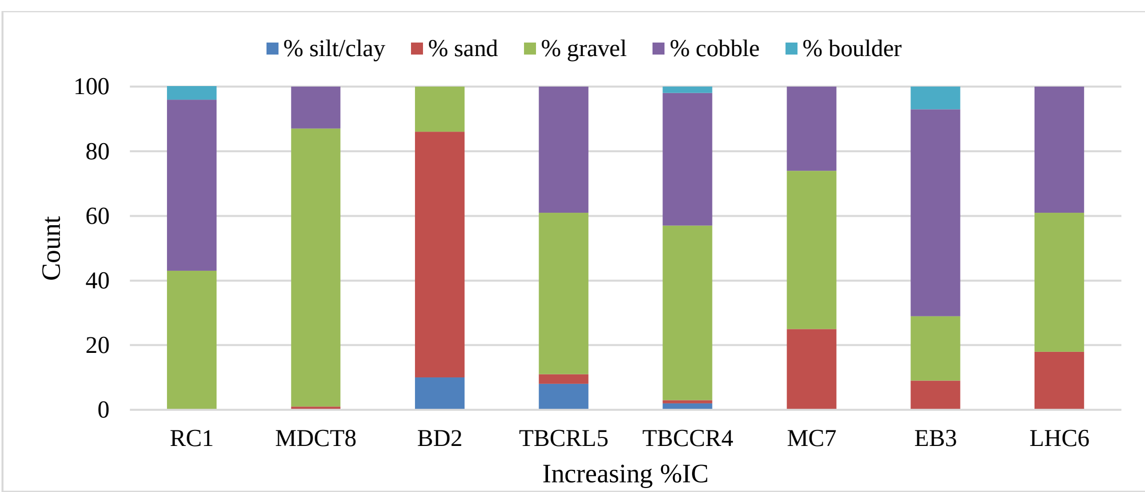

Figure 29: Grain size distribution for all sites compared to percent impervious cover for the winter sampling date

3.4.2 Median Grain Size

The median grain size (D_{50}) values are presented in Table 14 and the grain size distribution figures can be found in Appendix B. The variation in the median grain size varied between both sampling dates for RC1, TBCCR4, TBCRL5, and EB3. The significant difference for RC1 is attributed to the restoration of the sampling site before the winter sampling date. The other variation among the sites are explained by different sampling zigzag transects based on current field conditions. Figure 30 shows the median grain size with increasing impervious cover, which resulted in a general increase in D_{50} as percent impervious cover increased.

Table 14: Median Grain Size (D_{50})

Sites	Fall D_{50} (mm)	Winter D_{50} (mm)
RC1	2	100
MDCT8	38	34
BD2	2	1.4
TBCRL5	37	58
TBCCR4	49	60
MC7	37	40
EB3	92	140
LHC6	41	52

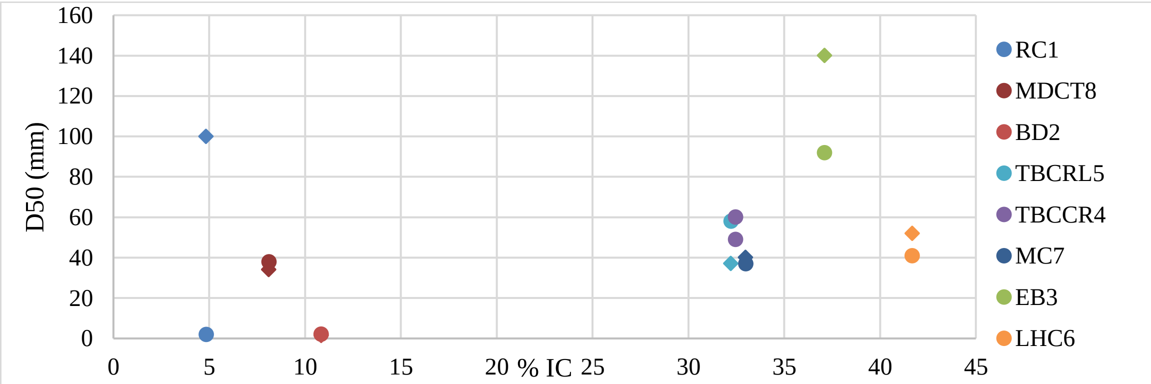

Figure 30: Median size distribution for all sites compared to percent impervious cover during both sampling dates. Dots represent the fall sampling and the diamonds represent the winter sampling.

3.4.3 Correlation Coefficients

Table 15 below indicates all of the correlation coefficients and probabilities for grain size distribution and median grain size (D_{50}). The percent of silt/clay and percent of sand had a weak negative correlation between the parameter and increasing impervious cover for the entire study, however only the percent sand was significant. The percent of gravel and the percent of boulders had weak positive correlation between the parameter and increasing impervious cover for the entire study. The percent of cobble had a moderate positive correlation with increasing impervious cover for the entire study. The moderate positive correlation of D_{50} with increasing impervious cover was significant.

Table 15: Correlation Coefficients for Grain Size. Green shading indicates there is a positive association between the two parameters and red shading indicated there is a negative association. Bolded correlation probability values indicate statistical significance.

Percent Impervious Cover versus:	Correlation Coefficient	Correlation Probability
% silt/clay	-0.2688	0.3141
% sand	**-0.4420**	**0.0865**
% gravel	0.0290	0.9152
% cobble	**0.4875**	**0.0554**
% boulder	0.1282	0.6360
median grain size (D_{50})	**0.4014**	**0.1233**

3.5 Hydrologic Metrics

3.5.1 Tractive Force

The tractive force is the average shear stress required to move a specific grain size into motion, which is directly proportional to the sediment grain size in centimeters. Figures 31 and 32 display the range of tractive force needed to move the grain size distribution of each of the sites for both seasons. The tractive force increases with grain size. During the fall and winter season, BD2 had the narrowest range of tractive force needed to move the distribution of grains. Whereas, LHC6 had the widest range of tractive force values in the fall and EB3 had the widest range of tractive force values in the winter.

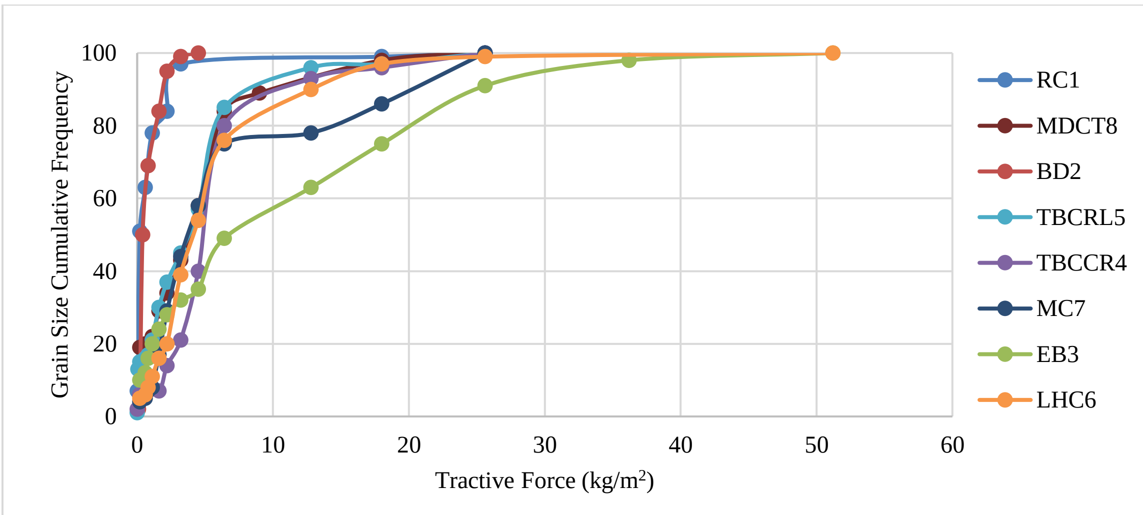

Figure 31: Tractive force for corresponding grain size Fall 2018

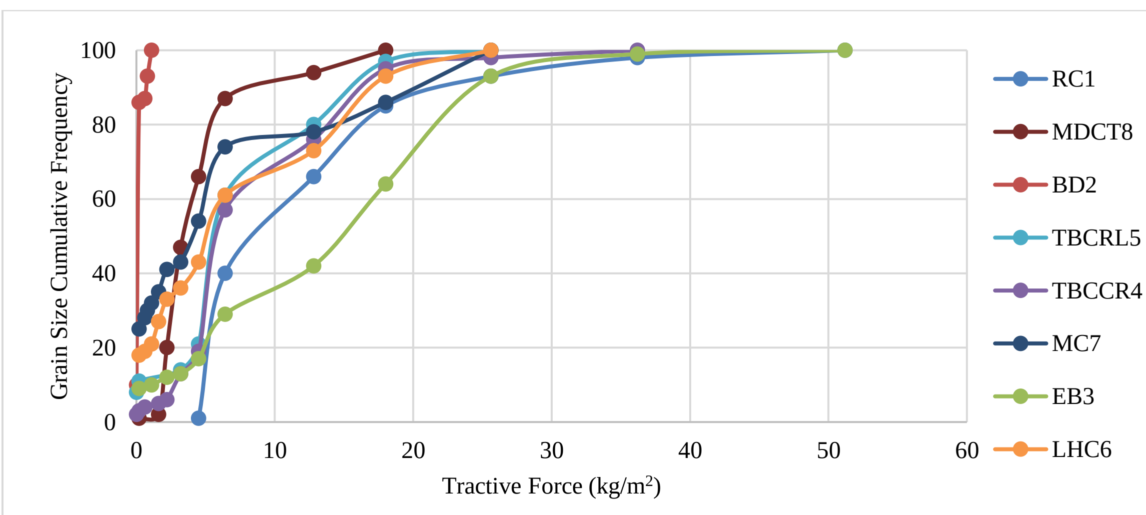

Figure 32: Tractive Force for corresponding grain size Winter 2019

3.5.2 Bed Mobility

The percent bed mobility indicates how often the sediment grains were actively moving for two years prior to sampling each study location. Figure 33 and Figure 34, indicate that larger grains sizes found at the study sites did not move as often as the smaller grains.

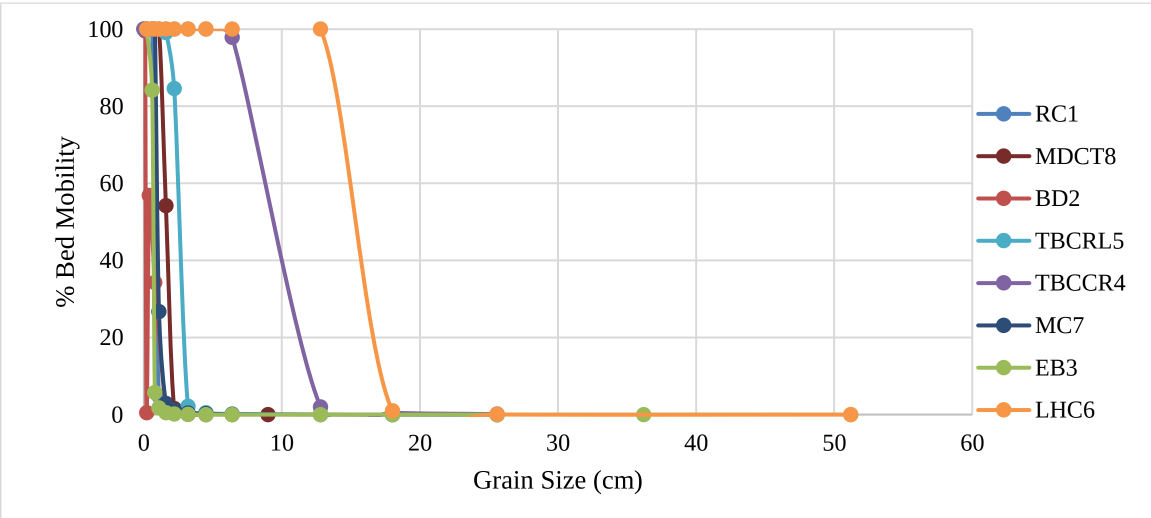

Figure 33: % Bed Mobility based on grain size Fall 2018

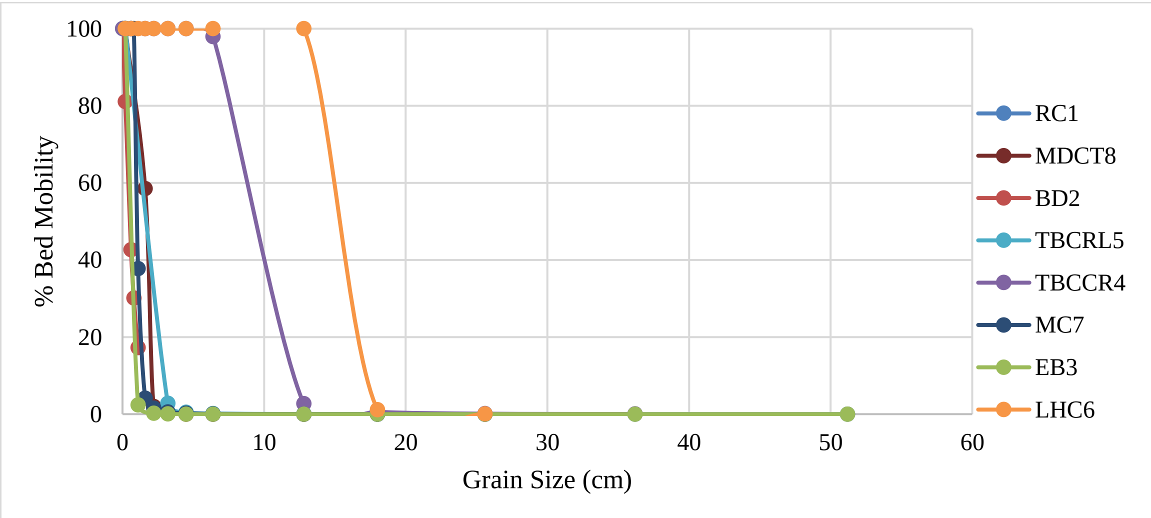

Figure 34: % Bed Mobility based on grain size Winter 2019

The D_{50} or median grain size bed mobility is the movement across sites and seasons varied based on the size of the grain, with larger grains being less mobile than smaller grains. RC1 median grain size of 2 millimeters in the fall was 100% active for two years prior to sampling, while in winter the D_{50} increased to 100 millimeters and was not mobile (Figures 35-36). Both TBCRL5 and MC7 had ~100% bed mobility during both seasons whereas the remaining sites had very low bed mobility (Figures 35-36).

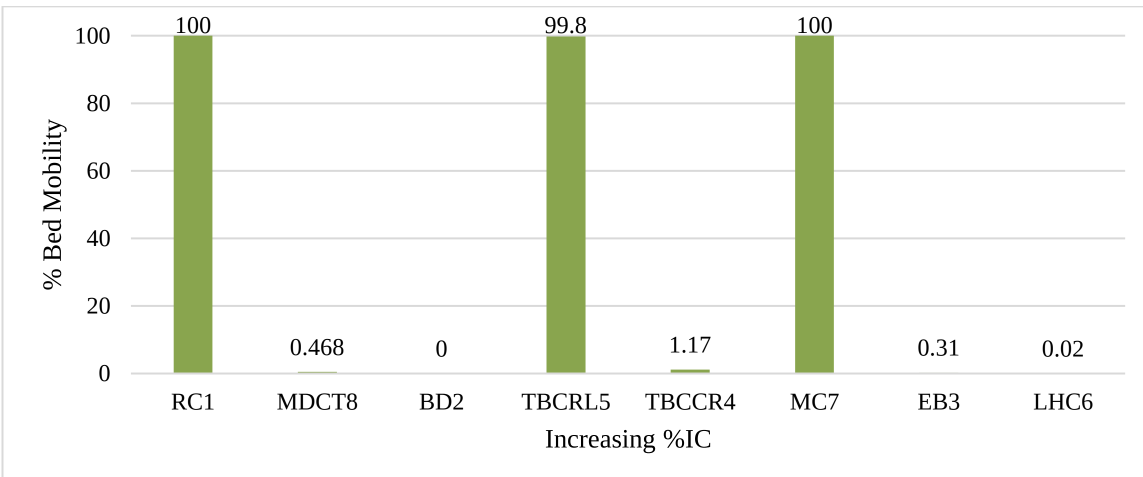

Figure 35: D_{50} bed mobility Fall 2019

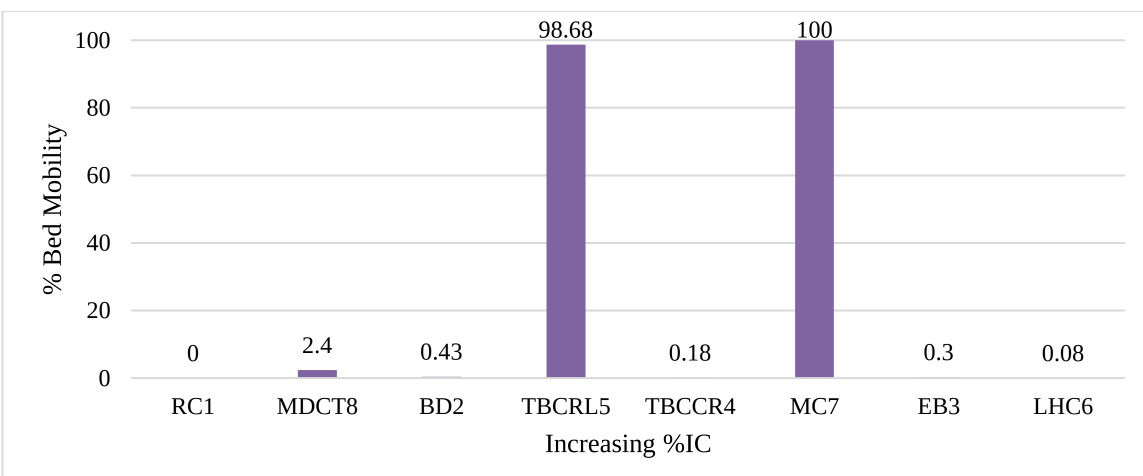

Figure 36: D_{50} bed mobility Winter 2019

3.5.3 Threshold Discharge

The threshold discharge increased or decreased depending on the change in median grain size between the sites. for each sampling date. The same 2-year peak flow value was used for both sampling dates. The threshold discharge increased as percent impervious cover increased, except for RC1 which saw an increase with the change of median grain size from restoration of the study location.

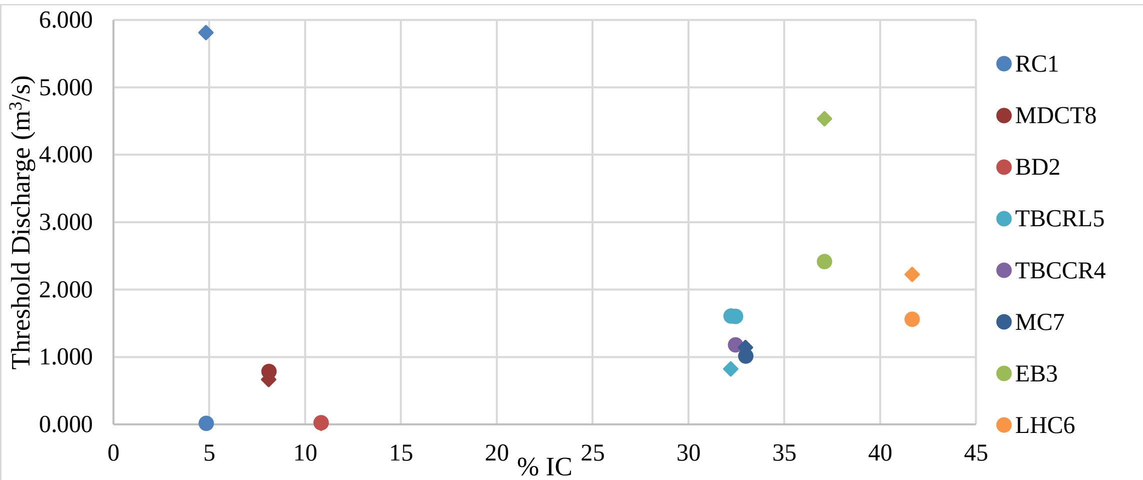

Figure 37: Threshold Discharge for all sites compared to percent impervious cover during both sampling dates. Dots represent the fall sampling and the diamonds represent the winter sampling.

Typical mean threshold discharge values (m^3/s) for the dominant grain size of the stream bed are as follows: sand ~0.001, gravel 0.15, cobble 2.5, and boulder 8 (Hawley and Vietz, 2016). The threshold discharge for sand, indicates that the channel is unstable and that frequent flows of a magnitude of a less than one-year storm can cause the grains to become mobile. The fall sampling values for RC1 and BD2 and the winter sampling of BD2 correspond with sand grain threshold discharge values. The flow duration curves of these sites show that the probability of exceedance of threshold discharge flow values are met or exceeded almost 100% of the time (Appendix D). The gravel threshold discharge, shows that sub-bankfull flows will cause the movement of the grains. The fall sampling threshold discharge values, listed in increasing order, for MDCT8, TBCRL5, MC7, TBCCR4, LHC6, and EB3 are classified as gravel size grain discharge.

The winter sampling threshold discharge values, listed in increasing order, for MDCT8, MC7, TBCCR4, TBCRL5, and LHC6 are determined to be from the gravel size threshold discharge. EB3 and RC1, during the winter sampling, had values that are cobble grain size threshold discharge values. EB3 during the fall sampling was within 0.1 of meeting the cobble size threshold discharge range. The threshold discharge for cobble, indicates that the channel is vulnerable to flows of a magnitude of sub-bankfull to overbank events which can cause the grains to become mobile.

Table 16: Percent of Exceedance of Q_c

Site	Fall	Winter
RC1	100.0	0.9
MDCT8	0.12	0.22
BD2	38.8	61.8
TBCRL5	0.60	0.31
TBCCR4	0.44	0.98
MC7	0.94	1.09
EB3	0.002	0.00
LHC6	1.01	0.82

The flow duration curves of these sites in Appendix D, show that the probability of exceedance of threshold discharge flow values are met or exceeded. Table 16 below summarizes the flow duration curves for both sampling dates. The percent of exceedance varied between the sites and seasons. RC1 had 100% exceedance of Q_c in the fall, while in the winter the exceedance decreased to 0.9%.

The decrease in Q_c % exceedance was due to the change in median grain size from 2 millimeters to 100 millimeters. Alternatively, BD2 median grain size changed from 2 millimeters to 1.4 millimeters; which resulted in a decrease in 23% exceedance of Q_c.

3.5.4 Correlation Coefficients

Table 17 below summarizes the correlation coefficients and probabilities for tractive force and threshold discharge. The D_{50} tractive force had a significant moderate positive correlation with increasing impervious cover for the entire study. The D_{50} % bed mobility had a weak positive correlation with increasing impervious cover which was not significant. D_{50} threshold discharge had a weak positive correlation between the parameter and increasing impervious cover for the entire study. The frequency of threshold discharge had a moderate negative correlation with increasing impervious cover, which was statistically significant.

Table 17: Correlation Coefficients for Hydrologic Metrics. Green shading indicates there is a positive association between the two parameters and red shading indicated there is a negative association. Bolded correlation probability values indicate statistical significance.

Percent Impervious Cover versus:	Correlation Coefficient	Correlation Probability
D_{50} Tractive Force	**0.4014**	**0.1233**
D_{50} % Bed Mobility	0.2753	0.3021
D_{50} Threshold Discharge	0.1772	0.5114
Frequency of Threshold Discharge	**-0.5555**	**0.0255**

3.6 Relationship between Hydrologic and Macroinvertebrate Metrics

Table 18 below displays all of the correlation coefficients and Table 19 indicates the correlation probabilities for the hydrologic and macroinvertebrate metrics. The D_{50} tractive force and the D_{50} threshold discharge relationships with the macroinvertebrate metrics varied with positive and negative correlations but they were not significant. The D_{50} percent bed mobility had a moderate positive correlation with species richness, diversity and evenness that was significant. The frequency of threshold discharge had a significant weak positive relationship with percent EPT and a significant weak negative correlation with species richness.

