PRE-RESTORATION BASEFLOW DISSOLVED NUTRIENT DYNAMICS IN AN URBAN FORESTED HEADWATER SYSTEM, CHARLOTTE NC

by

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ABSTRACT

ELLA BETH WICKLIFF. Pre-restoration baseflow dissolved nutrient dynamics in an urban forested headwater system, Charlotte NC. (Under the direction of DR. SANDRA CLINTON)

Headwaters provide ecosystem services for humans such as clean water, recreational opportunities, nutrient removal, and biodiversity. Baseline stream nutrient and TSS concentrations and loadings are valuable water quality characteristics to quantify changes following landuse or land management activities.

I quantified baseline concentrations for a study period of 18 months in the Reedy Creek headwaters, located in the Piedmont of North Carolina. Surface water samples were collected in the nested landuse subwatersheds (agricultural, developed, and forested control) to be used as a pre-restoration dataset. 2016-2017 monthly surface water concentrations were used to calculate annual loading for the subwatersheds for ammonium, nitrate, phosphate, total suspended solids (TSS) and total phosphorus (TP). Concurrent flow and area ratio discharge approximations were used to estimate stream discharge at ungaged tributaries from the USGS gage located at the outlet of the total watershed USGS gage (0212427947 Reedy Creek at SR 2803 NR Charlotte, NC).

At the monthly time scale, dissolved nutrient concentrations varied with landuse, however, the results were not statistically significant. There were significant seasonal differences in concentrations for ammonium, TSS and TP concentrations. The average concentration of these three constituents vary significantly with growing season having a greater average concentration than the average concentration for the dormant season

Nitrate loading was highest from the agricultural watershed (0.57 kg/ha) compared to the whole watershed (0.54 kg/ha), the developed subwatershed (0.35 kg/ha) and the control subwatershed (0.18 kg/ha). The phosphate annual load from developed

subwatershed was 0.024 kg/ha which is 2.2 times greater than the control subwatershed. The mainstem had a phosphate annual load of 0.026 kg/ha which was 2.4 times greater than the control (C2) subwatershed. These results suggest that the development does influence the annual nutrient loads for nitrate and phosphorus at baseflow when compared to the control (C2) subwatershed, although there was not a statistically significant difference.

There was shown to be a significant difference in the growing season and dormant season means for daily loading in g/hectare for all constituents analyzed, suggesting that nutrient and TSS loading during the growing season is greater than loading during the dormant season.

The mainstem sites (R2 and R1) had the greatest monthly loading for all constituents. The agricultural and developed subwatersheds had greater peak loading at the monthly scale compared to the control subwatershed. The large spikes in loading are most likely due to increased concentrations resulting from landuse disturbance and increased discharge due to channel incision and scour in all impacted tributaries. The results demonstrate that landuse affects nutrient loading through changing the discharge regime at baseflow and by altering nutrient concentrations in a primarily forested watershed.

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1 Introduction

1.1 Headwater Ecosystems at the Watershed Scale

Headwaters, the sequence of first order streams that mark the beginning of a watershed, provide ecosystem services for humans such as clean water, recreational opportunities, nutrient removal, and biodiversity (Lowe and Likens, 2005). In the literature, there are many examples that show water quality, biodiversity, and ecological health of freshwater systems depend on the functions of headwater streams (Alexander et al., 2007, Violin et al., 2011, Palmer et al., 2005). According to Leopold et al. (1964), headwater streams account for more than 70 percent of stream channel length in the United States. The small drainage areas of headwater streams give these systems hydrologic independence and ecological significance (Lowe and Likens, 2005).

Headwater streams function by maintaining natural discharge regimes, regulating sediment export, retaining nutrients, processing terrestrial organic matter, and establishing the chemical signature for water quality in the landscape (Lowe and Likens, 2005). In addition, these small streams have diverse habitats which create niches for headwater-specialist species (Lowe and Likens, 2005). Terrestrial inputs, including dissolved nutrients, toxins, and particulate matter, are important for determining the physical and chemical conditions of headwater streams (Likens and Bormann, 1974). There is a terrestrial-aquatic linkage in headwater systems that, if disrupted by anthropogenic activities, can be detrimental to the ecosystem services provided by these streams and to the species they support.

Protecting headwater streams from physical and chemical human disturbance may help to protect the water quality in downstream networks. One question raised by Bernhardt et al. (2005) is, “to what extent do these [headwater] streams act to modify nutrients exported from the surrounding watershed, as opposed to simply being passive conduits of these nutrients?" There is growing evidence that in-stream processes play a significant role in modifying the nitrogen input-output balance of headwater watersheds (Lowe and Likens, 2005). Findings suggest understanding nutrient levels in headwater streams must account for both terrestrial and in-stream processes, which may act independently or together to affect the overall watershed export values (Lowe and Likens, 2005).

1.2 Effects of Urbanization on streams

Common disruptions in the hydrology and ecology of urban streams is referred to the Urban Stream Syndrome (Walsh et al., 2005). Disturbances associated with the urban stream syndrome include urban landuse, the amount of impervious cover, deforestation, and infrastructure leakage (Walsh et al., 2005).

Urbanization has had a large effect on freshwater ecosystems worldwide through changes in dissolved nutrient dynamics. There is a need for a quantitative understanding of how cumulative impacts to headwater streams affect downstream resources. The nutrient dynamics of headwater streams are important for management of larger scale fluvial systems, especially in response to large drivers of ecosystem changes such as urbanization. To manage freshwater ecosystems, it is important to understand hydrologic controls that affect nutrient concentrations in surface water, and how landuse practices affect these dynamics.

1.3 Current studies of nutrient export

Riverine nutrient loading for dissolved nitrogen and phosphorus is increasing in watersheds across the globe due to anthropogenic changes in land management, farming practices, and urbanization (Blaen et al., 2017). In an individual watershed, the distribution of human and animal populations, landuse, and characteristics of the vegetation and soils set the stage for the types, magnitudes and geography of nutrient inputs. Nitrogen and phosphorus are found in streams as both organic and inorganic compounds in both dissolved and particulate bound forms. Identifying landscape source zones of nutrients in a watershed is important for water quality management at the watershed scale. Identification of dominant landscape source zones that contribute to nutrient export and loading is often challenging, as the transfer of nitrogen and phosphorus from and to the stream is variable spatially and temporally. Water and dissolved nutrients can reach the stream through surface water and groundwater pathways (McGlynn et al. 1999). The response of the water table to storms strongly influences both subsurface discharge and the nature of the chemical and biological conditions under which water is transported to the stream (McGlynn et al. 1999).

Nitrogen and phosphorus are influenced by flow paths and residence times of water throughout the watershed (Band et al., 2001). Heterogeneous distributions of nutrient inputs control nutrient fluxes in surface waters (Alexander et al., 2007). To understand how stream nutrient concentrations are linked to landscape inputs it is important to note that riverine nutrient concentrations can exhibit highly dynamic and nonlinear behavior (Krause et al., 2015) that has been observed over a wide range of temporal scales (Blaen et al., 2017). Variability in past sampling regimes for nutrient concentrations (i. e. days to weeks) may not have provided as much information about short-term nutrient concentration variability that can be captured with more frequent sampling (Blaen et al., 2017).

1.3.1 Nitrogen Export and the influence of Biogeochemical Processes

Nitrogen is highly soluble and easily transported dissolved in water. Nitrogen sources to landscapes along with coupled hydrological and biogeochemical processes occurring through the watershed strongly affect the timing and form of nitrogen delivery to surface waters. Hydrologically connected soils expand and contract laterally and vertically during periods of wetting and drying and groundwater movement. These variable source areas are what facilitate the delivery of nitrogen to the stream from the watershed. During wet periods, saturated areas of the landscape are expanded, especially in riparian areas, and deliver nitrogen to streams allowing denitrification to occur.

Once nitrogen is delivered to streams or rivers, instream processes modify nitrogen fluxes. Groundwater, surfacewater interactions in hyporheic zones play a key role in nitrogen transformations (uptake and cycling) and permanent removal through denitrification as water interacts with low-oxygen benthic sediments during transport. Sebestyen et al. (2008), studying the Sleeper's River in Vermont, found the supply of nitrogen from this forested, headwater watershed to its receiving waters is controlled to a large degree by soil biogeochemical processes and hydrological processes that connect the landscape to streamflow. Similar results are referenced in Tersoriero et al. (2009) and Outram et al. (2016).

According to Alexander et al. (2007), flow paths and residence times in the landscape strongly influence nitrogen concentrations in the stream. The temporal variability of nitrogen is linked to cycles of water and DOC reflecting contributions of flow and solutes from upland hillslopes and stream riparian zones. Sebestyen et al. (2008) found instream nitrogen concentrations are notably influenced by season. During the growing season plants utilize nitrogen inputs to support growth and productivity.

Denitrification is temperature dependent and consumes nitrate at high temperatures. These results further support the importance of coupled hydrological and biogeochemical controls on water quality.

1.3.2 Phosphorus Export and the influence of Biogeochemical Processes

In urban areas, phosphorus inputs to streams from the watershed have been primarily attributed to inputs from wastewater treatment plants, sewer discharges, and direct runoff from impervious surfaces or construction areas (Roy and Bickerton, 2014). Most phosphorus compounds tend to precipitate or adsorb to soil and sediment. Findings from the USGS National Water Quality Assessment Program (NAWQA) for nutrient concentrations in US surface and ground water reports that a background groundwater concentration of 0.03 mg/L as orthophosphate was derived from 166 wells in areas of little anthropogenic disturbance (Dubrovsky, 2010). Dubrovsky (2010) found in most watersheds terrestrial phosphorus exports are greatest where surface waters transport phosphorus-rich particulates rapidly to streams.

However, other studies show that groundwater transport of phosphorus may also contribute to in-stream phosphorus concentrations despite the immobilization and sorption process that occur in the soil under certain geochemical conditions. Groundwater reaches the stream by a variety of pathways and the water chemistry alteration along these paths is critical to understanding stream biogeochemistry (McGlynn et al. 1999). Along the pathway from the riparian zone to the stream net phosphorus release has been observed (Hoffmann et al., 2009). In anthropogenically disturbed areas, Roy and Bikerton (2014) found phosphorus can be mobilized from sediments under reducing geochemical conditions including high organic content, and anoxic conditions. The Roy and Bikerton (2014) study found natural aquifer or stream sediments to be a contributor to high concentrations of soluble reactive phosphorus (SRP). Phosphorus can also be released when retention sites in the soils or sediments become saturated, generally following long periods of phosphorus application such as in agricultural areas (Roy and Bickerton, 2014).

1.3.3 Urban Nutrient Export

Altered nutrient concentrations are typically found in urban systems (Walsh et al., 2005). Studies have documented declines in nitrogen retention (Grimm et al., 2005) and assimilation (Kaushal et al., 2006) in urban streams, leading to increased nitrogen loading in surface waters, and euthrophic areas in urban streams. Dissolved phosphorus patterns however are less straightforward. Sprague et al. (2007), indicates urban inputs of dissolved phosphorus are less than agricultural inputs, resulting in a decreasing trend in phosphorus concentrations as urbanization of agricultural land occurs. Stream restoration has been shown initially to increase phosphorus uptake based on algal growth (McMillan et al., 2014).

1.4 Restoration

Stream restoration is one tool used to address altered nutrient concentrations in urban systems. Stream restoration, as defined by the National Research Council (1992), is the structural and functional return of a degraded riverine ecosystem to a pre-disturbance condition. Stream restoration is carried out in urban systems in response to channel incision and bank erosion, water quality degradation, and habitat and biodiversity loss which are all typically associated with an urban system (Violin et al., 2011). Stream restoration is considered compensatory mitigation for urban development (Bronner et al., 2013).

Restoration success in degraded streams is related to reducing stormwater or agricultural runoff for recovery of natural processes (Violin et al., 2011, Kolpin et al., 2004). The biogeochemical and hydrologic processes that need to be restored for functional restoration include infiltration within the watershed, ground-water surface-water (hyporheic) exchange rates, and hydraulic connectivity with the floodplain (Palmer et al., 2014). Ecologists are actively researching direct measurements of processes like whole-stream metabolism, nitrogen uptake, or rates of decomposition (Palmer et al., 2014) to understand how to restore streams to their natural functions. Rather than traditional natural channel design restoration projects, the literature is now shifting toward functional restoration projects that include implementation stormwater controls in urban areas (Palmer et al., 2014).

A better understanding of how restoring headwater streams will affect downstream water quality is needed in the literature. This study will provide data that can inform larger long-term studies about the impact of restoration on nutrient dynamics on headwaters and the downstream network. My ***overall research goal*** is to help answer the question of whether restoring headwater ecosystems can help mediate the effects of urbanization on streams.

In this study a pre-restoration dataset was collected to assess nutrient export in an unrestored forested, urban headwater system. This will serve as a resource to a post-restoration study of same system. The study characterized discharge and nutrient concentrations in headwater subwatersheds of variable landuses within an urban, forested, watershed. The nutrient export at baseflow was quantified for each subwatershed using 11 stream reaches throughout a year long, monthly, sampling.

Subwatershed nutrient loading was compared to the total watershed export of the Reedy Creek headwaters in Charlotte, North Carolina. Data was collected pre-restoration and the restoration construction began December 2017.

2 Research Questions

Q1: What are the controls of dissolved nutrient concentration for each watershed?

H1.1: Dissolved nutrient concentrations significantly vary with landuse. Nitrogen loading will be highest from the agricultural watershed. The developed watershed will have high loading of nitrogen and phosphorus compared to the control watershed.

H1.2: Dissolved nutrient concentrations do not vary with landuse

Q2: What is the effect of seasonality on dissolved nutrient concentrations?

H2.1: Both dissolved nitrogen and dissolved phosphorus will exhibit a seasonal trend in concentration across monthly samplings. There will be higher nutrient concentrations in the dormant season.

H2.2: There are no seasonal differences in dissolved nutrient concentrations.

3 Methods

3.1 Site Description

Reedy Creek is a 5.70 square kilometer forested headwater, stream located in the urbanized area of Charlotte, North Carolina (Figure 1). The watershed is divided into Upper and Lower headwater reaches where the confluence of the tributaries is located. The Upper headwater reaches are located within Reedy Creek Park with some tributaries found within a nature preserve. Because of the nature preserve the watershed is largely forested compared to the urban surroundings (Figure 2). The stream drains soil-covered hillslides typical of the Piedmont physiographic province, interspersed with bedrock outcrops of meta-quartz diorite and residual saprolite (1985 Geologic Map of North Carolina).

The watershed has a past landuse history of agriculture and the stream was seemingly straightened in the early 20th century. The levees on the bank of the stream are assumed to have been anthropogenically made and were most likely composed of the sediment that was removed from the stream during straightening. In many locations, the stream cut down into the geomorphic floodplain and the floodplain is no longer connected. The streambed is predominately sand and gravel with some sections composed of saprolite and bedrock.

Reedy Creek is a watershed embedded within urban landuse and demonstrates characteristics of a stream affected by urban stream syndrome (Figure 3). Reedy Creek has a flashy hydrograph and heavy sediment loads. In the main channel, poor macroinvertebrate diversity is found, although in some of the tributaries the macroivertebrate NCBI scores are good to excellent during certain times of the year. The flashy discharge has channelized the gravel and sand-bed stream, reducing the amount of geomorphic features present. The banks of the stream are subjected to a high degree of incision. Large amounts of vegetation have been removed from the banks of the channel.

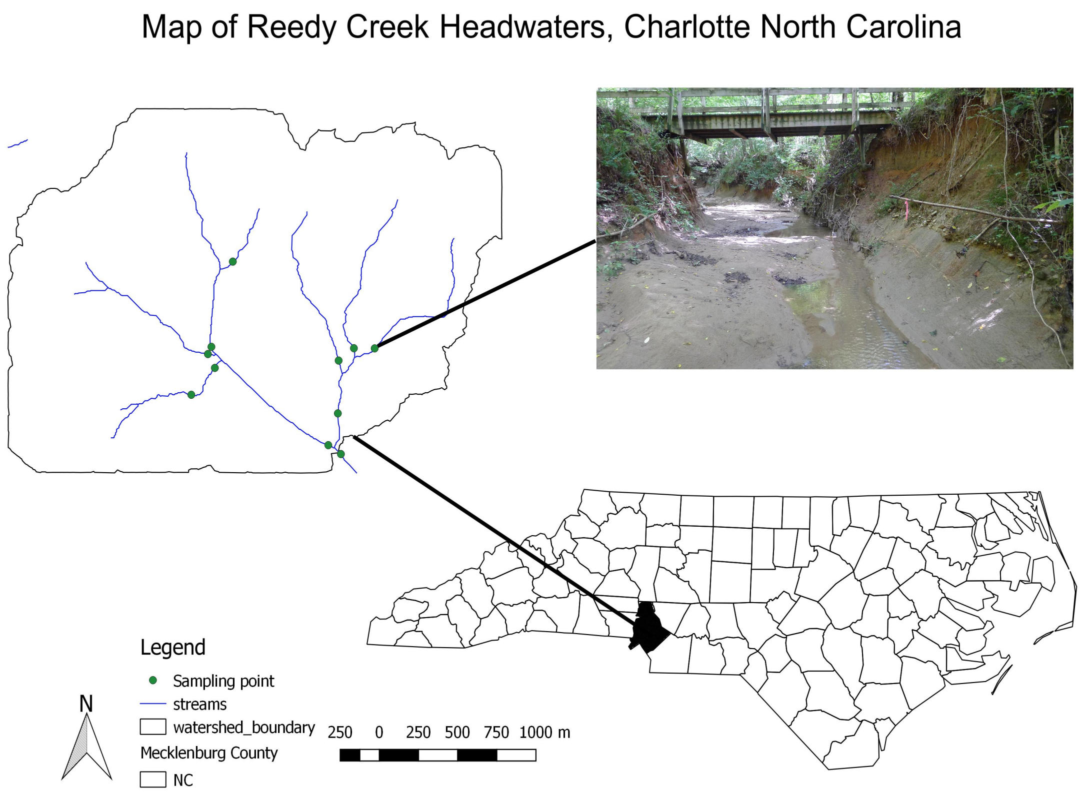

Figure 1. Site map of Mecklenburg County North Carolina, the outline of the watershed with tributaries and sampling points, and an in-stream view at site D1.

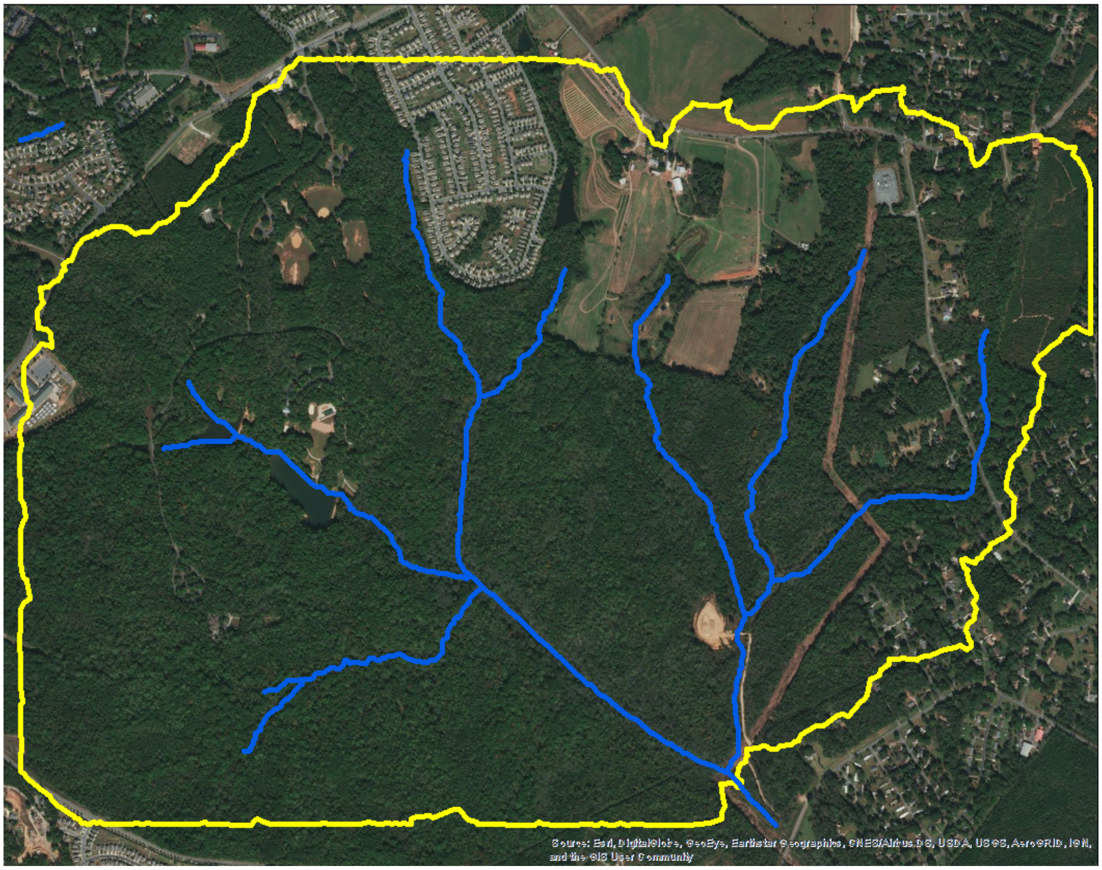

Figure 2. Aerial photograph of the Reedy Creek Headwaters outlined in yellow, streams in blue.

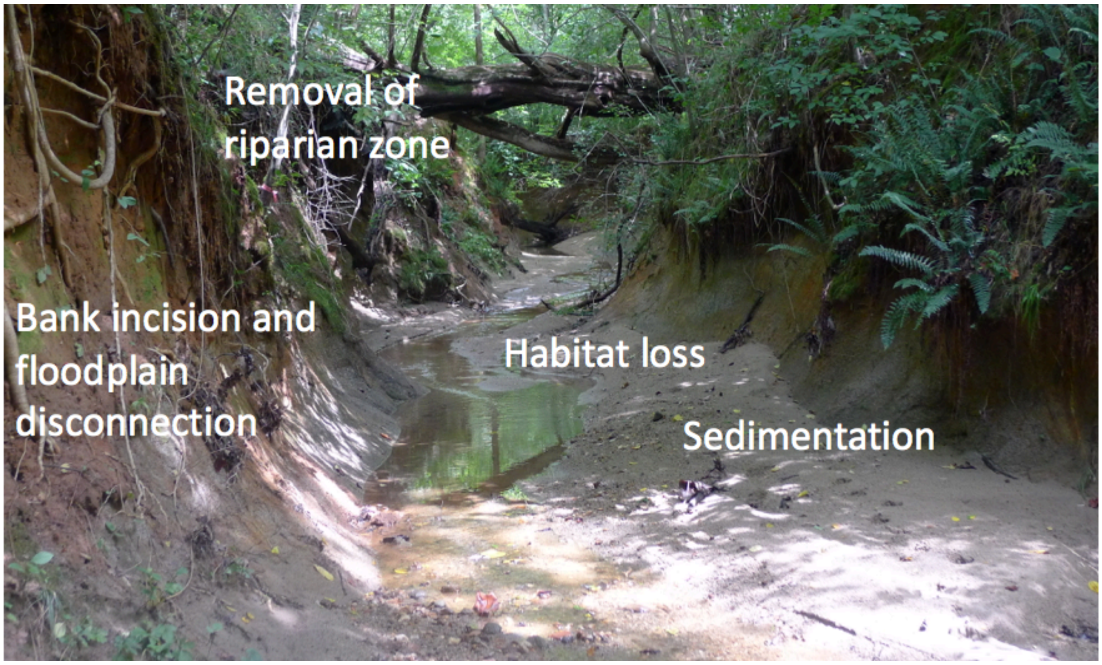

Figure 3. Image of Reedy Creek labeled to demonstrate symptoms of the Urban Stream Syndrome (Walsh et al., 2005).

Because Reedy Creek displays the indications of urban stream syndrome, the Reedy Creek Watershed was selected for stream restoration to improve the current state of the stream. In the original Reedy Creek Restoration Monitoring Project design by McMillan and Clinton, the Reedy Creek Watershed was sub-divided into 5 different reaches or subwatersheds based on landuse. Figure 4 shows a classified raster image from the 2012 Mecklenburg County Landcover/ Tree Canopy dataset. There is an undisturbed forested control (C) subwatershed, a pond-influenced (P) subwatershed, a developed subwatershed (D), and an agricultural subwatershed (A). The lower reaches of the Creek form the mainstem of the creek that are no longer first order, headwater, streams. The lower reaches are the (R) watershed outlet.

The percent forested and percent impervious cover, derived from the classified raster image using ArcGIS, differentiate each of the subwatersheds. The control subwatershed is 98% forested cover. The developed subwatershed is 13% impervious cover. The agricultural subwatershed is 61% forested with 28% cultivated land. The pond subwatershed is 89% forested but contains a pond with 2% water cover (Table 1, Figure 4). All landuse subwatersheds, and the total Reedy Creek watershed (R1), are forested when compared to the urbanized region of Mecklenburg county which has lower forested cover and higher impervious cover overall (Figure 5).

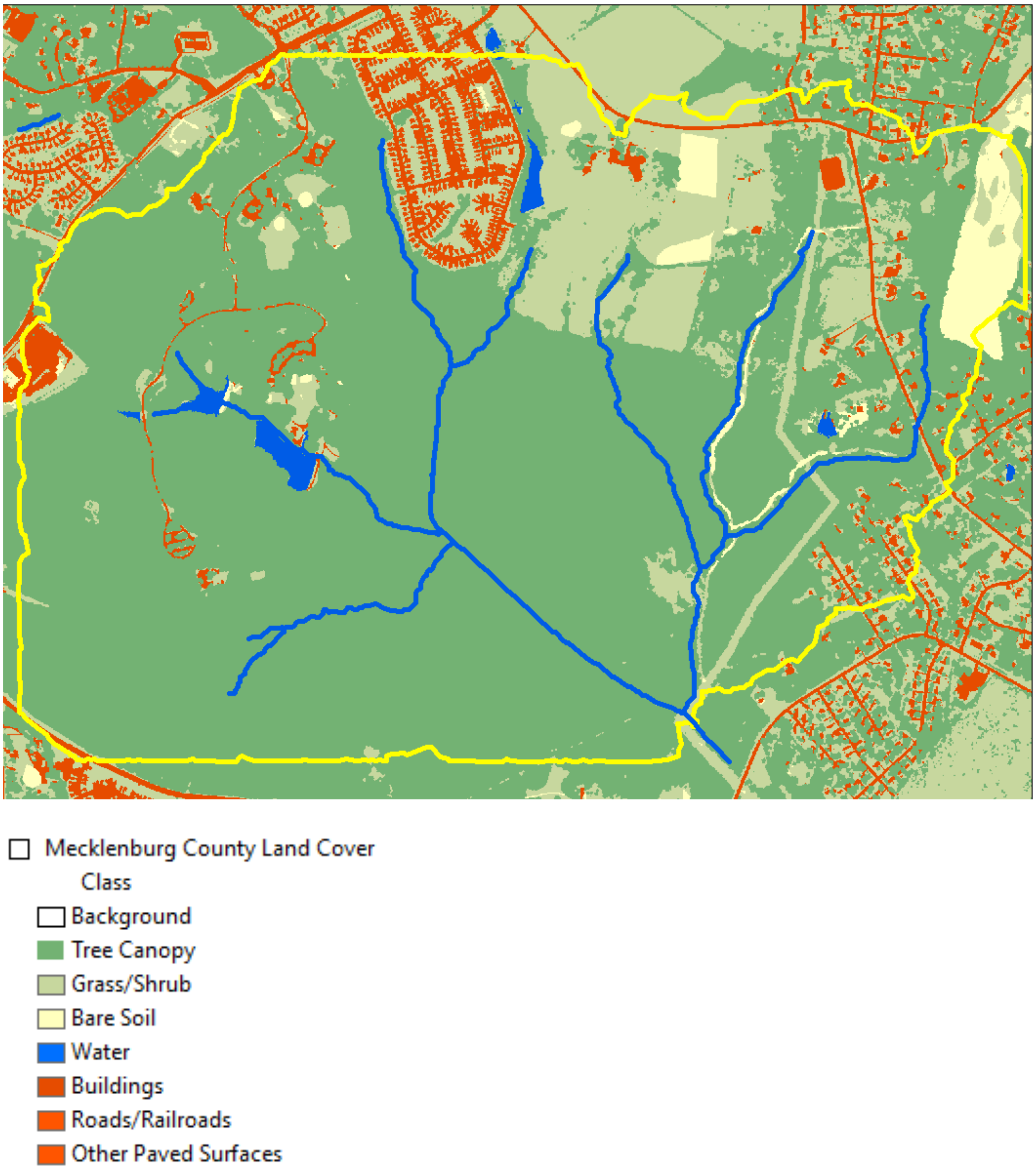

Figure 4. Map of 2012 Mecklenburg County Tree Canopy/ Landcover dataset for the Reedy Creek Watershed. Each of the seven land cover classifications is shown in the legend. The watershed boundary is outlined in yellow. Red represents areas of development. Dark green represents tree canopy. Blue represents water. Pale yellow represents bare soil and light green represents grassland.

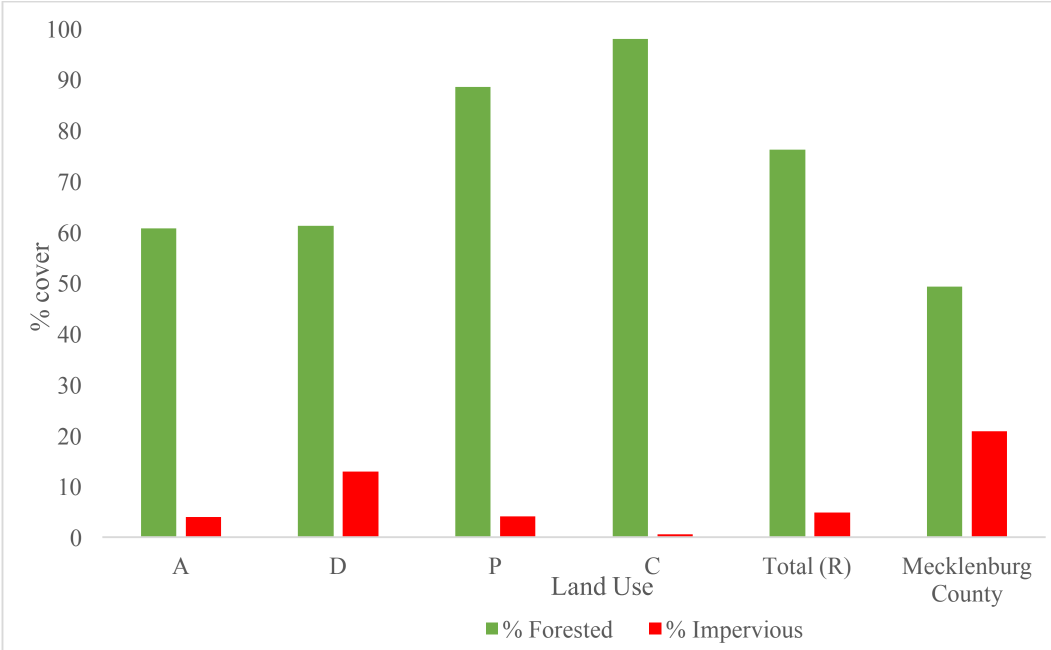

Figure 5. Each landuse subwatershed, the total Reedy Creek watershed (R) compared to all of Mecklenburg County for % forested cover and % impervious cover.

The forested section of the watershed will serve as a control and will not be restored, while the remainder of the watershed undergoes restoration. The control in Reedy Creek, the C2 site, (Figure 6) was selected because it exhibits a lack of incision in the subwatershed which is primarily found in the undeveloped nature center preserve.

The sampling within the control watershed was set up differently than the other watersheds because sampling sites C2 and C1 are located on the same tributary. This is because C1 is located at the outlet of the watershed but exhibits areas of backwatering that do not reflect the conditions like the rest of the control watershed. For this reason, the C1 sampling site will undergo restoration and the control sampling site was moved further upstream to the C2 site. However, C2 is not a watershed outlet. Nevertheless, C2 is treated as a subwatershed for the purposes of this project. All sampling points are shown as green dots and represent a designated transect that is just above the confluence with the mainstem of Reedy Creek. All other sampling points are located at the confluence of the headwater tributaries.