Table 18: Correlation Coefficients for Hydrologic and Macroinvertebrate Metrics. Green shading indicates there is an association between the two parameters and red shading indicated there is no association.

	D_{50} Tractive Force	D_{50} % Bed Mobility	D_{50} Threshold Discharge	Frequency of Threshold Discharge
NCBI	-0.1210	0.0890	0.4306	-0.0455
% EPT	0.2227	-0.5757	0.0070	**0.1621**
Species Richness	-0.2368	**0.6670**	-0.3881	**-0.2917**
Species Diversity	-0.1145	**-0.0962**	-0.3756	-0.0577
Species Evenness	-0.1003	**-0.1027**	-0.3737	-0.0467
% Shredders	-0.1890	-0.2609	-0.0230	-0.0791
% Scrapers	-0.2281	-0.1945	0.0931	-0.1370
% Predators	0.0330	0.0031	-0.3386	0.1736
% Collectors	-0.0900	-0.3491	0.0307	-0.0739
% Intolerant Species	-0.1125	-0.1990	-0.2579	-0.1861
% Tolerant Species	0.1157	0.1986	0.2572	0.1878

Table 19: Correlation Probabilities for Hydrologic and Macroinvertebrate Metrics. Bolded correlation probability values indicate statistical significance.

	D_{50} Tractive Force	D_{50} % Bed Mobility	D_{50} Threshold Discharge	Frequency of Threshold Discharge
NCBI	0.8672	0.0959	0.6552	0.7432
% EPT	0.5486	0.9794	0.4070	**0.0196**
Species Richness	0.2731	**0.1374**	0.3772	**0.0048**
Species Diversity	0.8319	**0.1517**	0.6727	0.7230
Species Evenness	0.8637	**0.1539**	0.7117	0.7051
% Shredders	0.7708	0.9327	0.4832	0.3292
% Scrapers	0.6129	0.7315	0.3956	0.4703
% Predators	0.5203	0.1995	0.9035	0.9909
% Collectors	0.7856	0.9103	0.7403	0.1851
% Intolerant Species	0.4901	0.3349	0.6783	0.4599
% Tolerant Species	0.4861	0.3363	0.6696	0.4609

4. DISCUSSION

The overall purpose of my research is to understand the forces driving sediment movement and it's impacts on the biological condition of urban headwater streams. Headwater streams play key roles in controlling downstream impacts of nutrient loading, biological health, and sediment movement (Alexander et al., 2007, Clarke et al., 2008). By connecting sediment mobilization and macroinvertebrate diversity, urban systems can be restored using designs that control sediment transport while improving the biological condition. These urban systems convey runoff impervious to the small-scale watershed, which flows into the major rivers and finally into the ocean.

The background environmental parameters and water quality assessed for the entire study provided insight into the current conditions of the study locations. The pH, dissolved oxygen, air saturation, temperature, specific conductance, and the percentage of tree canopy cover all had positive relationships with increasing impervious cover. However, the percent of air saturation was significant and many sites exceeded 100%. These values could be credited to the excess amounts of photosynthetically- active species such as plants and algae that were found at these sites during the winter sampling (YSI, 2005). It would be expected, that as impervious cover increases tree canopy cover would decrease, but due to urban infrastructure causing constraints on the landscape such as bordering roads and buildings, this was not the case due to the maintenance of a riparian corridor in Charlotte Mecklenburg County streams.

The concentrations of nitrate, orthophosphate, and total phosphorus increased with increasing impervious cover. However, the concentrations of ammonium and DOC found during the entire study decreased as impervious cover increased. The TSS collected at baseflow, stormflow, and storm runoff decreased along the urban gradient. The sampler TSS had a strong negative correlation with increasing impervious cover that was significant, however the samples were not collected from all sites for both sampling dates and the sampler samples were not representative of the pre-stormflow due to continuous stormflow cycling into the bottle altering the TSS concentration detected.

The distribution of grain sizes found at the study locations varied between sites and sampling dates. The sand grain size was seen across the study sites and had a significant negative correlation with the urban gradient. The percent of cobble had a significant positive correlation with the urban gradient. The median grain size had a weak positive correlation with the urban gradient that was significant. There was a significant difference in the median grain size for RC1 from fall to winter, which is due to the restoration of the study location in February of 2019, before the winter sampling date. Other factors that could contribute to larger grains being found at the sampling locations, are the restorations of EB3 in 2003 and upstream of the MDCT8 sampling location in 2012. The remainder of the sampling locations have undergone varying levels of bank stabilization to prevent erosion of the channel using medium to large grain sizes of cobble to boulder riprap. The introduction of bank stabilizing grains changes the natural median grain size of the sampling location.

4.1 Macroinvertebrate Metrics across an Urban Gradient

The overall community composition across sites indicated an impoverished community as seen by the poor to good-fair NCBI ratings even at sites that had low %IC. Other studies have concluded that biological integrity can be diminished at %IC as low as 5% (Brown et al., 2009). The distribution of macroinvertebrates varied with the different metrics that were compared with impervious cover. The NCBI score and impervious cover relationship indicated that as the NCBI scores increases, meaning it represents decreasing water quality; the percentage of impervious cover increases similarly. The macroinvertebrate community can be degraded when background land cover is disturbed, as a result of urbanization (Brown et al., 2009). The percentage of EPT, the sensitive to pollution species, had a positive correlation with the percentage of impervious cover. This means that as impervious cover increases, the percentage of EPT increased, which can be attributed to the large numbers of *Trichoptera Hydropsychidae Cheumatopsyche spp.* The species were found at a majority of the sites during both sampling dates and have been labeled as an irruptive species that is dominant in riffle habitats under excess nutrients or other stressors (Pond et al., 2003).

The species richness, diversity, and evenness negative correlation with increasing impervious cover indicates that the number of species found and the distribution of the species decreased as impervious cover increased. Species diversity decreasing along the urban gradient supports my hypothesis that the impact from impervious cover runoff would impact the habitat of the macroinvertebrates. The percentage of shredders and scrapers collected decreased with increasing impervious cover while the percentage of predators and collectors increased. The functional feeding group dynamics show that the macroinvertebrates rely on fine particulate organic matter or other macroinvertebrates as their food source. The percent of intolerant species decreased while tolerant species increased as impervious cover increased, which support my hypothesis that tolerant species would increase as a result of runoff from impervious surfaces impacting the system which alters the quality of the habitat of the macroinvertebrates. The increased dominance of tolerant species is a symptom of the urban stream syndrome (Walsh et al, 2007).

4.2 Hydrologic Metrics

The hydrologic metrics take into account the current hydrologic conditions that impact sediment movement. The D_{50} tractive force had a significant moderate positive correlation with the urban gradient which indicated that the median grain size increased concurrently with the tractive force needed to move the sediment grain. The D_{50} % bed mobility had a weak positive correlation with increasing impervious cover which was not significant. D_{50} threshold discharge had a weak positive correlation between the parameter and increasing impervious cover for the entire study.

The restoration of RC1 after the fall sampling increased the median grain size 98% and changed the D_{50} bed mobility from 100% to 0%. Both sampling dates exhibited threshold discharge values were sand, gravel, and cobble. The threshold discharge values were within the ranges provided in Hawley and Vietz (2016) and therefore showed that the increasing sensitivity to urban disturbance increases as the grain size decreases. The frequency of threshold discharge had a moderate negative correlation with increasing impervious cover, which was statistically significant. The rate of urbanization and the location of the study site within a watershed can be determining factors in the channel stability of a stream (Doyle et al., 2000).

4.3 Relationship between Macroinvertebrate and Hydrologic Metrics

The macroinvertebrate communities were affected differently by the hydrologic metrics that were quantified during the study. The D_{50} tractive force and the D_{50} threshold discharge relationships with the macroinvertebrate metrics varied with positive and negative correlations but they were not significant. The D_{50} percent bed mobility had a moderate positive correlation with species richness, diversity and evenness that was significant.

Threshold discharge and the percent of EPT and tolerant species positive correlation shows that the flow that moves the median grain size increases similarly as the number of tolerant species and sensitive species are found. The impact of impervious cover runoff affects the quality of the macroinvertebrate habitats from changing to the hydrology and geomorphology of the channel, therefore increasing the number of tolerant species. The correlation with the number of EPT can be attributed to the large numbers of *Trichoptera Hydropsychidae Cheumatopsyche spp.*, that were found at a majority of the sites during both sampling dates.

The frequency of threshold discharge and percent EPT significant weak positive relationship indicates that the more frequent the threshold discharge occurs the greater number of EPT are found. The frequency of threshold discharge and species richness significant weak negative correlation indicates that the number of taxa found decrease with as the frequency of threshold discharge decreases. This can be explained by the exceedance of Q_c values being less than 2% for all sites except RC1 in the fall and BD2 during both seasons.

There are few studies relating bed mobility to %IC or to restoration and its effects on macroinvertebrates. This lack of research in this discipline indicates a need for studies that understand not only the mechanics of erosion and sediment movement, but the connection of improving channel stability in order to create macroinvertebrate habitat that can support a diverse and dense community of taxa.

5. CONCLUSIONS

My research aimed to understand the impacts of sediment mobilization on macroinvertebrate diversity of urban headwater streams. The background environmental parameters and water quality assessed for the entire study provided insight into the current conditions of the study locations, resulting in positive relationships with increasing impervious cover. In contrast however, the percent air saturation increased with the urban gradient and was statistically significant most likely due to the presence of algae. The water quality concentrations studied yielded mixed results when compared to impervious cover. The distribution of grain sizes found for the study locations varied across the sites and sampling dates due to current conditions of bank stabilization and past restoration.

The overall community composition across sites indicated an impoverished community as seen by the poor to good-fair NCBI ratings even at sites that had low %IC. The percentage of EPT's positive correlation with the percentage of impervious cover was attributed to the large numbers of *Trichoptera Hydropsychidae Cheumatopsyche spp.* that were collected. Species diversity, richness, and evenness decreased along the urban gradient, indicating that the impact from impervious cover runoff did impact the habitat of the macroinvertebrates. The functional feeding groups were not evenly distributed among the sampling sites and dates, but collectors were the dominant group found overall. The percent tolerant species increased as impervious cover increased, indicating that the quality of the habitat of the macroinvertebrates was impaired.

The macroinvertebrate communities were affected differently by the hydrologic metrics that were quantified during the study. The D_{50} tractive force and the D_{50} threshold discharge relationships with the macroinvertebrate metrics yielded mixed positive and negative correlations that were not significant. Species richness, diversity and evenness had a significant moderate positive correlation with the D_{50} percent bed mobility. Threshold discharge and the percent of EPT and tolerant species positive correlation shows that the flow that moves the median grain size increases similarly as the number of tolerant species and sensitive species are found. The impact of impervious cover runoff affects the quality of the macroinvertebrate habitats from changing to the hydrology and geomorphology of the channel, therefore increasing the number of tolerant species. The correlation with the number of EPT can be attributed to the large numbers of *Trichoptera Hydropsychidae Cheumatopsyche spp.*, that were found at a majority of the sites during both sampling dates.

The macroinvertebrate community dynamics assessed in this study showed the interconnected relationships between sediment grain size and the bed mobility. The hypotheses stated were supported by the results of the study. Macroinvertebrate diversity decreased and tolerant species increased along the urban gradient. The frequency of threshold discharge increased as impervious cover increased. As the bed mobility increased, macroinvertebrate diversity decreased among the study sites. The grain size movement affected the quality of the macroinvertebrate habitats as a result of changes to the hydrology and geomorphology of the channel from impervious cover runoff. Further studies are needed to understand the relationship between bed mobility and macroinvertebrates to better inform restoration practices.

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APPENDIX A: MULTI-STAGE PASSIVE SAMPLERS SCHEMATIC

Figure A1: Photo of Multi-stage Passive Sampler

Table A1: Multi-stage Passive Sampler Measurements

Sites	Total Height (cm)	Water Depth (cm)	Base to 1st Bottle (cm)	Base to 2nd Bottle (cm)	Base to 3rd Bottle (cm)
MDCT8	122	10	40	70	100
RC1	Lost				
BD2	117	8	40	70	100
TBCCR4	123	10	42	72	102
TBCRL5	128	4	40	70	100
MC7	120	5	40	70	100
EB3	122	7	40	70	100
LHC6	128	14	50	80	110

APPENDIX B: SEASONAL DATA FIGURES

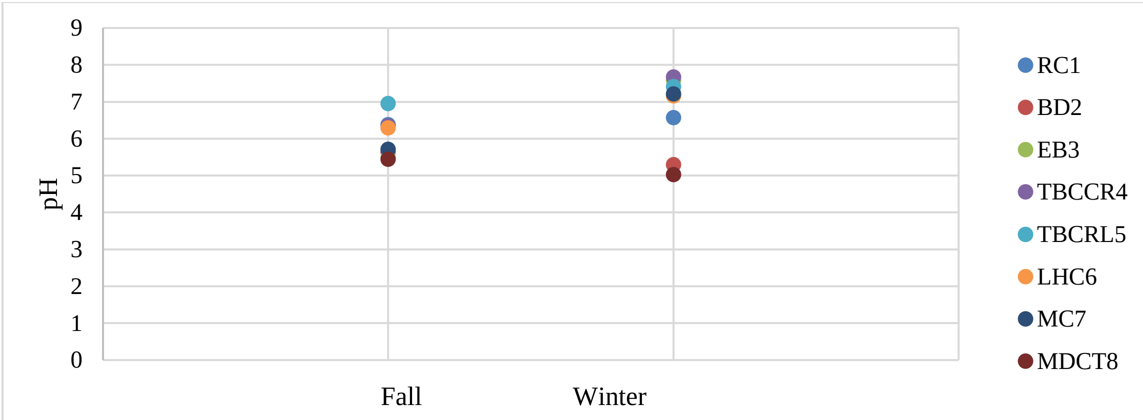

Figure B1: pH values for all sites during the entire study

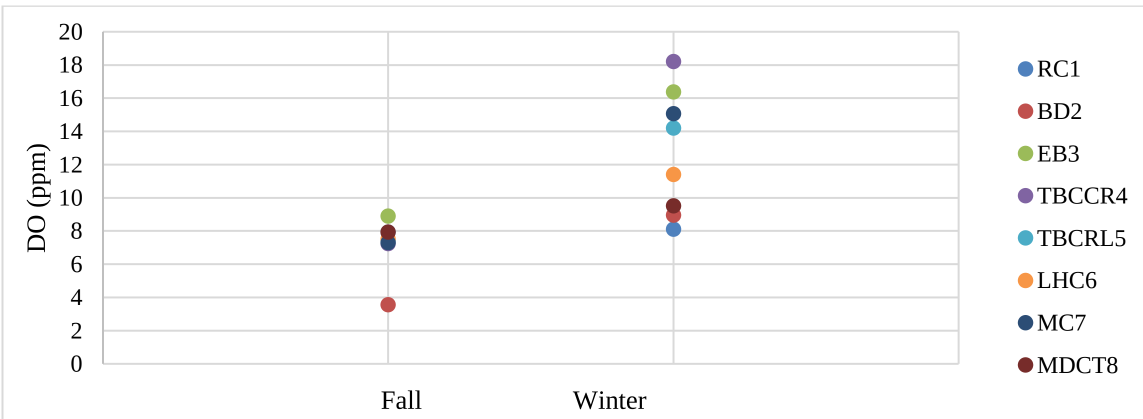

Figure B2: Dissolved Oxygen values for all sites during the entire study

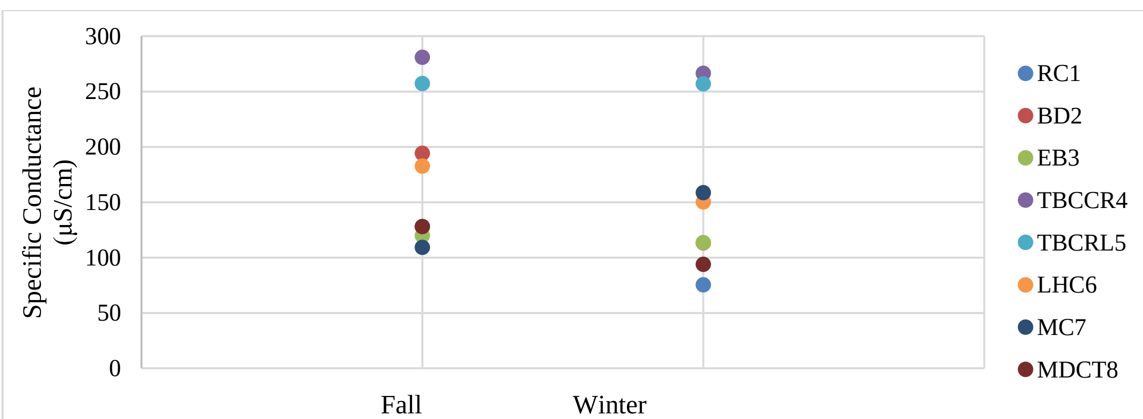

Figure B3: Specific Conductance values for all sites during the entire study

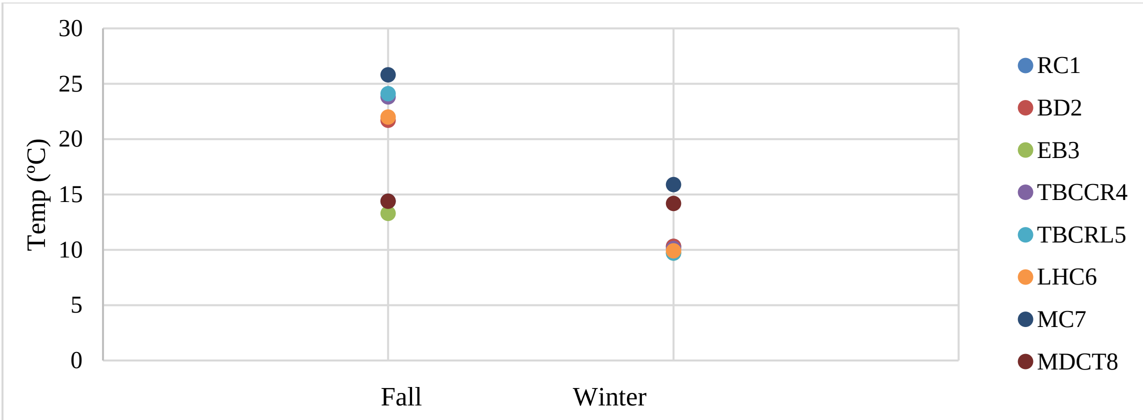

Figure B4: Temperature (ºC) values for all sites during the entire study

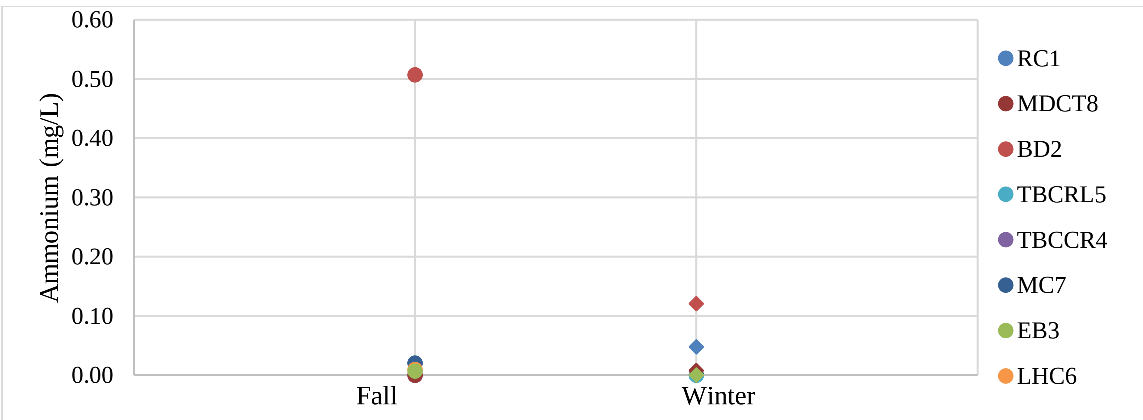

Figure B5: Ammonium concentrations (mg/L) for all sites during the entire study. Dots represent the fall sampling and the diamonds represent the winter sampling.

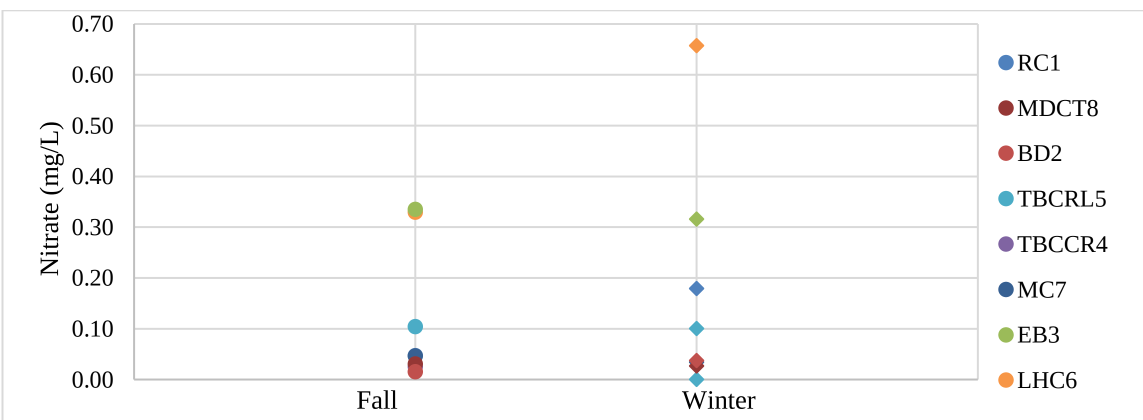

Figure B6: Nitrate concentrations (mg/L) for all sites during the entire study. Dots represent the fall sampling and the diamonds represent the winter sampling.

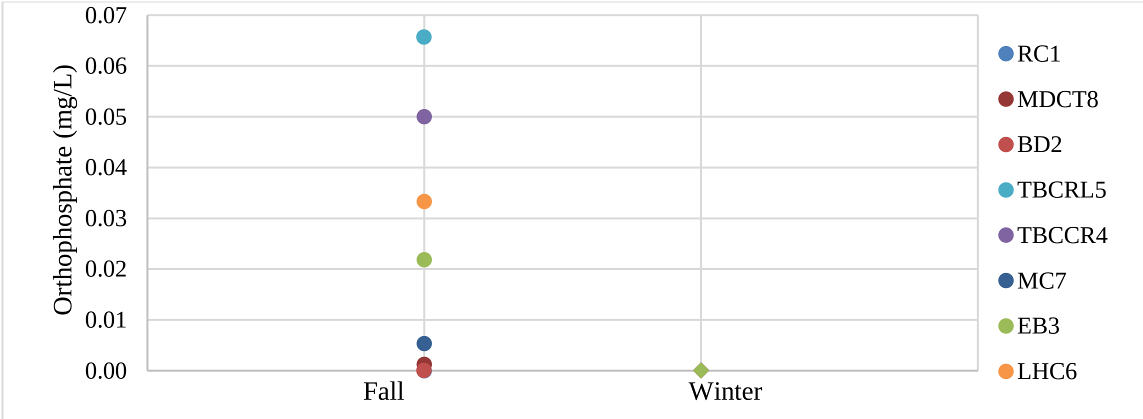

Figure B7: Orthophosphate concentrations (mg/L) for all sites during the entire study. Dots represent the fall sampling and the diamonds represent the winter sampling.

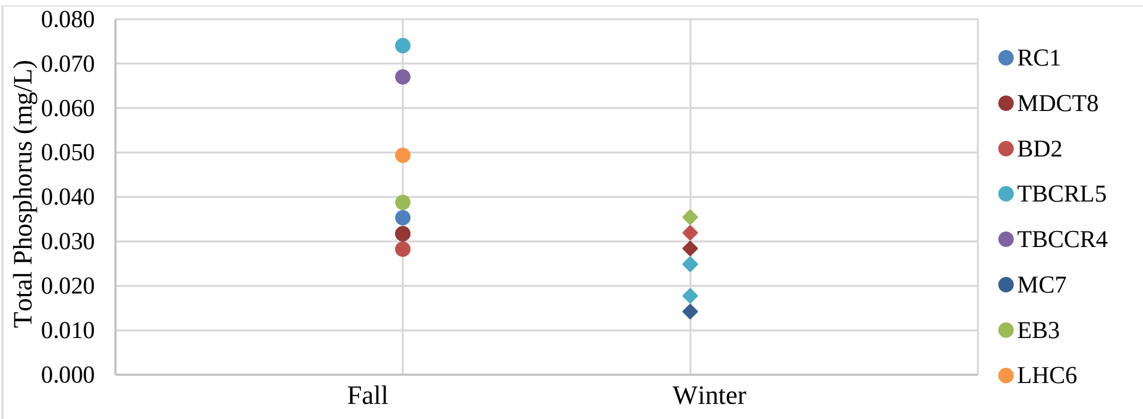

Figure B8: Total Phosphorus concentrations (mg/L) for all sites during the entire study. Dots represent the fall sampling and the diamonds represent the winter sampling.

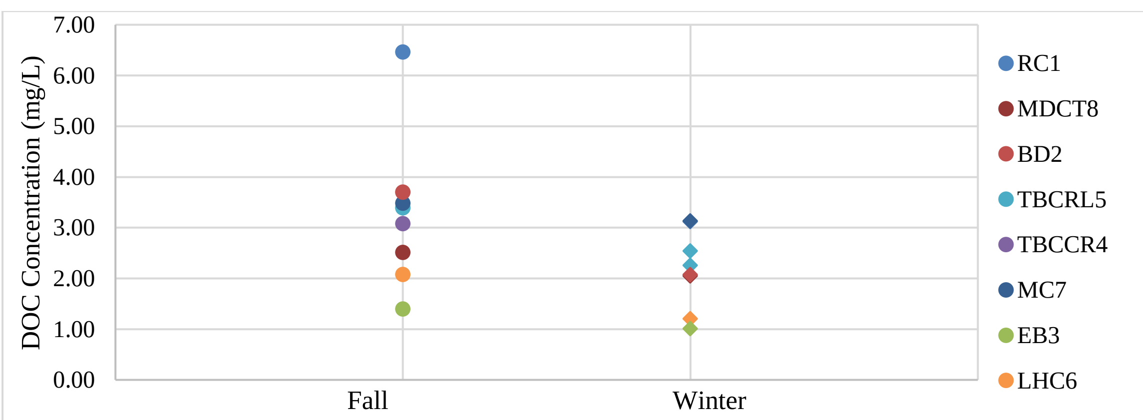

Figure B9: DOC concentrations (mg/L) for all sites during the entire study. Dots represent the fall sampling and the diamonds represent the winter sampling.

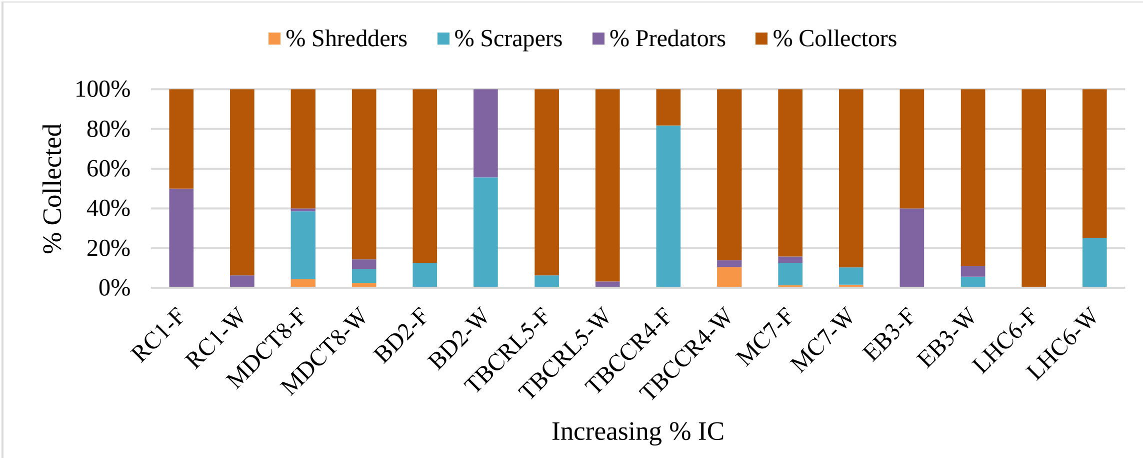

Figure B10: Functional Feeding Groups across percent impervious cover during study

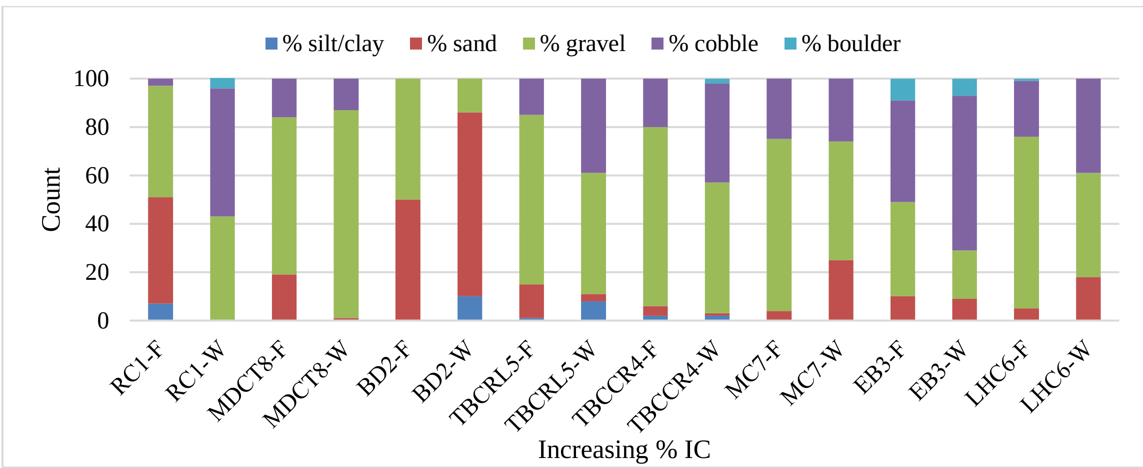

Figure B11: Grain size distribution across percent impervious cover during study

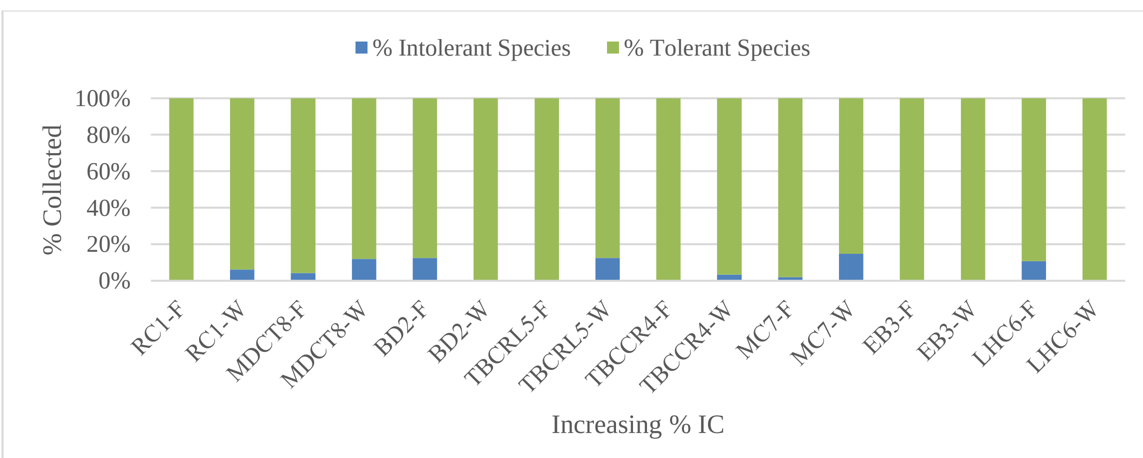

Figure B12: Tolerant vs. Intolerant species across percent impervious cover during study