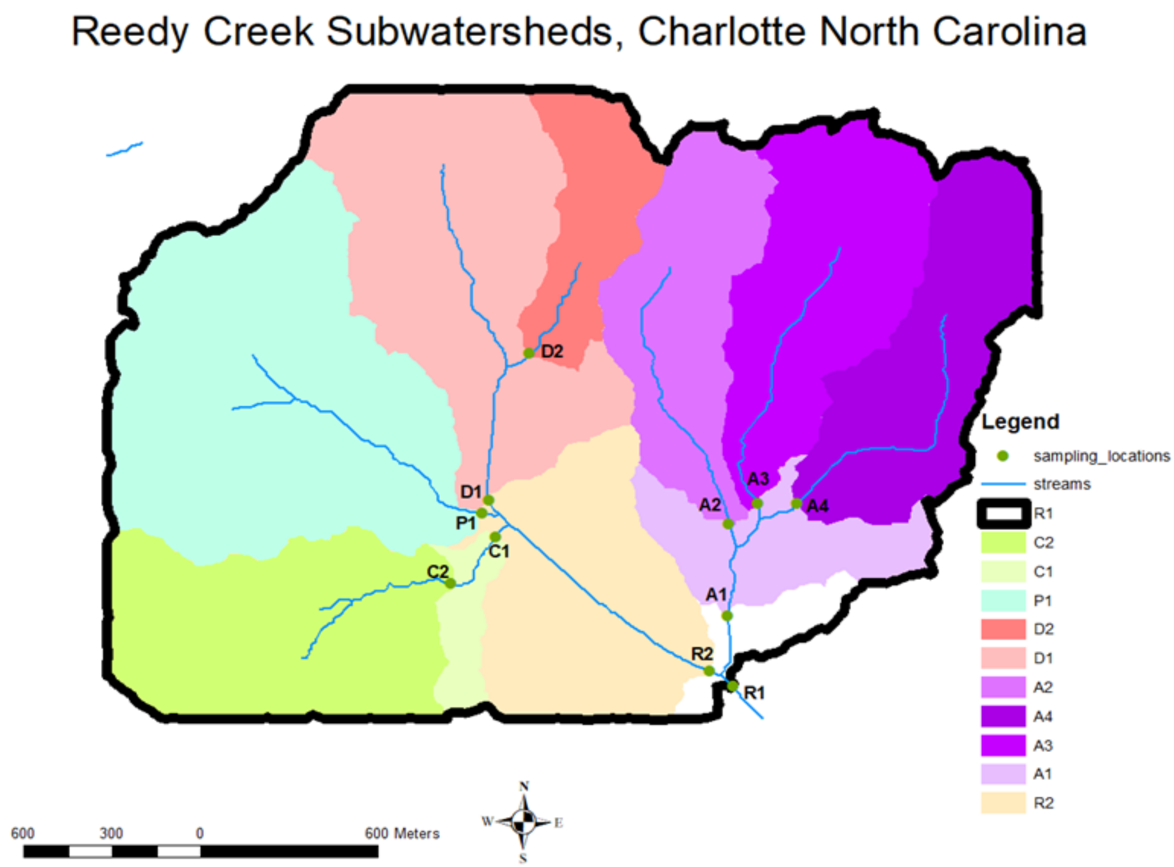

Figure 6. Map of subwatersheds. The pour point of each subwatershed shown as a green dot with the site label. Each outline shows a separate watershed delineated from each watershed all nested within the larger watershed of the Reedy Creek headwaters. The agricultural sunwatershed (A) in purple, the developed subwatershed (D) in red, the pond subwatershed (P) in blue, the control watershed (C) in green and the mainstem outlet (R) in orange. The total Reedy Creek Headwaters is outlined in black defined by the R1 pour point.

Each sampling point was used as a watershed pour point to divide the landuse subwatersheds further into smaller tributary-scale subwatersheds (Figure 6). The agricultural subwatershed drains into the A1 watershed shown in light purple and contains the A2, A3 and A4 subwatersheds. The developed subwatershed drains into the D1 watershed and contains the D2 subwatershed. The control subwatershed drains into the C1 and contains the C2 watershed. R2 is the watershed defined by the mainstem of Reedy Creek above the confluence with the agricultural watershed. R1 is the total Reedy Creek headwaters outlined in black that encompasses all the other subwatersheds and is the outlet from the headwaters. The percent landuse within each subwatershed varies across seven classifications as designated by the 2012 Mecklenburg County Tree Canopy/ Landcover dataset (Figure 4, Figure 5,Table 1). For reference, the UNC Charlotte pre-restoration site names listed above are presented with the Wildlands Restoration site names in Appendix A.

Table 1. Percent land cover within each subwatershed based on the 2012 Mecklenburg County Tree Canopy/ Landcover datatset. The landcover was classified into five categories as buildings, roads, and other paved surfaces were all considered impervious cover (Figure 4).

Subwatershed	*% Impervious Cover*	*% Forested Cover*	*% Grass/shrub Cover*	*% Bare Soil Cover*	*% Water Cover*
A1	4	61	28	7	0
A2	2	46	46	7	0
A3	6	62	30	1	0
A4	4	64	14	17	1
R1	5	76	16	3	1
R2	6	84	9	0	1
P1	4	89	5	0	2
C1	1	98	1	0	0
C2	1	98	2	0	0
D1	13	61	24	1	1
D2	7	38	51	1	4

3.2 Watershed Area

Esri ArcGIS® Arcmap™ 10.6 was used to find the total area of the watershed that drains to the United States Geologic Survey (USGS) discharge gage 0212427947. Watershed area, or drainage area, was calculated for all 11 subwatersheds defined by the site sampling points (Figure 6).

3.3 Baseflow Discharge

3.3.1 Antecedent Conditions

The Antecedent Precipitation Index (API) is a metric that describes watershed wetness as a running day by day measurement based on the rainfall that has occurred over the preceding days. An API was used to determine the amount of cumulative precipitation 2 and 7 days prior to the sampling date (Equation 1). Precipitation data were downloaded from the USGS 351540080430045 CRN-16 rain gage at Reedy Creek Park Environmental Center. Without rain, the watershed wetness recesses by a factor of *K*. A constant, year-round, value of 0.88 was used as *K* is usually between 0.85 and 0.90 over most of the eastern and central portions of the United States, according to Kohler and Linsley (1951). Kohler and Linsley (1951) also state that the recession factor *K* is a function of physiographic characteristics of the basin, but most basins fall within the above range.

Equation 1 $$API(t) = K * P_{t-1} + K2 * P_{t-2} + K3 * P_{t-3} \dots K7 * P_{t-7}$$

API of day t, Pt-1 , Pt-2 , ... , Pt-3 , Pt-15, ... is the rainfall of 1, 2, ..., 7, ... days before day t, K is daily recession coefficient. K is 0.88, and the day numbers of attenuation is 7 in this study.

3.3.2 Stream Gage Baseflow Discharge

Discharge data from the Reedy Creek mainstem outlet USGS gage (0212427947 Reedy Creek at SR 2803 NR Charlotte, NC) was downloaded from the gage station, for each sampling date from May 2016- October 2017. All discharges for all sampling dates were approved for publication by the USGS. The gage is located in Mecklenburg County, North Carolina, Hydrologic Unit Code, 03040105. The latitude was 35°15'23", the longitude was 80°42'02" NAD83, and the drainage area 5.7 square kilometers. Gage datum was 637.45 feet above NAVD88. Average daily data that corresponded with sampling date was used to determine average discharge in L/s from the R1 study area on each surface water sampling date.

3.3.3 Ungaged Field Discharge Measurements

Ungaged field measurements were taken using the velocity-area method (Levesque and Oberg, 2012). An unobstructed cross-section (Figure 7) over which to take measurements was defined by a measuring tape to divide the channel into equal sections. The depth and width of each section were determined. The velocity was measured with a Swoffer Velocity Meter (meters/second). The 0.6 rule found the appropriate depth for the measurements and the velocity was averaged at each station for 60 seconds. The cross-sectional area for each stream subsection was calculated. The cross-sectional area for each stream subsection was multiplied by the velocity to calculate discharge in m^3/s and multiplied by 1000 to get L/s. Discharge from each subsection was summed to obtain the total discharge at the stream cross-section. A cross-section was set up and field measurements taken at each of the 11 sites.

Figure 7. Cross-section of Reedy Creek headwater measurements at baseflow. Image intended to show average size of cross-sections not to demonstrate field technique.

3.4 Estimated Discharge

3.4.1 Drainage Area Ratio Approach

To determine the discharge of the tributaries on dates during the study period when discharge measurements were not collected the drainage area ratio discharge estimation was used. The drainage area ratio was calculated by dividing the area of the ungaged watershed by the gaged area. This ratio was multiplied by the known gage discharge to determine discharge at the ungaged site. This approach assumes that discharge scales with drainage area.

The drainage area ratio method is most appropriate to estimate discharge from an ungaged tributary when the ungaged site is on the same stream as a stream-gaging station (Flynn, 2003). Therefore, this method can be applied to the Reedy Creek study site. The accuracy of the drainage-area ratio method is dependent on how close the gaged and ungaged sites are to each other, similarities in the drainage area, and other physical and climatic characteristics of the drainage basins, (Ries and Friesz, 2000). Equation 2 was used to calculate the drainage area ratio for Reedy Creek according to the method by State of Ohio Environmental Protection Agency Division of Surface Water (2006).

Equation 2 $$Q_{ungaged} = \frac{Aungaged}{Agaged} x\ Qgaged$$

$Q_{ungaged}$: Flow at the ungaged location

Q_{gaged}: Flow at surrogate USGS gage station

$A_{ungaged:}$ Drainage Area of the ungaged location

$A_{gaged:}$ Drainage Area at surrogate USGS gage station

3.4.2 Concurrent Flow Approach

To determine the discharge of the tributaries on dates during the study period when discharge measurements were not collected the concurrent flow discharge estimation was used (Flynn, 2003). Discrete measurements of discharge were taken on 8/28/17, 9/20/17, 10/18/17 and 10/20/17. All measurements were taken at the same cross-section on each of the ungaged tributaries of interest. Measured flows were then related to the concurrent flow at the nearby stream-gaging station, located just below the R1 sampling point, by regression analysis to determine the baseflow value at the ungaged reach. The equation of the regression line estimated the discharge from the gage data at time points where field measurements were not taken.

The concurrent flow approach generally provides more reliable estimates of low-flow characteristics than other methods in which discharge measurements are not used (Parrett and Cartier, 1990) the two basins should be similar in size, geology, topography, and climate.

3.5 Chemical Analysis for Dissolved and Particulate Constituents

3.6 Sample Collection

Baseflow surface water sampling occurred monthly from May 2016 through October 2017 at 11 transects currently established at Reedy Creek (Figure 5). Grab sampling technique was used for surface water samples with one sample collected at each site.

3.6.1 Nitrate, Phosphorus, and Ammonium

Surface water grab samples were filtered through Whatman (GF/F; 0.7µm) glass microfiber filters. Once filtered, samples were stored in 50mL centrifuge tubes and stored in the freezer until analysis. Water samples were analyzed for dissolved nutrients (ammonia, nitrate, and phosphate). Nitrate/Nitrite concentrations (mg N/L) were found using the QuikChem® Method 10-107-04-1-A, which has a detection limit of 0.01 mg N/L. Orthophosphate was assessed using the QuikChem® Method 10-115-01-1-A methods and has a detection limit of 0.3 µg P/L. To complete the analysis for ammonia, the QuikChem® Method 10-107-06-1-C was implemented and had a detection limit of 0.004 mg/N. Concentrations that were found to be below the detection limits for analysis, but were greater than zero, were halved (EPA, 1990).

3.6.2 Total Suspended Solids

Total Suspended Solids (TSS) are suspended or colloidal particles. The samples were filtered using a 0.45 micron filter. The filter was pre-weighed and recorded in grams prior to the passing of the water, and weighed again after the sample was passed through the filter. The volume of water filtered was also recorded. The difference between the two weights divided by the volume of water resulted in the TSS concentration in mg/L.

3.6.3 Total Phosphorus

Total Phosphorus (TP) was analyzed according to the USEPA 1978 method number 365.3. The samples were collected and refrigerated at 4°C until analyzed. The method used was specific to orthophosphate ion. The method has a detection limit of 0.01 to 1.2 mg P/L. For concentrations that were below the detection limit, the measured concentration was halved for use in data analysis (EPA, 1990). TP was measured by direct colorimetric analysis procedure using a spectrophotometer. The color is proportional to the total phosphorus concentration in mg/L.

3.7 Watershed Export and Loading

Watershed export for each concentration (ammonium, phosphate, nitrate, TSS and TP) was calculated by multiplying the estimated discharge by concentration for each subwatershed (Equation 3). Loading was then calculated by dividing the export by the watershed area of each subwatershed (Equation 4).

Equation 3. Export $(\frac{mass}{time})$ = Discharge $(\frac{m^3}{s})$* Concentration $(\frac{mg}{L})$

Equation 4. Loading $(\frac{mass}{time*length^2})$= $\frac{\text{Export}}{\text{Watershed Area}}$ $(\frac{mg}{s\ km^2})$

Watershed loading for each subwatershed for each sampling date was calculated in (g/day*hectare), except for sites P1 and C1. To get an estimate of annual loading, months where there were two sampling dates within the study (May 2016 and May 2017, June 2016 and June 2017, July 2016 and July 2017, August 2016 and August 2017, September 2016 and September 2017, October 2016 and October 2017) were averaged together. The loadings for each month of the year were then multiplied by the number of days in the month and summed to get an approximate yearly loading value in kg/hectare for both the drainage area ratio loading and the concurrent flow loading.

3.8 Missing data

When analysis for sample concentrations was performed, site A2 was not analyzed for ammonium, phosphate, nitrate, TSS or TP on the date 9/20/2016 because no sample was taken at this site on this date. Site C2 was not analyzed from ammonium, phosphate, nitrate, TSS or TP on the date 5/31/16 because no sample was taken at this site on this date. For TP samples R2 (10/25/16), P1 (11/16/16), and D1 (2/17/17) were not analyzed because the samples could not be located. These sites and dates concentration data were not included in any of the analysis performed or in loading calculations.

3.9 Data Analysis

The distributions of the data for ammonium, nitrate, phosphate, TSS, TP were checked for normality and were determined to have a normal distribution that allowed t-tests and ANOVA statistical analyses to be appropriate. A regression analysis was done to analyze the relationship between concentration and % impervious or % forested cover. To determine seasonal differences among the subwatersheds the eighteen sampling dates from May 2016 to October 2017 were separated into dormant and growing season for each individual sampling site. Dormant season is from October to March, growing season from April to September. A two-tailed student's t-test was used with a 95% confidence interval to determine if there were significant differences in nutrient concentration between growing season and the dormant season for each subwatershed and site.

The constituent concentration data were analyzed for site and seasonal differences and their interaction were analyzed using a two-way ANOVA. For those that were significant by the ANOVA, a post-hoc mean comparison was done to examine the significant seasonal and site differences with an all pairs Tukey HSD.

The loading data for sites A1, R2, C2, D1 and R1 were analyzed using two-way ANOVA for significant differences between site and season as well as the interaction term of site*season. To compare concurrent flow loading between growing and dormant season a post-hoc Tukey HSD mean comparison was performed for each analysis.

4 Results

4.1 Watershed Area and Drainage Area Ratio

The results of the Esri ArcGIS® Arcmap™ and the USGS Streamstats area approximations of watershed area and the results drainage area ratio calculation are shown in Table 2. The ArcGIS® watershed area and the stream stats areas were very similar. The ArcGIS® areas were used in all calculations. The drainage area ratio is the ratio of the subwatershed area to the total watershed area defined by R1. Site R1 was treated as the pour point of the total watershed with an area of 5.70 km^2 and has a drainage area ratio of 1.

R2, with an area of 3.96 km^2 and a drainage area ratio of 0.65, was nested within the R1 watershed. The Pond-influenced watershed had an area of 1.18 km^2 and a drainage area ratio of 0.21 and was found within the R2 watershed. The D2 subwatershed had an area of 0.27 km^2 and a drainage area ratio of 0.05 and was nested within the D1 subwatershed which had an area on 1.15km^2 and a drainage area ratio of 0.20. The P1 and D1 watershed were of comparable size and had similar drainage area ratios. The C2 subwatershed had an area of 0.67 km^2 and a drainage area ratio of 0.12 and was nested within the C1 watershed which had an area of 0.77 km^2 and a drainage area of 0.14. A2, A3, and A4 were tributaries with small watershed areas of comparable size nested within the agricultural subwatershed delineated by the A1 pour point. Table 1 shows A2, A3, and A4 have watershed areas of 0.48 km^2, 0.60 km^2, and 0.55 km^2 respectively with small drainage area ratios while A1 has a watershed of 1.90 km^2 and a drainage area ratio of 0.33.

Table 2. Each sampling site as a pour point and the corresponding area and drainage area ratio for USGS Streamstats and GIS.

Watershed	*GIS Area Km²*	*Streamstats Area Km²*	*GIS (Aungaged/ Agaged)*	Streamstats (Aungaged/ Agaged)
A1	1.90	2.02	0.33	0.32
A2	0.48	0.49	0.08	0.08
A3	0.60	0.50	0.11	0.08
A4	0.55	0.59	0.10	0.09
R1	5.70	6.40	1.00	1.00
R2	3.69	4.24	0.65	0.66
P1	1.18	1.27	0.21	0.20
C1	0.77	0.88	0.14	0.14
C2	0.68	0.80	0.12	0.13
D1	1.15	1.45	0.20	0.23
D2	0.27	0.41	0.05	0.06

4.2 Baseflow Discharge

4.2.1 Antecedent Conditions and USGS gage discharge

Sampling for baseflow took place on dates with a total precipitation of 0 mm, except for dates 6/20/17 and 8/15/17 (Table 3), where there was measurable precipitation at the rain gage on those dates. Both dates were checked with the 5-minute precipitation from the USGS Reedy Creek Nature Center rain gage and precipitation occurred after the time of sampling. The average daily discharge recorded from USGS gage 0212427947 for each sampling date and the discharge in L/s was converted to runoff depth in mm/day (Table 3). The precipitation on the sampling date and the antecedent precipitation demonstrate a seasonal influence in the precipitation measurements with the highest API values in the growing season (Figure 8).

Table 3. Total precipitation on sampling date (mm), antecedent precipitation index two days prior to sample date (API 2) and seven days prior (API 7). Average discharge (L/s) recorded from USGS gage 0212427947 and runoff (mm/day).

Sampling date	*Total Precipitation (mm)*	*API 2 (mm)*	*API 7 (mm)*	*Average (R1) gage discharge (L/s)*	*Total watershed (R1) runoff (mm/day)*
5/31/16	0	2.2	2.2	45.1	0.68
6/20/16	0	0.0	6.7	32.2	0.49
7/28/16	0	11.8	11.8	42.1	0.64
8/4/16	0	31.3	31.3	57.8	0.88
9/20/16	0	0.0	0.0	14.5	0.22
10/25/16	0	0.0	0.0	9.0	0.14
11/14/16	0	0.2	0.2	7.0	0.11
12/7/16	0	17.7	34.0	10.7	0.16
1/19/17	0	0.0	0.1	9.5	0.14
2/17/17	0	7.9	8.5	37.9	0.57
3/16/17	0	4.9	10.2	61.4	0.93
4/28/17	0	0.4	58.4	29.2	0.44
5/26/17	0	16.0	59.1	133.9	2.03
6/20/17	15.7	3.4	30.6	50.4	0.76
7/25/17	0	19.3	19.3	14.3	0.22
8/15/17	1.02	13.4	46.6	58.2	0.88
9/20/17	0	0.0	0.1	16.0	0.24
10/18/17	0	26.2	28.3	8.5	0.13
10/20/17	0	0.0	21.9	8.1	0.12

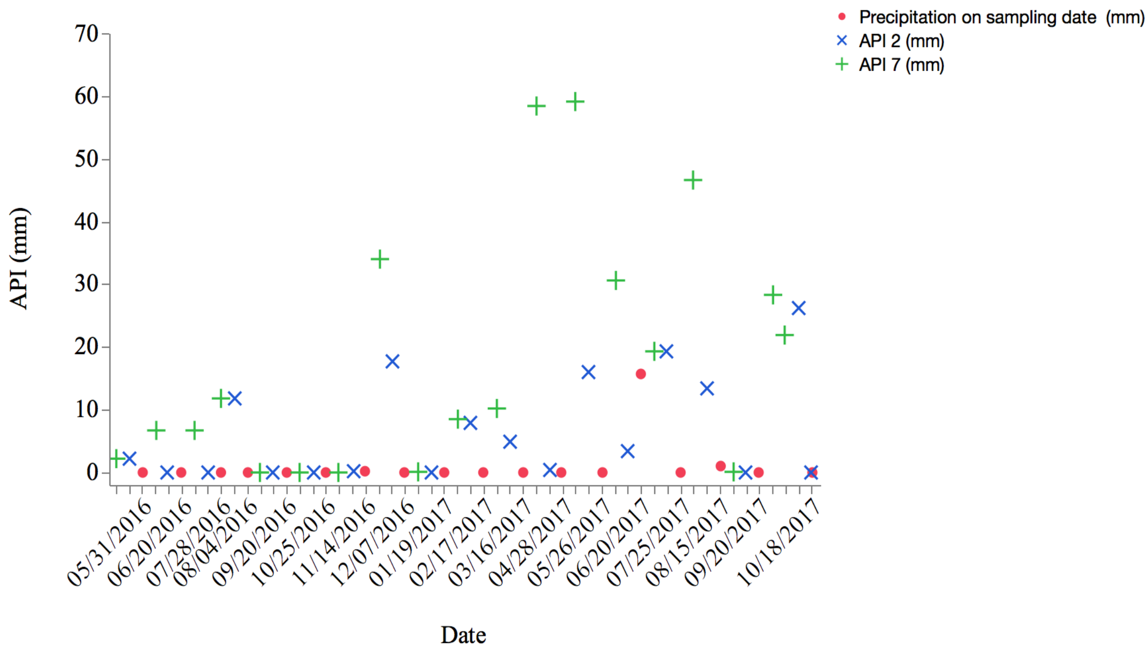

Figure 8. Precipitation in mm on sampling date (red circles), API two days prior to sampling (blue x's), API seven days prior to sampling (green pluses).

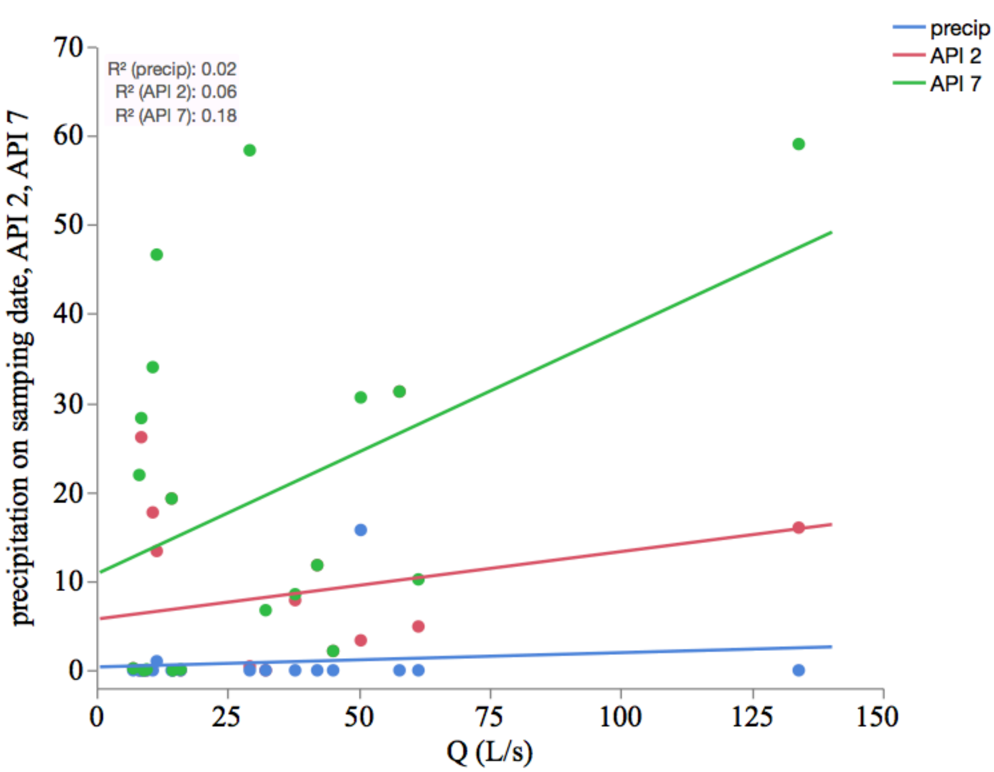

Figure 9. Regression relationship between measured discharge in L/s on sampling date and precipitation on sampling date (blue) p=0.573, API2 (red) p=0.331, and API 7 (green) p=0.068.

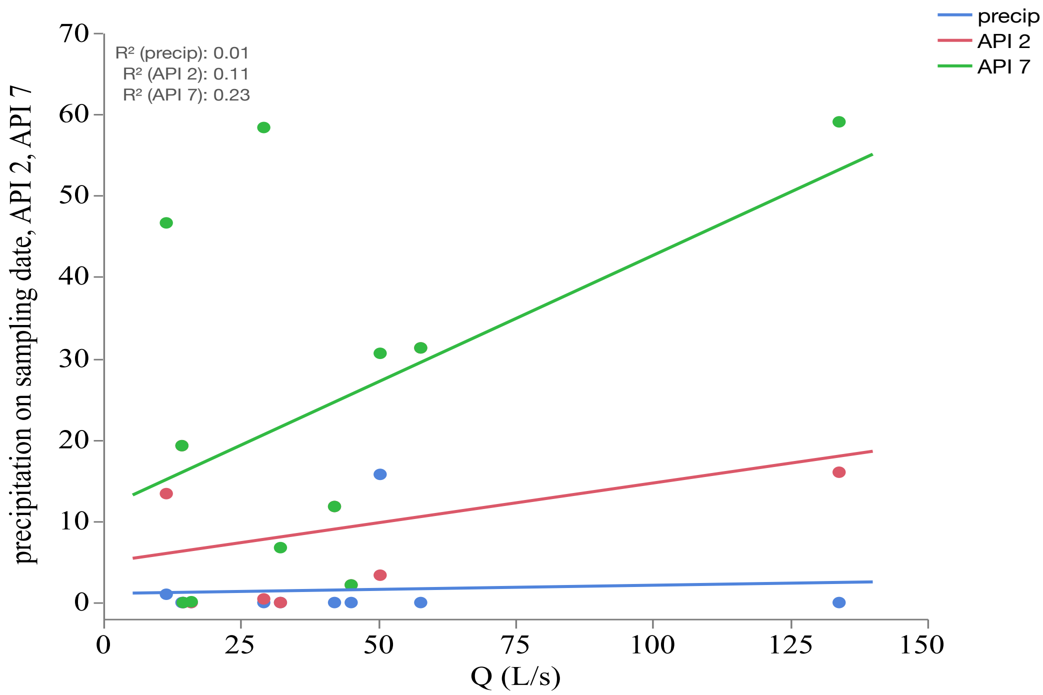

Figure 10. Growing season regression relationship between measured discharge in L/s on sampling date and precipitation on sampling date (blue) p= 0.0826, API2 (red) p=0.3240, and API 7 (green) p=0.136.

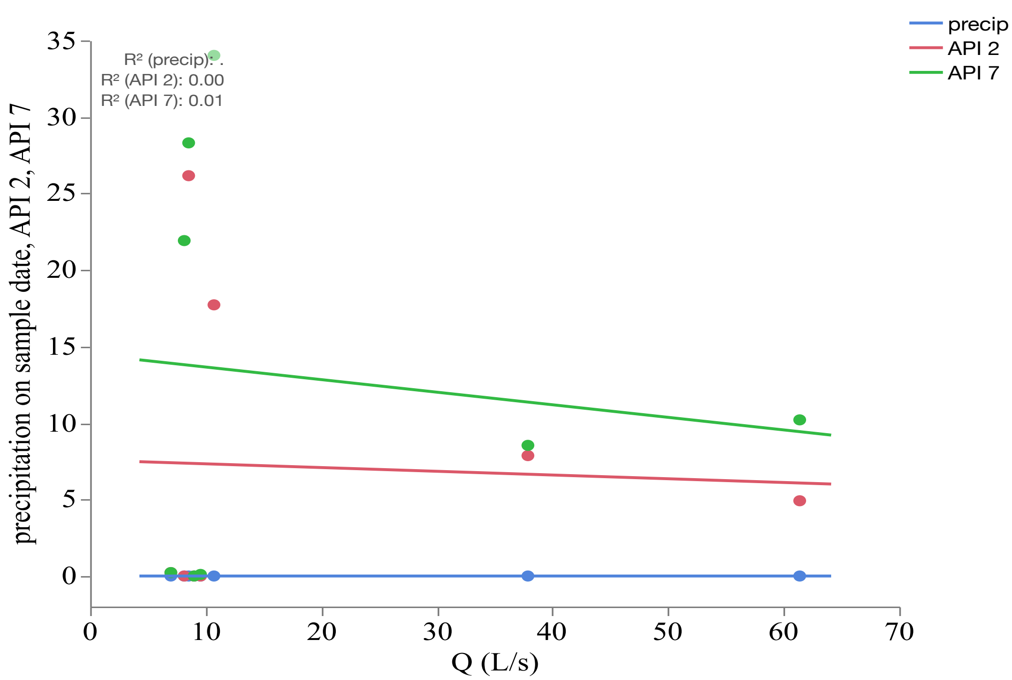

Figure 11. Dormant season regression relationship between measured discharge in L/s on sampling date and precipitation on sampling date (blue), API2 (red) p=0.908, and API 7 (green) p=0.775.

4.2.2 Stream-Gage Baseflow Discharge

4.2.3 Ungaged Field Measurements (velocity-area method)

Velocity-area discharge measurements were collected from each site on 4 dates in 2017 (Table 4). Discharge was lowest in October compared to August and September reflecting the drier conditions. Across all dates the measurements at each site are generally the same order of magnitude. No flow indicates that there was water in the stream but velocity measurements were not able to be taken with the Swoffer velocity meter. As expected, R1 and R2 on the mainstem have higher measured discharges than the smaller tributaries.

Table 4. Field velocity-area discharge measurements by site (L/s). Sites with no reported values were not measured on those dates. No flow indicates that there was water in the stream but flow was not detectable by the velocity meter.

Site	*8/28/17*	*9/20/17*	*10/18/17*	*10/20/17*
A1	2.02	2.46	0.7	-
A2	-	2.22	0.84	-
A3	-	0.68	0.04	-
A4	-	0.3	no flow	-
R1	-	14.63	5.43	-
R2	6.60	12.49	5.14	-
C1	-	1.17	-	1.98
C2	1.87	1.18	-	0.66
D1	2.00	1.64	-	0.1
D2	-	0.13	-	no flow
P1	0.89	0.86	-	no flow

The field measurements tended to under-estimate flow based on the 2 dates where field measurements were taken and compared to the USGS gage at R1 (Table 5). For both dates the field measurements and the gage measurements were the same order of magnitude but the percent difference on 10/18/17 was greater.

Table 5. Calculated difference between the R1 USGS gage discharge measurements and the R1 velocity-area field measurements.

Date	*R1 USGS Gage*	*R1 measured*	*% difference*
9/20/17	16.02	14.63	9
10/18/17	8.52	5.43	36

4.3 Estimated Discharge Approaches

4.3.1 Drainage Area Ratio

Sites C1 and P1 were not estimated by the drainage area ratio approach and are not included in the watershed loading and export calculations, unless the discharge was measured in the field. Site P1 acted hydrologically differently from the other sites because of the pond present in the subwatershed. Site C1 had areas of backwater which affected accurately taking discharge measurements.

Site R1 represented the total gaged watershed area and so had a drainage area-ratio of 1. The ratios of ungaged area to gaged area were summarized in Table 2. The estimated discharge values were summarized and compared to the other methods in Table 8.