APPENDIX C: WOLMAN PEBBLE COUNT FIGURES

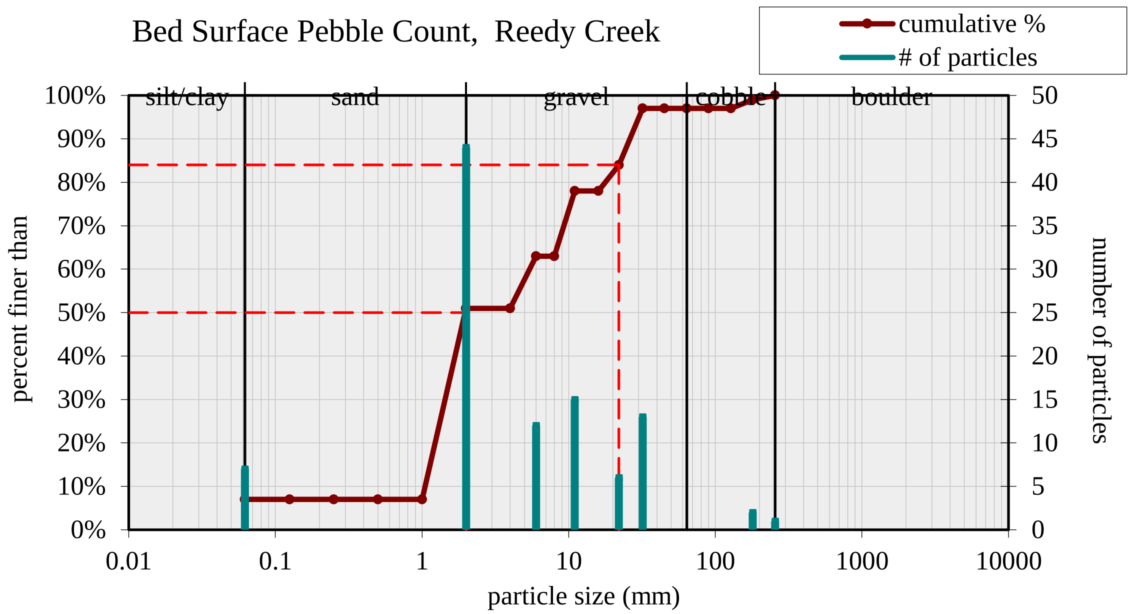

Figure C1: Wolman Pebble Count Results RC1 Fall Sampling

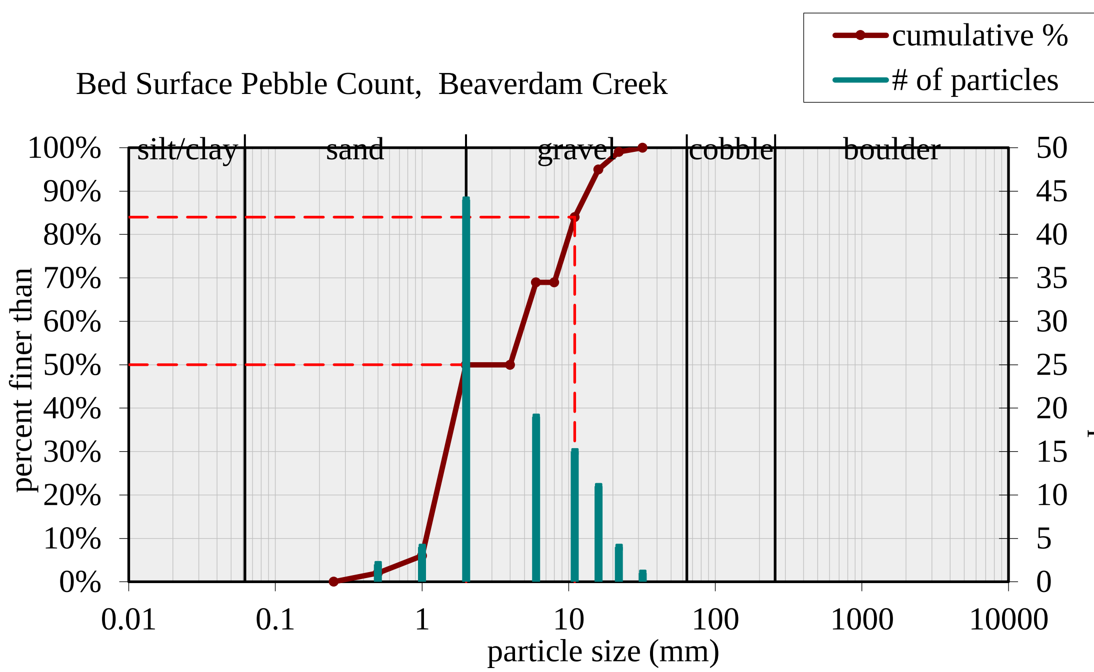

Figure C2: Wolman Pebble Count Results BD2 Fall Sampling

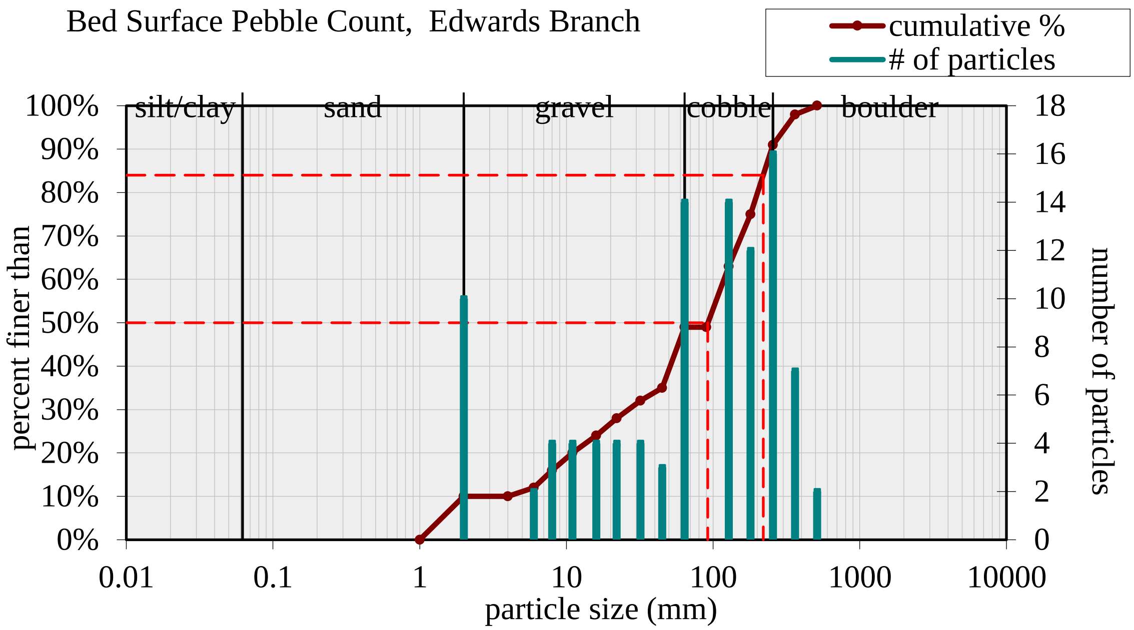

Figure C3: Wolman Pebble Count Results EB3 Fall Sampling

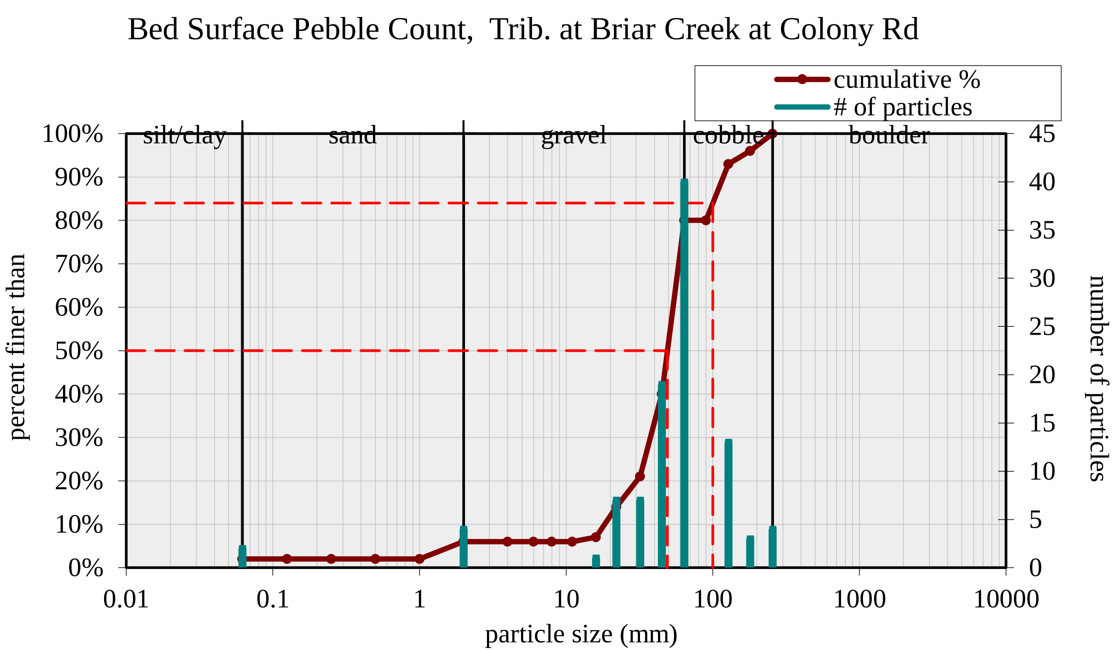

Figure C4: Wolman Pebble Count Results TBCCR4 Fall Sampling

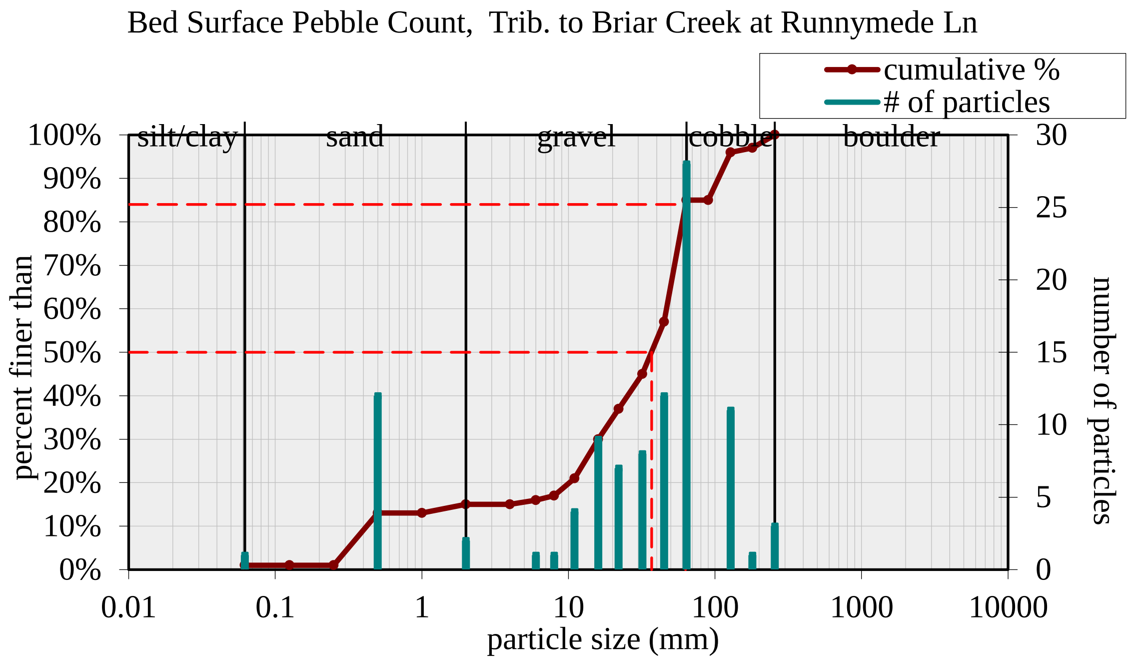

Figure C5: Wolman Pebble Count Results TNCRL5 Fall Sampling

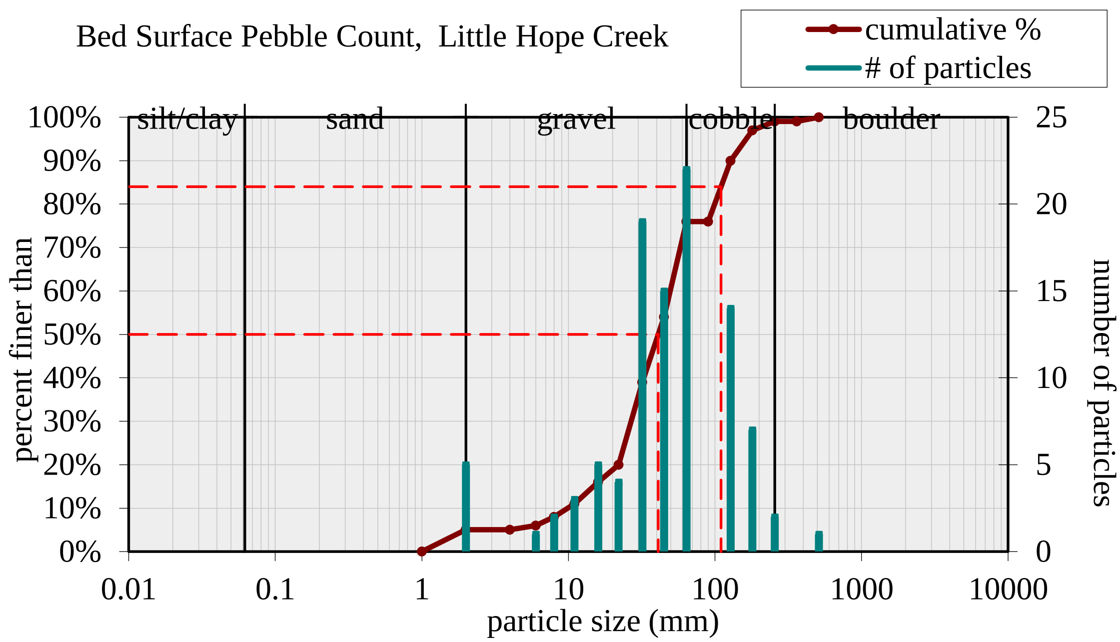

Figure C6: Wolman Pebble Count Results LHC6 Fall Sampling

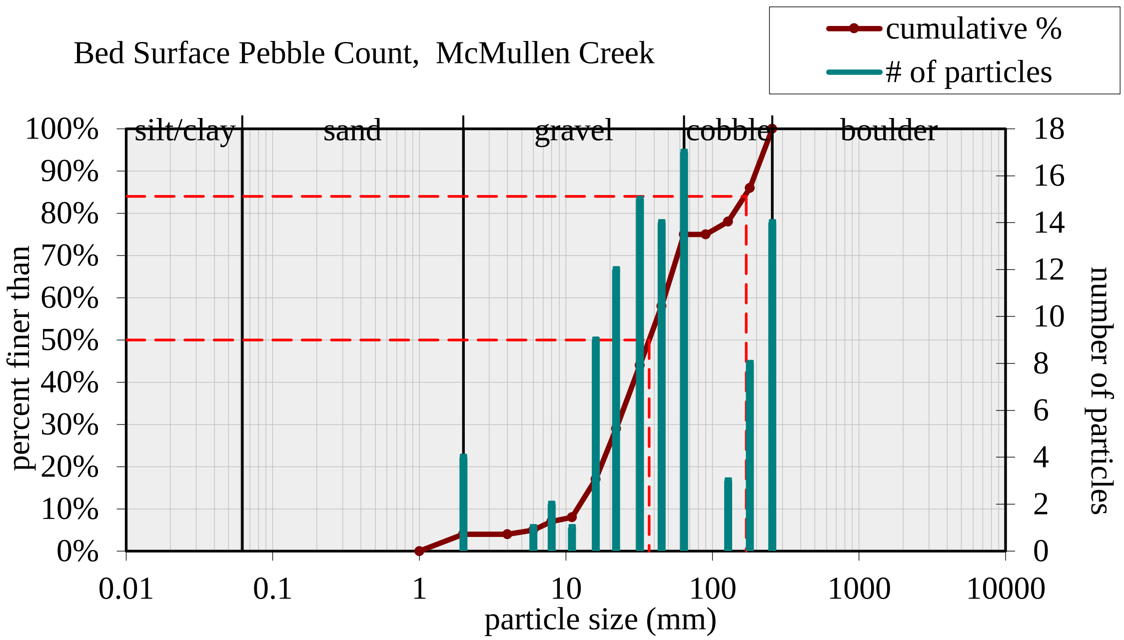

Figure C7: Wolman Pebble Count Results MC7 Fall Sampling

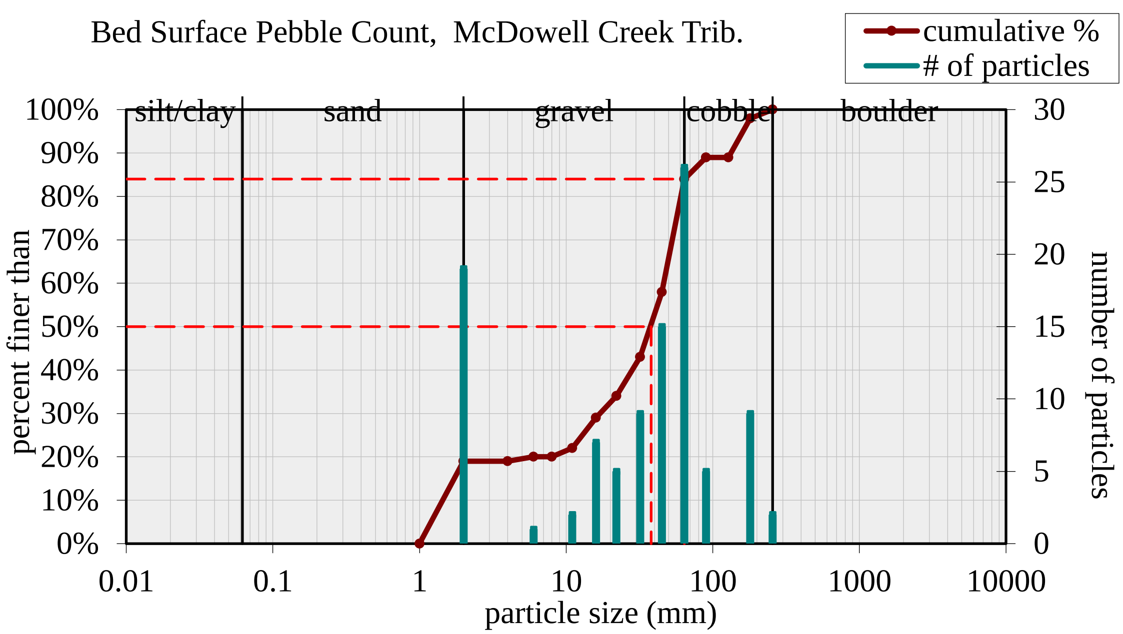

Figure C8: Wolman Pebble Count Results MDCT8 Fall Sampling

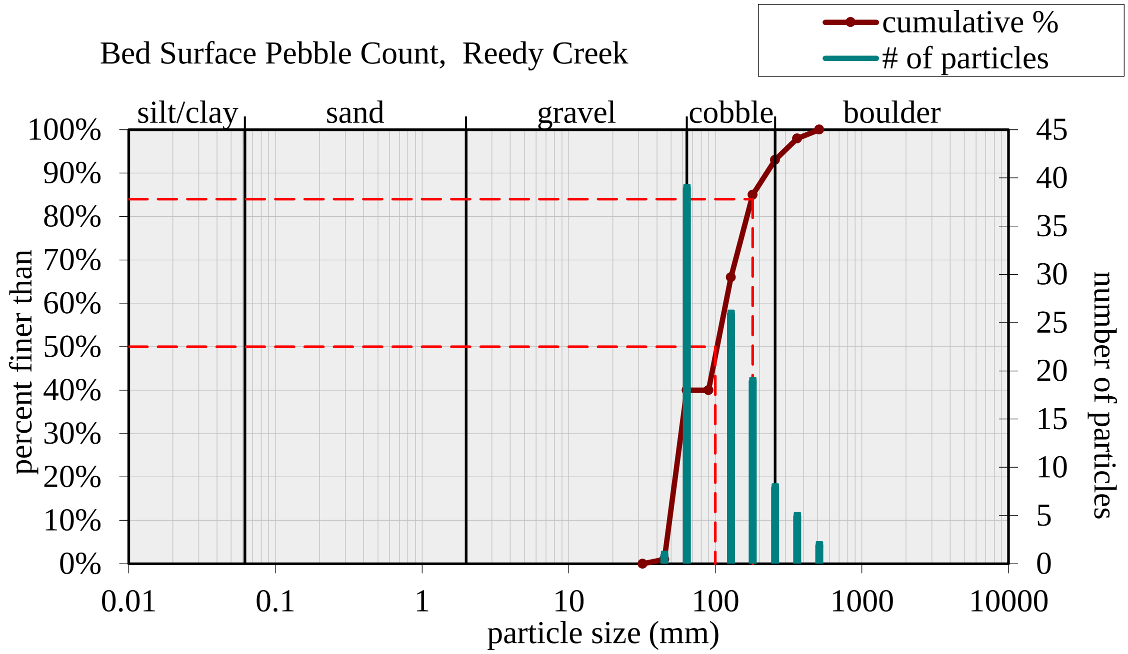

Figure C9: Wolman Pebble Count Results RC1 Winter Sampling

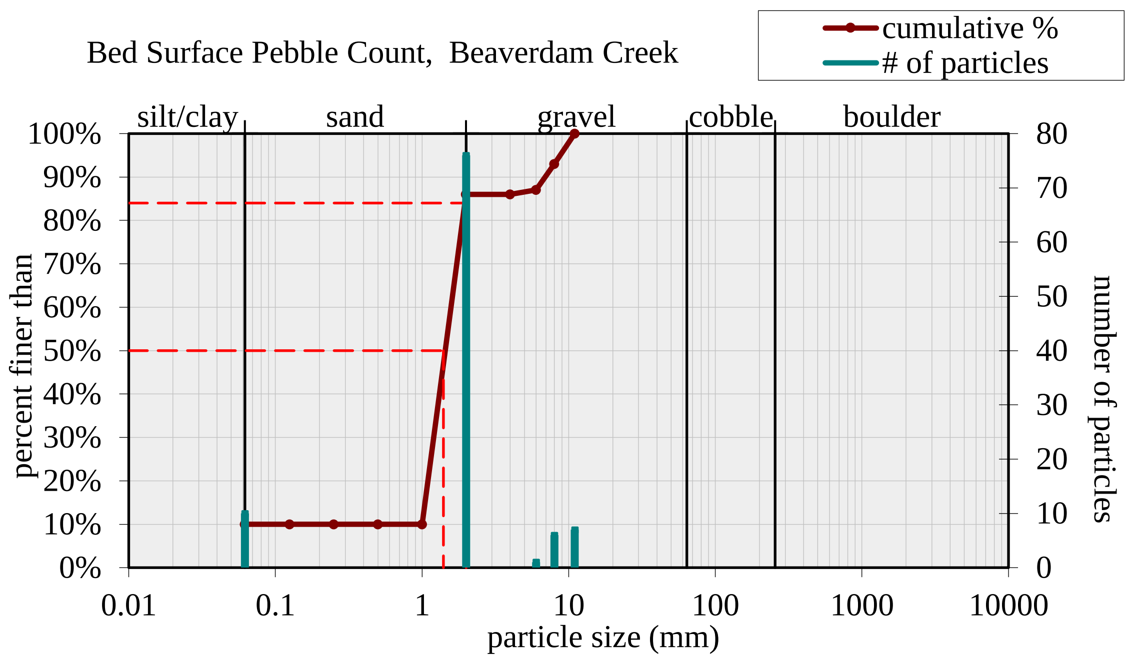

Figure C10: Wolman Pebble Count Results BD2 Winter Sampling

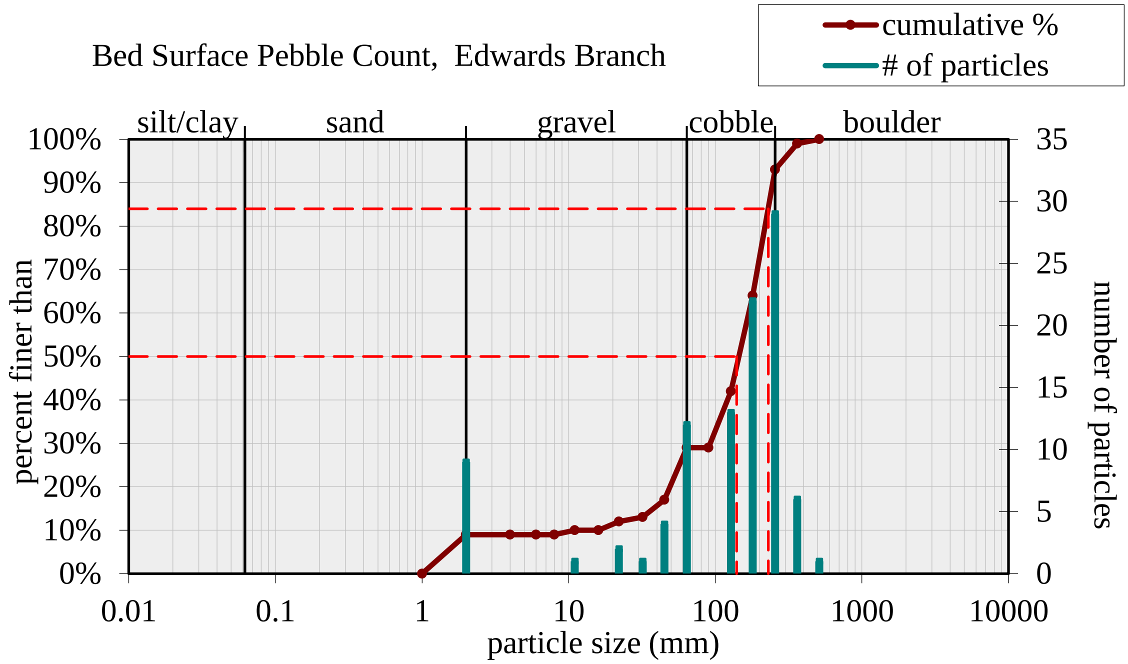

Figure C11: Wolman Pebble Count Results EB3 Winter Sampling

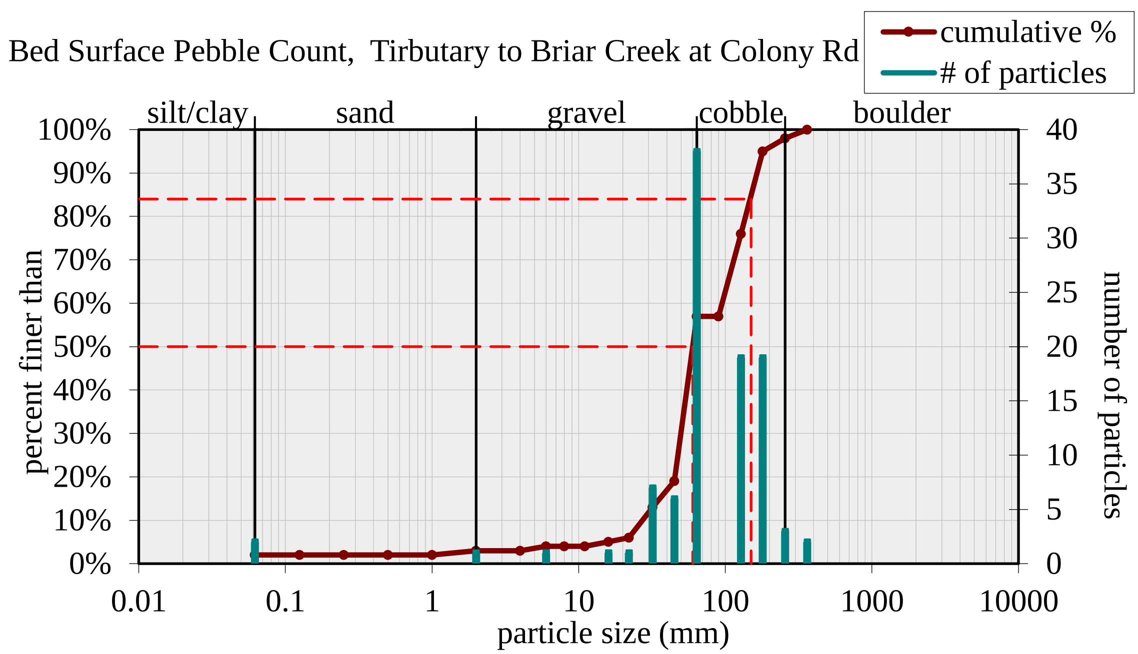

Figure C12: Wolman Pebble Count Results TBCCR4 Winter Sampling

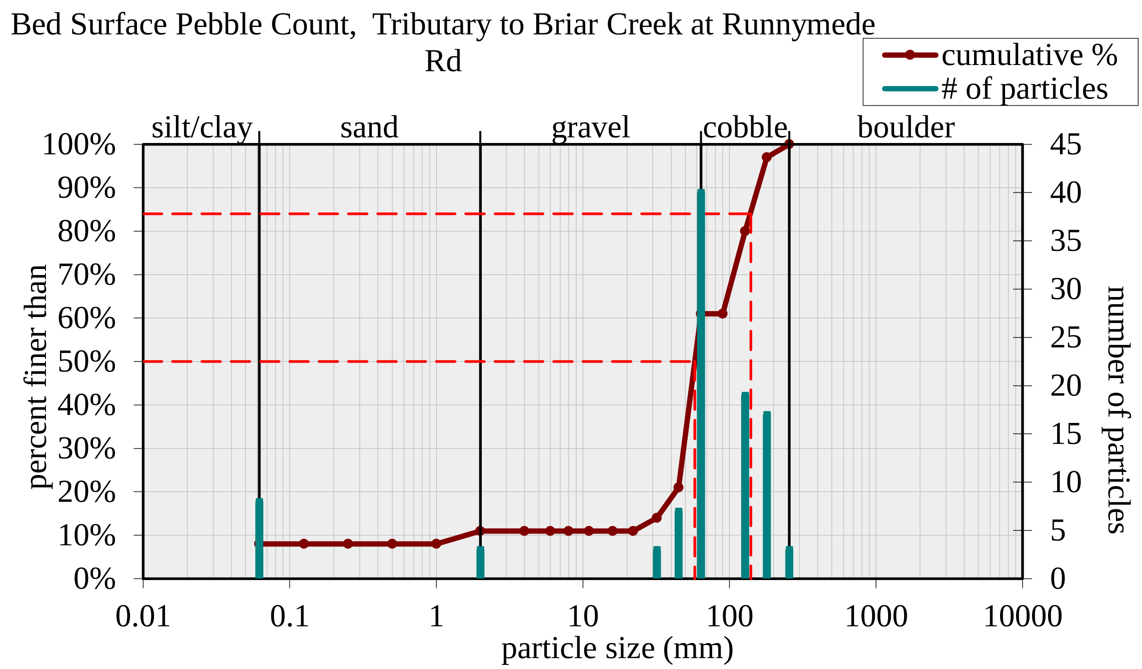

Figure C13: Wolman Pebble Count Results TBCRL5 Winter Sampling

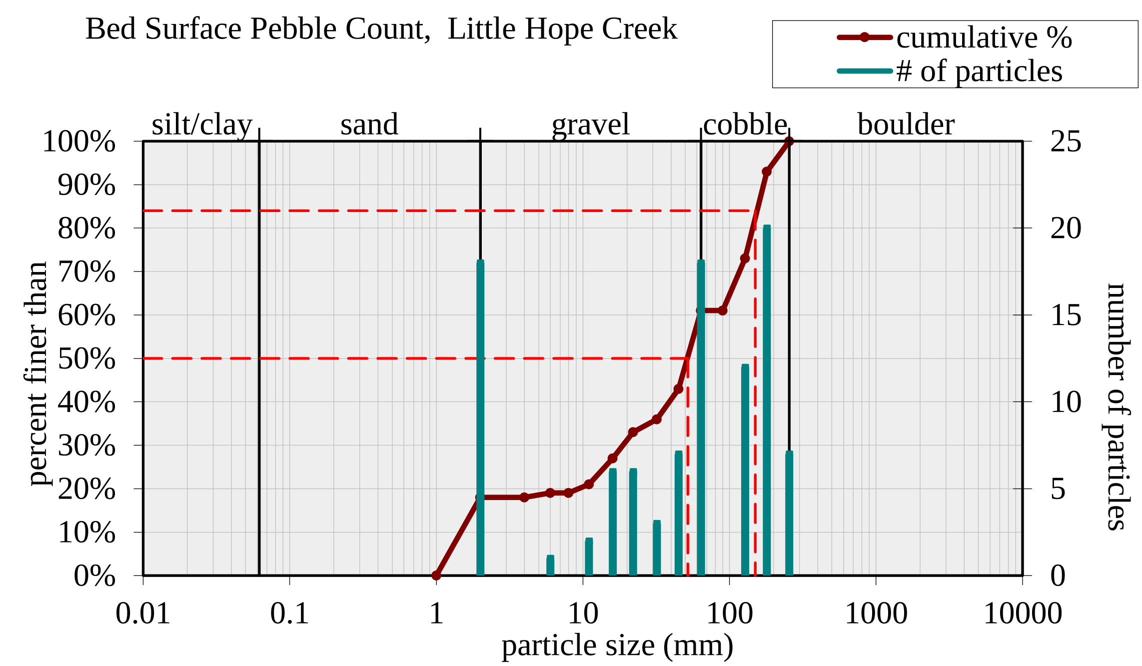

Figure C14: Wolman Pebble Count Results LHC6 Winter Sampling

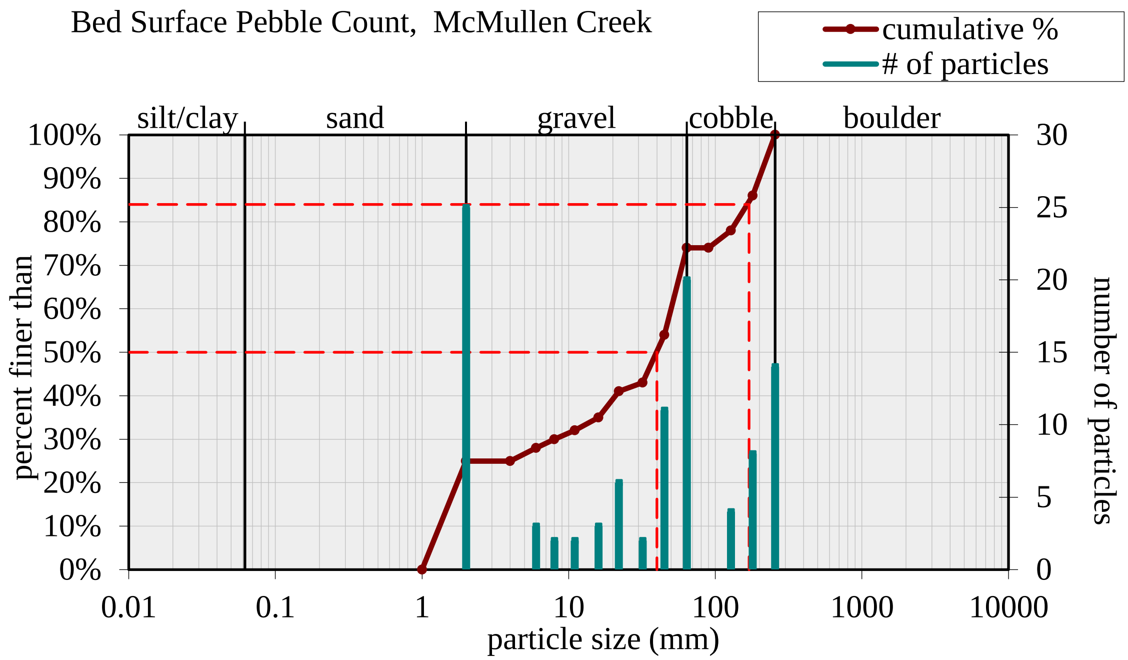

Figure C15: Wolman Pebble Count Results MC7 Winter Sampling

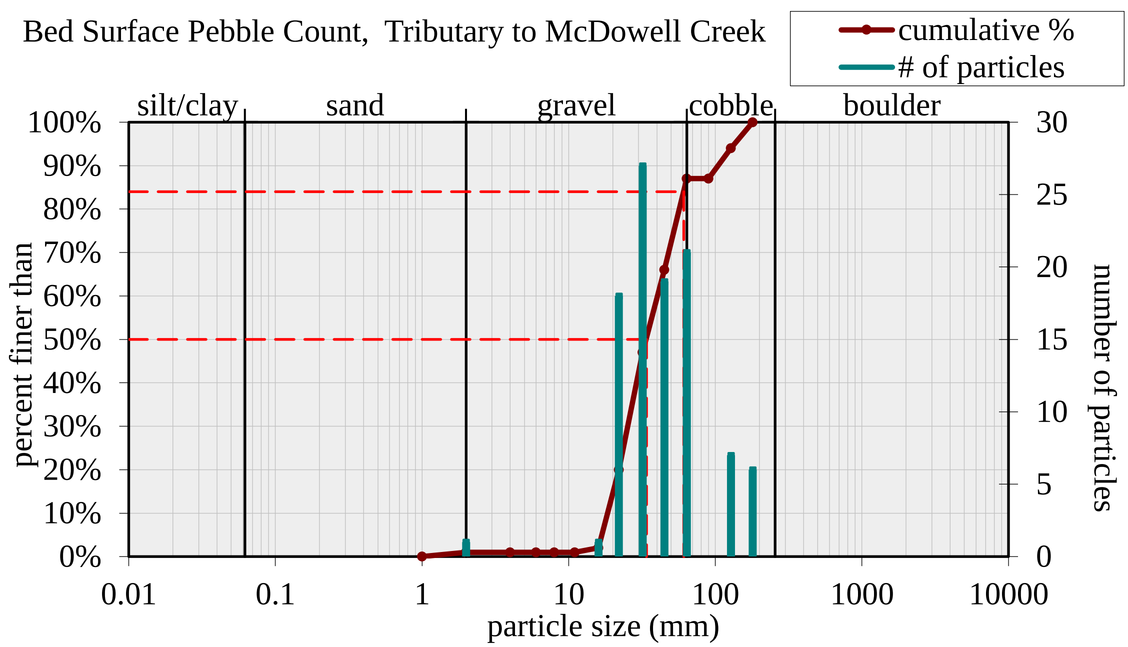

Figure C16: Wolman Pebble Count Results MDCT8 Winter Sampling

APPENDIX D: FLOW DURATION CURVES

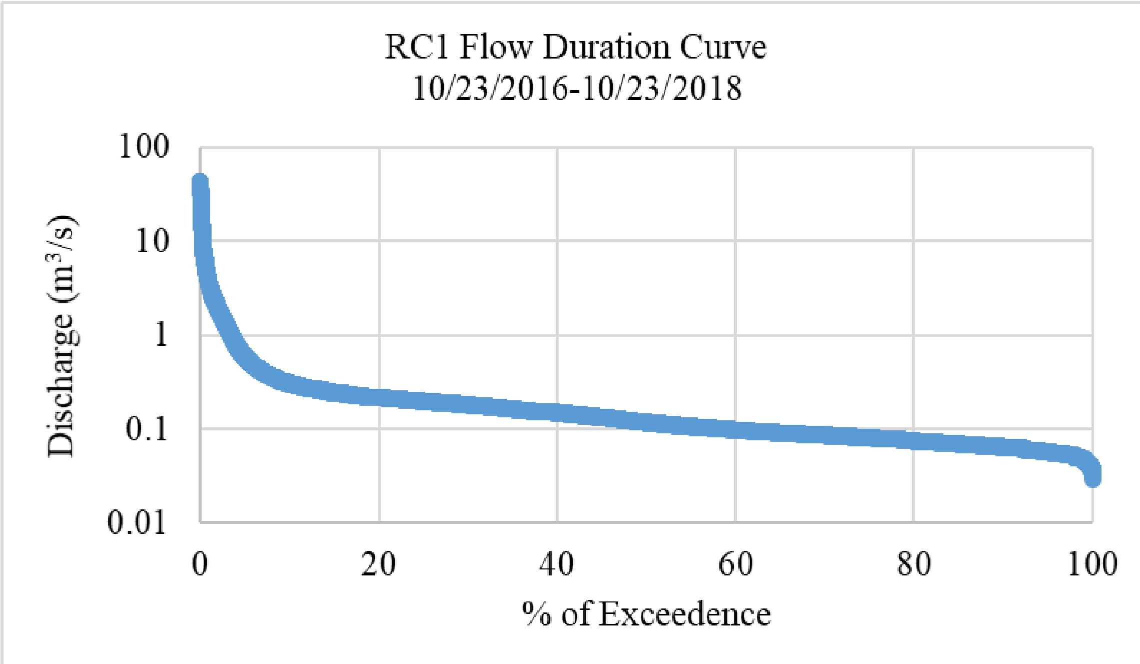

Figure D1: RC1 Flow Duration Curve Two-years Prior to Fall Sampling

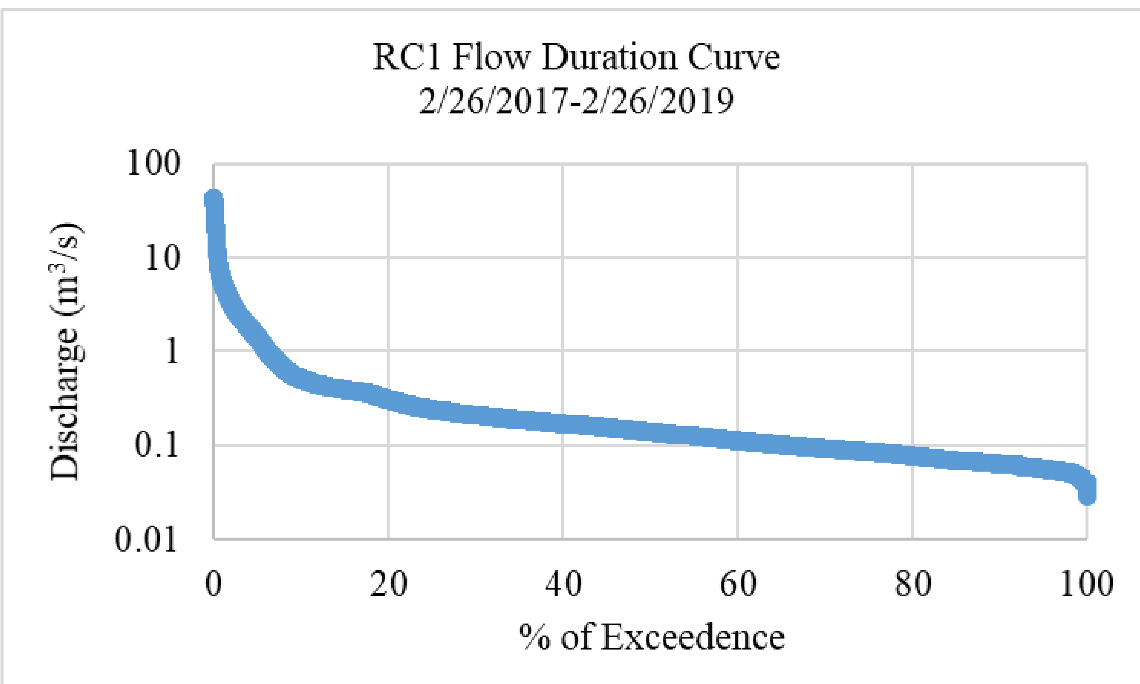

Figure D2: RC1 Flow Duration Curve Two-years Prior to Winter Sampling

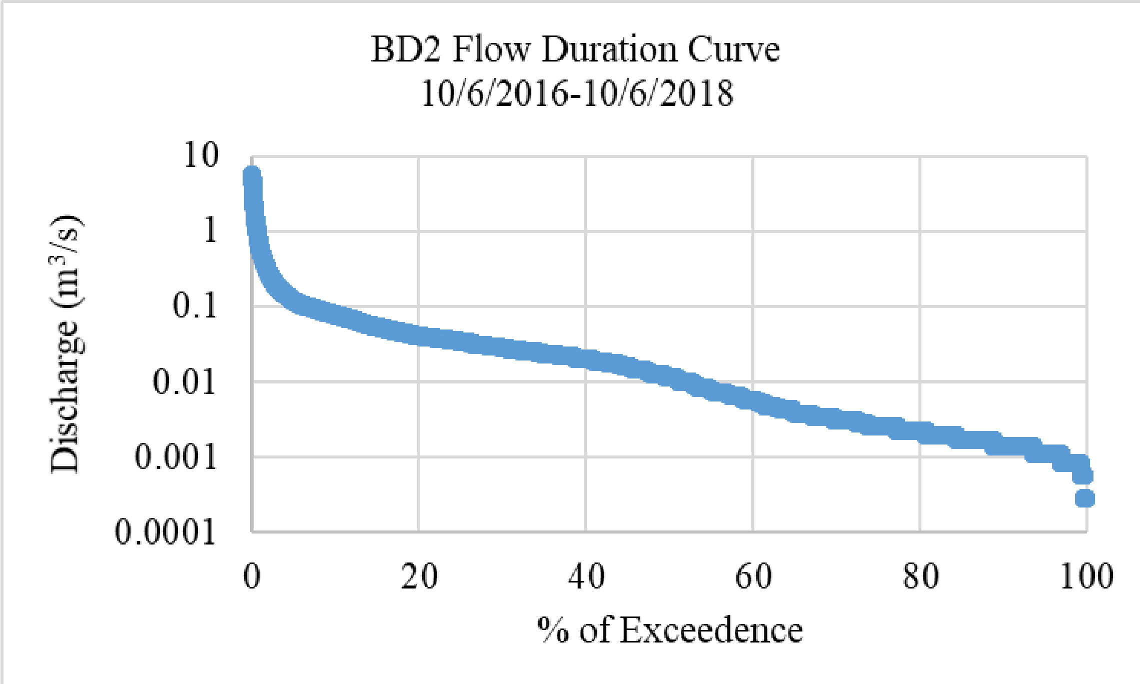

Figure D3: BD2 Flow Duration Curve Two-years Prior to Fall Sampling

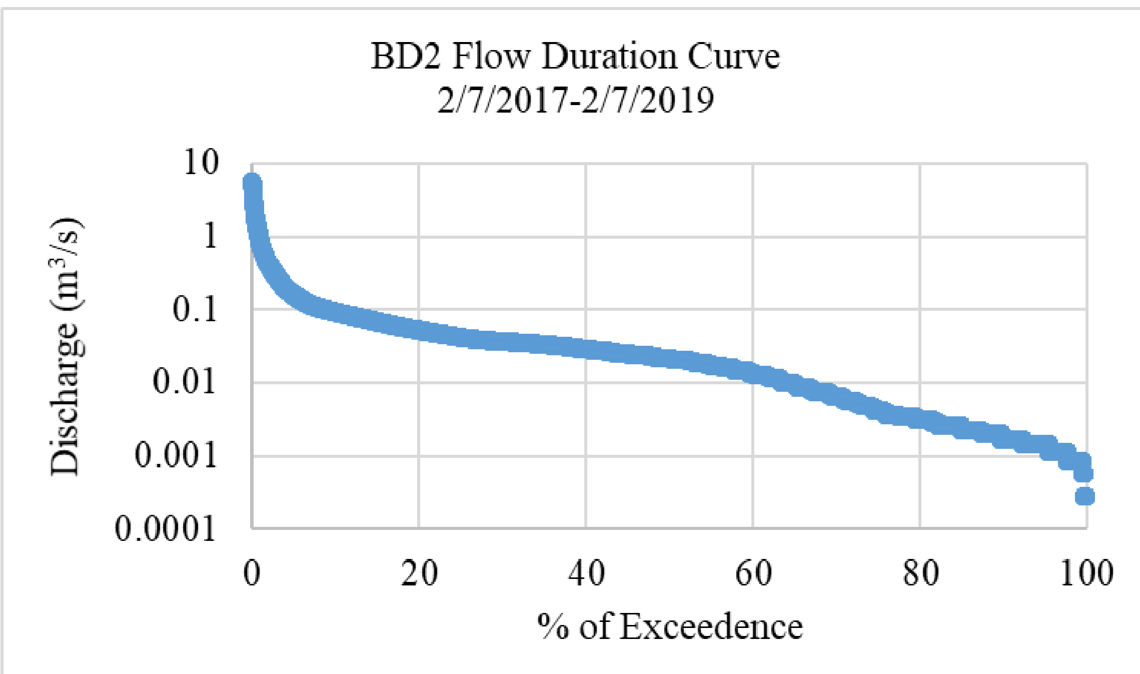

Figure D4: BD2 Flow Duration Curve Two-years Prior to Winter Sampling

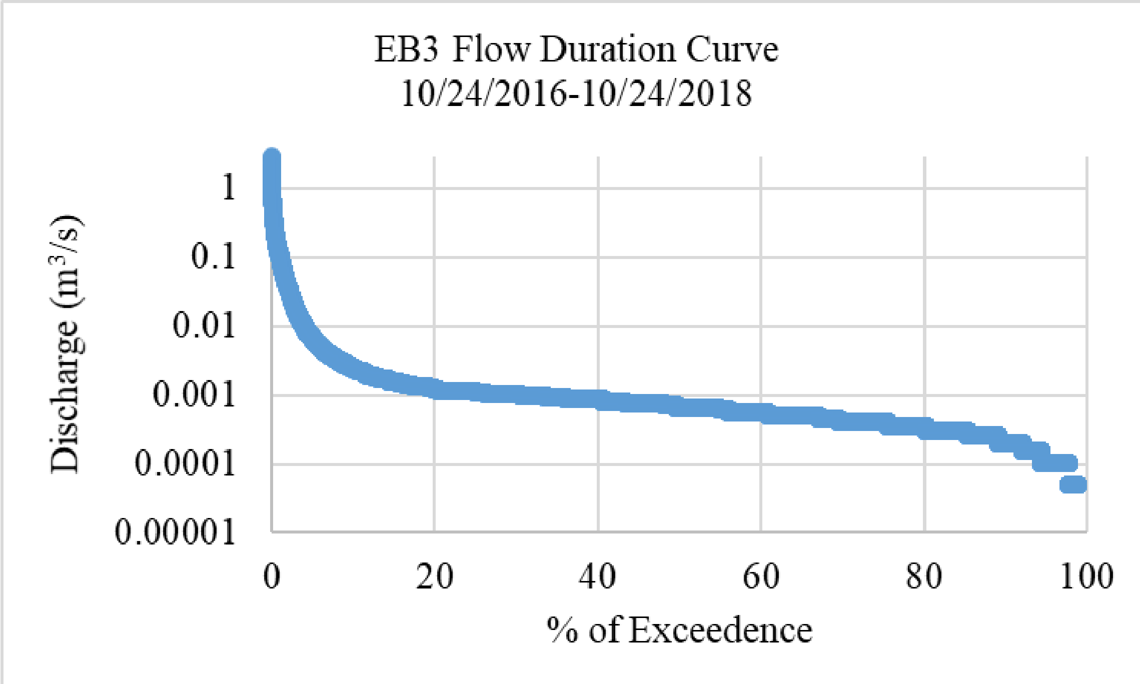

Figure D5: EB3 Flow Duration Curve Two-years Prior to Fall Sampling

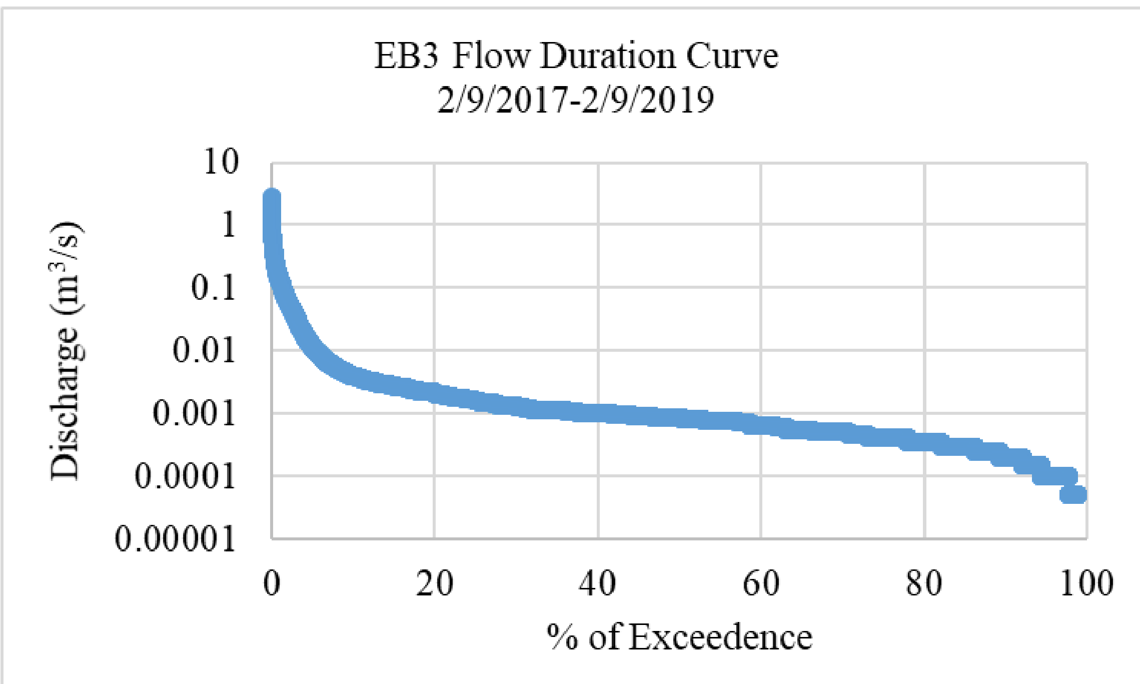

Figure D6: EB3 Flow Duration Curve Two-years Prior to Winter Sampling

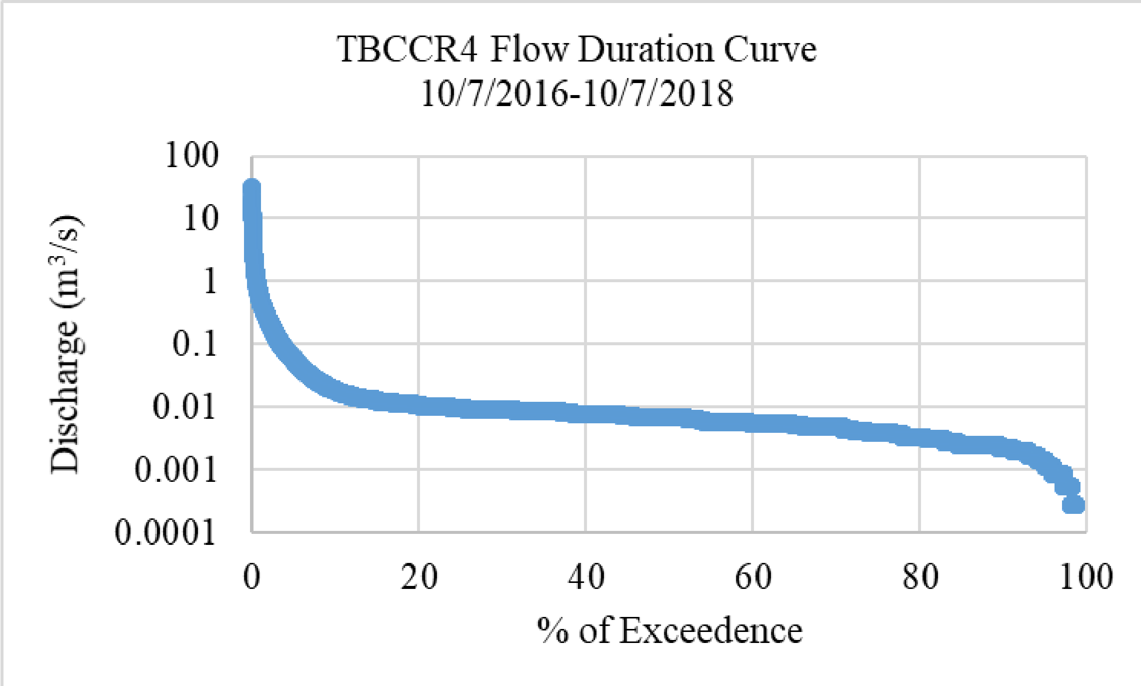

Figure D7: TBCCR4 Flow Duration Curve Two-years Prior to Fall Sampling

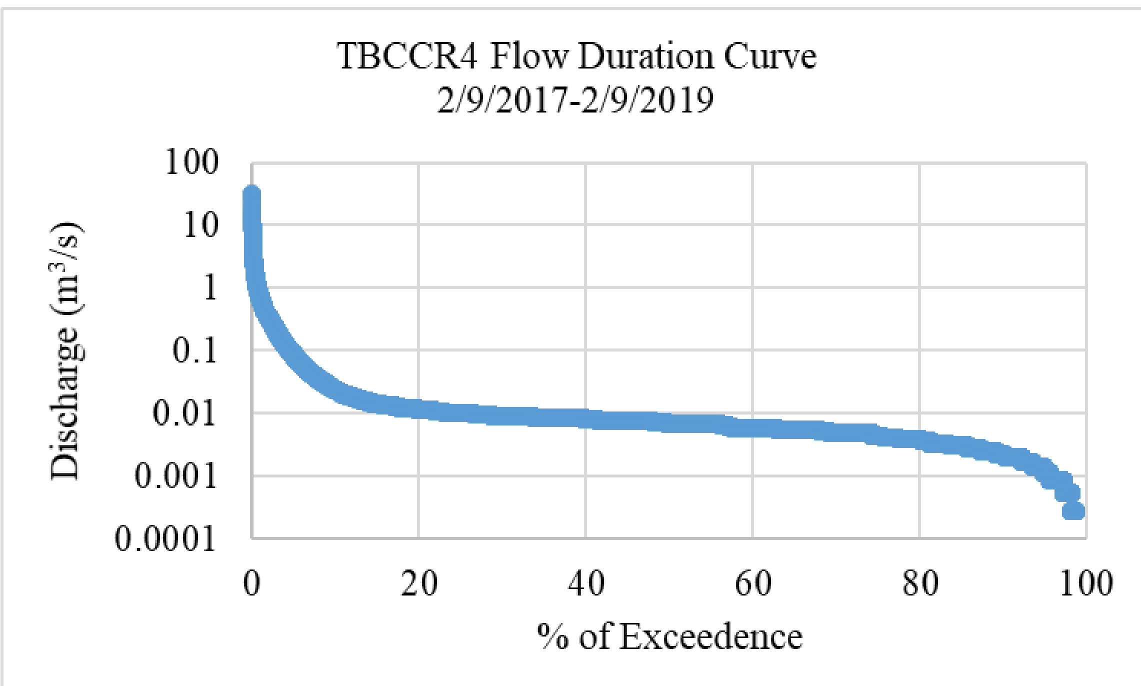

Figure D8: TBCCR4 Flow Duration Curve Two-years Prior to Winter Sampling

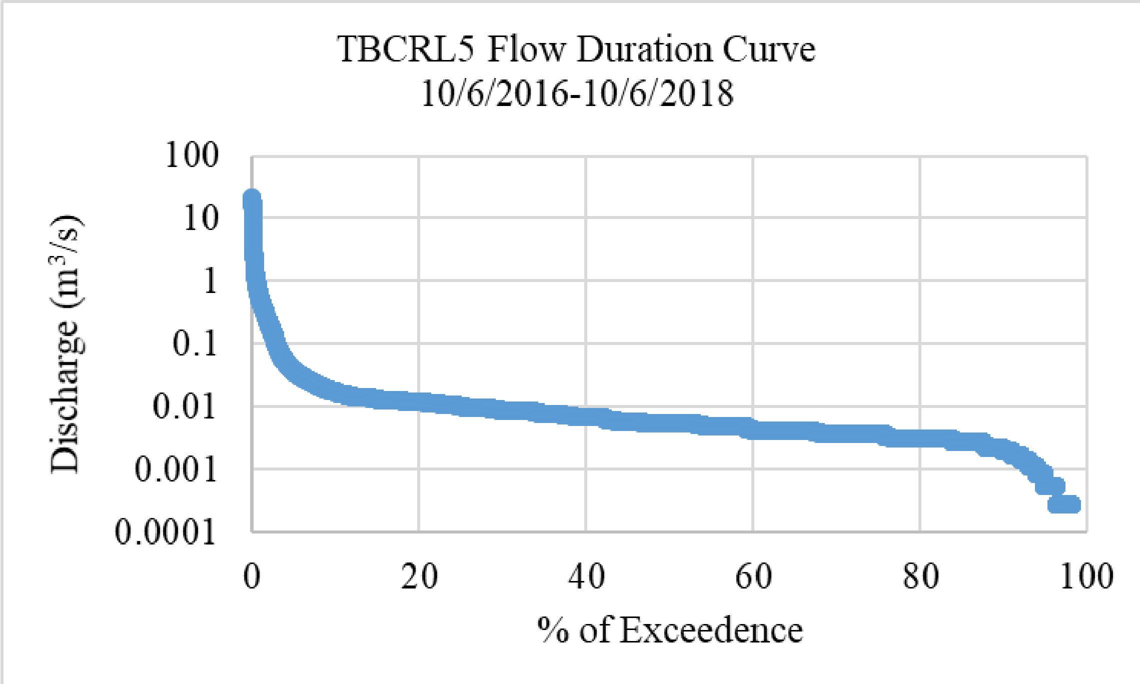

Figure D9: TBCRL5 Flow Duration Curve Two-years Prior to Fall Sampling

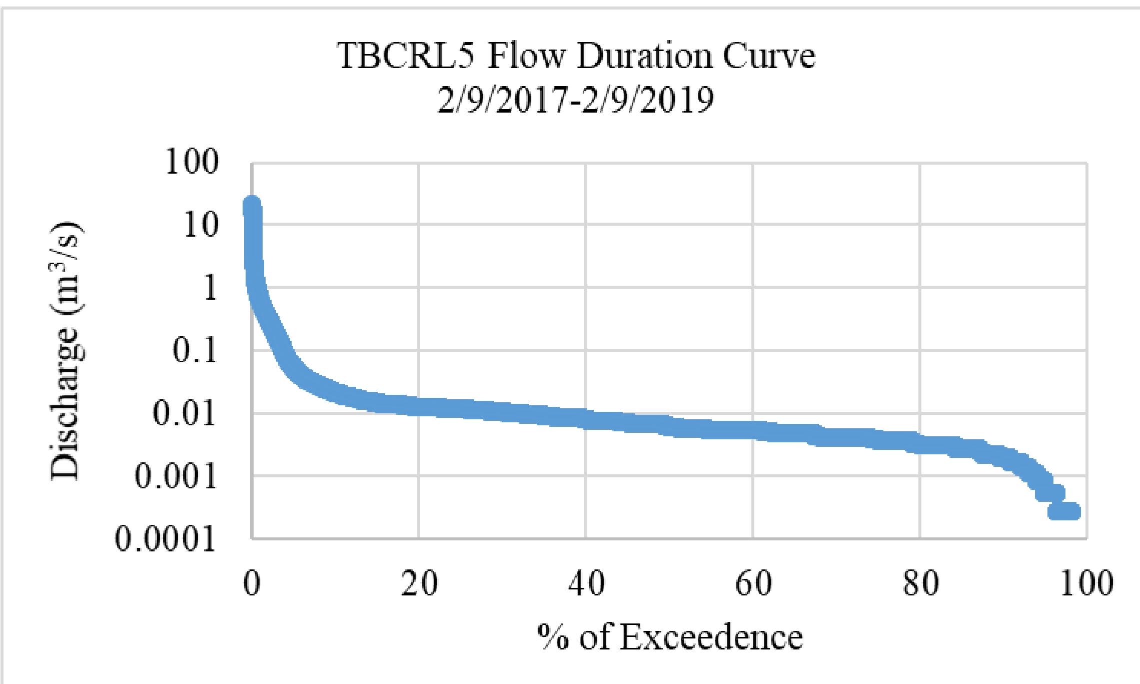

Figure D10: TBCRL5 Flow Duration Curve Two-years Prior to Winter Sampling

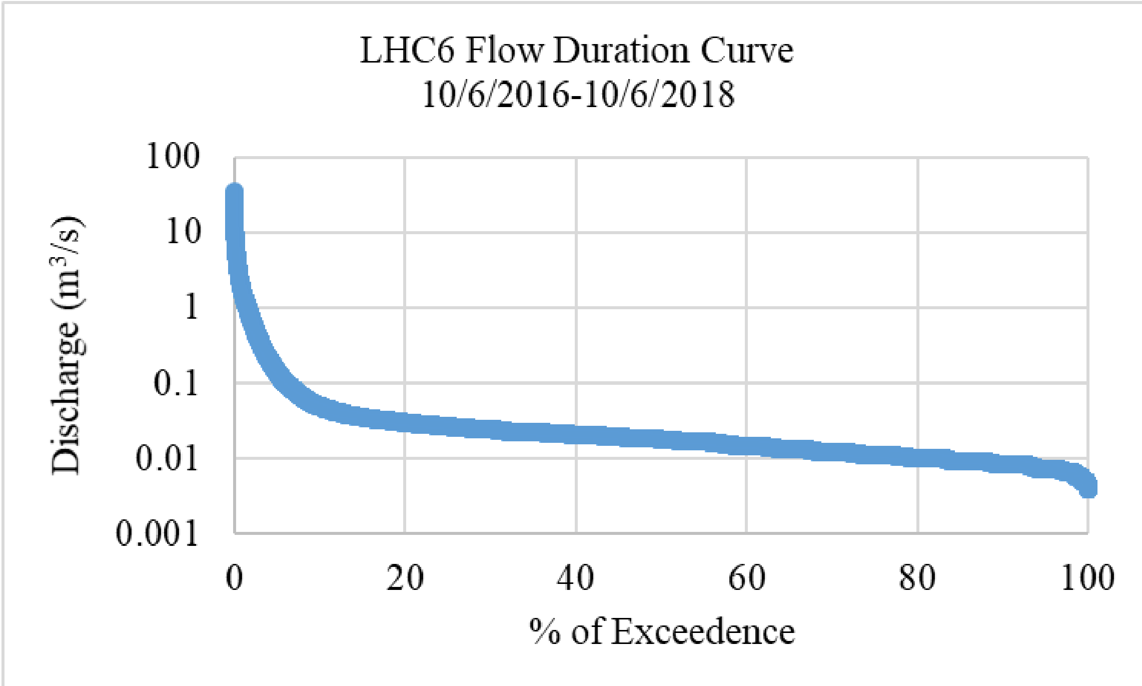

Figure D11: LHC6 Flow Duration Curve Two-years Prior to Fall Sampling

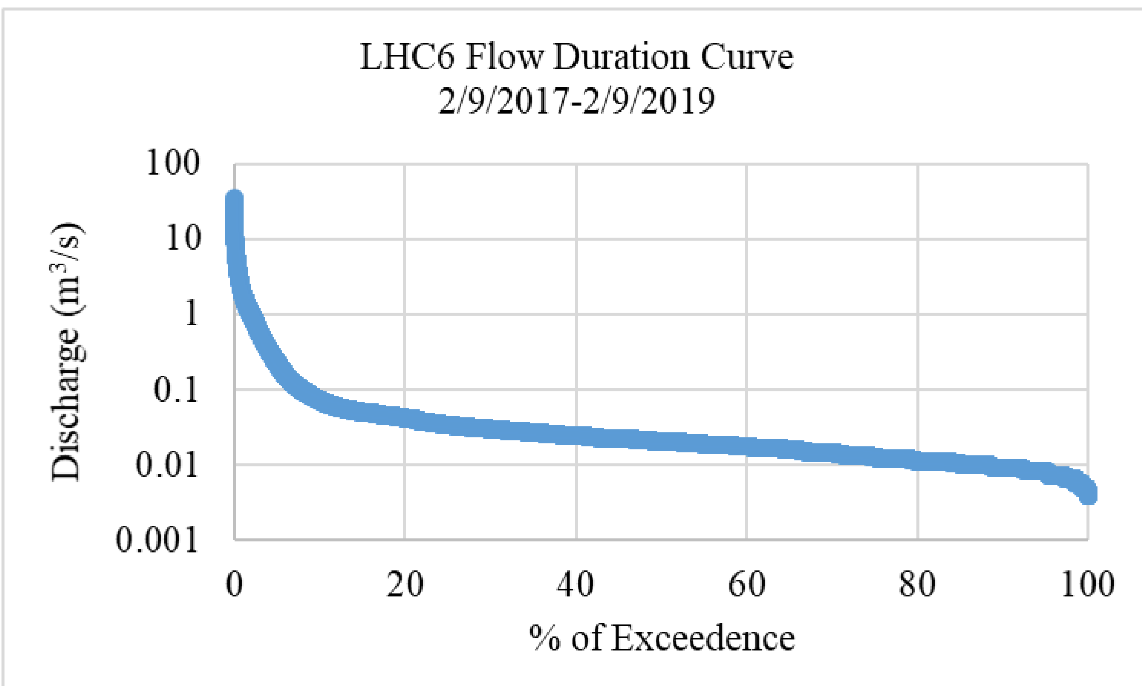

Figure D12: LHC6 Flow Duration Curve Two-years Prior to Winter Sampling

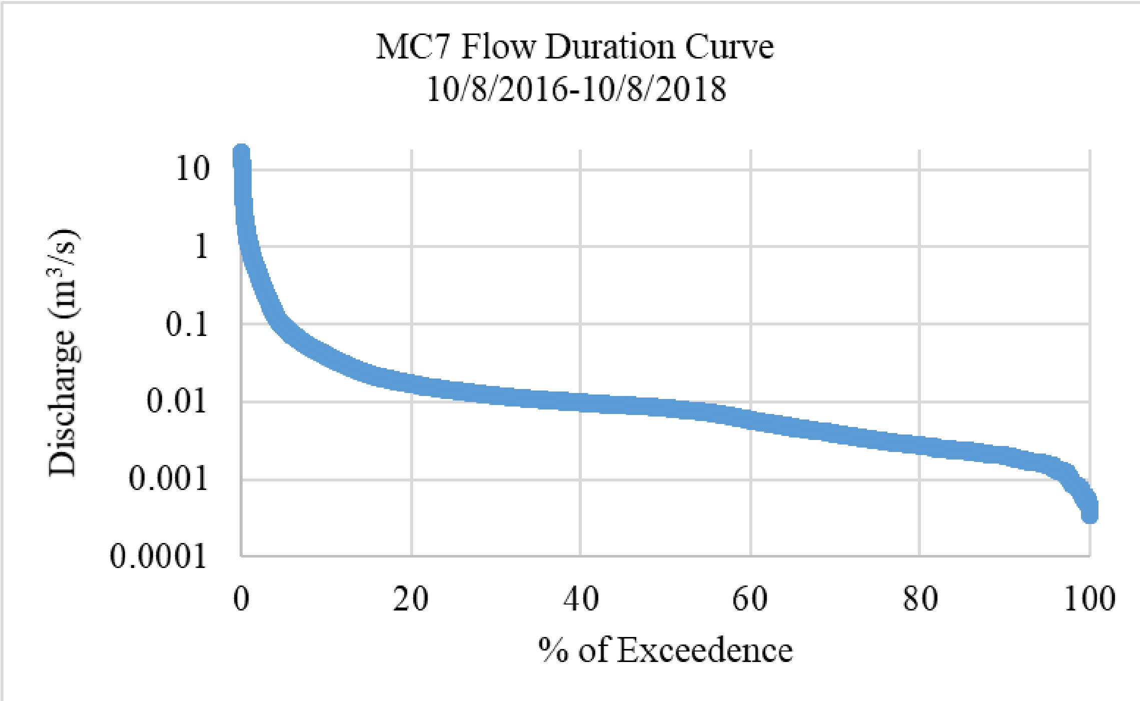

Figure D13: MC7 Flow Duration Curve Two-years Prior to Fall Sampling

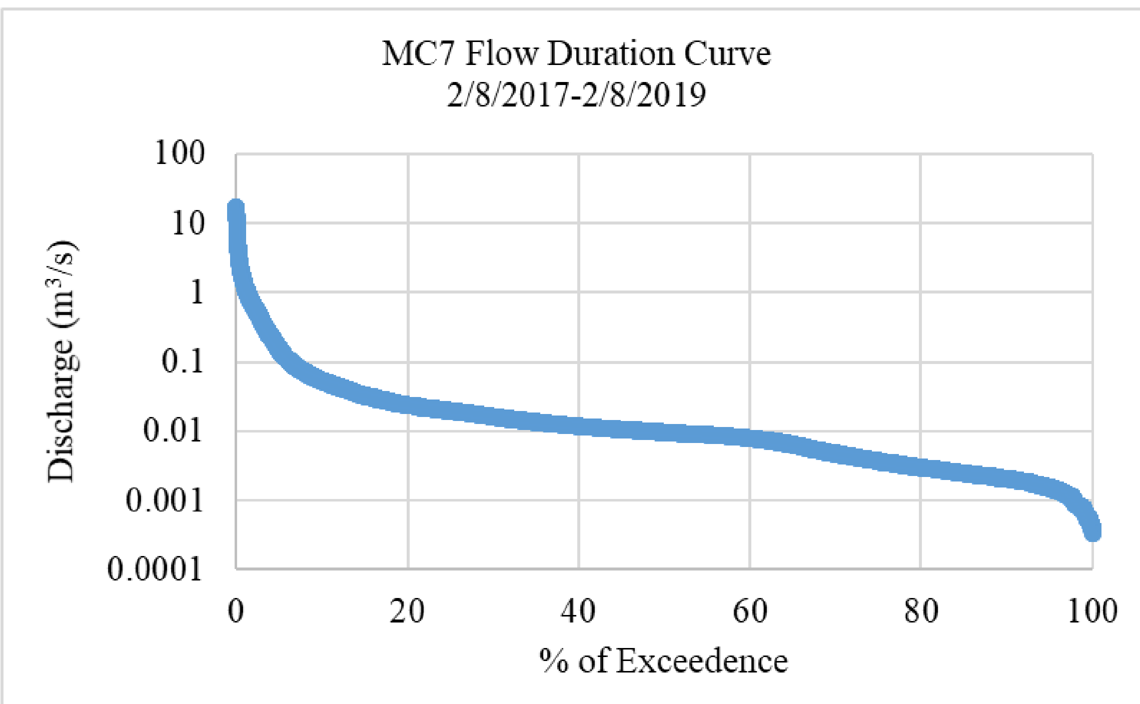

Figure D14: MC7 Flow Duration Curve Two-years Prior to Winter Sampling

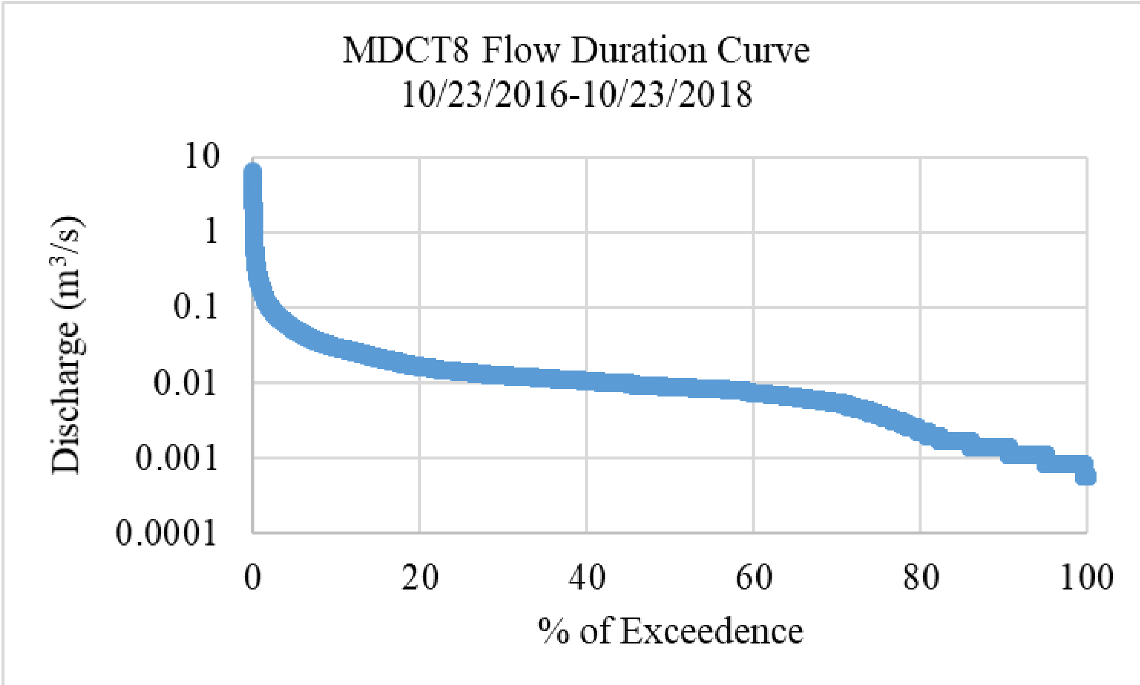

Figure D15: MDCT8 Flow Duration Curve Two-years Prior to Fall Sampling

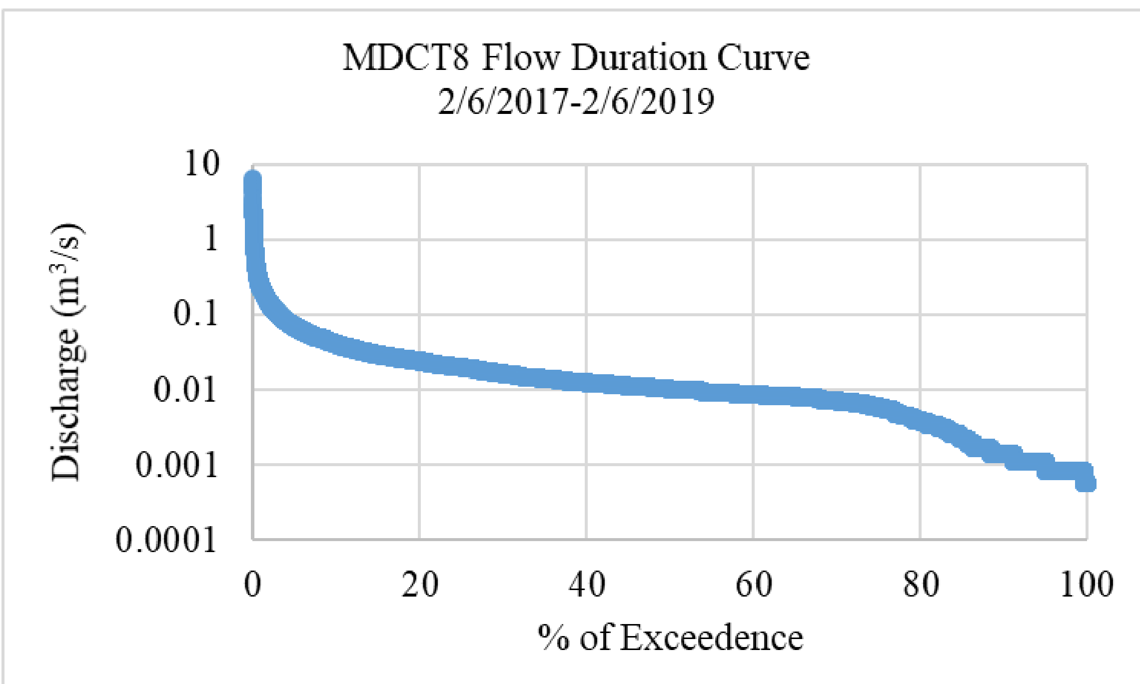

Figure D16: MDCT8 Flow Duration Curve Two-years Prior to Winter Sampling

APPENDIX E: DATA TABLES OF ALL PARAMETERS FOR STUDY LOCATIONS

Table E1: Sampling Dates for all measurements

Sites	Fall 2018	Winter 2019	Stormflow 1	Stormflow 2	Sampler Collection
MDCT8	10/23/2018	2/6/2019	2/16/2019	2/25/2019	2/25/2019
RC1	10/25/2018	2/26/2019	2/16/2019	2/25/2019	N/A
BD2	10/6/2018	2/7/2019	2/16/2019	2/25/2019	N/A
TBCCR4	10/7/2018	2/9/2019	2/16/2019	2/25/2019	N/A
TBCRL5	10/6/2018	2/9/2019	2/16/2019	2/25/2019	2/16/2019
MC7	10/8/2018	2/8/2019	2/16/2019	2/25/2019	N/A
EB3	10/24/2018	2/9/2019	2/16/2019	2/25/2019	2/16/2019
LHC6	10/6/2018	2/9/2019	2/16/2019	2/25/2019	N/A

Table E2: GPS Coordinates of all Mecklenburg County, NC Sites Fall 2018

Sites	Beginning point GPS Coordinates	Endpoint GPS Coordinates
MDCT8	35.40128735, -80.91756511	35.40053893, -80.9175066
RC1	35.25818769, -80.70273894	35.25745964, -80.70191533
BD2	35.16944505, -80.98770414	35.1686396, -80.98794249
TBCCR4	35.16870025, -80.8310032	35.16824073, -80.83205251
TBCRL5	35.16750287, -80.8358439	35.16695859, -80.8363427
MC7	35.1705587, -80.78509258	35.17002111, -80.78609098
EB3	35.20495212, -80.76876404	35.20447186, -80.76752992
LHC6	35.16432303, -80.85316836	35.16365514, -80.85367959

Table E3: GPS Coordinates change for RC1 Winter 2019

Sites	Beginning point GPS Coordinates	Endpoint GPS Coordinates
RC1	35.2573293, -80.70159313	35.25794742, -80.7021077

Table E4: TSS Fall 2018

Site	Filter +Tin (mg)	Dry Weight (mg)	Volume Filtered (L)	TSS (mg/L)
MDCT8	1484.23	1485.82	0.3	5.30
RC1	1477.20	1479.68	0.3	8.27
BD2	1505.75	1510.76	0.3	16.70
TBCCR4	1502.78	1502.89	0.3	0.37
TBCRL5	1490.09	1490.36	0.3	0.90
MC7	1494.69	1495.19	0.3	1.67
EB3	1482.17	1482.50	0.3	1.10
LHC6	1471.99	1472.07	0.3	0.27

Table E5: Background Environmental Parameters Fall 2018

Site	pH	Specific Conductance (µs/cm)	DO (mg/L)	Temperature (˚C)
MDCT8	5.44	127.8	7.93	14.4
RC1	6.38	111.2	10.15	11.2
BD2	5.64	194.0	3.56	21.7
TBCCR4	6.35	280.9	7.23	23.8
TBCRL5	6.95	257.1	7.42	24.1
MC7	5.71	109.0	7.30	25.8
EB3	5.49	119.7	8.90	13.3
LHC6	6.29	182.6	7.51	22.0

Table E6: Densiometer Readings RC1 Fall 2018

Reedy Creek 10/25/18				
(m)	North	East	South	West
0	13	8	8	20
20	50	14	93	90
40	35	10	40	50
60	15	20	82	73
80	20	30	35	30
100	30	36	50	88

Table E7: Densiometer Readings BD2 Fall 2018

Beaverdam Creek above Windy Gap Road 10/6/18				
(m)	North	East	South	West
0	71	75	87	79
20	24	80	91	90