4.3.2 Concurrent Flow

To use the concurrent flow approach, three measured discharge points at each ungaged tributary were regressed against the R1 gage discharge for sites A1, R2, C2, and D1. Not all sites had three field measured discharge points. The regression relationship graphs are shown in Appendix B.

Equations were used to predict discharges at sites A1, R2, C2, and D1 from the R1 gage discharge values for dates when no field measurements were taken (Table 6). The estimated discharge values are summarized with the other methods in Table 8.

R2 (R^2= 0.96) and A1 (R^2= 0.84) had strong relationships between the gage and the ungaged site derived from the concurrent flow approach. The C2 (R^2= 0.10) and D1 (R^2= 0.46) had weak relationships. Despite the low R^2 the concurrent flow method was closest to the field measured discharges and were based on the gage discharge results.

Table 6. Concurrent Flow approach for applicable sites with the equation of the regression line used to estimate discharge at each site and the R^2.

Site	*Equation of Regression Line*	R^2
A1	y=0.2223x-0.9431	0.84
R2	y=1.0065x- 4.0074	0.96
C2	y= 0.0506x + 0.63	0.1
D1	y= 0.1813x- 0.9288	0.46

4.4 Comparison of Gaged and Ungaged Discharge Results

Overall, the drainage area ratio method overestimated discharge compared to field measured discharge. In both figures, the zero indicates flows that were too small to measure with the velocity meter but were not necessarily dry and most likely underestimated flow for the field measured discharge at A4, P1, and D2 on 10/18/17.

Several sites had large differences between the measured discharge and the area predicted discharge as indicated by the gray highlights in Table 7 (A1, R1, D1, P1 for 10/18/17; A1, R1, P1, D1 for 9/20/17). Field measurement error on 10/18/17 at R1 might explain the difference between this value and the area predicted value (Figure 13) since it was not close to the value from the USGS gage (Table 5).

For both dates the difference between the measured discharge and the area predicted discharge are greatest for the mid-sized compared to the smallest and largest watershed areas (Table 7, Figures 12-13). From this analysis the study areas least likely to be represented correctly by the area relationship are A1, P1, R2 and D1 because of the size of the watershed tends to over approximate discharge in the drainage area ratio method.

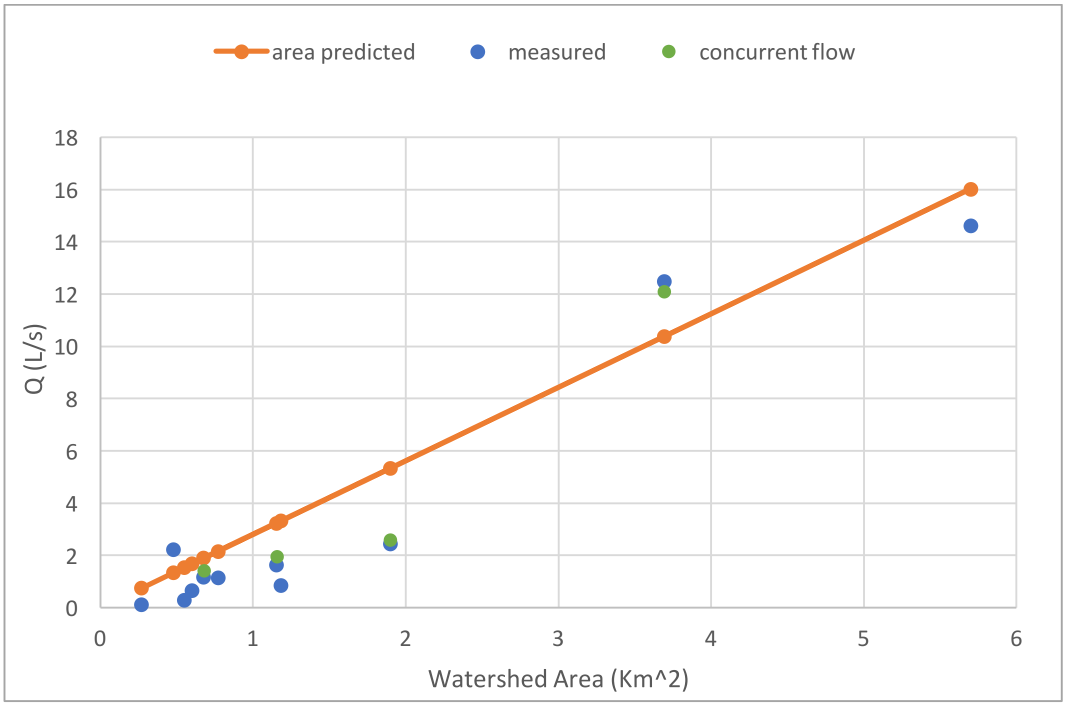

Figure 12. Relationship between watershed area and discharge for 9/20/17. Blue shows the measured discharge for each site based on the corresponding watershed area. Orange shows the drainage area ratio approximation and green shows the concurrent flow approximation.

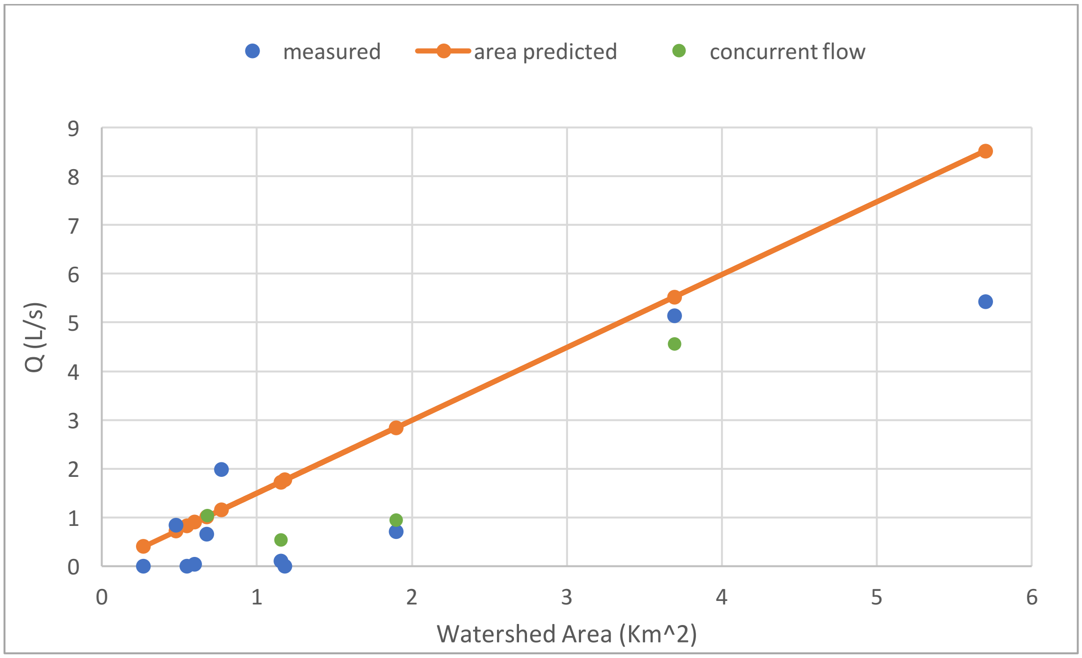

Figure 13. Relationship between watershed area and discharge for 10/18/17. Blue shows the measured discharge for each site based on the corresponding watershed area. Orange shows the drainage area ratio approximation and green shows the concurrent flow approximation.

Table 7. Data used in figures of the discharge, watershed area relationship. Watershed area for each site, field measured discharge and the drainage area ratio predicted discharge and the difference between the two measurements. Grey highlights represent largest differences.

Date	*Site*	*Watershed Area (Km^2)*	*Field measured discharge (L/s)*	*Drainage area ratio discharge (L/s)*	*Difference (measured-predicted)*
9/20/17	A1	1.90	2.455	5.33	2.88
	A2	0.48	2.22	1.34	-0.88
	A3	0.60	0.675	1.69	1.01
	A4	0.55	0.3	1.54	1.24
	R1	5.70	14.63	16.02	1.39
	R2	3.69	12.485	10.38	-2.11
	P1	1.18	0.858	3.32	2.46
	C1	0.77	1.165	2.17	1.00
	C2	0.68	1.18	1.90	0.72
	D1	1.15	1.64	3.24	1.60
10/18/17	A1	1.90	0.7	2.84	-2.14
	A2	0.48	0.84	0.71	0.13
	A3	0.60	0.04	0.90	-0.86
	A4	0.55	0	0.82	-0.82
	R1	5.70	5.425	8.52	-3.10
	R2	3.69	5.14	5.52	-0.38
	P1	1.18	0	1.77	-1.77
	C1	0.77	1.98	1.15	0.83
	C2	0.68	0.66	1.01	-0.35
	D1	1.15	0.1	1.73	-1.63
	D2	0.27	0	0.40	-0.40

Table 8. Discharge estimations for dates that had area ratio discharge, concurrent flow discharge, and measured discharge in L/s. Concurrent flow runoff depth and measured discharge runoff depth are also reported in (mm/day). * not good candidates for discharge approximation

Date	*Site*	*Area ratio discharge (L/s)*	*Concurrent flow discharge (L/s)*	*Measured discharge (L/s)*	*Concurrent flow runoff depth (mm/day)*	*Measured runoff depth (mm/day)*
8/28/17	A1	3.8	1.6	2.0	0.07	0.09
	A2	0.1	-	-	-	-
	A3	1.2	-	-	-	-
	A4	1.1	-	-	-	-
	R1	11.5	11.5	-	0.17	-
	R2	7.4	7.5	6.6	0.18	0.15
	P1*	-	-	0.9	-	0.07
	C1*	1.6	-	-	-	-
	C2	1.4	1.2	1.9	0.15	0.24
	D1	2.3	1.2	2.0	0.09	0.15
	D2	0.5	-	-	-	-
9/20/17	A1	5.3	2.6	2.5	0.12	0.11
	A2	1.3	-	2.2	-	0.40
	A3	1.7	-	0.7	-	0.10
	A4	1.5	-	0.3	-	0.05
	R1	16.0	16.0	14.6	0.24	0.22
	R2	10.4	12.1	12.5	0.28	0.29
	P1*	-	-	0.9	-	0.06
	C1*	2.1	-	1.2	-	0.13
	C2	1.9	1.4	1.2	0.18	0.15
	D1	3.2	1.1	1.6	0.15	0.12
	D2	0.8	-	0.1	-	0.04
10/18/17	A1	2.8	0.1	0.7	0.04	0.03
	A2	0.7	-	0.8	-	0.15
	A3	0.9	-	0.04	-	0.01
	A4	0.8	-	no flow	-	no flow
	R1	8.5	8.5	5.4	0.13	0.08
	R2	5.5	4.6	5.1	0.11	0.12
10/20/17	P1*	-	-	no flow	-	no flow
	C1*	1.1	-	2.0	-	0.22
	C2	0.1	1.0	0.7	0.13	0.08
	D1	1.7	0.6	0.1	0.04	0.01
	D2	0.4	-	no flow	-	no flow

When discharge methods were compared, the concurrent flow approximation is closer to the measured discharge value as indicated by similar runoff depth values (Table 8). Because there was a range of estimated discharge values, a range of loading for all sites was calculated using the three discharge values for applicable dates and sites. Statistical analysis was performed only on the concurrent flow loading. The concurrent flow discharge was a good approximation for the measured values and had a sample size of n= 18 for each site to include all sampling dates. The discharge estimation from the concurrent flow method is expressed as a runoff depth in Table 9. Cumulative concurrent flow discharge curves for each of the applicable watersheds indicates that the mainstem has higher discharge than the headwater tributaries (Figure 14). Concurrent flow discharge was used to approximate baseflow downstream constituent loading for all study dates.

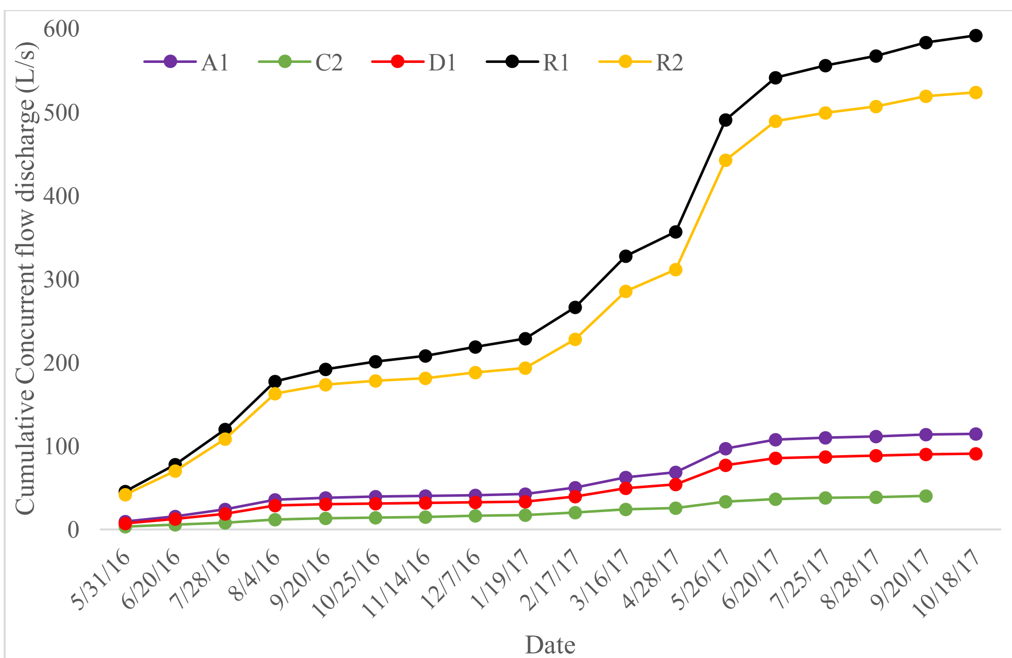

Figure 14. Cumulative concurrent flow discharge curve for sites A1 (purple), C2 (green), D1 (red), R1 (black), R2 (yellow) over the course of the study.

Table 9. All dates, runoff depth in mm/day based on the concurrent flow discharge prediction.

Date	*Site*	*Concurrent flow runoff depth (mm/day)*	*Date*	*Site*	*Concurrent flow runoff depth (mm/day)*
5/31/16	A1	0.41		C2	0.15
	R1	0.68		D1	0.08
	R2	0.97	1/19/17	A1	0.05
	C2	0.37		R1	0.14
	D1	0.54		R2	0.13
6/20/16	A1	0.28		C2	0.14
	R1	0.49		D1	0.06
	R2	0.67	2/17/17	A1	0.34
	C2	0.29		R1	0.57
	D1	0.37		R2	0.80
7/28/16	A1	0.38		C2	0.32
	R1	0.64		D1	0.44
	R2	0.90	3/16/17	A1	0.58
	C2	0.35		R1	0.93
	D1	0.50		R2	1.35
8/4/16	A1	0.54		C2	0.48
	R1	0.88		D1	0.76
	R2	1.27	4/28/17	A1	0.25
	C2	0.45		R1	0.44
	D1	0.71		R2	0.59
9/20/16	A1	0.10		C2	0.27
	R1	0.22		D1	0.33
	R2	0.25	5/26/17	A1	1.31
	C2	0.17		R1	2.03
	D1	0.13		R2	3.06
10/25/16	A1	0.05		C2	0.95
	R1	0.14		D1	1.75
	R2	0.12	6/20/17	A1	0.47
	C2	0.14		R1	0.76
	D1	0.05		R2	1.09
11/14/16	A1	0.03		C2	0.41
	R1	0.11		D1	0.61
	R2	0.07	7/25/17	A1	0.10
	C2	0.13		R1	0.22
	D1	0.03		R2	0.24
12/7/16	A1	0.07		C2	0.17
	R1	0.16		D1	0.12
	R2	0.16			

4.5 Concentrations for Dissolved and Particulate Constituents

Concentration means and ranges for all constituents on all dates and sites are summarized in Appendix C. These data were divided seasonally into growing and dormant season. There were 7 dormant sampling dates (October- March) per sampling site. There were 11 growing sampling dates (April- September) per sampling site. The mean concentrations for each season are in Table 10.

Table 10. Mean concentration (mg/L) by season at each site for each analysis sample number, standard deviation and standard error.

Analysis	*Site*	*Season*	*N*	*Mean (mg/L)*	*Standard Deviation*	*Standard Error*
Ammonium	A1	growing	11	0.012	0.014	0.004
		dormant	7	0.004	0.004	0.001
	A2	growing	10	0.009	0.007	0.002
		dormant	7	0.005	0.006	0.002
	A3	growing	11	0.014	0.026	0.008
		dormant	7	0.004	0.006	0.002
	A4	growing	11	0.025	0.028	0.009
		dormant	7	0.002	0.003	0.001
	R1	growing	11	0.008	0.010	0.003
		dormant	7	0.004	0.004	0.002
	R2	growing	11	0.005	0.007	0.002
		dormant	7	0	0.000	0.000
	P1	growing	11	0.015	0.013	0.004
		dormant	7	0.004	0.009	0.003
	C1	growing	11	0.013	0.015	0.005
		dormant	7	0	0.001	0.000
	C2	growing	10	0.006	0.007	0.002
		dormant	7	0	0.000	0.000
	D1	growing	11	0.005	0.007	0.002
		dormant	7	0	0.000	0.000
	D2	growing	11	0.013	0.016	0.005
		dormant	7	0.005	0.005	0.002
Phosphate	A1	growing	11	0.02	0.012	0.004
		dormant	7	0.016	0.011	0.004
	A2	growing	10	0.052	0.034	0.011
		dormant	7	0.026	0.026	0.010

Analysis	*Site*	*Season*	*N*	*Mean (mg/L)*	*Standard Deviation*	*Standard Error*
	A3	growing	11	0.022	0.022	0.007
		dormant	7	0.01	0.011	0.004
	A4	growing	11	0.015	0.020	0.006
		dormant	7	0.01	0.009	0.004
	R1	growing	11	0.019	0.011	0.003
		dormant	7	0.02	0.016	0.006
	R2	growing	11	0.017	0.012	0.004
		dormant	7	0.018	0.016	0.006
	P1	growing	11	0.011	0.015	0.005
		dormant	7	0.012	0.009	0.003
	C1	growing	11	0.019	0.020	0.006
		dormant	7	0.026	0.022	0.008
	C2	growing	10	0.013	0.016	0.005
		dormant	7	0.011	0.008	0.003
	D1	growing	11	0.029	0.020	0.006
		dormant	7	0.018	0.017	0.007
	D2	growing	11	0.022	0.019	0.006
		dormant	7	0.014	0.011	0.004
Nitrate	A1	growing	11	0.39	0.26	0.08
		dormant	7	0.41	0.34	0.13
	A2	growing	10	1.59	0.96	0.30
		dormant	7	1.47	1.55	0.58
	A3	growing	11	0.28	0.26	0.08
		dormant	7	0.26	0.36	0.14
	A4	growing	11	0.16	0.09	0.03
		dormant	7	0.12	0.05	0.02
	R1	growing	11	0.29	0.16	0.05
		dormant	7	0.22	0.12	0.05
	R2	growing	11	0.29	0.26	0.08
		dormant	7	0.32	0.46	0.18
	P1	growing	11	0.22	0.39	0.12
		dormant	7	0.23	0.32	0.12
	C1	growing	11	0.38	0.84	0.25
		dormant	7	0.75	0.93	0.35
	C2	growing	10	0.11	0.06	0.02
		dormant	7	0.21	0.27	0.10
	D1	growing	11	0.28	0.14	0.04
		dormant	7	0.20	0.10	0.04
	D2	growing	11	0.94	1.05	0.32

Analysis	*Site*	*Season*	*N*	*Mean (mg/L)*	*Standard Deviation*	*Standard Error*
		dormant	7	0.77	0.49	0.19
TSS	A1	growing	11	19.7	19.9	6.0
		dormant	7	4.7	5.5	2.1
	A2	growing	10	7.1	9.9	3.1
		dormant	7	2.5	2.7	1.0
	A3	growing	11	6.5	5.5	1.6
		dormant	7	1.9	1.2	0.4
	A4	growing	11	10.5	6.6	2.0
		dormant	7	6.6	4.0	1.5
	R1	growing	11	19.9	15.9	4.8
		dormant	7	8.1	4.0	1.5
	R2	growing	11	6.6	5.2	1.6
		dormant	7	6.3	8.1	3.0
	P1	growing	11	7.1	4.5	1.4
		dormant	7	4.6	6.2	2.3
	C1	growing	11	14.9	28.4	8.6
		dormant	7	0.8	0.9	0.3
	C2	growing	10	7.1	5.6	1.8
		dormant	7	4.3	5.1	1.9
	D1	growing	11	5.9	5.7	1.7
		dormant	7	6.2	7.4	2.8
	D2	growing	11	6.1	3.0	0.9
		dormant	7	7.6	6.9	2.6
TP	A1	growing	11	0.051	0.026	0.008
		dormant	7	0.037	0.025	0.010
	A2	growing	10	0.099	0.084	0.027
		dormant	7	0.051	0.013	0.005
	A3	growing	11	0.055	0.055	0.017
		dormant	7	0.062	0.107	0.041
	A4	growing	11	0.074	0.070	0.021
		dormant	7	0.04	0.042	0.016
	R1	growing	11	0.057	0.033	0.010
		dormant	7	0.035	0.022	0.008
	R2	growing	11	0.044	0.025	0.008
		dormant	6	0.033	0.018	0.008
	P1	growing	11	0.057	0.057	0.017
		dormant	6	0.033	0.015	0.006
	C1	growing	11	0.027	0.020	0.006
		dormant	7	0.019	0.014	0.005

Analysis	*Site*	*Season*	*N*	*Mean (mg/L)*	*Standard Deviation*	*Standard Error*
	C2	growing	10	0.031	0.015	0.005
		dormant	7	0.028	0.027	0.010
	D1	growing	11	0.045	0.018	0.005
		dormant	6	0.033	0.021	0.008
	D2	growing	11	0.064	0.063	0.019
		dormant	7	0.021	0.012	0.004

Ammonium was higher in the dormant compared to the growing season regardless of landuse (Table 11). In comparison, nitrate did not vary with season for any landuse. At some subwatersheds (e.g. A4, C1, C2, D1, R1, and P1) ammonium showed a difference between growing and dormant season while nitrate did not vary with season in any landuse (Table 11, Table 12). Phosphate varied with season in the agricultural subwatershed and TP results indicated a seasonal difference in the developed subwatershed (Table 11).

Table 11. Student's t-test P-values between seasonal means for each subwatershed per analysis, significant P-values (α=0.05) are shown in red.

	Agricultural n= 72	*Control n=36*	*Developed n=36*	*Outlet (R) n=36*	*Pond n=18*
Ammonium	0.001	0.002	0.031	0.022	0.039
Phosphate	0.033	0.794	0.086	0.825	0.850
Nitrate	0.934	0.324	0.563	0.809	0.956
TSS	0.001	0.077	0.681	0.075	0.377
TP	0.140	0.427	0.017	0.056	0.212

Table 12. Student's t-test P-values between seasonal means for each site per analysis, significant P-values (α=0.05) are shown in red.

Analysis	*A1 n=18*	*A2 n=17*	*A3 n=18*	*A4 n=18*	*C1 n=18*	*C2 n=17*	*D1 n=18*	*D2 n=18*	*R1 n=18*	*R2 n=18*	*P1 n=18*
Ammonium	0.104	0.226	0.219	0.021	0.017	0.029	0.036	0.142	0.040	0.211	0.033
Phosphate	0.537	0.100	0.136	0.476	0.487	0.672	0.207	0.273	0.850	0.846	0.917
Nitrate	0.906	0.862	0.903	0.227	0.406	0.328	0.185	0.656	0.957	0.302	0.915
TSS	0.036	0.185	0.020	0.136	0.138	0.301	0.925	0.020	0.377	0.036	0.931
TP	0.266	0.110	0.881	0.224	0.294	0.819	0.249	0.054	0.212	0.112	0.310

4.5.1 Concentrations by constituent

4.5.1.1 Ammonium

Data Ranges

Site:

Sites A3, A4, P1 and D2 had the highest mean ammonium concentration (0.01 mg/L) across all dates (Appendix C) although A3 and A4 had greater variability around the mean compared to the other sites. All other sites had an average mean concentration of ammonium between 0.003 mg/L and 0.009 mg/L. Several sites and dates were too low to measure ammonium concentration (0.00 mg/l) while the maximum concentration ranged from of 0.020 mg/L at site R2 and D2 to 0.101 mg/L at A4.

Season:

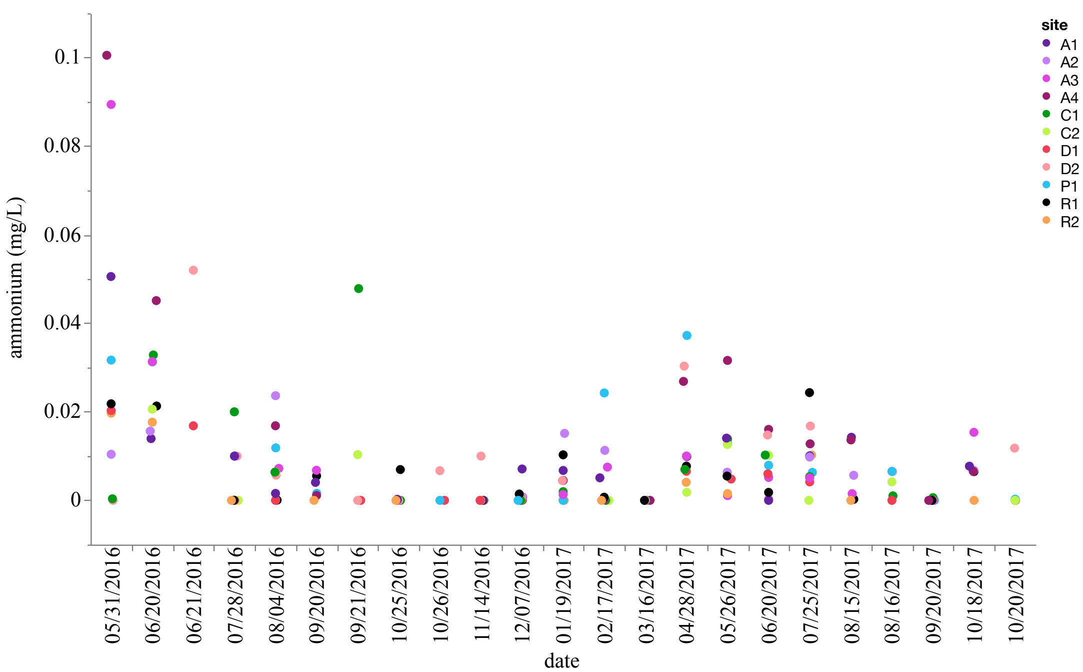

Figure 15. Ammonium concentrations in mg/L for all sites over the course of the study.

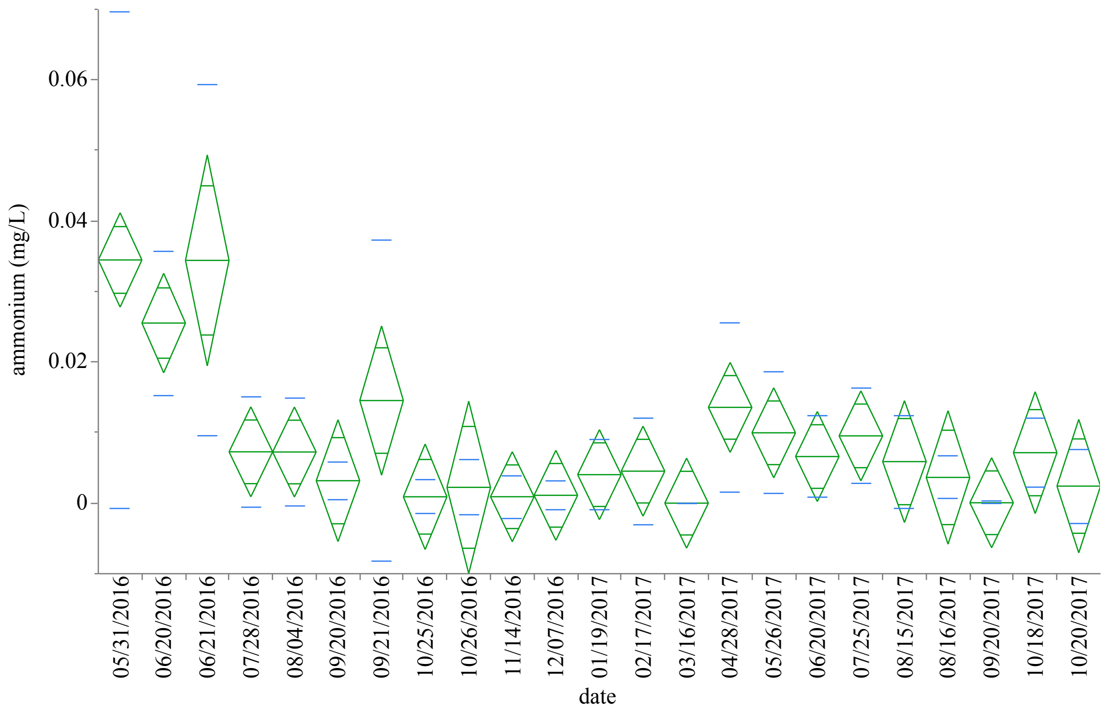

Figure 16. Mean ammonium concentration in mg/L averaged across all sites over time, showing mean error (green diamonds) and standard deviation (blue bars).

All ammonium concentrations are shown in Figure 15. When averaged across all sites, mean ammonium concentration values ranged from less than 0.0 mg/L to 0.04 mg/L (Figure 16) and there is a clear trend of higher ammonium concentrations during the growing season and lower ammonium concentrations during the dormant season. May 2016 had the highest mean and standard deviation around the mean. Generally, the average concentration for the watershed across all dates varies around 0.01 mg/L ammonium.

Student's t-test difference in seasonal means

Subwatershed:

The seasonal comparison of ammonium of the subwatersheds indicated that the agricultural, control, developed, pond and the outlet all have significant difference between the growing and the dormant season with P-values of 0.001, 0.002, 0.031, 0.022, 0.039 respectively (Table 11).

Site:

Ammonium at all sites had growing season means that were higher than the dormant season means (Table 10). Ammonium concentration means for growing season per site range from 0.005 mg/L at R2 to 0.025 mg/L at A4. Means for the dormant season per site range from 0 mg/L at R2, C1, C2, D1 and D2 to 0.005 mg/L at A2 and D2.

For the seasonal comparison of ammonium per each site, A4, C1, C2, D1, R1, and P1 had significant p-values of 0.021, 0.017, 0.029, 0.036, 0.04, and 0.033 respectively (Table 12).

Two-way ANOVA

There was a significant seasonal trend for ammonium (p <0.0001, Table 13) where ammonium was higher during the growing versus dormant season (Tukey's HSD p<0.001), Figure 17).

Table 13. Ammonium Two-way ANOVA for season, site, and season*site.