40	76	82	84	83
60	42	92	88	26
80	27	14	44	27
100	59	29	48	34

Table E8: Densiometer Readings EB3 Fall 2018

Edwards Branch 10/24/18				
(m)	North	East	South	West
0	83	80	98	96
20	97	88	84	90
40	80	82	94	90
60	80	92	88	80
80	100	94	100	97
100	73	85	98	84

Table E9: Densiometer Readings TBCCR4 Fall 2018

Tributary to Briar Creek at Colony Road 10/7/18				
(m)	North	East	South	West
0	43	10	83	30
20	82	70	80	82
40	88	98	96	93
60	78	88	100	96
80	91	89	100	92
100	87	84	90	91

Table E10: Densiometer Readings LHC6 Fall 2018

Little Hope Creek 10/6/18				
(m)	North	East	South	West
0	64	90	96	99
20	86	86	87	82
40	91	87	38	27
60	40	26	46	87
80	86	87	97	88
100	82	93	88	89

Table E11: Densiometer Readings MC7 Fall 2018

McMullen Creek 10/8/18				
(m)	North	East	South	West
0	4	0	13	0
20	0	0	20	12
40	0	3	24	0
60	9	4	57	56
80	69	75	4	3
100	3	43	49	16

Table E12: Densiometer Readings MDCT8 Fall 2018

McDowell Creek Tributary 10/23/18				
(m)	North	East	South	West
0	50	55	40	90
20	82	47	64	91
40	98	76	100	98
60	49	59	96	88
80	62	84	98	95
100	90	88	88	84

Table E13: Densiometer Readings TBCRL5 Fall 2018

Tributary to Briar Creek at Runnymede Lane 10/6/18				
(m)	North	East	South	West
0	85	88	73	89
20	85	86	73	78
40	91	84	88	64
60	96	94	94	100
80	78	88	89	73
100	96	85	92	92

Table E14: TSS Winter 2019

Site	Filter +Tin (mg)	Dry Weight (mg)	Volume Filtered (L)	TSS (mg/L)
MDCT8	1484.01	1486.64	0.3	8.77
RC1	1489.32	1493.30	0.3	13.27
BD2	1500.74	1502.27	0.3	5.09
TBCCR4	1488.91	1489.18	0.3	0.90
TBCRL5	1493.92	1494.06	0.3	0.47
MC7	1476.18	1476.83	0.3	2.17
EB3	1477.43	1478.14	0.3	2.37
LHC6	1471.67	1471.73	0.3	0.20

Table E15: Background Environmental Parameters Winter 2019

Site	pH	Specific Conductance (µs/cm)	DO (mg/L)	Temperature (˚C)
MDCT8	5.03	93.8	9.51	14.2
RC1	6.57	75.3	8.11	10.3
BD2	5.30	113.1	8.95	16.7
TBCCR4	7.67	266.5	18.20	10.1
TBCRL5	7.41	256.8	14.2	9.7
MC7	7.21	158.5	15.06	15.9
EB3	7.59	113.4	16.38	11.8
LHC6	7.16	150.3	11.40	9.9

Table E16: Densiometer Readings MC7 Winter 2019

McMullen Creek 2/8/19				
(m)	North	East	South	West
0	0	0	11	0
20	8	3	27	0
40	15	0	20	4
60	16	14	32	8
80	14	26	20	0
100	0	30	47	15

Table E17: Densiometer Readings RC1 Winter 2019

Reedy Creek 2/26/19				
(m)	North	East	South	West
0	26	0	0	0
20	0	12	0	10
40	12	16	8	0
60	20	30	8	6
80	21	30	16	6
100	8	28	2	6

Table E18: Densiometer Readings BD2 Winter 2019

Beaverdam Creek above Windy Gap Road 2/7/19				
(m)	North	East	South	West
0	31	40	37	30
20	10	20	30	27
40	29	30	29	40
60	20	30	26	28
80	25	25	27	23
100	37	16	30	14

Table E19: Densiometer Readings TBCRL5 Winter 2019

Tributary to Briar Creek at Runnymede Lane 2/9/19				
(m)	North	East	South	West
0	28	16	13	20
20	40	26	27	27
40	60	29	20	60
60	34	27	20	24
80	20	27	16	26
100	30	24	27	22

Table E20: Densiometer Readings MDCT8 Winter 2019

McDowell Creek Tributary 2/6/19				
(m)	North	East	South	West
0	10	12	20	20
20	45	32	26	70
40	30	20	20	30
60	48	32	24	30
80	36	10	40	28
100	30	20	10	28

Table E21: Densiometer Readings LHC6 Winter 2019

Little Hope Creek 2/9/19				
(m)	North	East	South	West
0	33	70	76	30
20	24	32	20	22
40	20	30	62	34
60	30	24	22	25
80	32	31	30	32
100	29	25	36	24

Table E22: Densiometer Readings TBCCR4 Winter 2019

Tributary to Briar Creek at Colony Road 2/9/19				
(m)	North	East	South	West
0	85	25	24	25
20	18	19	22	24
40	29	27	16	23
60	24	20	31	31
80	20	16	70	32
100	24	27	28	15

Table E23: Densiometer Readings EB3 Winter 2019

Edwards Branch 2/9/19				
(m)	North	East	South	West
0	16	20	6	20
20	20	20	8	10
40	16	27	8	18
60	70	30	15	30
80	32	50	30	22
100	8	60	12	26

Table E24: Grain Size Distribution Fall 2018

Sites	% silt/clay	% sand	% gravel	% cobble	% boulder
RC1	7	44	46	3	0
MDCT8	0	19	65	16	0
BD2	0	50	50	0	0
TBCRL5	1	14	70	15	0
TBCCR4	2	4	74	20	0
MC7	0	4	71	25	0
EB3	0	10	39	42	9
LHC6	0	5	71	23	1

Table E25: Grain Size Distribution Winter 2019

Sites	% silt/clay	% sand	% gravel	% cobble	% boulder
RC1	0	0	43	53	7
MDCT8	0	1	86	13	0
BD2	10	76	14	0	0
TBCRL5	8	3	50	39	0
TBCCR4	2	1	54	41	2
MC7	0	25	49	26	0
EB3	0	9	20	64	7
LHC6	0	18	43	39	0

Table E26: Stormflow and Sampler Flow TSS

Sites	Date Sampled	Sampler or Storm	Filter +Tin (mg)	Dry Weight (mg)	Volume Filtered (L)	TSS (mg/L)
BD2	2/16/19	Storm	1496	1502.44	0.3	21.47
BD2	2/25/19	Storm	1507.72	1513.57	0.3	19.50
LHC6	2/16/19	Storm	1505.38	1508.51	0.3	10.43
LHC6	2/25/19	Storm	1484.76	1485.58	0.3	2.73
MC7	2/16/19	Storm	1492.23	1498.33	0.2	30.50
MC7	2/25/19	Storm	1498.76	1501.5	0.3	9.13
TBCCR4	2/16/19	Storm	1517.67	1523.08	0.3	18.03
TBCCR4	2/25/19	Storm	1498.71	1504.44	0.3	19.10
TBCRL5	2/16/19	Storm	1482.37	1488.1	0.3	19.10
TBCRL5	2/16/19	Sampler	1485.8	1493.15	0.2	36.75
TBCRL5	2/25/19	Storm	1500.69	1501.06	0.3	1.23
MDCT8	2/16/19	Storm	1481.44	1496.62	0.15	101.20
MDCT8	2/25/19	Storm	1497.99	1507.17	0.3	30.60
MDCT8	2/25/19	Sampler	1506.39	1520.65	0.2	71.30
EB3	2/16/19	Storm	1524.79	1530.31	0.3	18.40
EB3	2/16/19	Sampler	1501.76	1506.33	0.2	22.85
EB3	2/25/19	Storm	1500.9	1501.48	0.3	1.93
RC1	2/16/19	Storm	1466	1472.79	0.2	33.95
RC1	2/25/19	Storm	1511.98	1516.6	0.3	15.40

Table E27: RC1 Macroinvertebrate Data Fall 2018

Order	Family	Genus/ Species	Tolerance Value	Total # Found
Ephemeroptera	*Baetidae*	*Baetis intercalaris*	5.0	
Ephemeroptera	*Heptageniidae*	*Maccaffertium modestum*	5.7	
Ephemeroptera	*Ephemerellidae*	*Ephemerella dorothea*	3.3	
Plecoptera	*Perlidae*	*Isoperla spp.*	4.8	
Trichoptera	*Hydropsychidae*	*Cheumatopsyche spp.*	6.6	
Trichoptera	*Hydropsychidae*	*Diplectrona modesta*	2.3	
Trichoptera	*Hydropsychidae*	*Hydropsyche betteni*	7.9	
Coleoptera	*Elmidae*	*Dubiraphia spp.*	5.5	
Coleoptera	*Dytiscidae*	*Neoclypeodytes spp.*	5.0	
Diptera	*Chironomidae*		7.0	1
Diptera	*Simuliidae*	*Cnephia ornithophila*	4.0	
Diptera	*Tabanidae*	*Tabanus spp.*	8.5	
Diptera	*Tipulidae*	*Tipula spp.*	9.5	
Odonata	*Coenagrionidae*	*Argia spp.*	8.3	
Odonata	*Coenagrionidae*	*Enallagma spp.*	8.5	
Odonata	*Cordulegastridae*	*Cordulegaster spp.*	5.7	
Odonata	*Gomphidae*	*Progomphus obscurus*	8.2	1
Oligochaeta	*Haplotaxidae*	*Haplotaxis gordioides*	3.6	
Hirudinea	*Erpobdellidae*	*Erpobdella/Mooreobdella*	8.6	
Gastropoda	*Physidae*	*Physa spp.*	8.7	
Gastropoda	*Planorbidae*	*Helisoma anceps*	6.6	
Bivalvia	*Corbiculidae*	*Corbicula fluminea*	6.6	

Table E28: RC1 Macroinvertebrate Data Fall 2018

Total Organisms	2
Total Taxa	2
Total EPT	0
NCBI Score	7.6
NCBI Rating	Poor

Table E29: BD2 Macroinvertebrate Data Fall 2018

Order	Family	Genus/ Species	Tolerance Value	Total # Found
Ephemeroptera	*Baetidae*	*Baetis intercalaris*	5.0	
Ephemeroptera	*Heptageniidae*	*Maccaffertium modestum*	5.7	
Ephemeroptera	*Ephemerellidae*	*Ephemerella dorothea*	3.3	
Plecoptera	*Perlidae*	*Isoperla spp.*	4.8	
Trichoptera	*Hydropsychidae*	*Cheumatopsyche spp.*	6.6	
Trichoptera	*Hydropsychidae*	*Diplectrona modesta*	2.3	1
Trichoptera	*Hydropsychidae*	*Hydropsyche betteni*	7.9	
Coleoptera	*Elmidae*	*Dubiraphia spp.*	5.5	1
Coleoptera	*Dytiscidae*	*Neoclypeodytes spp.*	5.0	
Diptera	*Chironomidae*		7.0	6
Diptera	*Simuliidae*	*Cnephia ornithophila*	4.0	
Diptera	*Tabanidae*	*Tabanus spp.*	8.5	
Diptera	*Tipulidae*	*Tipula spp.*	9.5	
Odonata	*Coenagrionidae*	*Argia spp.*	8.3	
Odonata	*Coenagrionidae*	*Enallagma spp.*	8.5	
Odonata	*Cordulegastridae*	*Cordulegaster spp.*	5.7	
Odonata	*Gomphidae*	*Progomphus obscurus*	8.2	
Oligochaeta	*Haplotaxidae*	*Haplotaxis gordioides*	3.6	
Hirudinea	*Erpobdellidae*	*Erpobdella/Mooreobdella*	8.6	
Gastropoda	*Physidae*	*Physa spp.*	8.7	
Gastropoda	*Planorbidae*	*Helisoma anceps*	6.6	
Bivalvia	*Corbiculidae*	*Corbicula fluminea*	6.6	

Table E30: BD2 Macroinvertebrate Data Fall 2018

Total Organisms	8
Total Taxa	3
Total EPT	1
NCBI Score	5.76
NCBI Rating	Good-Fair

Table E31: EB3 Macroinvertebrate Data Fall 2018

Order	Family	Genus/ Species	Tolerance Value	Total # Found
Ephemeroptera	*Baetidae*	*Baetis intercalaris*	5.0	
Ephemeroptera	*Heptageniidae*	*Maccaffertium modestum*	5.7	
Ephemeroptera	*Ephemerellidae*	*Ephemerella dorothea*	3.3	
Plecoptera	*Perlidae*	*Isoperla spp.*	4.8	
Trichoptera	*Hydropsychidae*	*Cheumatopsyche spp.*	6.6	8
Trichoptera	*Hydropsychidae*	*Diplectrona modesta*	2.3	
Trichoptera	*Hydropsychidae*	*Hydropsyche betteni*	7.9	1
Coleoptera	*Elmidae*	*Dubiraphia spp.*	5.5	
Coleoptera	*Dytiscidae*	*Neoclypeodytes spp.*	5.0	
Diptera	*Chironomidae*		7.0	6
Diptera	*Simuliidae*	*Cnephia ornithophila*	4.0	
Diptera	*Tabanidae*	*Tabanus spp.*	8.5	
Diptera	*Tipulidae*	*Tipula spp.*	9.5	
Odonata	*Coenagrionidae*	*Argia spp.*	8.3	4
Odonata	*Coenagrionidae*	*Enallagma spp.*	8.5	6
Odonata	*Cordulegastridae*	*Cordulegaster spp.*	5.7	
Odonata	*Gomphidae*	*Progomphus obscurus*	8.2	
Oligochaeta	*Haplotaxidae*	*Haplotaxis gordioides*	3.6	
Hirudinea	*Erpobdellidae*	*Erpobdella/Mooreobdella*	8.6	1
Gastropoda	*Physidae*	*Physa spp.*	8.7	
Gastropoda	*Planorbidae*	*Helisoma anceps*	6.6	
Bivalvia	*Corbiculidae*	*Corbicula fluminea*	6.6	

Table E32: EB3 Macroinvertebrate Data Fall 2018

Total Organisms	26
Total Taxa	6
Total EPT	2
NCBI Score	7.69
NCBI Rating	Poor

Table E33: TBCCR4 Macroinvertebrate Data Fall 2018

Order	Family	Genus/ Species	Tolerance Value	Total # Found
Ephemeroptera	*Baetidae*	*Baetis intercalaris*	5.0	1
Ephemeroptera	*Heptageniidae*	*Maccaffertium modestum*	5.7	
Ephemeroptera	*Ephemerellidae*	*Ephemerella dorothea*	3.3	
Plecoptera	*Perlidae*	*Isoperla spp.*	4.8	
Trichoptera	*Hydropsychidae*	*Cheumatopsyche spp.*	6.6	3
Trichoptera	*Hydropsychidae*	*Diplectrona modesta*	2.3	
Trichoptera	*Hydropsychidae*	*Hydropsyche betteni*	7.9	
Coleoptera	*Elmidae*	*Dubiraphia spp.*	5.5	
Coleoptera	*Dytiscidae*	*Neoclypeodytes spp.*	5.0	
Diptera	*Chironomidae*		7.0	4
Diptera	*Simuliidae*	*Cnephia ornithophila*	4.0	
Diptera	*Tabanidae*	*Tabanus spp.*	8.5	
Diptera	*Tipulidae*	*Tipula spp.*	9.5	
Odonata	*Coenagrionidae*	*Argia spp.*	8.3	
Odonata	*Coenagrionidae*	*Enallagma spp.*	8.5	
Odonata	*Cordulegastridae*	*Cordulegaster spp.*	5.7	
Odonata	*Gomphidae*	*Progomphus obscurus*	8.2	
Oligochaeta	*Haplotaxidae*	*Haplotaxis gordioides*	3.6	
Hirudinea	*Erpobdellidae*	*Erpobdella/Mooreobdella*	8.6	
Gastropoda	*Physidae*	*Physa spp.*	8.7	36
Gastropoda	*Planorbidae*	*Helisoma anceps*	6.6	
Bivalvia	*Corbiculidae*	*Corbicula fluminea*	6.6	

Table E34: TBCCR4 Macroinvertebrate Data Fall 2018

Total Organisms	44
Total Taxa	4
Total EPT	2
NCBI Score	7.81
NCBI Rating	Poor

Table E35: TBCRL5 Macroinvertebrate Data Fall 2018

Order	Family	Genus/ Species	Tolerance Value	Total # Found
Ephemeroptera	*Baetidae*	*Baetis intercalaris*	5.0	
Ephemeroptera	*Heptageniidae*	*Maccaffertium modestum*	5.7	
Ephemeroptera	*Ephemerellidae*	*Ephemerella dorothea*	3.3	
Plecoptera	*Perlidae*	*Isoperla spp.*	4.8	
Trichoptera	*Hydropsychidae*	*Cheumatopsyche spp.*	6.6	8
Trichoptera	*Hydropsychidae*	*Diplectrona modesta*	2.3	
Trichoptera	*Hydropsychidae*	*Hydropsyche betteni*	7.9	2
Coleoptera	*Elmidae*	*Dubiraphia spp.*	5.5	
Coleoptera	*Dytiscidae*	*Neoclypeodytes spp.*	5.0	
Diptera	*Chironomidae*		7.0	35
Diptera	*Simuliidae*	*Cnephia ornithophila*	4.0	
Diptera	*Tabanidae*	*Tabanus spp.*	8.5	
Diptera	*Tipulidae*	*Tipula spp.*	9.5	
Odonata	*Coenagrionidae*	*Argia spp.*	8.3	
Odonata	*Coenagrionidae*	*Enallagma spp.*	8.5	
Odonata	*Cordulegastridae*	*Cordulegaster spp.*	5.7	
Odonata	*Gomphidae*	*Progomphus obscurus*	8.2	
Oligochaeta	*Haplotaxidae*	*Haplotaxis gordioides*	3.6	
Hirudinea	*Erpobdellidae*	*Erpobdella/Mooreobdella*	8.6	
Gastropoda	*Physidae*	*Physa spp.*	8.7	3
Gastropoda	*Planorbidae*	*Helisoma anceps*	6.6	
Bivalvia	*Corbiculidae*	*Corbicula fluminea*	6.6	

Table E36: TBCRL5 Macroinvertebrate Data Fall 2018

Total Organisms	48
Total Taxa	4
Total EPT	2
NCBI Score	7.28
NCBI Rating	Poor

Table E37: LHC6 Macroinvertebrate Data Fall 2018

Order	Family	Genus/ Species	Tolerance Value	Total # Found
Ephemeroptera	*Baetidae*	*Baetis intercalaris*	5.0	
Ephemeroptera	*Heptageniidae*	*Maccaffertium modestum*	5.7	
Ephemeroptera	*Ephemerellidae*	*Ephemerella dorothea*	3.3	
Plecoptera	*Perlidae*	*Isoperla spp.*	4.8	
Trichoptera	*Hydropsychidae*	*Cheumatopsyche spp.*	6.6	96
Trichoptera	*Hydropsychidae*	*Diplectrona modesta*	2.3	6
Trichoptera	*Hydropsychidae*	*Hydropsyche betteni*	7.9	9
Coleoptera	*Elmidae*	*Dubiraphia spp.*	5.5	
Coleoptera	*Dytiscidae*	*Neoclypeodytes spp.*	5.0	
Diptera	*Chironomidae*		7.0	36
Diptera	*Simuliidae*	*Cnephia ornithophila*	4.0	11
Diptera	*Tabanidae*	*Tabanus spp.*	8.5	
Diptera	*Tipulidae*	*Tipula spp.*	9.5	
Odonata	*Coenagrionidae*	*Argia spp.*	8.3	
Odonata	*Coenagrionidae*	*Enallagma spp.*	8.5	
Odonata	*Cordulegastridae*	*Cordulegaster spp.*	5.7	
Odonata	*Gomphidae*	*Progomphus obscurus*	8.2	
Oligochaeta	*Haplotaxidae*	*Haplotaxis gordioides*	3.6	
Hirudinea	*Erpobdellidae*	*Erpobdella/Mooreobdella*	8.6	
Gastropoda	*Physidae*	*Physa spp.*	8.7	
Gastropoda	*Planorbidae*	*Helisoma anceps*	6.6	
Bivalvia	*Corbiculidae*	*Corbicula fluminea*	6.6	

Table E38: LHC6 Macroinvertebrate Data Fall 2018

Total Organisms	158
Total Taxa	5
Total EPT	3
NCBI Score	5.74
NCBI Rating	Good-Fair

Table E39: MC7 Macroinvertebrate Data Fall 2018

Order	Family	Genus/ Species	Tolerance Value	Total # Found
Ephemeroptera	*Baetidae*	*Baetis intercalaris*	5.0	1
Ephemeroptera	*Heptageniidae*	*Maccaffertium modestum*	5.7	
Ephemeroptera	*Ephemerellidae*	*Ephemerella dorothea*	3.3	
Plecoptera	*Perlidae*	*Isoperla spp.*	4.8	
Trichoptera	*Hydropsychidae*	*Cheumatopsyche spp.*	6.6	43
Trichoptera	*Hydropsychidae*	*Diplectrona modesta*	2.3	
Trichoptera	*Hydropsychidae*	*Hydropsyche betteni*	7.9	1
Coleoptera	*Elmidae*	*Dubiraphia spp.*	5.5	14
Coleoptera	*Dytiscidae*	*Neoclypeodytes spp.*	5.0	
Diptera	*Chironomidae*		7.0	83
Diptera	*Simuliidae*	*Cnephia ornithophila*	4.0	
Diptera	*Tabanidae*	*Tabanus spp.*	8.5	
Diptera	*Tipulidae*	*Tipula spp.*	9.5	2
Odonata	*Coenagrionidae*	*Argia spp.*	8.3	2
Odonata	*Coenagrionidae*	*Enallagma spp.*	8.5	
Odonata	*Cordulegastridae*	*Cordulegaster spp.*	5.7	
Odonata	*Gomphidae*	*Progomphus obscurus*	8.2	
Oligochaeta	*Haplotaxidae*	*Haplotaxis gordioides*	3.6	3
Hirudinea	*Erpobdellidae*	*Erpobdella/Mooreobdella*	8.6	3
Gastropoda	*Physidae*	*Physa spp.*	8.7	4
Gastropoda	*Planorbidae*	*Helisoma anceps*	6.6	
Bivalvia	*Corbiculidae*	*Corbicula fluminea*	6.6	3

Table E40: MC7 Macroinvertebrate Data Fall 2018

Total Organisms	159
Total Taxa	11
Total EPT	3
NCBI Score	6.61
NCBI Rating	Fair

Table E41: MDCT8 Macroinvertebrate Data Fall 2018

Order	Family	Genus/ Species	Tolerance Value	Total # Found
Ephemeroptera	*Baetidae*	*Baetis intercalaris*	5.0	
Ephemeroptera	*Heptageniidae*	*Maccaffertium modestum*	5.7	11
Ephemeroptera	*Ephemerellidae*	*Ephemerella dorothea*	3.3	
Plecoptera	*Perlidae*	*Isoperla spp.*	4.8	
Trichoptera	*Hydropsychidae*	*Cheumatopsyche spp.*	6.6	36
Trichoptera	*Hydropsychidae*	*Diplectrona modesta*	2.3	3
Trichoptera	*Hydropsychidae*	*Hydropsyche betteni*	7.9	
Coleoptera	*Elmidae*	*Dubiraphia spp.*	5.5	1
Coleoptera	*Dytiscidae*	*Neoclypeodytes spp.*	5.0	
Diptera	*Chironomidae*		7.0	3
Diptera	*Simuliidae*	*Cnephia ornithophila*	4.0	
Diptera	*Tabanidae*	*Tabanus spp.*	8.5	
Diptera	*Tipulidae*	*Tipula spp.*	9.5	3
Odonata	*Coenagrionidae*	*Argia spp.*	8.3	
Odonata	*Coenagrionidae*	*Enallagma spp.*	8.5	
Odonata	*Cordulegastridae*	*Cordulegaster spp.*	5.7	
Odonata	*Gomphidae*	*Progomphus obscurus*	8.2	1
Oligochaeta	*Haplotaxidae*	*Haplotaxis gordioides*	3.6	
Hirudinea	*Erpobdellidae*	*Erpobdella/Mooreobdella*	8.6	
Gastropoda	*Physidae*	*Physa spp.*	8.7	12
Gastropoda	*Planorbidae*	*Helisoma anceps*	6.6	
Bivalvia	*Corbiculidae*	*Corbicula fluminea*	6.6	

Table E42: MDCT8 Macroinvertebrate Data Fall 2018

Total Organisms	70
Total Taxa	8
Total EPT	3
NCBI Score	6.32
NCBI Rating	Fair

Table E43: RC1 Macroinvertebrate Data Winter 2019

Order	Family	Genus/ Species	Tolerance Value	Total # Found
Ephemeroptera	*Baetidae*	*Baetis intercalaris*	5.0	2
Ephemeroptera	*Heptageniidae*	*Maccaffertium modestum*	5.7	
Ephemeroptera	*Ephemerellidae*	*Ephemerella dorothea*	3.3	1
Plecoptera	*Perlidae*	*Isoperla spp.*	4.8	
Trichoptera	*Hydropsychidae*	*Cheumatopsyche spp.*	6.6	
Trichoptera	*Hydropsychidae*	*Diplectrona modesta*	2.3	
Trichoptera	*Hydropsychidae*	*Hydropsyche betteni*	7.9	
Coleoptera	*Elmidae*	*Dubiraphia spp.*	5.5	
Coleoptera	*Dytiscidae*	*Neoclypeodytes spp.*	5.0	
Diptera	*Chironomidae*		7.0	12
Diptera	*Simuliidae*	*Cnephia ornithophila*	4.0	
Diptera	*Tabanidae*	*Tabanus spp.*	8.5	
Diptera	*Tipulidae*	*Tipula spp.*	9.5	
Odonata	*Coenagrionidae*	*Argia spp.*	8.3	
Odonata	*Coenagrionidae*	*Enallagma spp.*	8.5	
Odonata	*Cordulegastridae*	*Cordulegaster spp.*	5.7	1
Odonata	*Gomphidae*	*Progomphus obscurus*	8.2	
Oligochaeta	*Haplotaxidae*	*Haplotaxis gordioides*	3.6	
Hirudinea	*Erpobdellidae*	*Erpobdella/Mooreobdella*	8.6	
Gastropoda	*Physidae*	*Physa spp.*	8.7	
Gastropoda	*Planorbidae*	*Helisoma anceps*	6.6	
Bivalvia	*Corbiculidae*	*Corbicula fluminea*	6.6	

Table E44: RC1 Macroinvertebrate Data Winter 2019

Total Organisms	16
Total Taxa	4
Total EPT	2
NCBI Score	6.46
NCBI Rating	Poor

Table E45: BD2 Macroinvertebrate Data Winter 2019

Order	Family	Genus/ Species	Tolerance Value	Total # Found
Ephemeroptera	*Baetidae*	*Baetis intercalaris*	5.0	
Ephemeroptera	*Heptageniidae*	*Maccaffertium modestum*	5.7	3
Ephemeroptera	*Ephemerellidae*	*Ephemerella dorothea*	3.3	
Plecoptera	*Perlidae*	*Isoperla spp.*	4.8	1
Trichoptera	*Hydropsychidae*	*Cheumatopsyche spp.*	6.6	
Trichoptera	*Hydropsychidae*	*Diplectrona modesta*	2.3	
Trichoptera	*Hydropsychidae*	*Hydropsyche betteni*	7.9	
Coleoptera	*Elmidae*	*Dubiraphia spp.*	5.5	
Coleoptera	*Dytiscidae*	*Neoclypeodytes spp.*	5.0	1
Diptera	*Chironomidae*		7.0	
Diptera	*Simuliidae*	*Cnephia ornithophila*	4.0	
Diptera	*Tabanidae*	*Tabanus spp.*	8.5	
Diptera	*Tipulidae*	*Tipula spp.*	9.5	
Odonata	*Coenagrionidae*	*Argia spp.*	8.3	
Odonata	*Coenagrionidae*	*Enallagma spp.*	8.5	
Odonata	*Cordulegastridae*	*Cordulegaster spp.*	5.7	1
Odonata	*Gomphidae*	*Progomphus obscurus*	8.2	
Oligochaeta	*Haplotaxidae*	*Haplotaxis gordioides*	3.6	
Hirudinea	*Erpobdellidae*	*Erpobdella/Mooreobdella*	8.6	1
Gastropoda	*Physidae*	*Physa spp.*	8.7	2
Gastropoda	*Planorbidae*	*Helisoma anceps*	6.6	
Bivalvia	*Corbiculidae*	*Corbicula fluminea*	6.6	