Source	*Nparm*	*DF*	*Sum of Squares*	*F Ratio*	*Prob > F*
Season	1	1	0.00	24.12	<.0001
Site	10	10	0.00	1.14	0.34
Season*Site	10	10	0.00	0.85	0.58

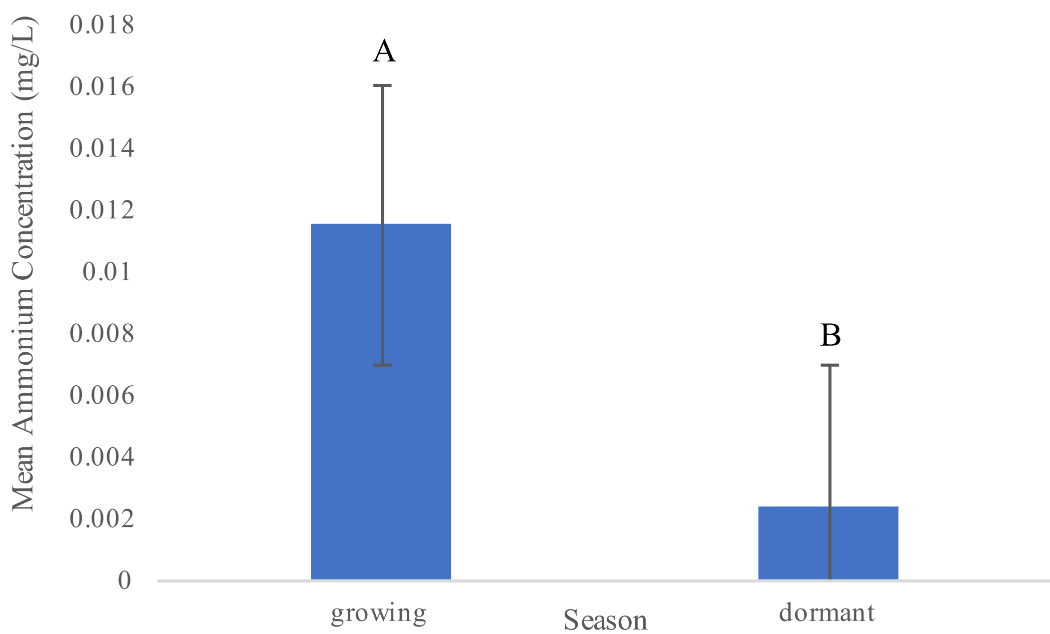

Figure 17. Post-hoc all pairs Tukey HSD mean comparison between growing season and dormant season ammonium concentration for all sites. A represents a mean that is significant from B. For the growing season N=119, for the dormant season N= 77.

4.5.1.2 Phosphate

Data Ranges

Site:

Site A2 had the highest mean phosphate concentration across all dates of 0.042 mg/L (Appendix C). All other sites had a mean concentration between 0.011 mg/L to 0.025 mg/L. All sites have a minimum concentration value in the rage of 0.0 mg/L to 0.002 mg/L. The maximum phosphate concentration value at each site ranges from 0.039 mg/L at A1 to 0.107 mg/L at A2.

Season:

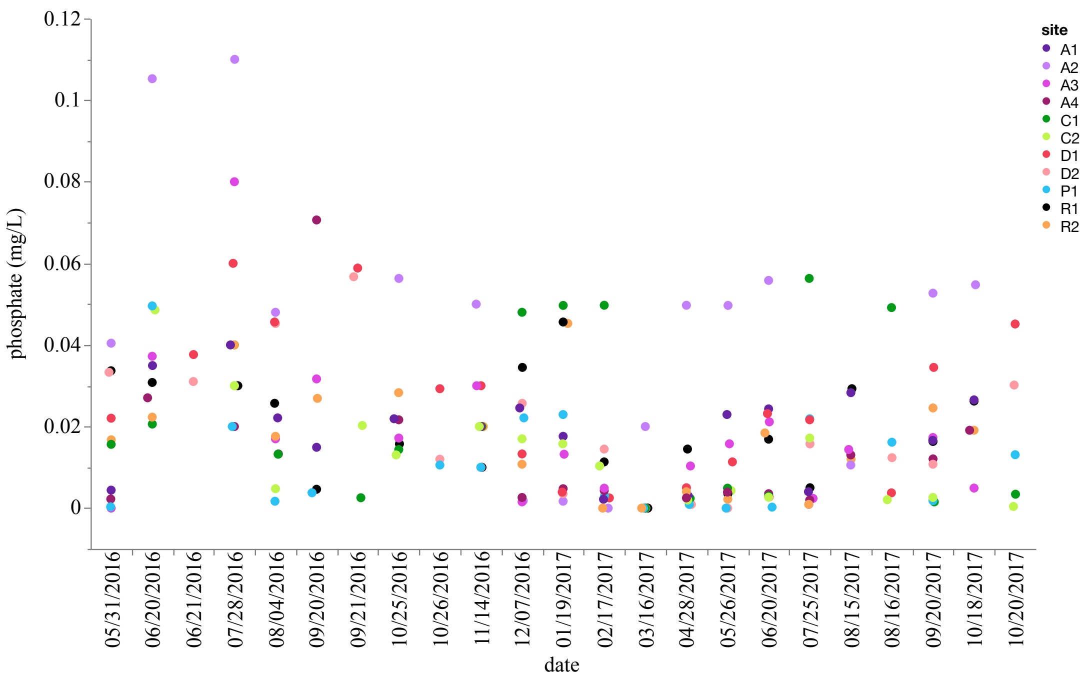

Figure 18. Phosphate concentrations in mg/L for all sites over the course of the study.

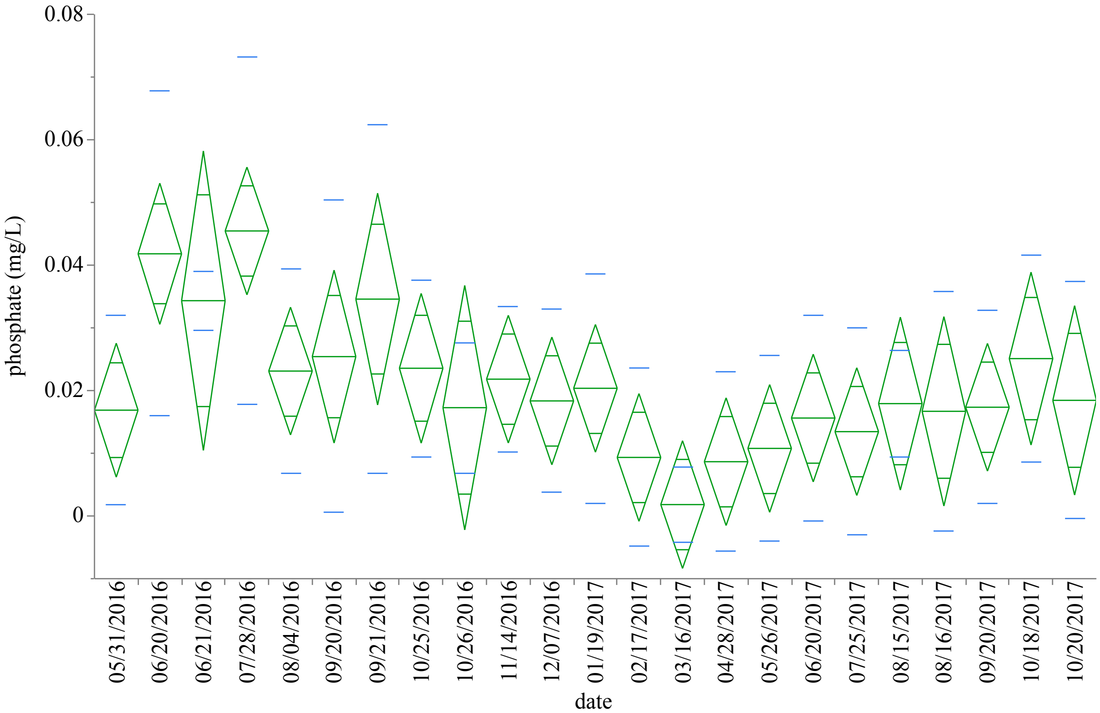

Figure 19. Mean phosphate concentration in mg/L averaged across all sites over time, showing mean error (green diamonds) and standard deviation (blue bars).

All phosphate concentrations for all sites are shown in Figure 18. When averaged across all sites, mean phosphate concentration values range from 0.05 mg/L to 0.0 mg/L. June 2016 had the highest mean and standard deviation around the mean. A trend arises in mean concentrations averaged across all sites over time, of higher phosphate concentrations in the growing season and lower values during the dormant season (Figure 19). Generally, the average concentration for the watershed across all dates varies around 0.02 mg/L phosphate.

Student's t-test difference in seasonal means

Subwatershed:

There was significant seasonal variation in the agricultural subwatershed (p=0.033, Table 11) where the growing season mean was greater than the dormant season.

Site:

Mean phosphate concentration for the growing season ranged from 0.011 mg/L at P1 to 0.52 mg/L at A2. Mean phosphate concentration for the dormant season ranged from 0.010 mg/L at A3 and A4 to 0.026 mg/L at C1.

There were no individual sites that had a significant difference between the dormant and growing season means (Table 12).

Two-way ANOVA

There was a significant seasonal trend in phosphate concentration (p= 0.04, Table 14) but mean phosphate concentration was not significantly different between growing and dormant season (Tukey's HSD p= 0.07, Figure 20). There was a significant site trend (p= 0.0009, Table 14). Site A2 (A) was significantly higher than all sites (Tukey's HSD, Figure 21, Table 15) except the (AB) sites, C1 and D1 (p= 0.0539, p= 0.1874). However, C1 and D1 did not have significantly different p-values when compared to any of the other (B) sites (Tukey's HSD, Table 15).

Table 14. Phosphate two-way ANOVA for season, site, and season*site.

Source	*Nparm*	*DF*	*Sum of Squares*	*F Ratio*	*Prob > F*
Season	1	1	0.00	4.12	0.0439
Site	10	10	0.01	3.17	0.0009
Season*Site	10	10	0.00	1.08	0.38

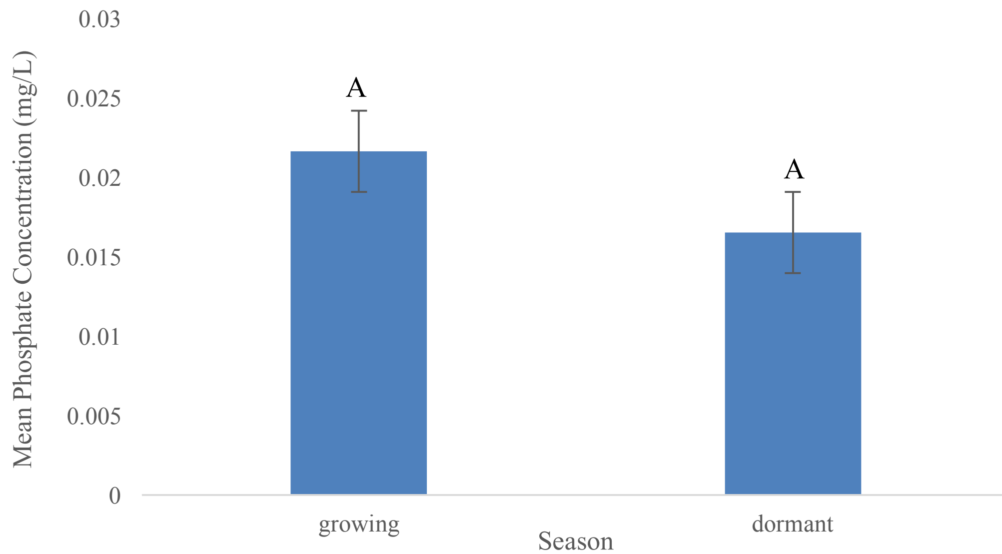

Figure 20. All pairs Tukey HSD mean comparison between growing season and dormant season phosphate concentration for all sites. A represents a mean that is significant from B. For the growing season, N= 119, for the dormant season, N= 77.

Table 15. P-values from Tukey HSD Mean Comparison, connected letters report shown in Figure 21.

Site	*Site of comparison*	*p-value*
A2	P1	<.0001
A2	C2	0.0002
A2	A4	0.0004
A2	R2	0.0041
A2	A3	0.0057
A2	A1	0.0078
A2	D2	0.0095
A2	R1	0.0172
A2	C1	0.0539
A2	D1	0.1874

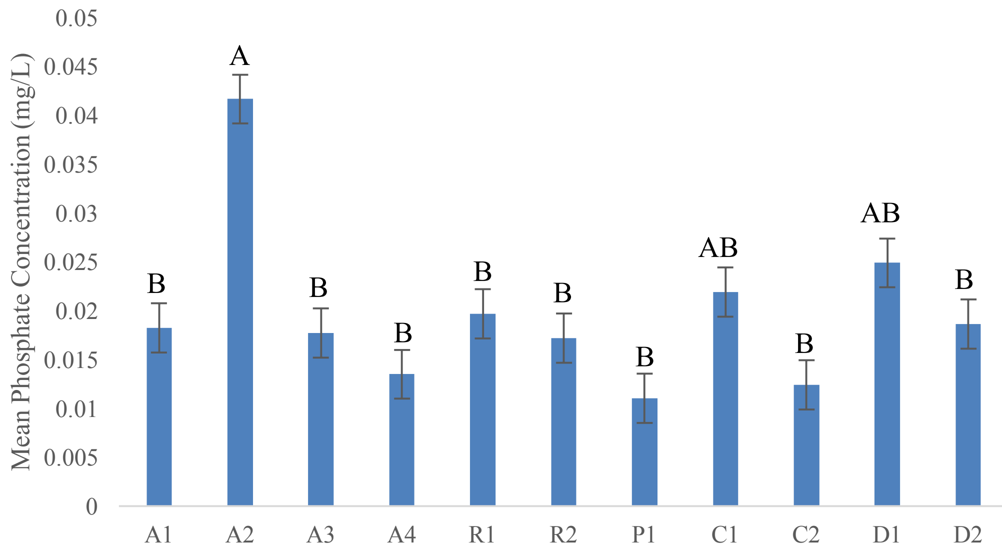

Figure 21. All pairs Tukey HSD mean comparison between all sites for phosphate concentration. A represents a mean that is significant from B. AB represents sites that are not significantly different from each other, A, or B. The sample number for each site N=18, except for A2 and C2 for which N=17.

4.5.1.3 Nitrate

Data Ranges

Site:

Site A2 had the highest mean nitrate concentration, across all dates of 1.54 mg/L with a standard deviation of 1.19 mg/L (Appendix C). Sites A4 and C2 had the lowest mean nitrate concentrations across all dates of 0.145 mg/L and 0.150 mg/L respectively. All other sites had a mean concentration that ranged from 0.227 mg/L to .871 mg/L. The minimum concentration ranged from 0.0 mg/L to .002 mg/L, except for site D1 which had the highest minimum value of 0.044 mg/L. Sites D2 and A2 had the highest nitrate values of 3.604 mg/L and 3.307 mg/L respectively. D2 had a standard deviation value of 0.871 mg/L. C1 also had a high maximum concentration value of 2.869 mg/L with a standard deviation of 0.868.

Season:

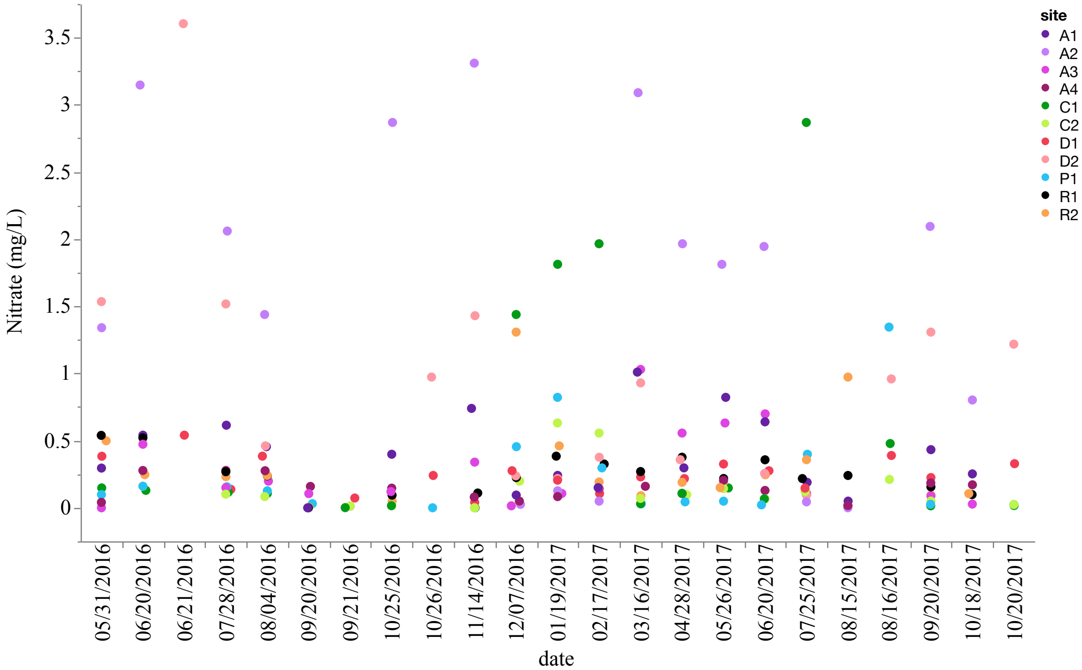

Figure 22. Nitrate concentrations in mg/L for all sites over the course of the study.

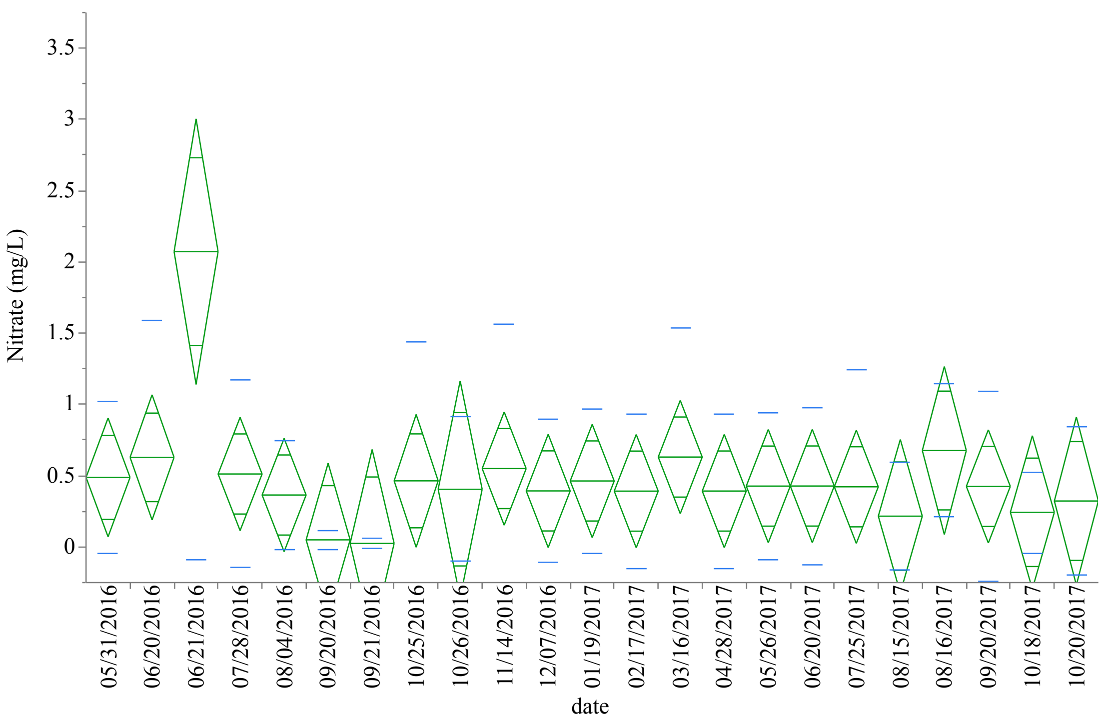

Figure 23. Mean nitrate concentration in mg/L averaged across all sites over time, showing mean error (green diamonds) and standard deviation (blue bars).

All nitrate concentrations for all sites are shown in Figure 22. When averaged across all sites, mean nitrate concentration values ranged from less 0.0 mg/L to 1 mg/L (Figure 23). June 2016 had the highest mean and standard deviation around the mean. All other dates the mean nitrate concentrations averaged across all sites over time are around 0.5 mg/L without a trend between growing and dormant season.

Student's t-test difference in seasonal means

Subwatershed:

Seasonal nitrate concentration by subwatershed did not show significant differences between the growing season and the dormant season mean concentration (p-values, Table 11).

Site:

A2, A3, A4, R1, and D2 had a growing season mean that was greater than the dormant season. A1, R2, P1, C1, and C2 had a dormant season mean that was greater than the growing season mean. Mean growing season nitrate concentration ranged from 0.105 mg/L at site C2 to 1.585 mg/L at site A2. Mean dormant season nitrate concentrations ranged from 0.119 mg/L at site A4 to 1.468 mg/L at site A2.

Seasonal difference of nitrate concentration between each site were not significant (Table 12).

Two-way ANOVA

There was a significant difference between sites ($p < .0001$, Table 16). Site A2 (A) had a significantly different nitrate concentration from all other sites (Tukey's HSD, Table 17, Figure 24). Site D2 (B) is significantly different from A or C but not significantly different than those sites that are BC (Tukey's HSD, Table 17, Figure 24).

Sites A3, A4, R1, P1, C2, and D1 are significantly different from D2 (Tukey's HSD, Table 17, Figure 24).

Table 16. Nitrate Two-way ANOVA for season, site, and season*site.

Source	*Nparm*	*DF*	*Sum of Squares*	*F Ratio*	*Prob > F*
Season	1	1	0.00	0.00	0.97
Site	10	10	28.36	8.93	<.0001
Season*Site	10	10	0.88	0.28	0.99

Table 17. P-values from Tukey HSD mean comparison, connected letters report shown in Figure 24.

Site	*Site of Comparison*	*P-value*
A2	A4	<.0001
A2	C2	<.0001
A2	P1	<.0001
A2	D1	<.0001
A2	R1	<.0001
A2	A3	<.0001
A2	R2	<.0001
A2	A1	<.0001
A2	C1	<.0001
D2	A4	0.0050
D2	C2	0.0068
A2	D2	0.0191
D2	P1	0.0235
D2	D1	0.0355
D2	R1	0.0394
D2	A3	0.0460
D2	R2	0.0787
D2	A1	0.2787
D2	C1	0.7292

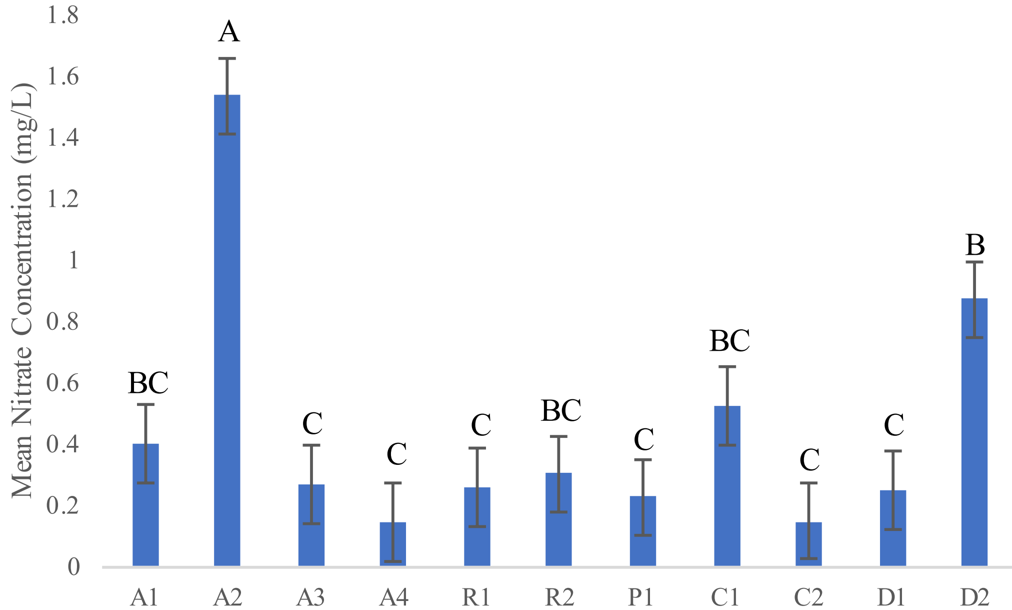

Figure 24. All pairs Tukey HSD mean comparison between all sites for nitrate concentration. A represents a mean that is significant from B which is significant from C. BC represents sites that are not significantly different from each other, B, or C. The sample number for each site N=18 except for A2 and C2 for which N=17.

4.5.1.4 Total Suspended Solids

Data Ranges

Site:

TSS had the largest standard deviation of any analysis performed with the standard deviation ranging from 4.7 at site D2 to 22.9 at site C2 (Appendix C). Sites A1 and R1 had the highest mean TSS concentration, averaged across all dates, of 13.9 mg/L to 15.3 mg/L respectively. A2, A3, and C2 had the lowest mean concentration of between 4 mg/L to 5 mg/L. All other sites had a mean TSS concentration that ranged from 6.0 mg/L to 9.4 mg/L. A2, C1, C2, D1 had a minimum concentration of 0.0 mg/L TSS. A1 and C1 had the highest reported TSS concentration values of 67.5 mg/L and 98.6 mg/L respectively.

Season:

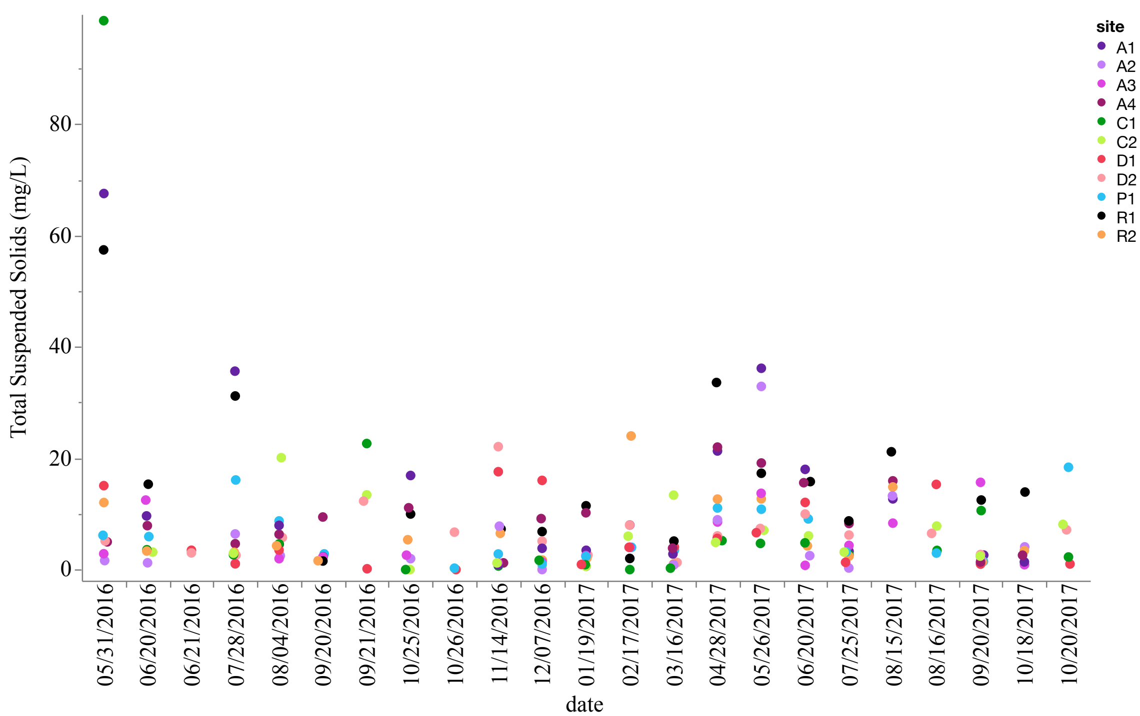

Figure 25. TSS concentrations in mg/L for all sites over the course of the study.

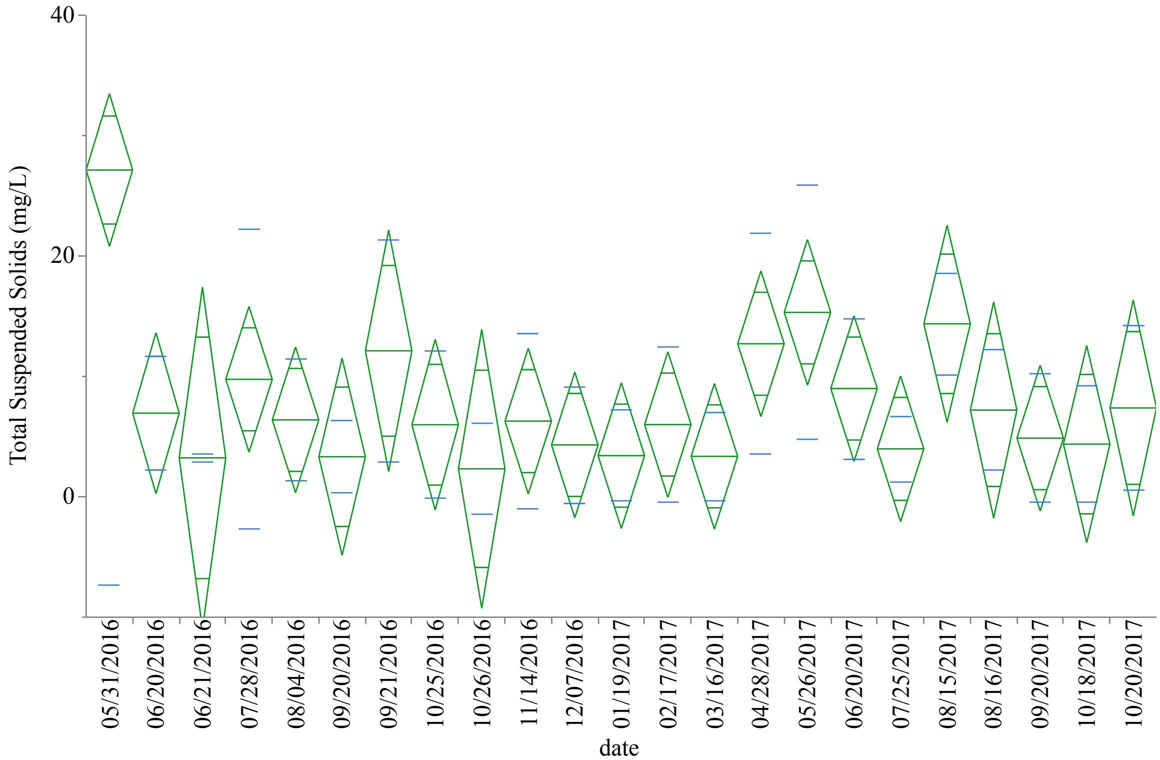

Figure 26. Mean TSS concentration in mg/L averaged across all sites over time, showing mean error (green diamonds) and standard deviation (blue bars).

All TSS concentrations for all sites are shown in Figure 25. When averaged across all sites, mean TSS concentration values ranged from less than 25 mg/L to slightly above 0.0 mg/L (Figure 26). May 2016 had the highest mean TSS concentration of around 23 mg/L with the highest standard deviation. Generally, there are slightly higher TSS values averaged across all sites in the growing season than the dormant season.

Student's t-test difference in seasonal means

Subwatershed:

The seasonal difference in TSS concentration in the agricultural subwatershed was significant (p= 0.001, Table 11).

Site:

Sites A1, A2, A3, A4, R1, P1, C1, and C2 had a growing season mean TSS concentration that was greater than the dormant season mean (Table 10). Site C1 had the greatest difference in means between the growing season and the dormant season with a standard deviation of 28.4. Mean TSS concentration for the growing season range from 5.9 mg/L at D1 to 19.9 mg/L at R1. Mean TSS concentration for the dormant season range from 0.8 mg/L at C1 to 8.8 mg/L at R1. Seasonal comparison of TSS concentration per each site showed significance at A1, A3, D2, and R2 (p=0.036, p=0.020, p=0.020, p=0.036, Table 12).

Two-way ANOVA

There was a significant seasonal trend for TSS concentration (p= 0.0007, Table 18). The growing season mean (A) was significantly higher than the dormant season mean (B) (Tukey's HSD p= .0009, Figure 27).

Table 18. TSS Two-way ANOVA for season, site and season*site.

Source	*Nparm*	*DF*	*Sum of Squares*	*F Ratio*	*Prob > F*
Season	1	1	1299	11.80	0.0007
Site	10	10	1591	1.44	0.16
Season*Site	10	10	1417	1.29	0.24

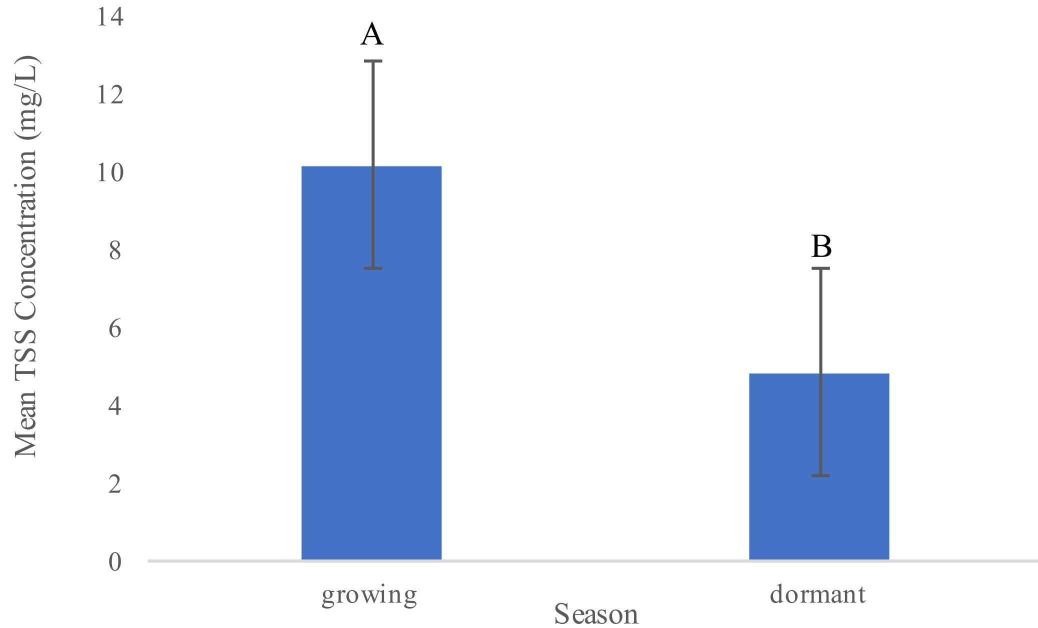

Figure 27. All pairs Tukey HSD mean comparison between growing season and dormant season TSS concentration for all sites. A represents a mean that is significant from B. For the growing season N=119, for the dormant season N=77.

4.5.1.5 Total Phosphorus

Data Ranges

Site:

Site A2 had the highest mean TP concentration averaged across all dates of 0.079 mg/L (Appendix C). All other sites ranged from 0.024 mg/L to 0.061 mg/L. Sites A3, R1, R2, C1, and D2 all had minimum TP concentration values of 0.0 mg/L. The highest TP concentration value reported was at site A2 with a value of 0.222 mg/L and site D2 with a value of 0.193 mg/L.

Season:

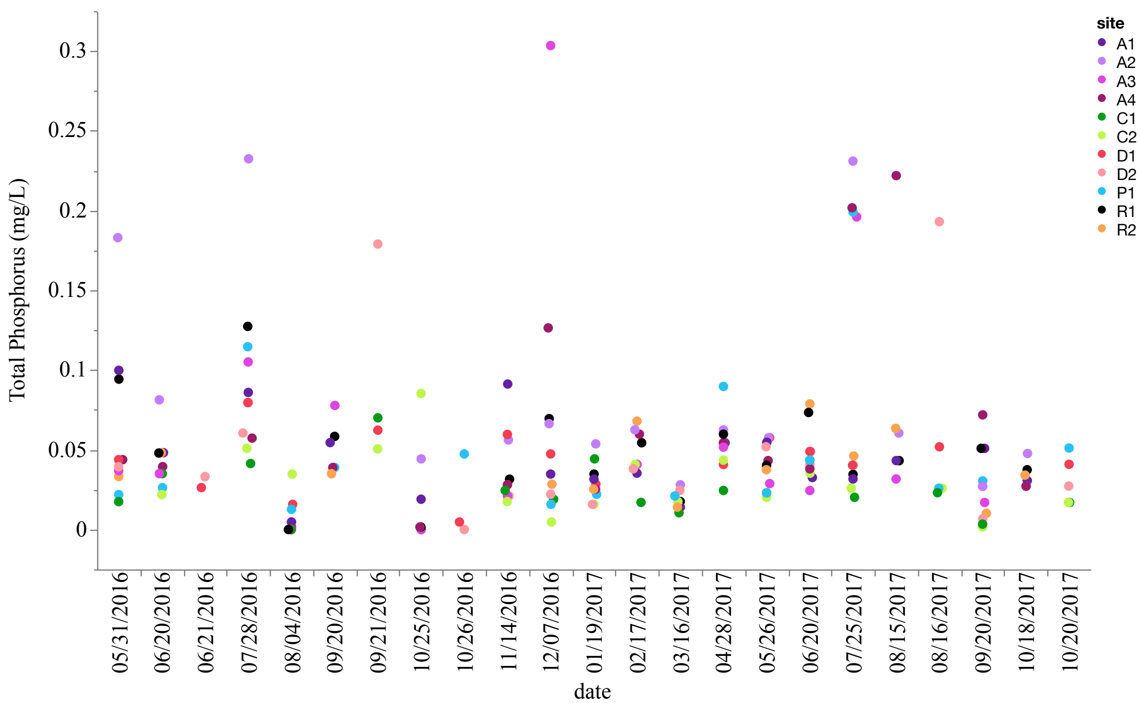

Figure 28. TP concentrations in mg/L for all sites over the course of the study.

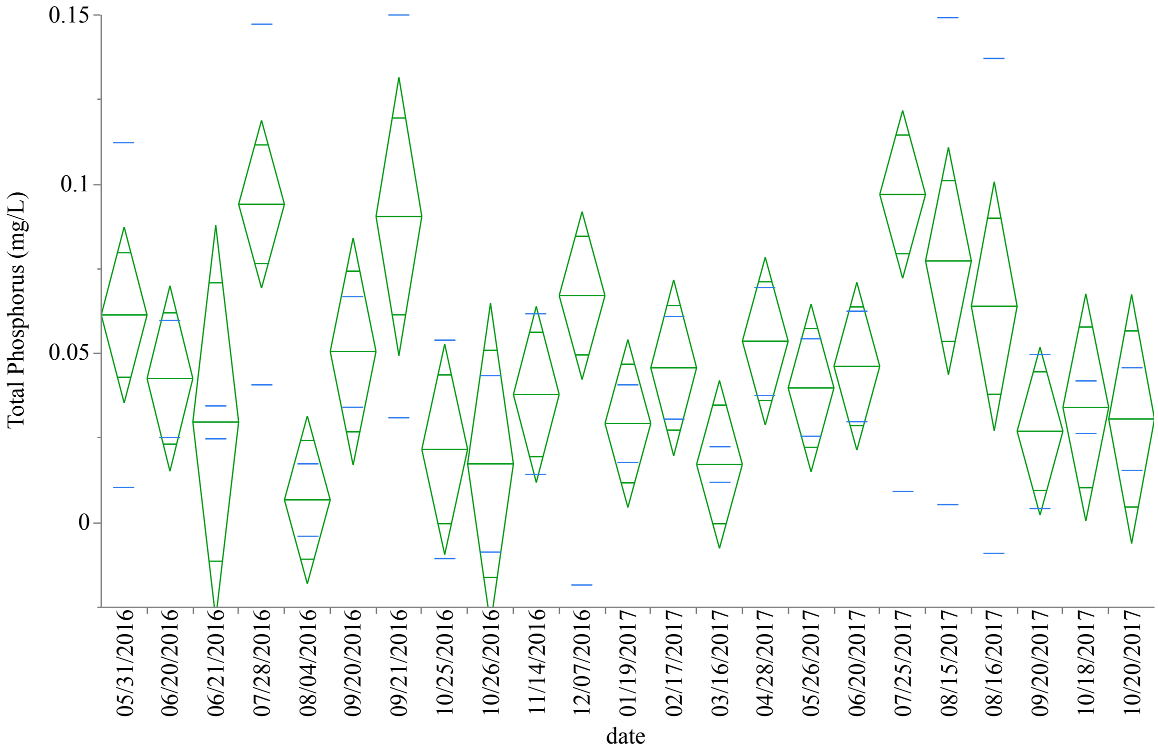

Figure 29. Mean TSS concentration in mg/L averaged across all sites over time, showing mean error (green diamonds) and standard deviation (blue bars).

All TP concentrations for all sites are shown in Figure 28. When averaged across all sites, mean TP concentration values over time range from to 0.0 mg/L to 0.1 mg/L (Figure 29). June 2017 had the highest mean TP concentration of around 0.1 mg/L as well as the highest standard deviation. June 2016 also had a high TP concentration of 0.1 mg/L.

Student's t-test difference in seasonal means

Subwatershed:

TP concentration by subwatershed was significant between the growing and dormant season only in the developed subwatershed (p= 0.017, Table 11).

Site:

All sites except site A3, which had a difference between growing and dormant season of .01 mg/L, had a growing season mean TP concentration that was greater than the dormant season mean (Table 10). Mean TP concentration for the growing season ranged from 0.027 mg/L at C1 to 0.099 mg/L at A2. Mean TP concentration for the dormant season ranged from 0.019 mg/L to 0.062 mg/L at A3.

Two-way ANOVA

There was a significant seasonal trend in TP (p =0.0045, Table 19). The growing season mean (A) was significantly higher than the dormant season mean (B) (Tukey's HSD p= 0.0056, Figure 30).

Table 19. TP Two-way ANOVA for season, site and season*site.

Source	*Nparm*	*DF*	*Sum of Squares*	*F Ratio*	*Prob > F*
Season	1	1	0.02	8.29	0.0045
Site	10	10	0.03	1.66	0.09
Season*Site	10	10	0.01	0.57	0.84

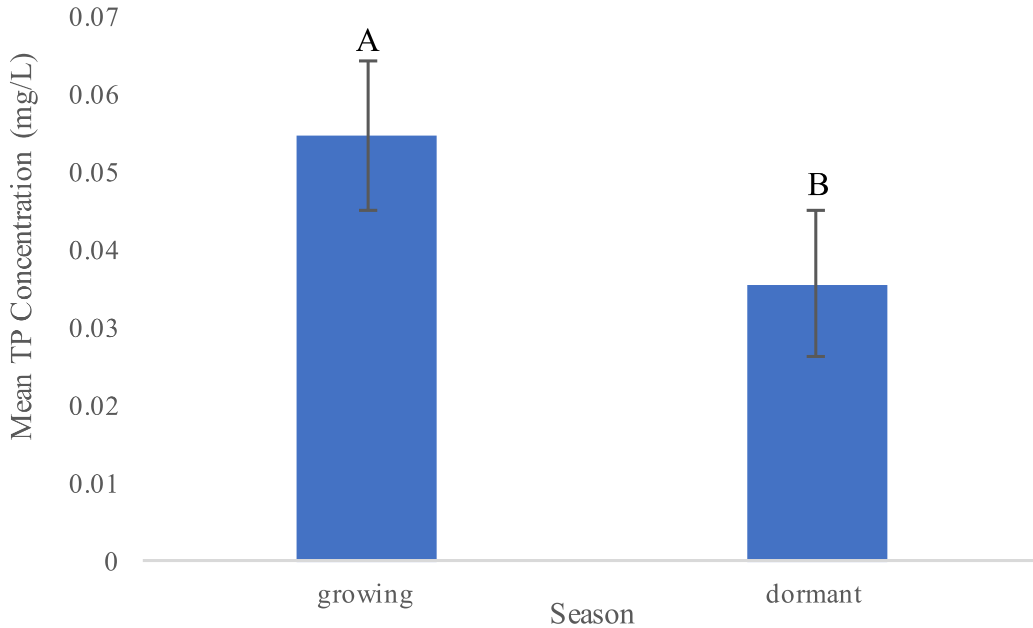

Figure 30. All pairs Tukey HSD mean comparison between growing season and dormant season TP concentration for all sites. A represents a mean that is significant from B. For the growing season N= 119, for the dormant season N=74.

4.6 Forested and Impervious Cover

The average concentration for every constituent (Appendix C) was regressed against the % impervious cover and the % forested cover (Table 1) to examine the effect of landuse on nutrient concentrations (Table 20). The relationship between percent impervious cover and overall mean concentration for all constituents was not significant ($p>0.05$) and explained very little of the variance. Percent forested cover at each site also had a weak relationship, according to the R^2, but was higher than percent impervious cover for every constituent except for TSS. TP had a strong negative relationship with percent forested cover ($R^2= 0.465$, $p = 0.021$) (Table 20, Figure 31). The growing season mean TP concentration was greater than the dormant season mean concentration (Figure 32) and had a stronger relationship ($R^2= 0.5266$) than dormant season ($R^2= 0.1271$) with percent forested cover.

Table 20. Regression relationship R^2 and p-value for mean constituent concentrations (mg/L) and % impervious and % forested cover.

Land Cover	*Mean Ammonium Concentration*	*Mean Phosphate Concentration*	*Mean Nitrate Concentration*	*Mean TSS Concentration*	*Mean TP Concentration*
% impervious	$R^2= 0.034$	$R^2= 5.0*10^{-7}$	$R^2= 0.053$	$R^2= 0.015$	$R^2= 8.0*10^{-5}$
	p= 0.59	p= 0.10	p=0.50	p=0.72	p=.98
% forested	$R^2= 0.082$	$R^2= 0.24$	$R^2= 0.34$	$R^2= 0.0079$	**$R^2= 0.47$**
	p=0.39	p=0.11	p=.06	p=0.80	**p=.021**

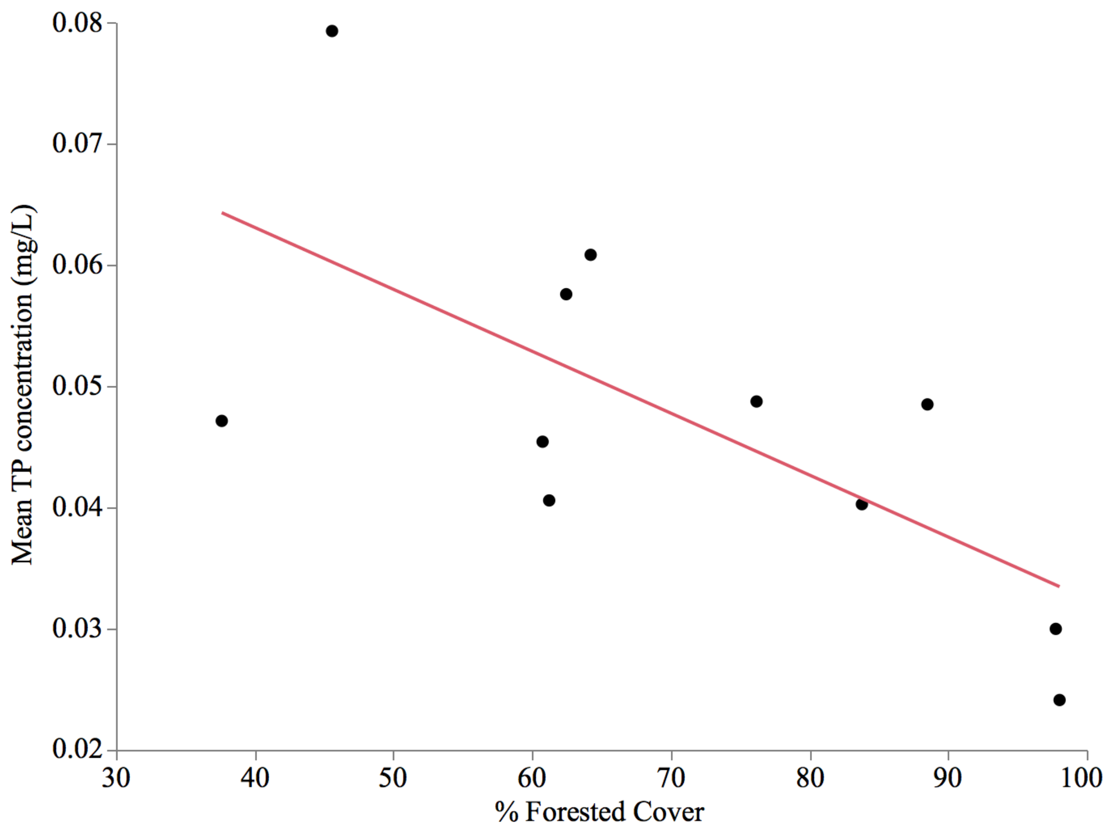

Figure 31. Line of best fit for the relationship between % forested cover and mean TP concentration in mg/L.

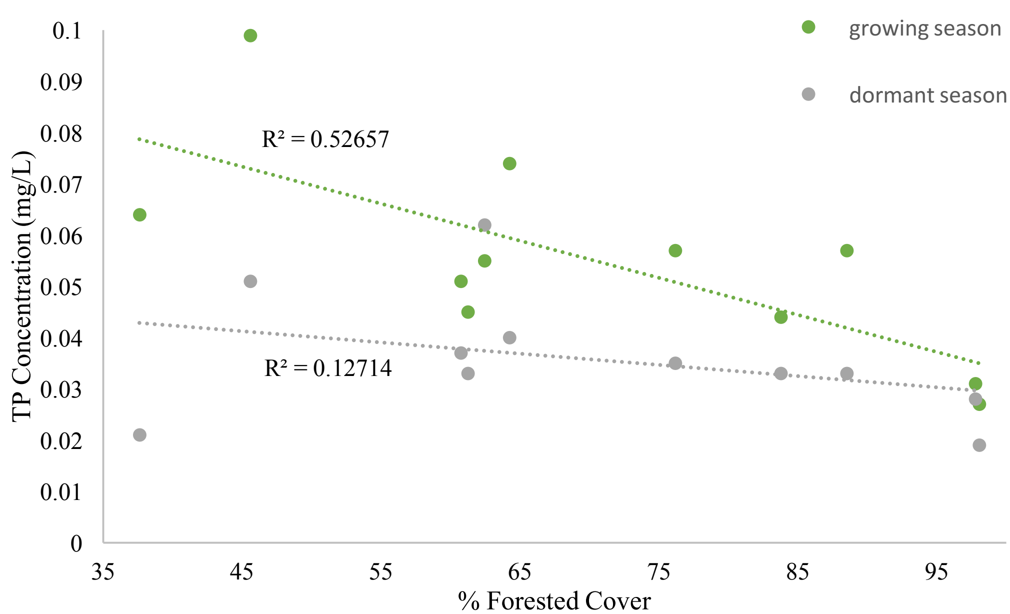

Figure 32. Regression relationship between TP mean concentration in mg/L by growing and dormant season.

4.7 Watershed Loading

The predicted loading at the yearly scale (Table 21) and the measured loading at the monthly scale (Table 22) are reported. A range for annual loading was calculated using both the drainage area ratio and concurrent flow discharge data (Table 21). Based on the results discussed in the discharge comparison, the concurrent discharge data are closest to the measured values, therefore only the concurrent flow loading was analyzed sites A1, C2, D1, R1, and R2.

Mean constituent loadings were calculated for these sites at the monthly scale in g/day*hectare (Table 23). The cumulative baseflow downstream loading was graphed over time for all months of the study for every constituent (Figures 33-37). Each watershed is represented by a cumulative loading curve (A1, D1, R1, R2, C2).

Table 21. Annual Loading in kg/year*hectare per constituent analysis.

Analysis	*Site*	*Drainage area ratio loading (kg/year* hectare)*	*Concurrent flow loading (kg/year* hectare)*	*Analysis*	*Site*	*Drainage area ratio loading (kg/year* hectare)*	*Concurrent flow loading (kg/year* hectare)*
Ammonium	A1	0.016	0.009	TSS	A1	31.6	19.2
	A2	0.012	-		A2	14.5	-
	A3	0.017	-		A3	9.3	-
	A4	0.034	-		A4	17.9	-
	C2	0.011	0.006		C2	15.0	6.8
	R1	0.009	0.009		R1	27.4	27.4
	R2	0.006	0.008		R2	13.9	19.3
	D1	0.007	0.005		D1	10.4	7.6
	D2	0.015	-		D2	10.0	-
Phosphate	A1	0.027	0.016	TP	A1	0.07	0.04
	A2	0.072	-		A2	0.12	-
	A3	0.033	-		A3	0.07	-
	A4	0.015	-		A4	0.08	-
	C2	0.017	0.011		C2	0.05	0.03
	R1	0.026	0.026		R1	0.08	0.08
	R2	0.020	0.026		R2	0.07	0.09
	D1	0.033	0.024		D1	0.07	0.05
	D2	0.024	-		D2	0.07	-
Nitrate	A1	0.96	0.57				
	A2	3.07	-				
	A3	0.98	-				
	A4	0.28	-				
	C2	0.30	0.18				
	R1	0.50	0.50				
	R2	0.42	0.54				
	D1	0.45	0.35				
	D2	1.30	-				

Table 22. Mean concurrent flow loading at the monthly scale in g/day*hectare by site, number of samples (N) and standard error.

Analysis	*Site*	*N*	*Mean*	*Standard Error*
Ammonium Loading (g/day*hectare)				
	A1	18	0.03	0.01
	C2	17	0.01	0.01
	D1	18	0.02	0.01
	R1	18	0.03	0.01
	R2	18	0.03	0.01
Phosphate Loading (g/day*hectare)				
	A1	18	0.05	0.02
	C2	17	0.03	0.02
	D1	18	0.08	0.02
	R1	18	0.08	0.02
	R2	18	0.08	0.02
Nitrate Loading (g/day*hectare)				
	A1	18	1.66	0.39
	C2	17	0.42	0.40
	D1	18	1.08	0.39
	R1	18	1.43	0.39
	R2	18	1.59	0.39
TSS Loading (g/day*hectare)				
	A1	18	64.5	21.3
	C2	17	21.1	21.9
	D1	18	23.2	21.3
	R1	18	85.7	21.3
	R2	18	55.4	21.3
TP Loading (g/day*hectare)				
	A1	18	0.13	0.06
	C2	17	0.08	0.06
	D1	17	0.16	0.06
	R1	18	0.25	0.06
	R2	17	0.29	0.06

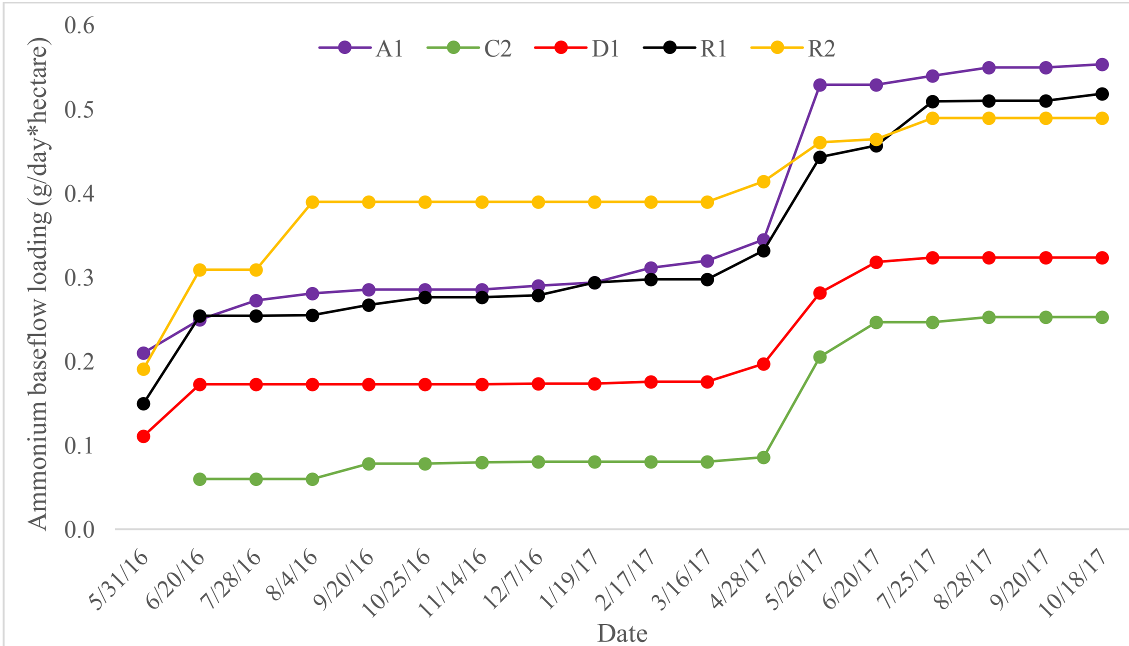

Figure 33. Monthly concurrent flow ammonium baseflow cumulative loading (g/day*hectare) over time. Agricultural outlet in purple, control in green, developed outlet in red, R2 mainstem in yellow, and the watershed loading (R1) in black.

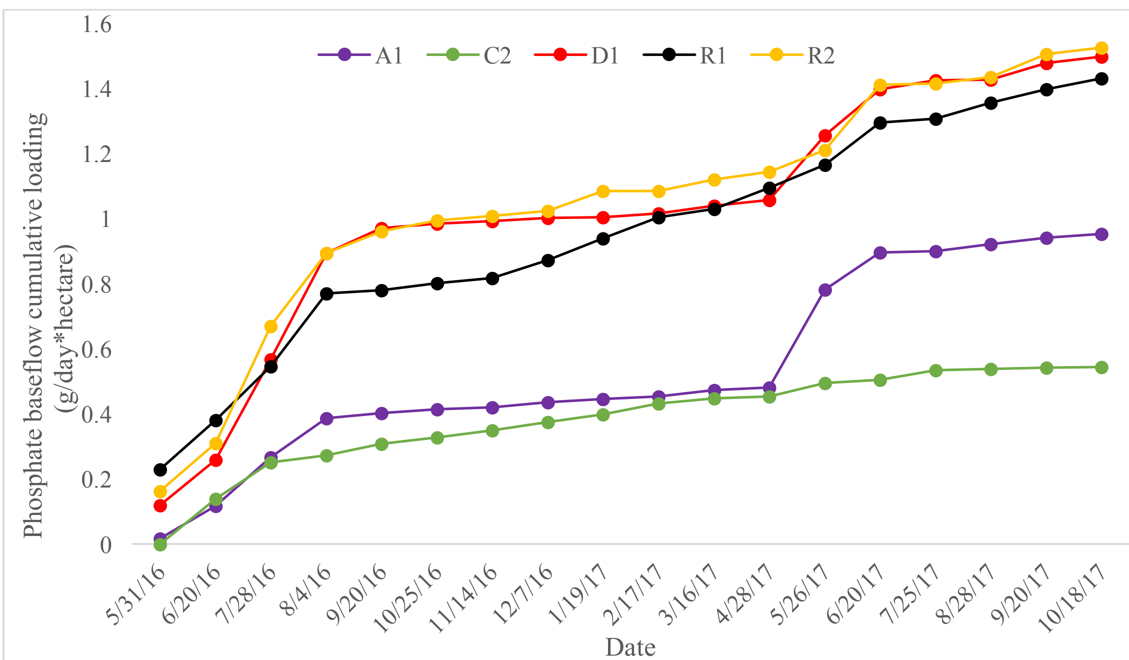

Figure 34. Monthly concurrent flow phosphate baseflow cumulative loading (g/day*hectare) over time. Agricultural outlet in purple, control in green, developed outlet in red, R2 mainstem in yellow, and the watershed loading (R1) in black.

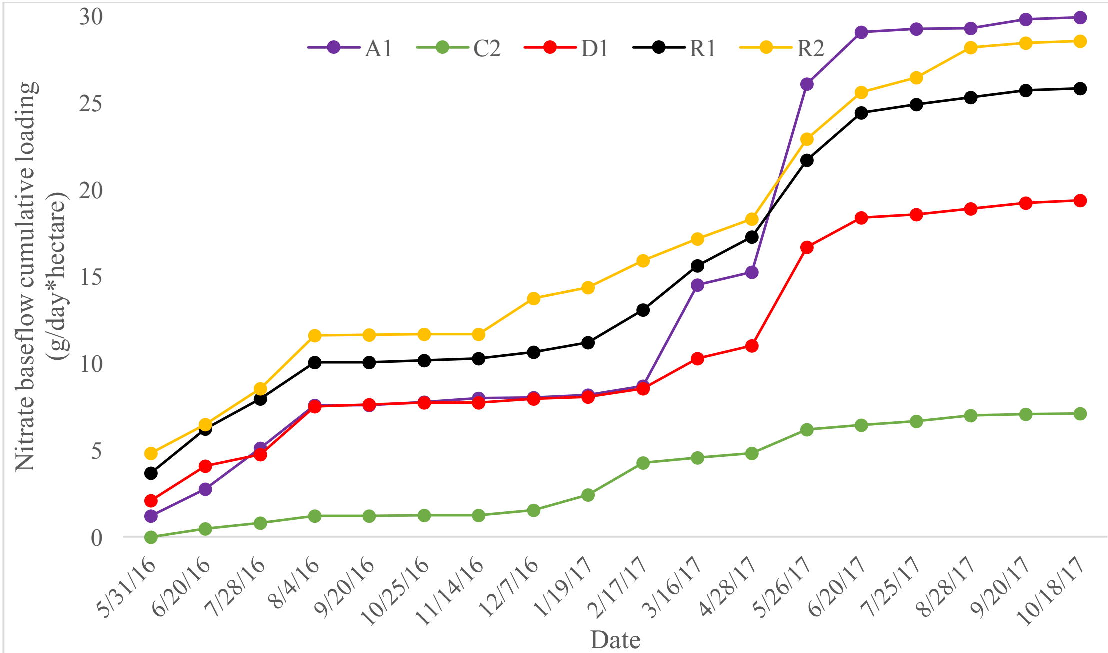

Figure 35. Monthly concurrent flow nitrate baseflow cumulative loading (g/day*hectare) over time. Agricultural outlet in purple, control in green, developed outlet in red, R2 mainstem in yellow, and the watershed loading (R1) in black

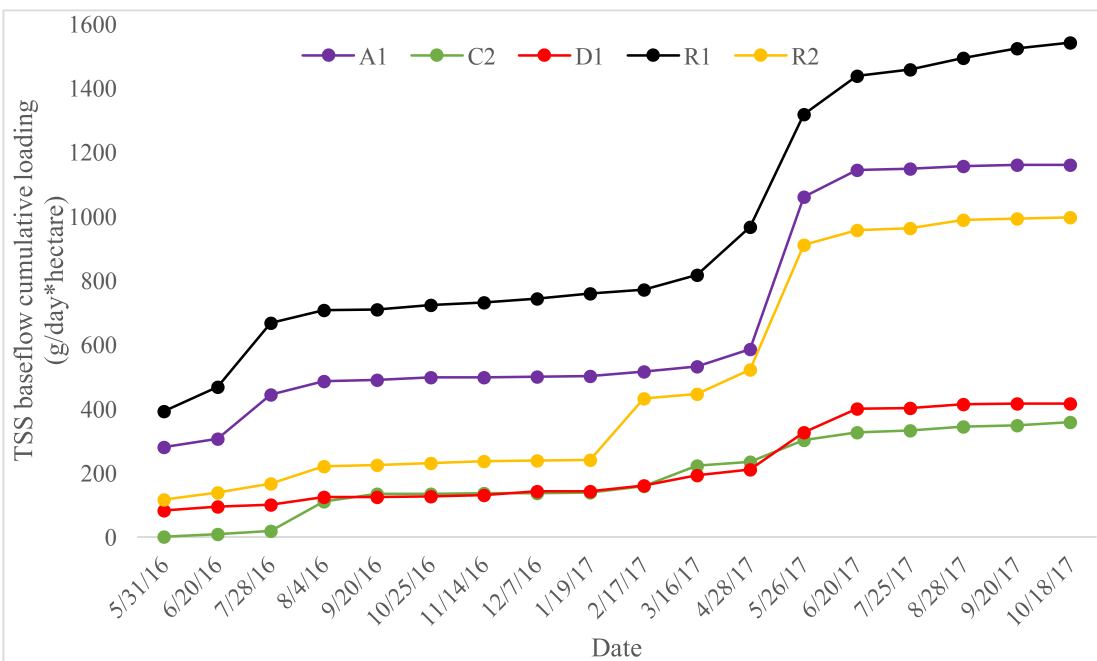

Figure 36. Monthly concurrent flow TSS baseflow cumulative loading (g/day*hectare) over time. Agricultural outlet in purple, control in green, developed outlet in red, R2 mainstem in yellow, and the watershed loading (R1) in black.