Table E46: BD2 Macroinvertebrate Data Winter 2019

Total Organisms	9
Total Taxa	6
Total EPT	2
NCBI Score	6.24
NCBI Rating	Fair

Table E47: EB3 Macroinvertebrate Data Winter 2019

Order	Family	Genus/ Species	Tolerance Value	Total # Found
Ephemeroptera	*Baetidae*	*Baetis intercalaris*	5.0	
Ephemeroptera	*Heptageniidae*	*Maccaffertium modestum*	5.7	
Ephemeroptera	*Ephemerellidae*	*Ephemerella dorothea*	3.3	
Plecoptera	*Perlidae*	*Isoperla spp.*	4.8	
Trichoptera	*Hydropsychidae*	*Cheumatopsyche spp.*	6.6	11
Trichoptera	*Hydropsychidae*	*Diplectrona modesta*	2.3	
Trichoptera	*Hydropsychidae*	*Hydropsyche betteni*	7.9	
Coleoptera	*Elmidae*	*Dubiraphia spp.*	5.5	
Coleoptera	*Dytiscidae*	*Neoclypeodytes spp.*	5.0	
Diptera	*Chironomidae*		7.0	5
Diptera	*Simuliidae*	*Cnephia ornithophila*	4.0	
Diptera	*Tabanidae*	*Tabanus spp.*	8.5	
Diptera	*Tipulidae*	*Tipula spp.*	9.5	
Odonata	*Coenagrionidae*	*Argia spp.*	8.3	
Odonata	*Coenagrionidae*	*Enallagma spp.*	8.5	1
Odonata	*Cordulegastridae*	*Cordulegaster spp.*	5.7	
Odonata	*Gomphidae*	*Progomphus obscurus*	8.2	
Oligochaeta	*Haplotaxidae*	*Haplotaxis gordioides*	3.6	
Hirudinea	*Erpobdellidae*	*Erpobdella/Mooreobdella*	8.6	
Gastropoda	*Physidae*	*Physa spp.*	8.7	1
Gastropoda	*Planorbidae*	*Helisoma anceps*	6.6	
Bivalvia	*Corbiculidae*	*Corbicula fluminea*	6.6	

Table E48: EB3 Macroinvertebrate Data Winter 2019

Total Organisms	18
Total Taxa	4
Total EPT	1
NCBI Score	5.78
NCBI Rating	Good-Fair

Table E49: TBCCR4 Macroinvertebrate Data Winter 2019

Order	Family	Genus/ Species	Tolerance Value	Total # Found
Ephemeroptera	*Baetidae*	*Baetis intercalaris*	5.0	
Ephemeroptera	*Heptageniidae*	*Maccaffertium modestum*	5.7	
Ephemeroptera	*Ephemerellidae*	*Ephemerella dorothea*	3.3	
Plecoptera	*Perlidae*	*Isoperla spp.*	4.8	
Trichoptera	*Hydropsychidae*	*Cheumatopsyche spp.*	6.6	24
Trichoptera	*Hydropsychidae*	*Diplectrona modesta*	2.3	
Trichoptera	*Hydropsychidae*	*Hydropsyche betteni*	7.9	
Coleoptera	*Elmidae*	*Dubiraphia spp.*	5.5	
Coleoptera	*Dytiscidae*	*Neoclypeodytes spp.*	5.0	
Diptera	*Chironomidae*		7.0	
Diptera	*Simuliidae*	*Cnephia ornithophila*	4.0	
Diptera	*Tabanidae*	*Tabanus spp.*	8.5	1
Diptera	*Tipulidae*	*Tipula spp.*	9.5	3
Odonata	*Coenagrionidae*	*Argia spp.*	8.3	
Odonata	*Coenagrionidae*	*Enallagma spp.*	8.5	
Odonata	*Cordulegastridae*	*Cordulegaster spp.*	5.7	
Odonata	*Gomphidae*	*Progomphus obscurus*	8.2	
Oligochaeta	*Haplotaxidae*	*Haplotaxis gordioides*	3.6	1
Hirudinea	*Erpobdellidae*	*Erpobdella/Mooreobdella*	8.6	
Gastropoda	*Physidae*	*Physa spp.*	8.7	
Gastropoda	*Planorbidae*	*Helisoma anceps*	6.6	
Bivalvia	*Corbiculidae*	*Corbicula fluminea*	6.6	

Table E50: TBCCR4 Macroinvertebrate Data Winter 2019

Total Organisms	29
Total Taxa	4
Total EPT	1
NCBI Score	7.11
NCBI Rating	Poor

Table E51: TBCRL5 Macroinvertebrate Data Winter 2019

Order	Family	Genus/ Species	Tolerance Value	Total # Found
Ephemeroptera	*Baetidae*	*Baetis intercalaris*	5.0	
Ephemeroptera	*Heptageniidae*	*Maccaffertium modestum*	5.7	
Ephemeroptera	*Ephemerellidae*	*Ephemerella dorothea*	3.3	
Plecoptera	*Perlidae*	*Isoperla spp.*	4.8	
Trichoptera	*Hydropsychidae*	*Cheumatopsyche spp.*	6.6	24
Trichoptera	*Hydropsychidae*	*Diplectrona modesta*	2.3	3
Trichoptera	*Hydropsychidae*	*Hydropsyche betteni*	7.9	
Coleoptera	*Elmidae*	*Dubiraphia spp.*	5.5	
Coleoptera	*Dytiscidae*	*Neoclypeodytes spp.*	5.0	
Diptera	*Chironomidae*		7.0	3
Diptera	*Simuliidae*	*Cnephia ornithophila*	4.0	
Diptera	*Tabanidae*	*Tabanus spp.*	8.5	
Diptera	*Tipulidae*	*Tipula spp.*	9.5	
Odonata	*Coenagrionidae*	*Argia spp.*	8.3	
Odonata	*Coenagrionidae*	*Enallagma spp.*	8.5	1
Odonata	*Cordulegastridae*	*Cordulegaster spp.*	5.7	
Odonata	*Gomphidae*	*Progomphus obscurus*	8.2	
Oligochaeta	*Haplotaxidae*	*Haplotaxis gordioides*	3.6	1
Hirudinea	*Erpobdellidae*	*Erpobdella/Mooreobdella*	8.6	
Gastropoda	*Physidae*	*Physa spp.*	8.7	
Gastropoda	*Planorbidae*	*Helisoma anceps*	6.6	
Bivalvia	*Corbiculidae*	*Corbicula fluminea*	6.6	

Table E52: TBCRL5 Macroinvertebrate Data Winter 2019

Total Organisms	33
Total Taxa	6
Total EPT	2
NCBI Score	5.79
NCBI Rating	Good-Fair

Table E53: LHC6 Macroinvertebrate Data Winter 2019

Order	Family	Genus/ Species	Tolerance Value	*Total # Found*
Ephemeroptera	*Baetidae*	*Baetis intercalaris*	5.0	
Ephemeroptera	*Heptageniidae*	*Maccaffertium modestum*	5.7	
Ephemeroptera	*Ephemerellidae*	*Ephemerella dorothea*	3.3	
Plecoptera	*Perlidae*	*Isoperla spp.*	4.8	
Trichoptera	*Hydropsychidae*	*Cheumatopsyche spp.*	6.6	
Trichoptera	*Hydropsychidae*	*Diplectrona modesta*	2.3	
Trichoptera	*Hydropsychidae*	*Hydropsyche betteni*	7.9	3
Coleoptera	*Elmidae*	*Dubiraphia spp.*	5.5	1
Coleoptera	*Dytiscidae*	*Neoclypeodytes spp.*	5.0	
Diptera	*Chironomidae*		7.0	3
Diptera	*Simuliidae*	*Cnephia ornithophila*	4.0	
Diptera	*Tabanidae*	*Tabanus spp.*	8.5	
Diptera	*Tipulidae*	*Tipula spp.*	9.5	
Odonata	*Coenagrionidae*	*Argia spp.*	8.3	
Odonata	*Coenagrionidae*	*Enallagma spp.*	8.5	
Odonata	*Cordulegastridae*	*Cordulegaster spp.*	5.7	
Odonata	*Gomphidae*	*Progomphus obscurus*	8.2	
Oligochaeta	*Haplotaxidae*	*Haplotaxis gordioides*	3.6	
Hirudinea	*Erpobdellidae*	*Erpobdella/Mooreobdella*	8.6	
Gastropoda	*Physidae*	*Physa spp.*	8.7	1
Gastropoda	*Planorbidae*	*Helisoma anceps*	6.6	
Bivalvia	*Corbiculidae*	*Corbicula fluminea*	6.6	

Table E54: LHC6 Macroinvertebrate Data Winter 2019

Total Organisms	8
Total Taxa	4
Total EPT	1
NCBI Score	7.36
NCBI Rating	Poor

Table E55: MC7 Macroinvertebrate Data Winter 2019

Order	Family	Genus/ Species	Tolerance Value	Total # Found
Ephemeroptera	*Baetidae*	*Baetis intercalaris*	5.0	
Ephemeroptera	*Heptageniidae*	*Maccaffertium modestum*	5.7	
Ephemeroptera	*Ephemerellidae*	*Ephemerella dorothea*	3.3	
Plecoptera	*Perlidae*	*Isoperla spp.*	4.8	
Trichoptera	*Hydropsychidae*	*Cheumatopsyche spp.*	6.6	15
Trichoptera	*Hydropsychidae*	*Diplectrona modesta*	2.3	7
Trichoptera	*Hydropsychidae*	*Hydropsyche betteni*	7.9	11
Coleoptera	*Elmidae*	*Dubiraphia spp.*	5.5	6
Coleoptera	*Dytiscidae*	*Neoclypeodytes spp.*	5.0	
Diptera	*Chironomidae*		7.0	25
Diptera	*Simuliidae*	*Cnephia ornithophila*	4.0	
Diptera	*Tabanidae*	*Tabanus spp.*	8.5	
Diptera	*Tipulidae*	*Tipula spp.*	9.5	1
Odonata	*Coenagrionidae*	*Argia spp.*	8.3	
Odonata	*Coenagrionidae*	*Enallagma spp.*	8.5	
Odonata	*Cordulegastridae*	*Cordulegaster spp.*	5.7	
Odonata	*Gomphidae*	*Progomphus obscurus*	8.2	
Oligochaeta	*Haplotaxidae*	*Haplotaxis gordioides*	3.6	3
Hirudinea	*Erpobdellidae*	*Erpobdella/Mooreobdella*	8.6	
Gastropoda	*Physidae*	*Physa spp.*	8.7	
Gastropoda	*Planorbidae*	*Helisoma anceps*	6.6	
Bivalvia	*Corbiculidae*	*Corbicula fluminea*	6.6	

Table E56: MC7 Macroinvertebrate Data Winter 2019

Total Organisms	68
Total Taxa	7
Total EPT	3
NCBI Score	6.67
NCBI Rating	Fair

Table E57: MDCT8 Macroinvertebrate Data Winter 2019

Order	Family	Genus/ Species	Tolerance Value	Total # Found
Ephemeroptera	*Baetidae*	*Baetis intercalaris*	5.0	
Ephemeroptera	*Heptageniidae*	*Maccaffertium modestum*	5.7	
Ephemeroptera	*Ephemerellidae*	*Ephemerella dorothea*	3.3	
Plecoptera	*Perlidae*	*Isoperla spp.*	4.8	
Trichoptera	*Hydropsychidae*	*Cheumatopsyche spp.*	6.6	14
Trichoptera	*Hydropsychidae*	*Diplectrona modesta*	2.3	5
Trichoptera	*Hydropsychidae*	*Hydropsyche betteni*	7.9	
Coleoptera	*Elmidae*	*Dubiraphia spp.*	5.5	
Coleoptera	*Dytiscidae*	*Neoclypeodytes spp.*	5.0	
Diptera	*Chironomidae*		7.0	17
Diptera	*Simuliidae*	*Cnephia ornithophila*	4.0	
Diptera	*Tabanidae*	*Tabanus spp.*	8.5	1
Diptera	*Tipulidae*	*Tipula spp.*	9.5	1
Odonata	*Coenagrionidae*	*Argia spp.*	8.3	1
Odonata	*Coenagrionidae*	*Enallagma spp.*	8.5	
Odonata	*Cordulegastridae*	*Cordulegaster spp.*	5.7	
Odonata	*Gomphidae*	*Progomphus obscurus*	8.2	
Oligochaeta	*Haplotaxidae*	*Haplotaxis gordioides*	3.6	
Hirudinea	*Erpobdellidae*	*Erpobdella/Mooreobdella*	8.6	
Gastropoda	*Physidae*	*Physa spp.*	8.7	2
Gastropoda	*Planorbidae*	*Helisoma anceps*	6.6	1
Bivalvia	*Corbiculidae*	*Corbicula fluminea*	6.6	

Table E58: MDCT8 Macroinvertebrate Data Winter 2019

Total Organisms	42
Total Taxa	8
Total EPT	2
NCBI Score	6.59
NCBI Rating	Fair

Table E59: Macroinvertebrate Metrics

Site- Season	NCBI	% EPT	Species Richness	Species Diversity	Evenness	% Intolerant Species	% Tolerant Species
RC1-F	7.6	0.0	1.41	0.69	0.22	0.0	100.0
RC1-W	6.46	50.0	1.00	0.82	0.27	6.3	93.8
BD2-F	5.76	33.3	1.06	0.74	0.24	4.3	95.7
BD2-W	6.24	33.3	2.00	1.68	0.54	11.9	88.1
EB3-F	7.69	33.3	1.18	1.58	0.51	12.5	87.5
EB3-W	5.78	25.0	0.94	0.98	0.32	0.0	100.0
TBCCR4-F	7.81	50.0	0.60	0.65	0.21	0.0	100.0
TBCCR4-W	7.11	40.0	0.74	0.62	0.20	12.5	87.5
TBCRL5-F	7.28	50.0	0.58	0.44	0.14	0.0	100.0
TBCRL5-W	6.24	25.0	0.88	0.88	0.28	3.4	96.6
LHC6-F	5.74	60.0	0.40	1.11	0.36	1.9	98.1
LHC6-W	7.36	25.0	0.49	1.26	0.41	14.7	85.3
MC7-F	6.61	27.3	0.87	1.40	0.45	0.0	100.0
MC7-W	6.47	42.9	0.85	1.64	0.53	0.0	100.0
MDCT8-F	6.32	37.5	0.96	1.46	0.47	10.8	89.2
MDCT8-W	6.59	25.0	1.23	1.49	0.48	0.0	100.0

Table E60: Functional Feeding Group Results

Sites-Season	# Shredders	# Scrapers	# Predators	# Collectors
RC1-F	0	0	1	1
RC1-W	0	0	1	15
BD2-F	0	1	0	7
BD2-W	0	5	4	0
EB3-F	0	0	10	15
EB3-W	0	1	1	16
TBCCR4-F	0	36	0	8
TBCCR4-W	3	0	1	25
TBCRL5-F	0	3	0	45
TBCRL5-W	0	0	1	31
LHC6-F	0	0	0	158
LHC6-W	0	2	0	6
MC7-F	2	18	5	134
MC7-W	1	6	0	61
MDCT8-F	3	24	1	42
MDCT8-W	1	3	2	36

Table E61: D_{50} Threshold Discharge Fall 2018

Site	Threshold Discharge (m^3/s)	D50 (mm)	2-yr peak flow (m^3/s)
RC1	0.016	2	8.18
BD2	0.021	2	10.45
EB3	2.413	92	3.85
TBCCR4	1.179	49	4.84
TBCRL5	0.819	37	5.13
LHC6	1.557	41	8.35
MC7	1.014	37	6.34
MDCT8	0.782	38	4.70

Table E62: D_{50} Threshold Discharge Winter 2019

Site	Threshold Discharge (m^3/s)	D50 (mm)	2-yr peak flow (m^3/s)
RC1	5.810	100	8.18
BD2	0.012	1.4	10.45
EB3	4.529	140	3.85
TBCCR4	1.598	60	4.84
TBCRL5	1.607	58	5.13
LHC6	2.224	52	8.35
MC7	1.139	40	6.34
MDCT8	0.662	34	4.70

Table E63: % Oxygen Saturation

Site	% Fall	% Winter
RC1	92.44	72.35
MDCT8	77.59	92.69
BD2	40.50	91.98
TBCRL5	88.33	121.89
TBCCR4	85.56	161.63
MC7	89.68	152.28
EB3	85.00	151.25
LHC6	85.93	100.80

Table E64: Tractive Force Values (kg/m^2) Fall 2018

RC1	BD2	EB3	TBCCR4	TBCRL5	LHC6	MC7	MDCT8
0.0062	0.1	0.2	0.0062	0.0062	0.2	0.2	0.2
0.2	0.2	0.6	0.2	0.05	0.6	0.6	0.6
0.6	0.4	0.8	1.6	0.2	0.8	0.8	1.1
1.1	0.8	1.1	2.2	0.6	1.1	1.1	1.6
2.2	1.6	1.6	3.2	0.8	1.6	1.6	2.2
3.2	2.2	2.2	4.5	1.1	2.2	2.2	3.2
18	3.2	3.2	6.4	1.6	3.2	3.2	4.5
25.6	4.5	4.5	12.8	2.2	4.5	4.5	6.4
		6.4	18	3.2	6.4	6.4	9
		12.8	25.6	4.5	12.8	12.8	18
		18		6.4	18	18	25.6
		25.6		12.8	25.6	25.6	
		36.2		18	51.2		
		51.2		25.6			

Table E65: Tractive Force Values (kg/m^2) Winter 2019

RC1	BD2	EB3	TBCCR4	TBCRL5	LHC6	MC7	MDCT8
4.5	0.0062	0.2	0.0062	0.0062	0.2	0.2	0.2
6.4	0.2	1.1	0.2	0.2	0.6	0.6	1.6
12.8	0.6	2.2	0.6	3.2	1.1	0.8	2.2
18	0.8	3.2	1.6	4.5	1.6	1.1	3.2
25.6	1.1	4.5	2.2	6.4	2.2	1.6	4.5
36.2		6.4	3.2	12.8	3.2	2.2	6.4
51.2		12.8	4.5	18	4.5	3.2	12.8
		18	6.4	25.6	6.4	4.5	18
		25.6	12.8		12.8	6.4	
		36.2	18		18	12.8	
		51.2	25.6		25.6	18	
			36.2			25.6	

Table E66: Bed Mobility Fall 2018

RC1		BD2		EB3		TBCCR4	
Grain Size (cm)	% Bed Mobility	Grain Size (cm)	% Bed Mobility	Grain Size (cm)	% Bed Mobility	Grain Size (cm)	% Bed Mobility
0.0062	100.00	0.1	99.518	0.2	100	0.0062	100.000
0.2	100.00	0.2	0.468	0.6	84	0.2	100.000
0.6	100.00	0.4	56.831	0.8	6	1.6	100.000
1.1	4.81	0.8	34.291	1.1	2	2.2	100.000
2.2	0.57	1.6	1.695	1.6	0	3.2	100.000
3.2	0.20	2.2	0.328	2.2	0	4.5	100.000
18	0.00	3.2	0.075	3.2	0	6.4	97.904
25.6	0.00	4.5	0.000	4.5	0	12.8	2.010
				6.4	0	18	0.498
				12.8	0	25.6	0.126
				18	0		
				25.6	0		
				36.2	0		
				51.2	0		

Table E67: Bed Mobility Fall 2018

TBCRL5		LHC6		MC7		MDCT8	
Grain Size (cm)	% Bed Mobility	Grain Size (cm)	% Bed Mobility	Grain Size (cm)	% Bed Mobility	Grain Size (cm)	% Bed Mobility
0.0062	100.000	0.2	100.000	0.2	100.000	0.2	100.000
0.05	100.000	0.6	100.000	0.6	100.000	0.6	100.000
0.2	100.000	0.8	100.000	0.8	100.000	1.1	100.000
0.6	100.000	1.1	100.000	1.1	26.703	1.6	54.183
0.8	100.000	1.6	100.000	1.6	2.920	2.2	1.578
1.1	100.000	2.2	100.000	2.2	1.143	3.2	0.071
1.6	99.089	3.2	100.000	3.2	0.436	4.5	0.002
2.2	84.595	4.5	100.000	4.5	0.206	6.4	0.000
3.2	2.154	6.4	100.000	6.4	0.086	9	0.000
4.5	0.447	12.8	100.000	12.8	0.000	18	0.000
6.4	0.167	18	0.950	18	0.000	25.6	0.000
12.8	0.038	25.6	0.054	25.6	0.000		
18	0.003	51.2	0.000				
25.6	0.000						

Table E67: Bed Mobility Winter 2019

RC1		BD2		EB3		TBCCR4	
Grain Size (cm)	% Bed Mobility	Grain Size (cm)	% Bed Mobility	Grain Size (cm)	% Bed Mobility	Grain Size (cm)	% Bed Mobility
4.5	0.06	0.0062	100.000	0.2	100.0000	0.0062	100
6.4	0.00	0.2	81.063	1.1	2.3956	0.2	100
12.8	0.00	0.6	42.655	2.2	0.1840	0.6	100
18	0.00	0.8	30.081	3.2	0.0323	1.6	100
25.6	0.00	1.1	17.239	4.5	0.0043	2.2	100
36.2	0.00			6.4	0.0000	3.2	100
51.2	0.00			12.8	0.000	4.5	100
				18	0.000	6.4	97.9041
				25.6	0.000	12.8	2.68455
				36.2	0.000	18	0.63195
				51.2	0.000	25.6	0.12689
						36.2	0.02438

Table E68: Bed Mobility Winter 2019

TBCRL5		LHC6		MC7		MDCT8	
Grain Size (cm)	% Bed Mobility	Grain Size (cm)	% Bed Mobility	Grain Size (cm)	% Bed Mobility	Grain Size (cm)	% Bed Mobility
0.0062	100.000	0.2	100.000	0.2	100.000	0.2	100
0.2	100.000	0.6	100.000	0.6	100.000	1.6	58.4816
3.2	2.777	1.1	100.000	0.8	100.000	2.2	1.97682
4.5	0.495	1.6	100.000	1.1	37.782	3.2	0.1183
6.4	0.146	2.2	100.000	1.6	4.105	4.5	0.0019
12.8	0.035	3.2	100.000	2.2	1.559	6.4	0
18	0.003	4.5	100.000	3.2	0.525	12.8	0
25.6	0.000	6.4	100.000	4.5	0.235	18	0
		12.8	100.000	6.4	0.079		
		18	1.168	12.8	0.000		
		25.6	0.074	18	0.000		
				25.6	0.000		

Table E69: D_{50} Bed Mobility Fall 2018

RC1		BD2		EB3		TBCCR4	
Grain Size (mm)	% Bed Mobility	Grain Size (mm)	% Bed Mobility	Grain Size (mm)	% Bed Mobility	Grain Size (mm)	% Bed Mobility
2	100	2	0.468	92	0	49	99.8

Table E70: D_{50} Bed Mobility Fall 2018

TBCRL5		LHC6		MC7		MDCT8	
Grain Size (mm)	% Bed Mobility	Grain Size (mm)	% Bed Mobility	Grain Size (mm)	% Bed Mobility	Grain Size (mm)	% Bed Mobility
37	0.31	41	100	37	0.31	38	0.02

Table E71: D_{50} Bed Mobility Fall 2018

RC1		BD2		EB3		TBCCR4	
Grain Size (mm)	% Bed Mobility	Grain Size (mm)	% Bed Mobility	Grain Size (mm)	% Bed Mobility	Grain Size (mm)	% Bed Mobility
100	0	1.4	2.4	140	0.43	60	98.68

Table E72: D_{50} Bed Mobility Fall 2018

TBCRL5		LHC6		MC7		MDCT8	
Grain Size (mm)	% Bed Mobility	Grain Size (mm)	% Bed Mobility	Grain Size (mm)	% Bed Mobility	Grain Size (mm)	% Bed Mobility
58	0.18	52	100	40	0.3	34	0.08