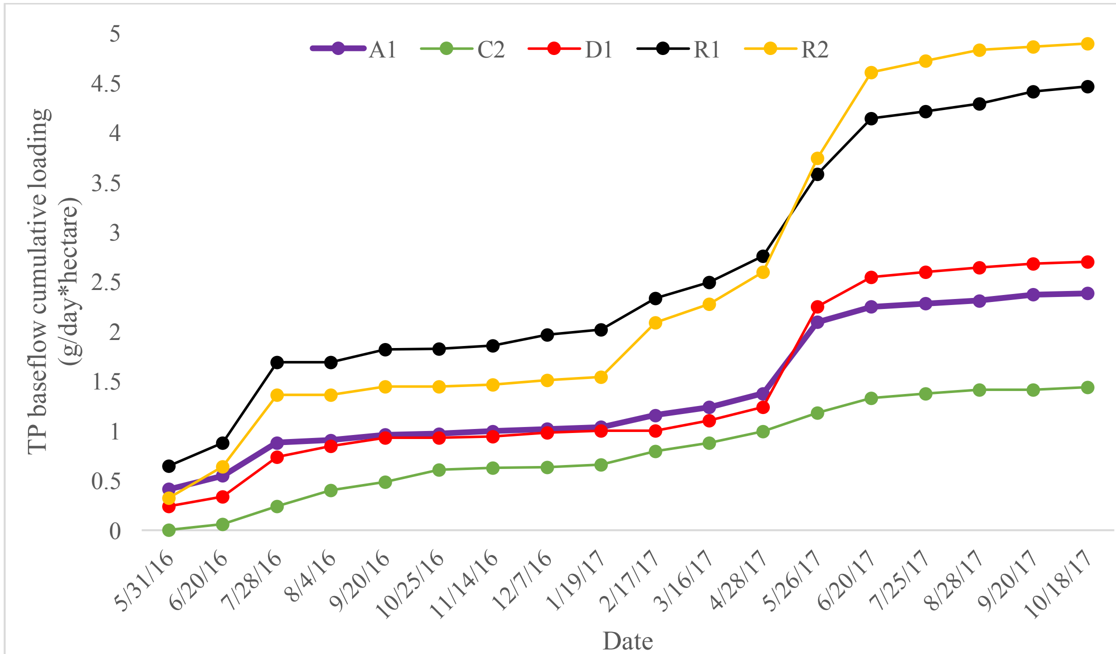

Figure 37. Monthly concurrent flow TP baseflow cumulative loading (g/day*hectare) over time. Agricultural outlet in purple, control in green, developed outlet in red, R2 mainstem in yellow, and the watershed loading (R1) in black.

R1 and R2 had similar loading for all constituents across time, while there was more variability among the other subwatersheds (Figures 33-37). A two-way ANOVA indicated every constituent analysis showed site was not a significant variable and season was significant (Table 23). For all constituents, the growing season mean loading is significantly greater than the dormant season mean loading (Tukey's HSD, Table 24).

Table 23. Two-way ANOVA for concurrent flow loading by analysis for site, season, and the interaction term.

Analysis	Two-way ANOVA variables	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Ammonium Loading (g/day*hectare)						
	Site	4	4	0.00203	0.260	0.9
	Season	1	1	0.0264	13.6	0.0004
	Season*Site	4	4	0.00107	0.137	0.9
Phosphate Loading (g/day*hectare)						
	Site	4	4	0.02607	1.30	0.3
	Season	1	1	0.111	20.8	<.0001
	Season*Site	4	4	0.0225	1.06	0.4
Nitrate Loading (g/day*hectare)						
	Site	4	4	13.9	1.30	0.3
	Season	1	1	16.1	6.01	0.02
	Season*Site	4	4	5.14	0.480	0.8
TSS Loading (g/day*hectare)						
	Site	4	4	36000	1.22	0.3
	Season	1	1	65700	8.88	0.004
	Season*Site	4	4	33700	1.14	0.3
TP Loading (g/day*hectare)						
	Site	4	4	0.355	1.70	0.2
	Season	1	1	0.582	11.2	0.001
	Season*Site	4	4	0.0976	0.468	0.8

Table 24. Concurrent flow loading in g/hectare*day by season, sample number, mean in kg/hectare*day, standard error, and post-hoc Tukey HSD p-value.

Analysis	*P-value*	*Season*	*N*	*Mean*	*Standard Error*
Ammonium loading (g/day*hectare)	<.0001	growing	54	0.037	0.007
		dormant	35	0.0017	0.008
Phosphate loading (g/day*hectare)	<.0001	growing	54	0.096	0.013
		dormant	35	0.023	0.003
Nitrate loading (g/day*hectare)	0.007	growing	54	1.60	0.26
		dormant	35	0.7	0.19
TSS loading (g/day*hectare)	0.0007	growing	54	72.5	14.0
		dormant	35	16.0	5.6
TP loading (g/day*hectare)	0.0001	growing	54	0.25	0.02
		dormant	33	0.08	0.04

4.7.1 Loading by constituent

4.7.1.1 Ammonium

Annual loading for ammonium ranged from 0.005- 0.007 kg/hectare at D1 to 0.034 kg/hectare at A4 (Table 21).

At the monthly scale, the agricultural and developed subwatersheds and the mainstem of R1 and R2 had increased ammonium loading from approximately May-July in both 2016 and 2017 (Figure 33). There was less fluctuation and lower loads in the control compared to the other watersheds (Figure 33) with an average loading of 0.01 g/day*hectare (Table 22). A1, R1, and R2 had an average loading of 0.03 g/day*hectare, while D1 had an average of 0.02 g/day*hectare (Table 22).

There were no significant differences in loading between sites (p= 0.9, Table 23). There was a significant difference between growing and dormant season for ammonium loading (Tukey's HSD p <.0001, Table 24).

4.7.1.2 Phosphate

Annual loading for phosphate ranged from 0.011 to 0.017 kg/hectare at C2 to 0.072 at site A2 (Table 21).

At the monthly scale, there was increased phosphate loading from approximately May- September for both 2016 and 2017 for all subwatersheds (Figure 34). The control displayed similar fluctuations to the other subwatersheds but had lower values. The control had a lower average loading of 0.03 g/day*hectare compared to the other subwatersheds (Table 22). A1 had a mean of 0.05 g/day*hectare. D1, R1, and R2 had a mean of 0.08 g/day*hectare.

There were not significant differences in loading between sites (p =0.3, Table 23). There was a significant difference between growing and dormant season for phosphate loading (Tukey's HSD p <.0001, Table 24).

4.7.1.3 Nitrate

Annual loading for nitrate ranged from 0.18 to 0.30 kg/hectare at site C2 to 3.07 kg/hectare at site A2 (Table 21).

At the monthly scale, all subwatersheds showed an increase nitrate loading from approximately May- July for both 2016 and 2017 (Figure 35). The control fluctuated less with lower loads with an average nitrate loading of 0.42 g/day*hectare (Table 22). All other sites had an average nitrate loading of greater than 1 g/day*hectare, A1 and R1 had loading greater than 1.5 g/day*hectare.

There were not differences in loading between sites (p= 0.3, Table 23). There was a significant difference between growing and dormant season for nitrate loading (Tukey's HSD p= 0.007, Table 24).

4.7.1.4 Total Suspended Solids

Annual loading for TSS ranged from 6.8 to 15 kg/hectare at site C2 to 19.2 to 31.6 kg/hectare at site A1 (Table 21).

At the monthly scale, all subwatersheds showed an increase in TSS loading from approximately May-July for both 2016 and 2017 (Figure 36). The control fluctuated similarly over time but had lower loads with an average TSS loading of 21.1 g/day*hectare (Table 22). This was close to D1 which had an average TSS loading of 23.2 g/day*hectare. A1, R2, and R1 all have higher TSS averages (Table 22). There was not a significant difference between sites (p= 0.3, Table 23). There was a significant difference between growing and dormant season for TSS loading (Tukey's HSD p=0.0007, Table 24).

4.7.1.5 Total Phosphorus

Annual loading for TP ranged from 0.03 kg/hectare to 0.05 kg/hectare at site C2 to 0.12 at site A2 (Table 21).

At the monthly scale, TP increased in loading from approximately March to July for all subwatersheds (Figure 37). The control fluctuated over time but had lower loads with an average TP loading of 0.08 g/day*hectare (Table 22). A1 had an average TP loading of 0.13 g/day*hectare and D1 has an average TP loading of 0.16 g/day*hectare. R1 and R2 average TP loading in g/day*hectare was 0.25 and 0.29 respectively.

There were no significant site differences (p= 0.2, Table 23). There was a significant difference between growing and dormant season with a (Tukey's HSD p=

0.0001, Table 24). Overall, there was not a strong relationship between TP baseflow loading and Phosphate baseflow loading (Figure 38), suggesting that not all TP is being converted directly to dissolved phosphate.

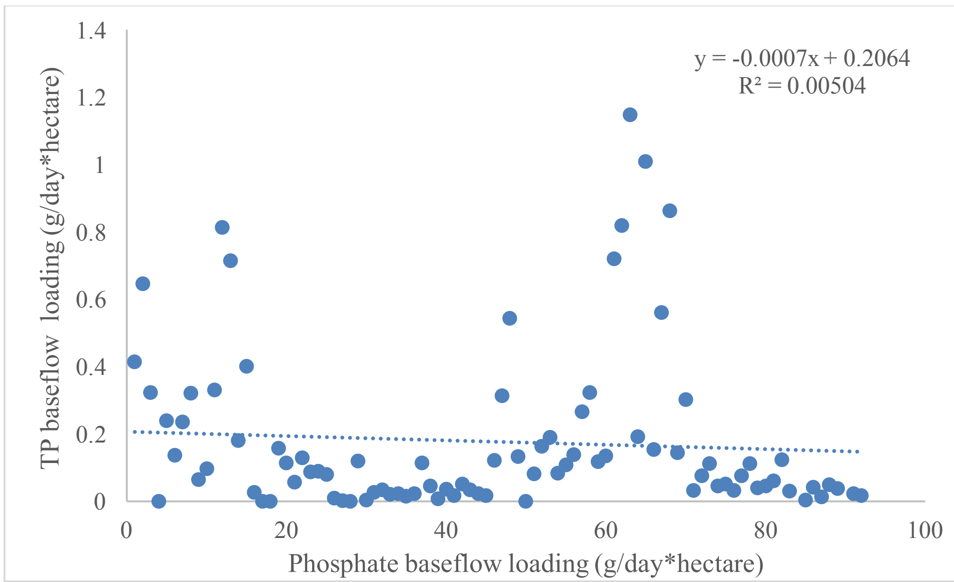

Figure 38. Relationship between TP baseflow loading and phosphate baseflow loading.

5 Discussion

Headwater streams are hydrologically and ecologically important and maintain water quality through natural discharge regimes, regulating sediment export, retaining nutrients, and processing terrestrial organic matter (Lowe and Likens, 2005). The question of how nutrient concentrations in headwater streams are controlled is important to stream productivity and to the amount and timing of nutrient inputs to larger downstream aquatic ecosystems (Mullholland, 1992). The overall research goal of this study was to understand how restoring a headwater stream in urbanized surroundings will affect downstream water quality. This study sought to provide data for pre-restoration baseflow nutrient concentration and annual loading in Reedy Creek.

The results in Reedy Creek indicate stream nutrient dynamics are affected by terrestrial nutrient inputs to the headwaters. Increased nutrient inputs may decrease the ability of streams to retain and transform nutrients, leading to longer nutrient uptake lengths (Wollheim et al., 2001). In flowing waters, nutrient cycles are longitudinally extended to become spirals and the length of the spiral is primarily determined by uptake length (Webster and Ehrman, 1996). Uptake length is a measure of the distance it takes the average molecule to be incorporated to biomass or a particle and is positively related to discharge (Gibson and Meyer, 2003). Thus, streams draining watersheds with landuses that increase nutrient inputs to streams may have longer uptake lengths than other streams of similar physical characteristics (Gibson and Meyer, 2003). The results in Reedy Creek suggest that increased loading from the headwaters results in increased nutrient loading downstream. The agricultural and developed landuses serve as controls on dissolved nutrient concentrations and contribute to elevated nutrient loading from the tributaries with those landuses.

5.1 Estimated Discharge Approaches

5.1.1 Drainage area ratio

The drainage area ratio approach assumes that flow scales directly with watershed area (Gianfanga et al, 2015). That is, as watershed area increases, flow rate increases at a fixed rate per unit area. Thus, the flow per unit area is assumed to be the same at both the ungaged location and gaged reference location. Gianfanga et al. (2015) found that the drainage area ratio was a valid approach for estimating discharge in the Catskills region of New York. The study found watershed area ratio was the most important basin parameter for estimating discharge with the area ratio alone explaining 93% of the variance in the slopes of relationships between upstream and downstream flows.

The area ratio method accurately predicted upstream flows at area ratios as low as 0.005 in the Gianfanga et al. (2015) study. In Massachusetts however, Ries and Friesz (2000) determined the recommended ratio to be between 0.3 and 1.5. Outside these ratios the authors recommend using regression equations. The Reedy Creek headwaters has small drainage areas. Subsequently the area ratios do not fall within the range recommended by Ries and Friesz (2000) (Table 2), except for A1 (ratio= 0.33) and R2 (ratio= 0.65). All other subwatersheds (A2, A3, A4, C1, C2, D1, D2) are below 0.3.

The difference between the area ratio predicted discharge and the measured discharge for Reedy Creek may be, in part, explained by zeros marking flows that were too small to measure. However, based on the limited comparison between field measured and area ratio predicted discharges, both dates have the largest difference between measured discharge and area predicted discharge for the mid-sized watershed areas, not the smallest or the largest (Table 7). It may be that the Reedy Creek results align with the results of the Gianfanga et al. (2015) study the discharge can be predicted for an area ratio as low as 0.005. The Reedy Creek watershed was an appropriate candidate to use the drainage area ratio approach because all the ungaged watersheds were nested within the gaged watershed.

However, the study areas least likely to have been represented correctly by the area relationship were A1 (ratio= 0.33), P1 (ratio= 0.21), R2 (ratio= 0.65) and D1 (ratio= 0.65) because of the size of the watershed area over-approximated discharge. P1 was not estimated using the area ratio because it is hydrologically dissimilar to the gaged watershed. The others subwatersheds (A, R and D) were estimated using the concurrent flow approach detailed in the section below to present a probable range of discharge and loading.

5.1.2 Concurrent Flow

A correlation of measured discharge with concurrent daily mean discharge from a nearby gage station requires numerous measurements to establish a relationship between low flows at the stream gaging station and the partial-record location. According to Riggs (1982), 8 to 10 measurements from separate hydrograph recessions minimizes errors and provides adequate data to define a relationship with concurrent flows at a stream gage station. The regression-equation coefficient of determination (R^2) should be at least 0.70 and the two basins should be similar in size, geology, topography, and climate (Riggs, 1982).

The concurrent flow approach used in this analysis was a limited estimation of discharge because there were only three measured data points used to create the line of best fit used to estimate ungaged discharge from the gage discharge (Table 6). This is significantly less than the number of points recommended by Riggs (1982). To improve the confidence of concurrent flow approximation more field measurements would be needed at each site. R2 (R^2= 0.96), and A1 (R^2= 0.84) had regression-equation coefficients that are consistent with Riggs, 1982. C2 (R^2= 0.10) and D1 (R^2= 0.46) are outside the recommended R^2 value from Riggs (1982).

Overall, the concurrent flow approach is a closer value to the in-stream field measured discharge value. The concurrent flow approach differed from the measured discharges by 0.2- 0.9 L/s (Table 8) and is the most accurate approximation of discharge at the ungaged sites for dates not field measured. To estimate annual baseflow loads for constituents, the concurrent flow approach discharge data were used.

5.2 Baseflow discharge

Streamflow is composed of overland flow, interflow, and groundwater flow. Based on the Bosch et al. (2017) study, annually baseflow was found to produce 53% of annual streamflow. The study also found that baseflow was greatest during the months of December through May (55-57%) and least from June through November (43-46%). From these results, the reason to study streams at baseflow becomes clear, as the stream is most frequently at baseflow rather than stormflow and because surface runoff has the potential to be of reduced water quality compared to groundwater.

Separating streamflow into the components of overland flow, interflow and groundwater flow is subjective because there is no method for precisely identifying each (Bosch et al., 2017). Stormflow contains true surface runoff and the quickflow portion of interflow, while baseflow contains groundwater flow and the portion of interflow moving slowly through the subsoil (Bosch et al., 2017). There has been a greater emphasis on studying stormflow in urban areas because of the impacts of impervious cover which has resulted in fewer studies of baseflow in urban areas. However, this study of Reedy Creek characterizes baseflow discharge rather than stormflow discharge.

Based on hyporheic research in Reedy Creek shallow groundwater exchange seems to occur (Vinson et al., 2017). However, the effect of shallow groundwater exchange on stream chemistry is not known as piezometer samples had varied stream chemistry inconsistent with simple interactions with downwelling stream water (Haydin, 2017). Bed hydraulic conductivity is expected to influence hyporhiec exchange in the post-restoration stream (Vinson et al., 2017) and this may influence the baseflow in Reedy Creek post-restoration.

For urban channels, Gibson and Meyer (2003) found in the Upper Etowah River watershed, GA, the urban channels had increased water residence time over forested streams because, although urban streams had fewer debris dams than forested streams, urban streams had large scour pools created and maintained by high peak discharges. Urban streams that have in-stream structures such as meanders and pools enable retention of water at baseflow, and this physical retention is likely important in nutrient retention as well (Gibson and Meyer, 2003).

Baseflow fluctuates with year and season. Bosch et al. (2017) found baseflow is greater during years of low precipitation. During high precipitation years streamflow is dominated by saturation excess driven surface runoff leading to a higher proportion of stormflow in the stream. Mullholand and Lenat (1992) state that despite lack of large seasonal differences in precipitation, Piedmont streams exhibit a large seasonal variation in flow. High rates of evapotranspiration in the growing season deplete soil moisture content and reduce groundwater input to streams. Average discharge during growing season is generally much lower compared with winter and early spring.

Streamflow during the summer and winter months contains a higher proportion of surface runoff (Mullholand and Lenat, 1992). Thunderstorms during the summer months can be intense and produce sharp increases in storm flow although the storm hydrograph is usually short (Mullholand and Lenat, 1992). The Reedy Creek data are consistent with Mullholand and Lenat (1992) through the influence of summer storms on antecedent precipitation prior to baseflow sampling (Figure 8).

As indicated by previous research by Bosch et al. (2017) streamflow is generally the greatest from January through April. During this period groundwater contributions to streamflow are the greatest. Conversely, streamflow during the months from September through November can be unreliable due to diminishing baseflow, high evapotranspiration, and largely unsaturated conditions. Again, Reedy Creek displayed similar seasonal trends during this study period (Table 3, Figure 8).

In Reedy Creek, Vinson et al. (2017) found the undeveloped forested (C2) subwatershed baseflow exhibited little or no enrichment of δD suggesting that baseflow is a mix of subsurface waters of undefined residence time. However, the developed subwatershed exhibited enrichment of δD in the summer, while winter δD resembled the undeveloped watershed. The timing of the δD enrichment indicated that summer precipitation dominates baseflow in the developed subwatershed due to evaporation effects, as generally enriched δD is heavier and is more likely to precipitate (Vinson et al., 2017). Evaporation effects may be caused by increased impervious cover that prevents infiltration causing more water to evaporate and decreasing inputs to the stream through groundwater. The Vinson et al. (2017) results are consistent with the Bosch et al. (2017) study and indicate that groundwater inputs may be less in the summer months.

In Reedy Creek, there were dates sampled encompassing more than only baseflow (Table 3). High values of API mean the catchment was wet so any rain is likely to occur as surface run off. Conversely, low values demonstrate the catchment was dry so the rain is likely to infiltrate. Sampling date 5/26/17 had an order of magnitude greater discharge in L/s and runoff depth in mm/day than all other sampling dates and should not be considered a baseflow sample for concentration or loading data.

The other samples that may have been influenced by stormflow conditions include 8/4/16 (runoff depth= 0.88 mm/day, API2= 31.3, API7= 31.3) because of the high runoff depth on this day and the high amount of precipitation two days prior. 3/16/18 (runoff depth= 0.93 mm/day, API2= 4.9, API7= 10.2) because of the high runoff depth. 7/25/17 (runoff depth= 0.22 mm/day, API2= 19.3, API7= 19.3) because while the runoff on the date measured was not as high as other dates measured, the antecedent precipitation two days prior was high. 8/15/17 (runoff depth= 0.88 mm/day, API2=13.4, API7= 46.6) because of the high runoff depth and the high amount of precipitation seven days prior.

When the outliers are removed from the dataset, the average baseflow discharge for Reedy Creek over the course of the study at the watershed outlet (R1) was 22.8 L/s with and average runoff depth of 0.35 mm/day.

The data in Table 3 can be read in conjunction with Figure 8 to identify dates where samples were taken where it was not raining at the time of sampling, but the sample most likely contained stormflow due to antecedent moisture conditions. Bosch et al. (2017) defined average stormflow duration of seven days to include both surface runoff and a faster portion of interflow. However, the hydrologic characteristics of the watershed vary based on climate, soil properties, and the underlying aquifer. The Bosch et al. (2017) study took place in the lower coastal plain aquifer rather than the Piedmont. Per the stormflow duration specified by Bosch et al. (2017) the only results from the Reedy Creek study not influenced by stormflow were on 9/20/16 and 10/25/16.

Kohler and Linsley (1951) stated baseflow indices are strongly dependent upon season of the year and do not necessarily reflect short-term changes in watershed state. A baseflow index may have been a more appropriate metric for determining baseflow in Reedy Creek. Overall, because interflow has the potential to have significantly different chemical characteristics than either direct surface runoff or groundwater flow, future research characterizing the separation of interflow from direct surface runoff and groundwater flow is warranted.

To have a better estimation of baseflow discharge for this study more field measured discharge data should have been collected from the ungaged sites. It would also have been ideal to have more field-measured data from the R1 gaged site. This would determine if there were discrepancies between the field measured discharge values and the gage measured discharge values. For example, in Figure 13, the R1 difference from 10/18/17 could have been field measurement error for the measured value, rather than the area predicted value, which should be the value from the USGS gage.

Field measurement error could have been from not picking an appropriate representative cross-section that captured all changes of velocity across the cross-section or using the Swoffer velocity meter at low flows in a small channel. However, based on the two measured data points that can be compared to the gage, it seems that the field measurements under-estimated flow. It would have been ideal to have more field measured R1 gage measurements to compare to the gage data throughout the course of the study to confirm this.

5.3 Concentrations for dissolved and particulate constituents

5.3.1 Concentrations by landuse

Landuse has been shown to influence dissolved nutrient and TSS concentrations. Omernik (1997) found that nitrate and phosphate draining agricultural land had nine times greater concentration than forestland. Blinkley and Brown (1993) also found legacy effects from the 19th- 20th century agricultural practices continue to contribute to water quality degradation due to increased channel erosion and nutrient load discharge. Because Reedy Creek is primarily a forested headwaters, much of the channel incision and increased nutrient load discharge may have resulted from past agricultural landuse.

The headwater restoration in Reedy Creek may help to mitigate some of the degradation from past agricultural landuse, and future work to document the effect of the natural channel design stream restoration on nutrient concentration would be a useful tool for watershed managers. Rattan et al. (2016) found stream water nutrients are associated with human activity on the landscape, whereas nutrient loads are largely influenced by hydrologic events. The objective of this study was to determine surface water baseline nutrient and TSS dynamics in Reedy Creek prior to restoration by analyzing nutrient concentrations at the reach scale using 18 months of monthly stream chemistry (2016-2017 using dates 5/31/16 to 10/20/17). This study contributes to our overall knowledge of the Reedy Creek headwaters with the addition of surface water processes to previous work which determined the role of subsurface processes in the pre-restored stream for later comparison to the post-restoration stream (Vinson et al. 2017, Haydin 2017).

The first research question for this study **(Q1)** was: what are the controls of dissolved nutrient concentrations for each landuse subwatershed? I hypothesized **(H1)** that dissolved nutrient concentrations vary significantly with landuse. At the monthly time scale, dissolved nutrient concentrations did vary with landuse, however the results were not statistically significant. A2 had the highest average phosphate, nitrate, and total phosphorus concentrations and the agricultural subwatershed outlet (A1) had the highest average TSS concentration.

Vinson et al. (2017) however, found that in the Reedy Creek watershed there was evident inter-site variation in nitrate concentrations at the weekly scale and that the agricultural and developed subwatersheds have the highest year-round nitrate concentrations. The results of this study are consistent with the results if the Vinson et al. (2017) for the same time-period.

Because nutrient concentrations directly influence nutrient loading, I hypothesized that landuse would affect nitrogen and phosphorus loading from the subwatersheds. Specifically, that nitrogen loading would be highest from the agricultural watershed **(H1)**. In the Reedy Creek study the highest average ammonium concentration came from the agricultural reaches A3 and A4 of .01 mg/L and .016 mg/L respectively. The agricultural sites had the highest ammonium concentrations relative to the other subwatersheds, but were not statistically significant.

The annual nitrate export from the agricultural watershed was 0.57 kg/ha which was only slightly higher than the R2 nitrate annual load of 0.54 kg/ha. The nitrate annual load from the agricultural subwatershed was 3.2 times greater than the annual load from the control (C2) subwatershed of 0.15 mg/L. The annual load in the mainstem at R2 was

3.0 times greater than the annual load from the control watershed. Overall, this supports my hypothesis that nitrate export would be greatest from the agricultural landuse watershed.

I also hypothesized that the developed watershed would have high export of nitrate and phosphorus compared to the control watershed **(H1)**. The annual nitrate export from the developed watershed was 0.35 kg/ha, 1.9 times greater than the control (C2) subwatershed. The phosphate annual load from developed subwatershed was 0.024 kg/ha which is 2.2 times greater than the control subwatershed 0.011 kg/ha. The mainstem had a phosphate annual load of 0.026 kg/ha which was 2.4 times greater than the control (C2) subwatershed.

These results suggest the developed landuse does influence the annual nutrient loads at baseflow for nitrogen and phosphorus when compared to the control (C2) subwatershed, although there was not a statistically significant difference. The elevated annual nitrogen loading in the agricultural and developed subwatersheds, and the elevated annual phosphorus loading in the developed subwatershed, were reflected in the mainstem R1 and R2 elevated loadings. These results indicate the movement of nutrients from the impacted subwatersheds downstream. Mainstem mixing was shown by Vinson et al. (2017), who determined using ion concentration data, the mainstem R2 tributary was a mixture of ions from contributing subwatersheds during the year.

Overall, landuse affects annual nutrient loading and this increased loading also occurs downstream at the R2 subwatershed and R1 watershed outlet. My data suggested that increased loading from the headwater subwatersheds resulted in increased nutrient loading downstream at the watershed outlet. The agricultural and developed landuses do serve as controls on dissolved nutrient concentrations and result in elevated loading from the tributaries based on watershed landuse. **H1** was supported by the results of this study at the monthly time-scale.

5.3.2 Concentrations by season

The second research question in this study (Q2) was: Are there seasonal differences in watershed nutrient concentrations? I hypothesized that both dissolved nitrogen and dissolved phosphorus would exhibit a seasonal trend in concentration across monthly samplings **(H2.1)**.

For the concentrations by site data neither dissolved nitrate nor dissolved phosphorus exhibit a significant seasonal trend and instead support the null hypothesis that there is no seasonal difference **(H2.2)**.

Dissolved phosphorus had a significant seasonal difference (Two-way ANOVA) but was not significant from the post-hoc Tukey HSD mean comparison. When looking at concentrations by subwatershed, only the agricultural subwatershed exhibits a seasonal trend in dissolved phosphorus using a student's t-test. My hypothesis that phosphorus exhibits seasonality would need more sampling dates to determine whether my hypothesis was supported.

Dissolved nitrate did not have a significant trend from the results of a two-way ANOVA between site and season. Nitrate concentrations did not show a significant seasonal difference in the forested control subwatershed (C2) at the monthly scale using a student's t-test. This does not support my hypothesis that dissolved nitrate would show seasonality. However, the Vinson et al. (2017) study found that at the weekly scale in the Reedy Creek watershed, nitrate concentrations fluctuate seasonally in the undeveloped subwatersed increasing during the growing season and reaching a minimum in the winter.

(H2.1) also stated that there would be higher dissolved nutrient concentrations in the dormant season than the growing season because of plant uptake during the growing season. For all analyses, concentrations were higher in the growing season which does not support my hypothesis. This may be because of seasonal fluctuation in groundwater inputs in combination with increased evapotranspiration and decreased precipitation during the growing season resulting in higher growing season concentrations.

However, there are significant seasonal differences in concentrations for ammonium, TSS and TP. There were significant differences between the growing season and dormant season means for daily loading in g/hectare for all constituents analyzed, suggesting that nutrient and TSS loading during the growing season is greater than loading during the dormant season.

5.3.3 Loading by contributing variable

For each contributing variable to the downstream watershed export (equation 3), discharge and concentration, the amount of contribution of each variable to the total was calculated. The percentage of discharge and the percentage of concentration was calculated for all concurrent flow loading sites (A1, C2, D1, R1, R2) and the percentage of contribution was averaged across sites. For each sampling date of the study there is a percentage contribution to the baseflow loading value for discharge and concentration (Table 25). Overall, the ammonium baseflow downstream loading was composed of 99-100% discharge in terms of downstream baseflow loading. The ammonium concentrations in Reedy Creek were low compared to other watersheds.

The phosphate baseflow downstream loading discharge percentage ranged from 97-100%, however the largest percentages of concentration occurred in the dormant season. However, the contributions to downstream baseflow loading of discharge and concentration were more variable than either ammonium or phosphate, suggesting a different watershed control on downstream loading. The nitrate baseflow downstream loading discharge percentage ranged from 72- 98%, again the largest percentages of concentration occurred in the dormant season. The TSS baseflow downstream loading discharge percentage ranged from 33-73%, with the largest percentages of concentration occurring in the dormant season. TSS downstream baseflow loading, overall, was controlled more by concentration than discharge compared to the other constituents. TP tends to behave more like ammonium and phosphate rather than TSS which again supports the finding that TSS and TP were not correlated in this study. The TP baseflow downstream loading discharge percentage ranged from 93-99%, with the largest concentration percentages occurring in the dormant season.

Overall, these data suggest that there are varying controls on downstream loading by constituent and that contribution that concentration plays in downstream loading is greater in the dormant season than the growing season. This aligns with the seasonal trend in baseflow discharge where in the dormant season lower discharge is present and so concentration plays a larger role in watershed downstream loading.

Table 25. Average percent contribution of discharge (Q) and concentration (conc) to downstream baseflow loading.

Date	NH_4	NH_4	PO_4	PO_4	NO_3	NO_3	TSS	TSS	TP	TP
	% Q	% conc	% Q	% conc	% Q	% conc	% Q	% conc	% Q	% conc
5/31/16	99.77	0.23	99.88	0.12	97.36	2.64	41.45	58.55	99.51	0.49
6/20/16	99.68	0.32	99.28	0.72	94.60	5.40	59.41	40.59	99.48	0.52
7/28/16	99.99	0.01	99.46	0.54	97.28	2.72	60.80	39.20	99.10	0.90
8/4/16	99.99	0.02	99.83	0.17	97.86	2.14	66.71	33.29	99.77	0.23
9/20/16	99.81	0.01	98.86	1.14	98.98	1.02	65.75	34.25	97.97	2.03
10/25/16	99.98	0.02	98.41	1.59	88.71	11.29	60.36	39.64	97.57	2.43
11/14/16	99.98	0.02	97.27	2.73	86.36	13.64	33.92	66.08	93.79	6.21
12/7/16	99.87	0.00	99.02	0.98	87.92	12.08	47.24	52.76	98.34	1.66
1/19/17	99.86	0.14	99.07	0.93	82.97	17.03	51.28	48.72	98.35	1.65
2/17/17	99.98	0.02	99.90	0.10	95.39	4.61	61.68	38.32	99.40	0.60
3/16/17	100.00	0.00	99.97	0.03	97.63	2.37	73.18	26.82	99.85	0.15
4/28/17	99.91	0.09	99.93	0.07	96.76	3.24	41.59	58.41	99.13	0.87
5/26/17	99.95	0.05	99.96	0.04	98.74	1.26	70.64	29.36	99.85	0.15
6/20/17	99.92	0.08	99.87	0.13	97.52	2.48	55.79	44.21	99.54	0.46
7/25/17	99.81	0.19	99.45	0.55	94.22	5.78	54.04	45.96	98.74	1.26
8/28/17	99.76	0.24	99.47	0.53	73.89	26.11	20.10	79.90	97.95	2.05
9/20/17	100.00	0.00	99.43	0.57	78.42	21.58	60.05	39.95	99.25	0.75
10/18/17	99.82	0.18	97.79	2.21	72.65	27.35	36.57	63.43	81.19	14.29

6 Monthly concentrations and approximate baseflow load by constituent

6.1.1.1 Ammonium

Monthly Concentrations:

Physical factors such as discharge, stream depth, and current velocity are important factors in determining ammonium uptake (Peterson et al. 2001). Therefore, changes in landuse affecting physical characteristics of the stream could influence ammonium uptake lengths (Gibson and Meyer, 2002) although the ammonium concentrations in this study were all relatively low.

Gibson and Meyer (2003) found background concentrations of ammonium were higher in urban sites than in forested sites. The authors studied a forested watershed area of 0.78 km^2, of similar size to the forested in Reedy Creek (C2= 0.68 km^2). The urban watershed area was 1.1km^2, similar in size to the developed subwatershed of Reedy Creek (D1=1.15 km^2). The average discharge from the Gibson and Meyer forested subwatershed was 2.4 L/s and the average discharge from the Reedy Creek forested control was 2.2 L/s. The average discharge from the urban watershed was 1.5 L/s in the Gibson and Meyer study, 4.8 L/s in Reedy Creek. The average % forested cover for the forested watershed was 61 whereas in the Reedy Creek the control had 98% forested cover. The averaged % cover in the urban watershed had 47 % forested cover whereas in Reedy Creek there was 61% forested cover. The average ammonium concentration from the Gibson and Meyer study was 0.014 mg/L for the forested stream. For the control at Reedy Creek the average ammonium concentration was lower, with a concentration of 0.004 mg/L. The average ammonium concentration from the Gibson and Meyer study was 0.045 mg/L for the urban stream. The average concentration from the D1 subwatershed was 0.003 mg/L.

In the Reedy Creek study the highest average ammonium concentrations came from the agricultural reaches A3 and A4 of 0.01 mg/L and 0.016 mg/L respectively. Overall, the ammonium concentrations reported for Reedy Creek were lower than those in the Gibson and Meyer study. The agricultural sites had the highest ammonium concentrations relative to the other subwatersheds, but not a statistically significant difference.

Boggs et al. (2013) found a mean annual concentration for the North Carolina Slate Belt forested headwaters of 0.02 mg/L in 2008 and 0.01 mg/L in 2009. While these concentrations are more similar to the average concentrations found in Reedy Creek, Reedy Creek generally has lower concentrations than either study. The forested control reach (C2) has an average concentration of 0.0004 mg/L ammonium. All Reedy Creek sites have a minimum concentration value of 0.0 mg/L and a maximum reported concentration 0.101 mg/L at A4. There were no statistical differences between sites (Table 13).

In the monitoring report by Allan et al. (2013), ammonium concentrations were found to be similar amongst the various Beaverdam Creek (BDC) subwatersheds and no clear temporal trends in loading or concentration were evident. In the study by Boggs et al. (2013) based on bi-weekly sampling in a Piedmont forested headwater watershed of North Carolina there was no seasonal in ammonium trend from November 2007- June 2010.

In Reedy Creek there was a significant seasonal trend ($p<.0001$, Table 13, Figure 17). Further, every subwatershed showed a significant seasonal trend (Table 11). Ammonium by subwatershed indicated the agricultural, control, developed, pond and the outlet had a significant seasonal difference between the growing and the dormant season (p =0.001, 0.002, 0.031, 0.022, 0.039 respectively).

Approximate baseflow loading:

Approximate baseflow ammonium downstream loading in Reedy Creek ranged from 0.005- 0.007 kg/hectare at D1 to 0.034 kg/hectare at A4 (Table 21). There were no significant differences in baseflow loading between sites (p= 0.9, Table 23). There was a significant seasonal trend for ammonium baseflow loading (Tukey's HSD p <.0001, Table 24).

6.1.1.2 Phosphate

Monthly Concentrations:

The Ortho-P fraction is the mineralized P fraction considered to be immediately available for algal uptake. Taylor et al. (1971) found that in Coshocton, Ohio, the average in stream concentration draining agricultural land was 0.022 mg/L phosphate and the average concentration draining forested land was .015 mg/L phosphate for the years 1966- 1969. The agricultural site A2 (average concentration= 0.042 mg/L, Appendix C) had an average phosphate concentration approximately twice the agricultural phosphate concentration of Taylor et al. (1971). Site C1 (average concentration= 0.022 mg/L) and D1 (average concentration= 0.025 mg/L) were also in the agricultural range for phosphate reported by Taylor et al. (1971). These concentrations mirror the finding that sites C1, D1, and A2 were significantly different from all other sites (p= 0.0009, Table 14). The forested control, C2, average phosphate concentration of 0.012 mg/L was similar to the Taylor et al. (1971) forested concentration. There was not a significant seasonal trend in phosphate concentration.

Approximate baseflow loading:

The approximate baseflow downstream loading for phosphate ranged from 0.011 to 0.017 kg/ha at C2 to 0.072 at site A2 as shown in Table 21. There were not significant differences in baseflow downstream loading between sites ($p = 0.3$, Table 23). There was a significant seasonal trend for phosphate baseflow downstream loading (Tukey's HSD $p < .0001$, Table 24).

6.1.1.3 Nitrate

Monthly Concentrations:

Inorganic nitrogen, including nitrate, can be used directly by algae, however, nitrogen is generally not limiting to primary productivity in most freshwater systems. However, in high concentrations nitrate can become a water quality contaminant. The NC statewide surface water criteria for nitrogen in water supply watersheds is 10 mg/L for NO_3-N (NCDENR, 2007). All recorded nitrate concentrations in mg/L ranged from a minimum concentration of 0 mg/L to 3.31 mg/L at site A2 and were below the North Carolina nitrate water criteria.

According to John (2008) across the US, the range of nitrate concentrations in urban areas is 0-6 mg/L, the range of nitrate concentration for agricultural lands is 0-10 mg/L, and the range of nitrate concentrations for forests is 0-2 mg/L. All Reedy Creek sites have an average concentration that fall within the forested nitrate concentration range. Forest soils generally have a high capacity to retain and process nutrient inputs through physical and chemical buffering, microbial nitrogen transformation, and plant uptake (Boggs et al., 2013). Forested buffers have been shown to capture 80% or more of nitrate draining from agricultural lands (Boggs et al., 2013) and this may contribute to the generally low nitrate concentrations observed in this Reedy Creek study. However, certain sites have maximum concentrations recorded that fall within the low range of the urban landuse (D2= 3.60 mg/L, A2= 3.31 mg/L, C1= 2.97 mg/L).

John (2008) observed nitrate concentrations in freshwater across the US, however, all ranges exceed the biological integrity standard set by the U. S. Environmental Protection Agency of 1.0 mg/L (USEPA, 2000). The average concentration at site A2 of 1.54 mg/L exceeds the standard for biological integrity and sites A1 (max= 1.01 mg/L), A3 (max= 1.04 mg/L), R2 (max= 1.31 mg/L), P1 (max=1.35 mg/L), C1 (max= 2.87 mg/L), and D2 (max= 3.60 mg/L) all have maximum concentrations that exceed that standard as well.

Further, 0.125 mg/L for NO3-N is given by the USEPA as reference concentrations for the S.E. Ecoregion IX (USEPA, 2000). Forested watersheds tend to have low nitrate concentrations that are generally driven by vegetation cover, soil development factor, and biogeochemistry that effects mineralization, nitrification, and denitrification rates in forested watersheds (Boggs et al., 2013). Only the C2 average concentration of 0.15 mg/L is near the reference reach value for nitrate concentration. When the C2 forested control is compared to the other reference headwater study (Boggs et al. 2013) there was a mean annual concentration for the Slate Belt forested headwaters of 0.02 mg/L in 2008 and 2009. Again, the Reedy Creek C2 forested control exceeds the nitrate concentration relative to other reference sites.

Approximate baseflow loading:

Approximate baseflow downstream loading for nitrate ranged from 0.18 to 0.30 kg/ha at site C2 to 3.07 kg/ha at site A2 (Table 21). However, the A2 baseflow loading is most likely an over-estimate as it was calculated only using the drainage area ratio discharge approximation. There were not significant differences in baseflow loading between sites (p= 0.3, Table 23). There was a significant seasonal trend for nitrate baseflow loading (Tukey's HSD p= 0.007, Table 24).

Interestingly, Swank and Johnson (1994) state that forest management activities in the Southern Appalachians that include harvesting have been shown to cause minimal nitrate concentration increases (0-0.15 mg/L) in streamwater. When these concentrations are combined with increased discharge from harvesting, however, significant increases in nutrient export can occur. Landuse altering nutrient concentrations in combination with altered discharges due to channel incision and limited access to the floodplain may have resulted in larger baseflow nitrate loads in Reedy Creek compared to the similar watershed study conducted by Boggs et al. (2013).

6.1.1.4 TSS

Monthly Concentrations:

The only existing NC criteria for TSS are for effluent concentrations in trout and high quality waters, (i.e., 10 and 20 mg/l, respectively) (Allan et al., 2013). These criteria do not apply to the Reedy Creek watershed. Boggs et al. (2013) found a mean annual concentration for the North Carolina Slate Belt headwaters of 18.8 mg/L in 2008 and 32.0 in 2009. When compared with the slate belt headwaters, the mean concentration for 18 months of study in Reedy Creek headwaters is lower, at 15 mg/L at the R1 outlet.

Boggs et al. (2013) found no seasonal trend in TSS concetration from November 2007- June 2010. However, in Reedy Creek, TSS concentration data displayed a seasonal trend. The average TSS concentration for the growing season was 10 mg/L and the dormant season was 5 mg/L and this was found to be significanat (p=.0007, Tukey's HSD p=.0009).

Approximate baseflow loading:

TSS downstream loadings in undisturbed, forested, watersheds have been linked to watershed differences in vegetation cover, geology, soil type, flow regime, and topography (Swank et al., 1989). The approximated annual loading for Reedy Creek in 2016-2017 was 27 kg/ha. The control (C2) subwatershed had an annual TSS loading of 7 kg/ha whereas the agricultural subwatershed (A1) had an annual TSS loading of 19 kg/ha. The agricultural subwatershed had a TSS loading 2.7x greater than the forested control. There was a significant seasonal trend for TSS loading (Tukey's HSD p= 0.0007, Table 24).

6.1.1.5 TP

Monthly Concentrations:

A TP value of 0.037 mg/L is given by the USEPA as a reference concentration for the S.E. Ecoregion IX (USEPA, 2000). All subwatersheds had an average concentration greater than the reference concentration except for the two control sites, C1 and C2, with an average concentration of 0.024 mg/L and 0.030 mg/L respectively. All other average Reedy Creek subwatershed TP concentrations range from 0.04- 0.08 mg/L (**Error! Reference source not found.**) which seem to be consistent with the findings of Boggs et al. (2013) with a mean annual concentration for the North Carolina Slate Belt headwaters of 0.07 kg/ha in 2008 and 0.09 kg/ha in 2009.

Boggs et al. (2013) did not find a seasonal trend in TP concentration from November 2007- June 2010. All Reedy Creek sites, except site A3, had a growing season mean TP concentration that were greater than the dormant season mean (Table 10) and resulted in a significant seasonal trend (p=.0045 Table 19, Tukey's HSD p=.0056, Figure 30).

Approximate baseflow loading:

The Reedy Creek A2 drainage area approximated baseflow downstream loading was 0.12 kg/ha, greater than the control baseflow loading of 0.05 kg/ha. However, due to the error in the drainage area ratio discharge approximation for A2, the value is most likely overestimated. There was a significant seasonal trend for TP loading (Tukey's HSD p= 0.0001, Table 24).

6.2 Forested and impervious cover

In most forested watersheds, biological and geochemical processes in upper soil horizons effectively retain N and P and thus reduce inputs to streams (Mulholland, 1992). The forested control (C2) had generally low average nutrient concentrations when compared to the other tributaries for both N and P (ammonium= 0.008 mg/L, nitrate= 0.15 mg/L, phosphate= 0 .012 mg/L, TP= .03 mg/L) (Appendix C).

All subwatersheds within Reedy Creek have a high forested percent cover (Table 1) with the lowest amounts found in the A2 (46%) and D2 (38%) subwatersheds. There was a low amount of impervious cover and a high amount of forested cover in all subwatersheds. The lack of difference between in forested and impervious percent coverage in the subwatersheds may be one reason why there were not strong relationships between land cover and concentration.

The relationship between percent impervious cover and percent forested cover at each site and the overall mean concentration for any of the constituents explained very little of the variance. However, TP had a strong negative relationship with percent forested cover (R^2= 0.465, p = 0.021) (Table 20, Figure 31). The growing season mean TP concentration was greater than the dormant season mean concentration (Figure 32) and had a stronger relationship (R^2= 0.5266) than dormant season (R^2= 0.1271) with percent forested cover.

Total phosphorus may be greater in the growing season because there are generally more frequent and larger storms in the Piedmont that transfer soil particles with TP sorbed to them to the stream during and after stormflow events. This could be because the likelihood of wet antecedent moisture conditions increases during the growing season (Figure 8). However, there was a weak regression relationship between TP and TSS concentrations in this study.

7 Conclusion

Baseline stream nutrient and TSS concentrations and loadings are valuable water quality characteristics to understand, particularly to quantify and model changes following landuse or land management activities. These baseline data help capture and refine the natural range of nutrient variability in a forested system and define background source conditions (Boggs et al., 2013).

Overall, the watershed loading for A1, D1, C2, R2 and the total watershed outlet (R1), tended to fluctuate with discharge at the monthly scale. All subwatersheds showed similar trends at the monthly scale. The mainstem sites (R2 and R1) had the greatest loading for all constituents. The agricultural and developed subwatersheds had greater downstream loading at the monthly scale compared to the control subwatershed. The large spikes in loading are most likely due to increased concentrations resulting from landuse and increased discharge due to channel incision and scour in all impacted tributaries.

Stream water nutrient concentrations are associated with human activity on the landscape, whereas nutrient loads are largely influenced by hydrologic events. This is evident in the Reedy Creek pre-restoration study. The Reedy Creek baseflow results support that a variety of watershed management practices are needed for protection of instream ecological processes. A management goal of addressing high nutrient levels may need to be addressed differently than a management goal of reducing overall nutrient loading downstream. Headwater stream restoration may be one way to reduce high nutrient loading as a result of high discharges as it will decrease channel incision, increase floodplain access and restore bed hyporheic exchange.

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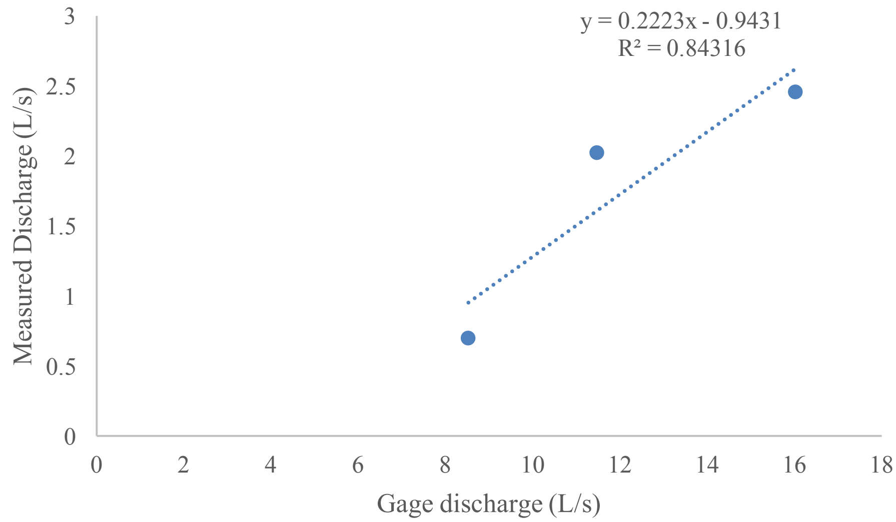
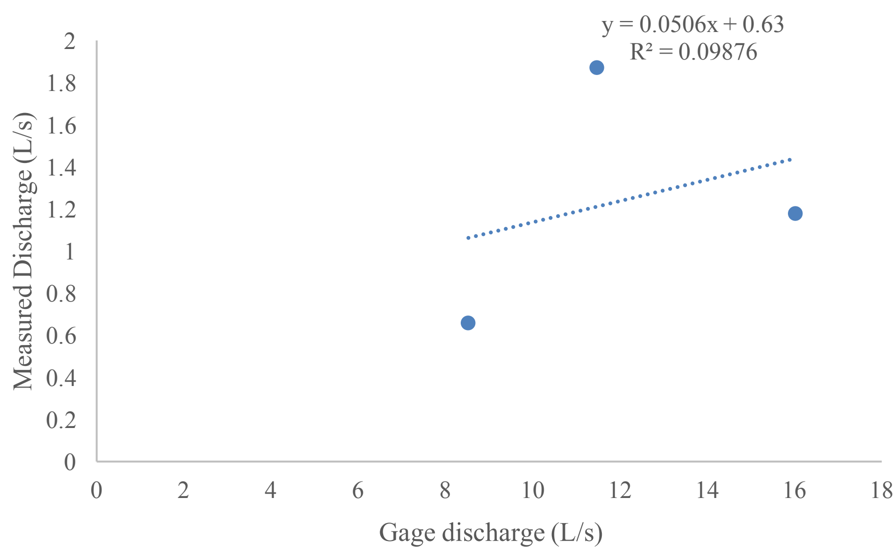
Appendix A: UNCC Pre-restoration and Wildlands Restoration Site Names

UNCC Site Names	*Wildlands Site Names*
A1	Hood Creek
A2	Hodges Branch
A3	Grier Branch
A4	Upper Hood Creek
R1	Reedy Creek
R2	Reedy Creek
D1	Sassafrass Creek
D2	Buckleigh Branch
P1	Dragonfly or Damselfly Tributary
C1	South Fork
C2	South Fork

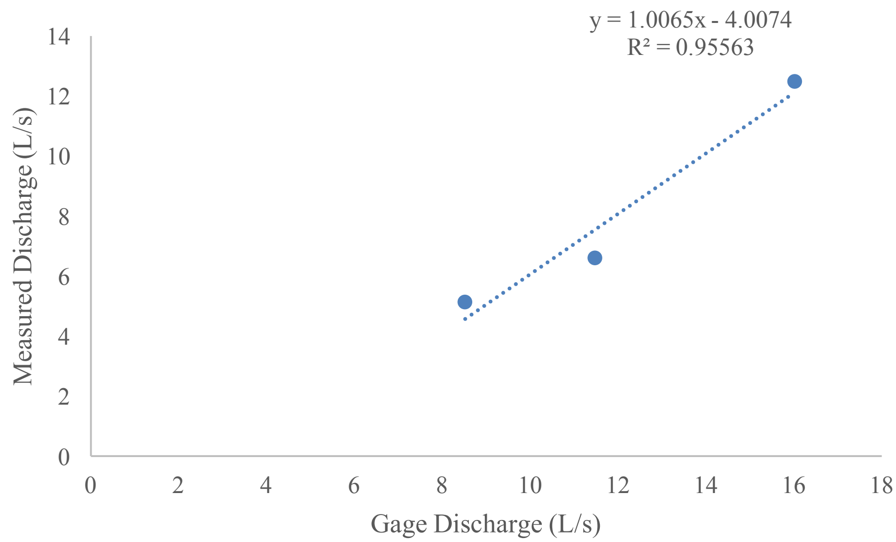
Appendix B: Concurrent Flow Regression Relationships



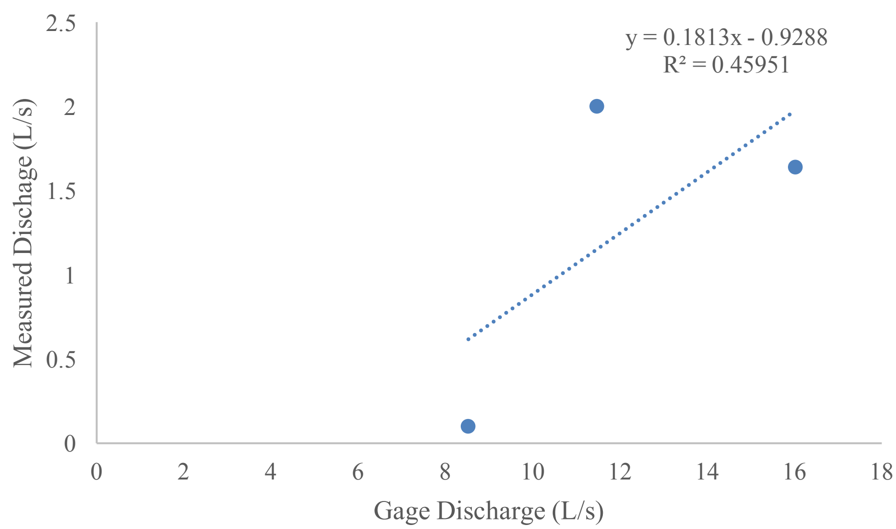
A1 Concurrent flow approach between R1 gage discharge and field measured discharge, regression formula and R^2.



C2 Concurrent flow approach between R1 gage discharge and field measured discharge, regression formula and R^2.



R2 Concurrent flow approach between R1 gage discharge and field measured discharge, regression formula and R^2.



D1 Concurrent flow approach between R1 gage discharge and field measured discharge, regression formula and R^2.

Appendix C: Mean Concentration data for all analyses

Mean concentration (mg/L) across all dates for each analysis, maximum, and minimum concentration by site, standard deviation and sample number.

Analysis	*Site*	*Mean (mg/L)*	*Standard Deviation*	*Min (mg/L)*	*Max (mg/L)*	*N*
Ammonium	A1	0.009	0.01	0	0.051	18
	A2	0.007	0.01	0	0.024	17
	A3	0.01	0.02	0	0.089	18
	A4	0.016	0.03	0	0.101	18
	R1	0.006	0.01	0	0.024	18
	R2	0.003	0.01	0	0.02	18
	P1	0.011	0.01	0	0.037	18
	C1	0.008	0.01	0	0.048	18
	C2	0.004	0.01	0	0.021	17
	D1	0.003	0.01	0	0.02	18
	D2	0.01	0.01	0	0.052	18
Phosphate	A1	0.018	0.01	0.002	0.039	18
	A2	0.042	0.03	0	0.107	17
	A3	0.018	0.02	0.002	0.078	18
	A4	0.013	0.02	0.002	0.071	18
	R1	0.02	0.01	0.003	0.046	18
	R2	0.017	0.01	0	0.045	18
	P1	0.011	0.01	0	0.05	18
	C1	0.022	0.02	0.002	0.056	18
	C2	0.012	0.01	0	0.049	17
	D1	0.025	0.02	0.002	0.062	18
	D2	0.019	0.02	0	0.057	18
Nitrate	A1	0.40	0.3	0.000	1.01	18
	A2	1.54	1.2	0.000	3.31	17
	A3	0.27	0.3	0.015	1.04	18
	A4	0.15	0.1	0.017	0.28	18
	R1	0.26	0.1	0.000	0.54	18
	R2	0.30	0.3	0.001	1.31	18
	P1	0.23	0.4	0.000	1.35	18
	C1	0.53	0.9	0.001	2.87	18
	C2	0.15	0.2	0.002	0.63	17
	D1	0.25	0.1	0.044	0.54	18
	D2	0.87	0.9	0.012	3.60	18
TSS	A1	13.9	17.3	0.84	67.5	18
	A2	5.2	8.0	0	32.9	17

Analysis	*Site*	*Mean (mg/L)*	*Standard Deviation*	*Min (mg/L)*	*Max (mg/L)*	*N*
	A3	4.7	4.8	0.76	15.7	18
	A4	9.0	5.9	1.2	22.0	18
	R1	15.3	13.8	1.54	57.4	18
	R2	6.5	6.3	1.02	24.0	18
	P1	6.1	5.2	0.255	18.4	18
	C1	9.4	22.9	0	98.6	18
	C2	5.9	5.4	0	20.1	17
	D1	6.0	6.2	0	17.6	18
	D2	6.7	4.7	1.275	22.1	18
TP	A1	0.045	0.03	0.005	0.1	18
	A2	0.079	0.07	0.005	0.232	17
	A3	0.058	0.08	0	0.303	18
	A4	0.061	0.06	0.002	0.222	18
	R1	0.049	0.03	0	0.127	18
	R2	0.040	0.02	0	0.08	17
	P1	0.048	0.05	0.013	0.199	17
	C1	0.024	0.02	0	0.07	18
	C2	0.030	0.02	0.002	0.085	17
	D1	0.041	0.02	0.005	0.08	17
	D2	0.047	0.05	0	0.193	18

Appendix D: All concentration data for every constituent

Site	*Date*	*Ammonium (mg/L)*	*Phosphate (mg/L)*	*Nitrate (mg/L)*	*Total Suspended Solids (mg/L)*	*Total Phosphorus (mg/L)*
A1	5/31/16	0.051	0.004	0.3	67.5	0.100
A2	5/31/16	0.010	0.040	1.3	1.6	0.183
A3	5/31/16	0.089	N/A	N/A	2.8	0.037
A4	5/31/16	0.101	0.002	0.0	5.0	0.044
R1	5/31/16	0.022	0.034	0.5	57.4	0.094
R2	5/31/16	0.020	0.017	0.5	12.0	0.033
P1	5/31/16	0.032	0.000	0.1	6.2	0.022
C1	5/31/16	0.000	0.016	0.1	98.6	0.018
D1	5/31/16	0.020	0.022	0.4	15.1	0.044
D2	5/31/16	0.000	0.033	1.5	5.1	0.039
A1	6/20/16	0.014	0.035	0.5	9.6	0.048
A2	6/20/16	0.016	0.105	3.1	1.2	0.081
A3	6/20/16	0.031	0.037	0.5	12.5	0.035
A4	6/20/16	0.045	0.027	0.3	7.9	0.039
R1	6/20/16	0.021	0.031	0.5	15.3	0.048
R2	6/20/16	0.018	0.022	0.2	3.3	0.048
P1	6/20/16	0.031	0.050	0.2	5.9	0.026
C1	6/20/16	0.033	0.021	0.1	3.6	0.035
C2	6/20/16	0.021	0.049	0.2	3.1	0.022
D1	6/21/16	0.017	0.038	0.5	3.5	0.026
D2	6/21/16	0.052	0.031	3.6	3.0	0.033
A1	7/28/16	0.006	0.039	0.6	35.6	0.086
A2	7/28/16	0.008	0.107	2.1	6.4	0.232
A3	7/28/16	0.000	0.078	0.1	1.1	0.105
A4	7/28/16	0.008	0.023	0.3	4.6	0.057
R1	7/28/16	0.000	0.026	0.3	31.2	0.127
R2	7/28/16	0.000	0.040	0.2	3.1	0.080
P1	7/28/16	0.016	0.020	0.2	16.1	0.115
C1	7/28/16	0.016	0.040	0.1	2.7	0.041
C2	7/28/16	0.000	0.032	0.1	2.9	0.051
D1	7/28/16	0.000	0.062	0.1	1.0	0.080
D2	7/28/16	0.012	0.034	1.5	2.6	0.060
A1	8/4/16	0.002	0.022	0.5	7.9	0.005
A2	8/4/16	0.024	0.048	1.4	2.5	0.005
A3	8/4/16	0.007	0.017	0.2	2.0	0.000

Site	*Date*	*Ammonium (mg/L)*	*Phosphate (mg/L)*	*Nitrate (mg/L)*	*Total Suspended Solids (mg/L)*	*Total Phosphorus (mg/L)*
A4	8/4/16	0.017	0.013	0.3	6.3	0.002
R1	8/4/16	0.000	0.026	0.2	4.6	0.000
R2	8/4/16	0.006	0.018	0.2	4.3	0.000
P1	8/4/16	0.012	0.002	0.1	8.7	0.013
C1	8/4/16	0.006	0.013	0.1	4.6	0.000
C2	8/4/16	0.000	0.005	0.1	20.1	0.035
D1	8/4/16	0.000	0.046	0.4	3.5	0.016
D2	8/4/16	0.006	0.045	0.5	5.8	0.000
A1	9/20/16	0.004	0.015	0.0	2.3	0.054
A3	9/20/16	0.007	0.032	0.1	2.3	0.078
A4	9/20/16	0.001	0.071	0.2	9.4	0.039
R1	9/20/16	0.006	0.005	0.0	1.5	0.058
R2	9/20/16	0.000	0.027	0.0	1.6	0.035
P1	9/20/16	0.002	0.004	0.0	2.8	0.039
C1	9/21/16	0.048	0.003	0.0	22.6	0.070
C2	9/21/16	0.010	0.020	0.0	13.4	0.051
D1	9/21/16	0.000	0.059	0.1	0.1	0.062
D2	9/21/16	0.000	0.057	0.0	12.3	0.179
A1	10/25/16	0.000	0.022	0.4	16.9	0.019
A2	10/25/16	0.000	0.056	2.9	2.0	0.044
A3	10/25/16	0.000	0.017	0.1	2.6	0.000
A4	10/25/16	0.000	0.022	0.1	11.1	0.002
R1	10/25/16	0.007	0.016	0.1	10.0	0.002
R2	10/25/16	0.000	0.028	0.0	5.4	N/A
P1	10/26/16	0.000	0.011	0.0	0.3	0.047
C1	10/25/16	0.000	0.014	0.0	0.0	0.000
C2	10/25/16	0.000	0.013	0.0	0.0	0.085
D1	10/26/16	0.000	0.029	0.2	0.0	0.005
D2	10/26/16	0.007	0.012	1.0	6.7	0.000
A1	11/14/16	0.000	0.022	0.7	0.8	0.091
A2	11/14/16	0.000	0.046	3.3	7.8	0.056
A3	11/14/16	0.000	0.030	0.3	1.2	0.021
A4	11/14/16	0.001	0.025	0.1	1.2	0.028
R1	11/14/16	0.000	0.014	0.1	7.3	0.032
R2	11/14/16	0.000	0.019	0.0	6.5	0.028
P1	11/14/16	0.000	0.011	0.0	2.8	N/A

Site	*Date*	*Ammonium (mg/L)*	*Phosphate (mg/L)*	*Nitrate (mg/L)*	*Total Suspended Solids (mg/L)*	*Total Phosphorus (mg/L)*
C1	11/14/16	0.000	0.018	0.0	0.6	0.025
C2	11/14/16	0.001	0.018	0.0	1.2	0.018
D1	11/14/16	0.000	0.028	0.0	17.6	0.060
D2	11/14/16	0.009	0.015	1.4	22.1	0.021
A1	12/7/16	0.007	0.025	0.1	3.8	0.035
A2	12/7/16	0.001	0.002	0.0	0.0	0.066
A3	12/7/16	0.001	0.002	0.0	1.4	0.303
A4	12/7/16	0.000	0.003	0.1	9.2	0.126
R1	12/7/16	0.001	0.034	0.2	6.8	0.070
R2	12/7/16	0.000	0.011	1.3	1.7	0.028
P1	12/7/16	0.000	0.022	0.5	1.0	0.016
C1	12/7/16	0.000	0.048	1.4	1.7	0.019
C2	12/7/16	0.001	0.017	0.2	0.7	0.005
D1	12/7/16	0.001	0.013	0.3	16.0	0.047
D2	12/7/16	0.001	0.026	0.2	5.1	0.022
A1	1/19/17	0.007	0.018	0.2	3.5	0.032
A2	1/19/17	0.015	0.002	0.1	0.6	0.054
A3	1/19/17	0.001	0.013	0.1	2.5	0.025
A4	1/19/17	0.004	0.005	0.1	10.2	0.025
R1	1/19/17	0.010	0.046	0.4	11.5	0.035
R2	1/19/17	0.000	0.045	0.5	2.0	0.025
P1	1/19/17	0.000	0.023	0.8	2.4	0.022
C1	1/19/17	0.002	0.050	1.8	0.9	0.044
C2	1/19/17	0.000	0.016	0.6	0.6	0.016
D1	1/19/17	0.000	0.004	0.2	0.9	0.028
D2	1/19/17	0.004	0.004	0.2	2.6	0.016
A1	2/17/17	0.005	0.002	0.2	4.0	0.035
A2	2/17/17	0.011	0.000	0.0	2.0	0.063
A3	2/17/17	0.008	0.005	0.1	4.0	0.041
A4	2/17/17	0.000	0.004	0.1	8.0	0.060
R1	2/17/17	0.001	0.011	0.3	2.0	0.054
R2	2/17/17	0.000	0.000	0.2	24.0	0.068
P1	2/17/17	0.024	0.003	0.3	4.0	0.041
C1	2/17/17	0.000	0.050	2.0	0.0	0.017
C2	2/17/17	0.000	0.010	0.6	6.0	0.041
D1	2/17/17	0.000	0.002	0.1	4.0	N/A

Site	*Date*	*Ammonium (mg/L)*	*Phosphate (mg/L)*	*Nitrate (mg/L)*	*Total Suspended Solids (mg/L)*	*Total Phosphorus (mg/L)*
D2	2/17/17	0.000	0.014	0.4	8.0	0.038
A1	3/16/17	0.002	0.004	1.0	2.8	0.014
A2	3/16/17	0.000	0.023	3.1	0.9	0.028
A3	3/16/17	0.000	0.004	1.0	0.8	0.014
A4	3/16/17	0.001	0.004	0.2	3.8	0.014
R1	3/16/17	0.000	0.003	0.3	5.1	0.018
R2	3/16/17	0.000	0.003	0.1	1.0	0.014
P1	3/16/17	0.000	0.001	0.0	3.5	0.021
C1	3/16/17	0.000	0.002	0.0	0.3	0.011
C2	3/16/17	0.000	0.004	0.1	13.4	0.018
D1	3/16/17	0.000	0.003	0.2	4.1	0.014
D2	3/16/17	0.002	0.001	0.9	1.3	0.025
A1	4/28/17	0.010	0.003	0.3	21.3	0.054
A2	4/28/17	0.008	0.050	2.0	8.9	0.063
A3	4/28/17	0.010	0.010	0.6	8.5	0.052
A4	4/28/17	0.027	0.002	0.1	22.0	0.054
R1	4/28/17	0.008	0.014	0.4	33.6	0.060
R2	4/28/17	0.004	0.004	0.2	12.7	0.054
P1	4/28/17	0.037	0.001	0.0	11.1	0.090
C1	4/28/17	0.007	0.002	0.1	5.2	0.024
C2	4/28/17	0.002	0.002	0.1	4.9	0.044
D1	4/28/17	0.007	0.005	0.2	5.6	0.041
D2	4/28/17	0.030	0.001	0.4	6.1	0.054
A1	5/26/17	0.014	0.023	0.8	36.2	0.055
A2	5/26/17	0.006	0.050	1.8	32.9	0.058
A3	5/26/17	0.001	0.016	0.6	13.7	0.029
A4	5/26/17	0.032	0.004	0.2	19.1	0.043
R1	5/26/17	0.005	0.004	0.2	17.3	0.040
R2	5/26/17	0.002	0.002	0.2	12.7	0.037
P1	5/26/17	0.013	0.000	0.0	10.8	0.023
C1	5/26/17	0.014	0.005	0.1	4.7	0.023
C2	5/26/17	0.013	0.004	0.1	7.1	0.020
D1	5/26/17	0.005	0.011	0.3	6.6	0.058
D2	5/26/17	0.005	0.000	0.2	7.4	0.052
A1	6/20/17	0.000	0.024	0.6	18.0	0.033
A2	6/20/17	0.000	0.056	1.9	2.5	0.049

Site	*Date*	*Ammonium (mg/L)*	*Phosphate (mg/L)*	*Nitrate (mg/L)*	*Total Suspended Solids (mg/L)*	*Total Phosphorus (mg/L)*
A3	6/20/17	0.005	0.021	0.7	0.8	0.024
A4	6/20/17	0.016	0.004	0.1	15.6	0.038
R1	6/20/17	0.002	0.017	0.4	15.8	0.073
R2	6/20/17	0.000	0.018	0.2	4.3	0.079
P1	6/20/17	0.008	0.000	0.0	9.1	0.044
C1	6/20/17	0.010	0.003	0.1	4.8	0.044
C2	6/20/17	0.010	0.003	0.1	6.1	0.035
D1	6/20/17	0.006	0.023	0.3	12.1	0.049
D2	6/20/17	0.015	0.003	0.3	10.0	0.041
A1	7/25/17	0.010	0.004	0.2	3.3	0.032
A2	7/25/17	0.010	0.001	0.0	0.3	0.231
A3	7/25/17	0.005	0.002	0.1	4.3	0.196
A4	7/25/17	0.013	0.002	0.1	8.3	0.202
R1	7/25/17	0.024	0.005	0.2	8.7	0.035
R2	7/25/17	0.010	0.001	0.4	2.4	0.046
P1	7/25/17	0.006	0.022	0.4	3.2	0.199
C1	7/25/17	0.005	0.056	2.9	2.7	0.020
C2	7/25/17	0.000	0.017	0.1	3.1	0.026
D1	7/25/17	0.004	0.022	0.1	1.3	0.040
D2	7/25/17	0.017	0.016	0.1	6.2	0.040
A1	8/15/17	0.014	0.028	0.0	12.7	0.043
A2	8/15/17	0.006	0.011	0.0	13.2	0.061
A3	8/15/17	0.002	0.014	0.0	8.3	0.032
A4	8/15/17	0.014	0.013	0.0	15.9	0.222
R1	8/15/17	0.000	0.029	0.2	21.2	0.043
R2	8/15/17	0.000	0.012	1.0	14.8	0.063
P1	8/16/17	0.007	0.016	1.3	3.0	0.026
C1	8/16/17	0.001	0.049	0.5	3.4	0.023
C2	8/16/17	0.004	0.002	0.2	7.8	0.026
D1	8/16/17	0.000	0.004	0.4	15.3	0.052
D2	8/16/17	0.006	0.012	1.0	6.5	0.193
A1	9/20/17	0.000	0.017	0.4	2.6	0.051
A2	9/20/17	0.000	0.053	2.1	1.9	0.027
A3	9/20/17	0.000	0.017	0.1	15.7	0.017
A4	9/20/17	0.000	0.012	0.2	1.4	0.072
R1	9/20/17	0.000	0.016	0.2	12.5	0.051

Site	*Date*	*Ammonium (mg/L)*	*Phosphate (mg/L)*	*Nitrate (mg/L)*	*Total Suspended Solids (mg/L)*	*Total Phosphorus (mg/L)*
R2	9/20/17	0.000	0.025	0.1	1.4	0.010
P1	9/20/17	0.000	0.002	0.0	1.5	0.031
C1	9/20/17	0.001	0.002	0.0	10.6	0.003
C2	9/20/17	0.000	0.003	0.1	2.4	0.002
D1	9/20/17	0.000	0.034	0.2	1.0	0.027
D2	9/20/17	0.000	0.011	1.3	2.7	0.007
A1	10/18/17	0.008	0.027	0.3	1.4	0.031
A2	10/18/17	0.007	0.055	0.8	4.1	0.048
A3	10/18/17	0.015	0.005	0.0	0.9	0.027
A4	10/18/17	0.007	0.019	0.2	2.6	0.027
R1	10/18/17	0.006	0.026	0.1	13.9	0.037
R2	10/18/17	0.000	0.019	0.1	3.4	0.034
P1	10/20/17	0.000	0.013	0.0	18.4	0.051
C1	10/20/17	0.000	0.003	0.0	2.3	0.017
C2	10/20/17	0.000	0.000	0.0	8.1	0.017
D1	10/20/17	0.000	0.045	0.3	1.0	0.041
D2	10/20/17	0.012	0.030	1.2	7.1	0.027
	* NA- not collected					

Appendix E: Approximate constituent loading for all sampling dates

Daily range of ammonium loading per site over course of study. R* represents measured discharge directly measured from USGS gage.

Date	Site	Drainage area ratio loading (g/day*ha)	Concurrent flow loading (g/day*ha)	Date	Site	Drainage area ratio loading (g/day*ha)	Concurrent flow loading (g/day*ha)	Field measured loading (g/day*ha)
5/31/16	A1	0.346	0.209	2/17/17	A1	0.029	0.017	
	A2	0.071			A2	0.065		
	A3	0.611			A3	0.043		
	A4	0.688			A4	0.001		
	R1*	0.149	0.149		R1*	0.004	0.004	
	R2	0.135	0.191		R2	0.000	0.000	
	C2	not collected	not collected		C2	0.000	0.000	
	D1	0.139	0.110		D1	0.003	0.002	
	D2	0.000			D2	0.002		
6/20/16	A1	0.068	0.040	3/16/17	A1	0.014	0.009	
	A2	0.076			A2	0.000		
	A3	0.153			A3	0.000		
	A4	0.221			A4	0.013		
	R1*	0.104	0.104		R1*	0.000	0.000	
	R2	0.086	0.118		R2	0.000	0.000	
	C2	0.101	0.059		C2	0.000	0.000	
	D1	0.082	0.062		D1	0.000	0.000	
	D2	0.255			D2	0.017		
7/28/16	A1	0.038	0.023	4/28/17	A1	0.044	0.025	
	A2	0.049			A2	0.034		
	A3	0.000			A3	0.044		
	A4	0.048			A4	0.119		
	R1*	0.000	0.000		R1*	0.034	0.034	
	R2	0.000	0.000		R2	0.018	0.024	
	C2	0.000	0.000		C2	0.008	0.005	
	D1	0.000	0.000		D1	0.029	0.021	
	D2	0.079			D2	0.134		
8/4/16	A1	0.014	0.009	5/26/17	A1	0.285	0.185	
	A2	0.207			A2	0.129		

Date	Site	Drainage area ratio loading (g/day*ha)	Concurrent flow loading (g/day*ha)	Date	Site	Drainage area ratio loading (g/day*ha)	Concurrent flow loading (g/day*ha)	Field measured loading (g/day*ha)
	A3	0.063			A3	0.022		
	A4	0.147			A4	0.642		
	R1*	0.000	0.000		R1*	0.111	0.111	
	R2	0.056	0.081		R2	0.031	0.047	
	C2	0.001	0.000		C2	0.256	0.119	
	D1	0.000	0.000		D1	0.098	0.084	
	D2	0.050			D2	0.112		
9/20/16	A1	0.009	0.004	6/20/17	A1	0.000	0.000	
	A2	not collected	not collected		A2	0.002		
	A3	0.015			A3	0.040		
	A4	0.002			A4	0.122		
	R1*	0.012	0.012		R1*	0.014	0.014	
	R2	0.000	0.000		R2	0.003	0.004	
	C2	0.023	0.018		C2	0.078	0.041	
	D1	0.000	0.000		D1	0.046	0.037	
	D2	0.000			D2	0.113		
10/25/16	A1	0.000	0.000	7/25/17	A1	0.022	0.010	
	A2	0.000			A2	0.021		
	A3	0.000			A3	0.011		
	A4	0.000			A4	0.028		
	R1*	0.009	0.009		R1*	0.053	0.053	
	R2	0.000	0.000		R2	0.022	0.025	
	C2	0.000	0.000		C2	0.000	0.000	
	D1	0.000	0.000		D1	0.009	0.005	
	D2	0.009			D2	0.037		
11/14/16	A1	0.000	0.000	8/28/17	A1	0.025	0.010	0.013
	A2	0.000			A2	0.010		
	A3	0.000			A3	0.003		
	A4	0.001			A4	0.024		
	R1*	0.000	0.000		R1*	0.000	0.000	
	R2	0.000	0.000		R2	0.000	0.000	0.000
	C2	0.001	0.001		P1	-		0.004
	D1	0.000	0.000		C2	0.007	0.006	0.010

Date	Site	Drainage area ratio loading (g/day*ha)	Concurrent flow loading (g/day*ha)	Date	Site	Drainage area ratio loading (g/day*ha)	Concurrent flow loading (g/day*ha)	Field measured loading (g/day*ha)
	D2	0.009			D1	0.000	0.000	0.000
12/7/16	A1	0.012	0.005		D2	0.011		
	A2	0.001		9/20/17	A1	0.000	0.000	0.000
	A3	0.001			A2	0.000		0.000
	A4	0.000			A3	0.000		0.000
	R1 *	0.002	0.002		A4	0.000		0.000
	R2	0.000	0.000		R1	0.000	0.000	0.000
	C2	0.001	0.001		R2	0.000	0.000	0.000
	D1	0.001	0.001		P1	-		0.000
	D2	0.001			C1	-		0.001
1/19/17	A1	0.010	0.004		C2	0.000	0.000	0.000
	A2	0.022			D1	0.000	0.000	0.000
	A3	0.002			D2	0.000		0.000
	A4	0.007		10/18/17	A1	0.010	0.003	0.002
	R1	0.015	0.015		A2	0.009		0.010
	R2	0.000	0.000		A3	0.020		0.001
	C2	0.000	0.000		A4	0.009		no flow
	D1	0.000	0.000		R1	0.008	0.008	0.005
	D2	0.006			R2	0.000	0.000	0.000
				10/20/17	P1	-		no flow
					C1	-		0.000
					C2	0.000	0.000	0.000
					D1	0.000	0.000	0.000
					D2	0.015		no flow

Daily range of phosphate loading per site over course of study. R* represents measured discharge directly measured from USGS gage.

Date	Site	Drainage area ratio loading (g/day*ha)	Concurrent flow loading (g/day*ha)	Date	Site	Drainage area ratio loading (g/day*ha)	Concurrent flow loading (g/day*ha)	Field measured loading (g/day*ha)
5/31/16	A1	0.030	0.018	2/17/17	A1	0.012	0.007	
	A2	0.276			A2	0.000		
	A3	not collected			A3	0.028		
	A4	0.015			A4	0.025		
	R1*	0.230	0.230		R1*	0.065	0.065	
	R2	0.114	0.162		R2	0.000	0.000	
	C2	not collected	not collected		C2	0.059	0.034	
	D1	0.151	0.120		D1	0.014	0.011	
	D2	0.228			D2	0.083		
6/20/16	A1	0.171	0.099	3/16/17	A1	0.034	0.021	
	A2	0.514			A2	0.211		
	A3	0.182			A3	0.038		
	A4	0.132			A4	0.035		
	R1*	0.151	0.151		R1*	0.027	0.027	
	R2	0.109	0.148		R2	0.025	0.036	
	C2	0.237	0.140		C2	0.033	0.017	
	D1	0.184	0.139		D1	0.030	0.025	
	D2	0.152			D2	0.007		
7/28/16	A1	0.251	0.150	4/28/17	A1	0.013	0.008	
	A2	0.682			A2	0.220		
	A3	0.497			A3	0.046		
	A4	0.148			A4	0.011		
	R1*	0.164	0.164		R1*	0.064	0.064	
	R2	0.256	0.360		R2	0.018	0.024	
	C2	0.203	0.112		C2	0.009	0.005	
	D1	0.394	0.310		D1	0.022	0.016	
	D2	0.217			D2	0.004		
8/4/16	A1	0.194	0.120	5/26/17	A1	0.466	0.301	
	A2	0.420			A2	1.009		
	A3	0.149			A3	0.320		

Date	Site	Drainage area ratio loading (g/day*ha)	Concurrent flow loading (g/day*ha)	Date	Site	Drainage area ratio loading (g/day*ha)	Concurrent flow loading (g/day*ha)	Field measured loading (g/day*ha)
	A4	0.116			A4	0.080		
	R1*	0.225	0.225		R1*	0.072	0.072	
	R2	0.154	0.223		R2	0.044	0.067	
	C2	0.042	0.022		C2	0.087	0.041	
	D1	0.400	0.326		D1	0.230	0.198	
	D2	0.396			D2	0.000		
9/20/16	A1	0.033	0.016	6/20/17	A1	0.186	0.114	
	A2	not collected			A2	0.426		
	A3	0.070			A3	0.162		
	A4	0.156			A4	0.027		
	R1*	0.010	0.010		R1*	0.129	0.129	
	R2	0.059	0.067		R2	0.141	0.201	
	C2	0.045	0.035		C2	0.020	0.011	
	D1	0.130	0.075		D1	0.177	0.142	
	D2	0.125			D2	0.021		
10/25/16	A1	0.030	0.011	7/25/17	A1	0.009	0.004	
	A2	0.076			A2	0.002		
	A3	0.023			A3	0.005		
	A4	0.029			A4	0.004		
	R1*	0.021	0.021		R1*	0.011	0.011	
	R2	0.039	0.033		R2	0.002	0.002	
	C2	0.018	0.018		C2	0.037	0.030	
	D1	0.040	0.015		D1	0.047	0.027	
	D2	0.017			D2	0.034		
11/14/16	A1	0.023	0.006	8/28/17	A1	0.049	0.021	0.026
	A2	0.049			A2	0.018		
	A3	0.032			A3	0.025		
	A4	0.026			A4	0.023		
	R1*	0.015	0.015		R1*	0.051	0.051	
	R2	0.021	0.014		R2	0.021	0.021	0.019
	C2	0.020	0.023		P1	-		0.011
	D1	0.029	0.007		C2	0.004	0.003	0.005

Date	Site	Drainage area ratio loading (g/day*ha)	Concurrent flow loading (g/day*ha)	Date	Site	Drainage area ratio loading (g/day*ha)	Concurrent flow loading (g/day*ha)	Field measured loading (g/day*ha)
	D2	0.015			D1	0.006	0.003	0.006
12/7/16	A1	0.040	0.016		D2	0.021		
	A2	0.003		9/20/17	A1	0.040	0.020	0.019
	A3	0.002			A2	0.128		0.212
	A4	0.004			A3	0.042		0.017
	R1*	0.056	0.056		A4	0.029		0.006
	R2	0.017	0.017		R1	0.040	0.040	0.036
	C2	0.028	0.025		R2	0.060	0.070	0.072
	D1	0.022	0.010		P1	-		0.001
	D2	0.042			C1	-		0.002
1/19/17	A1	0.025	0.009		C2	0.006	0.005	0.004
	A2	0.002			D1	0.084	0.051	0.042
	A3	0.019			D2	0.026		0.004
	A4	0.007		10/18/17	A1	0.034	0.011	0.008
	R1*	0.066	0.066		A2	0.070		0.083
	R2	0.066	0.059		A3	0.006		0.000
	C2	0.023	0.022		A4	0.025		no flow
	D1	0.006	0.002		R1	0.034	0.034	0.022
	D2	0.005			R2	0.025	0.020	0.023
				10/20/17	P1	-		no flow
					C1	-		0.008
					C2	0.000	0.001	0.000
					D1	0.056	0.019	0.003
					D2	0.038		no flow

Daily range of nitrate loading per site over course of study. R* represents measured discharge directly measured from USGS gage.

Date	Site	Drainage area ratio loading (g/day*ha)	Concurrent flow loading (g/day*ha)	Date	Site	Drainage area ratio loading (g/day*ha)	Concurrent flow loading (g/day*ha)	Field measured loading (g/day*ha)
5/31/16	A1	2.02	1.22	2/17/17	A1	0.86	0.51	
	A2	9.17			A2	0.28		
	A3	not collected	not collected		A3	0.85		
	A4	0.28			A4	0.82		
	R1*	3.69	3.69		R1*	1.87	1.87	
	R2	3.41	4.84		R2	1.10	1.54	
	C2	not collected	not collected		C2	3.20	1.81	
	D1	2.62	2.08		D1	0.61	0.47	
	D2	10.52			D2	2.16		
6/20/16	A1	2.64	1.53	3/16/17	A1	9.39	5.84	
	A2	15.37			A2	28.79		
	A3	2.31			A3	9.64		
	A4	1.36			A4	1.51		
	R1*	2.55	2.55		R1*	2.53	2.53	
	R2	1.21	1.64		R2	0.88	1.28	
	C2	0.79	0.46		C2	0.61	0.31	
	D1	2.64	1.99		D1	2.11	1.73	
	D2	17.66			D2	8.64		
7/28/16	A1	3.92	2.35	4/28/17	A1	1.32	0.75	
	A2	13.15			A2	8.71		
	A3	0.96			A3	2.47		
	A4	1.77			A4	0.47		
	R1*	1.72	1.72		R1*	1.67	1.67	
	R2	1.48	2.08		R2	0.84	1.13	
	C2	0.65	0.36		C2	0.43	0.26	
	D1	0.88	0.69		D1	0.96	0.71	
	D2	9.67			D2	1.58		
8/4/16	A1	3.99	2.47	5/26/17	A1	16.70	10.79	
	A2	12.59			A2	36.81		
	A3	1.74			A3	12.82		

Date	Site	Drainage area ratio loading (g/day*ha)	Concurrent flow loading (g/day*ha)	Date	Site	Drainage area ratio loading (g/day*ha)	Concurrent flow loading (g/day*ha)	Field measured loading (g/day*ha)
	A4	2.42			A4	4.17		
	R1*	2.09	2.09		R1*	4.43	4.43	
	R2	2.11	3.05		R2	3.05	4.60	
	C2	0.73	0.38		C2	2.90	1.35	
	D1	3.37	2.75		D1	6.61	5.70	
	D2	4.03			D2	3.91		
9/20/16	A1	0.00	0.00	6/20/17	A1	4.89	2.99	
	A2	not collected			A2	14.85		
	A3	0.23			A3	5.34		
	A4	0.35			A4	0.99		
	R1*	0.00	0.00		R1*	2.73	2.73	
	R2	0.01	0.01		R2	1.88	2.69	
	C2	0.03	0.02		C2	0.51	0.27	
	D1	0.16	0.09		D1	2.11	1.70	
	D2	0.03			D2	1.95		
10/25/16	A1	0.54	0.19	7/25/17	A1	0.41	0.19	
	A2	3.89			A2	0.10		
	A3	0.17			A3	0.23		
	A4	0.20			A4	0.21		
	R1*	0.13	0.13		R1*	0.47	0.47	
	R2	0.07	0.06		R2	0.78	0.87	
	C2	0.02	0.02		C2	0.26	0.21	
	D1	0.33	0.13		D1	0.32	0.18	
	D2	1.34			D2	0.21		
11/14/16	A1	0.78	0.21	8/28/17	A1	0.09	0.04	0.05
	A2	3.53			A2	0.00		
	A3	0.36			A3	0.03		
	A4	0.08			A4	0.03		
	R1*	0.12	0.12		R1*	0.42	0.42	
	R2	0.00	0.00		R2	1.69	1.72	1.50
	C2	0.00	0.00		P1	-		0.88
	D1	0.05	0.01		C2	0.37	0.33	0.50
	D2	1.51			D1	0.68	0.34	0.58

Date	Site	Drainage area ratio loading (g/day*ha)	Concurrent flow loading (g/day*ha)	Date	Site	Drainage area ratio loading (g/day*ha)	Concurrent flow loading (g/day*ha)	Field measured loading (g/day*ha)
12/7/16	A1	0.15	0.06		D2	1.66		
	A2	0.04		9/20/17	A1	1.05	0.52	0.48
	A3	0.02			A2	5.08		8.41
	A4	0.08			A3	0.21		0.09
	R1*	0.37	0.37		A4	0.45		0.09
	R2	2.12	2.07		R1	0.38	0.38	0.35
	C2	0.32	0.30		R2	0.23	0.27	0.28
	D1	0.45	0.21		P1	-		0.02
	D2	0.39			C1	-		0.02
1/19/17	A1	0.35	0.13		C2	0.12	0.09	0.08
	A2	0.18			D1	0.55	0.33	0.28
	A3	0.16			D2	3.18		0.54
	A4	0.12		10/18/17	A1	0.33	0.11	0.08
	R1*	0.56	0.56		A2	1.03		1.22
	R2	0.67	0.60		A3	0.04		0.00
	C2	0.91	0.89		A4	0.22		no flow
	D1	0.30	0.12		R1	0.13	0.13	0.08
	D2	0.31			R2	0.14	0.11	0.13
				10/20/17	P1	-		no flow
					C1	-		0.04
					C2	0.03	0.03	0.02
					D1	0.41	0.14	0.02
					D2	1.52		no flow

Daily range of TSS loading per site over course of study. R* represents measured discharge directly measured from USGS gage.

Date	Site	Drainage area ratio loading (g/day*ha)	Concurrent flow loading (g/day*ha)	Date	Site	Drainage area ratio loading (g/day*ha)	Concurrent flow loading (g/day*ha)	Measured flow loading (g/day*ha)
5/31/16	A1	462.02	279.61	2/17/17	A1	22.97	13.62	
	A2	11.02			A2	11.47		
	A3	19.41			A3	22.97		
	A4	34.08			A4	45.92		
	R1*	392.75	392.75		R1*	11.48	11.48	
	R2	82.34	116.65		R2	137.80	191.54	
	C2	not collected	not collected		C2	34.46	19.53	
	D1	103.07	81.84		D1	22.98	17.79	
	D2	35.22			D2	45.87		
6/20/16	A1	47.15	27.35	3/16/17	A1	26.03	16.17	
	A2	5.95			A2	8.20		
	A3	61.09			A3	7.84		
	A4	38.57			A4	35.80		
	R1*	74.96	74.96		R1*	47.65	47.65	
	R2	16.26	22.15		R2	9.49	13.79	
	C2	15.34	9.05		C2	124.42	63.83	
	D1	16.97	12.79		D1	37.78	31.00	
	D2	14.70			D2	11.84		
7/28/16	A1	227.36	136.48	4/28/17	A1	94.12	53.74	
	A2	40.86			A2	39.61		
	A3	6.80			A3	37.85		
	A4	29.61			A4	97.49		
	R1*	198.94	198.94		R1*	148.69	148.69	
	R2	19.84	27.91		R2	56.07	75.24	
	C2	18.76	10.36		C2	21.61	13.14	
	D1	6.64	5.22		D1	24.79	18.33	
	D2	16.45			D2	26.75		
8/4/16	A1	69.57	43.05	5/26/17	A1	734.23	474.72	
	A2	21.73			A2	667.80		
	A3	17.18			A3	277.36		

Date	Site	Drainage area ratio loading (g/day*ha)	Concurrent flow loading (g/day*ha)	Date	Site	Drainage area ratio loading (g/day*ha)	Concurrent flow loading (g/day*ha)	Measured flow loading (g/day*ha)
	A4	55.49			A4	388.78		
	R1 *	39.89	39.89		R1 *	350.44	350.44	
	R2	37.48	54.23		R2	257.87	388.70	
	C2	175.79	90.97		C2	143.36	66.77	
	D1	30.67	25.03		D1	134.40	115.81	
	D2	50.37			D2	149.88		
9/20/16	A1	5.07	2.40	6/20/17	A1	137.85	84.29	
	A2	not collected			A2	19.08		
	A3	4.98			A3	5.81		
	A4	20.84			A4	119.07		
	R1 *	3.39	3.39		R1 *	120.87	120.87	
	R2	3.50	3.94		R2	32.54	46.57	
	C2	29.63	23.46		C2	46.33	24.59	
	D1	0.32	0.19		D1	92.12	74.15	
	D2	27.19			D2	76.09		
10/25/16	A1	22.98	8.15	7/25/17	A1	7.11	3.35	
	A2	2.66			A2	0.61		
	A3	3.54			A3	9.43		
	A4	15.04			A4	18.02		
	R1 *	13.60	13.60		R1 *	18.96	18.96	
	R2	7.31	6.33		R2	5.21	5.83	
	C2	0.00	1.90		C2	6.81	5.41	
	D1	0.00	0.70		D1	2.82	1.63	
	D2	9.26			D2	13.51		
11/14/16	A1	0.89	0.23	8/28/17	A1	22.09	9.31	11.70
	A2	8.32			A2	22.99		
	A3	1.31			A3	14.52		
	A4	1.27			A4	27.64		
	R1 *	7.70	7.70		R1 *	36.79	36.79	
	R2	6.89	4.60		R2	25.80	26.18	22.92
	C2	1.27	1.50		P1	-		1.93
	D1	18.56	4.48		C2	13.57	12.08	18.68

Date	Site	Drainage area ratio loading (g/day*ha)	Concurrent flow loading (g/day*ha)	Date	Site	Drainage area ratio loading (g/day*ha)	Concurrent flow loading (g/day*ha)	Measured flow loading (g/day*ha)
	D2	23.34			D1	26.58	13.18	22.93
12/7/16	A1	6.21	2.50		D2	11.24		
	A2	0.00		9/20/17	A1	6.31	3.10	2.91
	A3	2.24			A2	4.65		7.71
	A4	14.87			A3	38.11		15.22
	R1*	11.07	11.07		A4	3.28		0.64
	R2	2.77	2.70		R1	30.33	30.33	27.70
	C2	1.17	1.08		R2	3.38	3.95	4.07
	D1	26.03	12.12		P1	-		0.92
	D2	8.33			C1	-		13.85
1/19/17	A1	5.01	1.86		C2	5.87	4.45	3.64
	A2	0.84			D1	2.38	1.46	1.21
	A3	3.66			D2	6.57		1.11
	A4	14.77		10/18/17	A1	1.78	0.60	0.44
	R1*	16.59	16.59		A2	5.24		6.19
	R2	2.95	2.67		A3	1.13		0.05
	C2	0.84	0.82		A4	3.34		no flow
	D1	1.33	0.55		R1	17.98	17.98	11.45
	D2	3.78			R2	4.40	3.64	4.10
				10/20/17	P1	-		no flow
					C1	-		5.02
					C2	10.05	10.78	6.84
					D1	1.24	0.41	0.07
					D2	8.92		no flow

Range of Daily TP Loading per site over course of study. R* represents measured discharge directly measured from USGS gage.

Date	Site	Drainage area ratio loading (g/day*ha)	Concurrent flow loading (g/day*ha)	Date	Site	Drainage area ratio loading (g/day*ha)	Concurrent flow loading (g/day*ha)	Field measured loading (g/day*ha)
5/31/16	A1	0.683	0.413	2/17/17	A1	0.203	0.120	
	A2	1.251			A2	0.359		
	A3	0.252			A3	0.234		
	A4	0.300			A4	0.343		
	R1*	0.645	0.645		R1*	0.312	0.312	
	R2	0.228	0.322		R2	0.390	0.542	
	C2	not collected	not collected		C2	0.234	0.133	
	D1	0.300	0.238		D1	not analyzed	not analyzed	
	D2	0.270			D2	0.218		
6/20/16	A1	0.236	0.137	3/16/17	A1	0.131	0.081	
	A2	0.397			A2	0.261		
	A3	0.172			A3	0.131		
	A4	0.193			A4	0.131		
	R1*	0.235	0.235		R1*	0.163	0.163	
	R2	0.236	0.321		R2	0.131	0.190	
	C2	0.107	0.063		C2	0.163	0.084	
	D1	0.129	0.097		D1	0.131	0.107	
	D2	0.163			D2	0.228		
7/28/16	A1	0.548	0.329	4/28/17	A1	0.241	0.137	
	A2	1.484			A2	0.277		
	A3	0.670			A3	0.229		
	A4	0.366			A4	0.241		
	R1*	0.813	0.813		R1*	0.265	0.265	
	R2	0.508	0.714		R2	0.241	0.323	
	C2	0.325	0.179		C2	0.193	0.117	
	D1	0.508	0.399		D1	0.180	0.133	
	D2	0.386			D2	0.240		
8/4/16	A1	0.042	0.026	5/26/17	A1	1.112	0.719	
	A2	0.042			A2	1.171		

Date	Site	Drainage area ratio loading (g/day*ha)	Concurrent flow loading (g/day*ha)	Date	Site	Drainage area ratio loading (g/day*ha)	Concurrent flow loading (g/day*ha)	Field measured loading (g/day*ha)
	A3	0.000			A3	0.585		
	A4	0.014			A4	0.878		
	R1 *	0.000	0.000		R1 *	0.819	0.819	
	R2	0.000	0.000		R2	0.761	1.147	
	C2	0.304	0.158		C2	0.410	0.191	
	D1	0.138	0.113		D1	1.170	1.008	
	D2	0.000			D2	1.054		
9/20/16	A1	0.120	0.057	6/20/17	A1	0.249	0.152	
	A2	not collected	not collected		A2	0.374		
	A3	0.171			A3	0.187		
	A4	0.086			A4	0.291		
	R1 *	0.129	0.129		R1 *	0.561	0.561	
	R2	0.077	0.087		R2	0.602	0.862	
	C2	0.112	0.088		C2	0.270	0.143	
	D1	0.137	0.080		D1	0.374	0.301	
	D2	0.396			D2	0.311		
10/25/16	A1	0.026	0.009	7/25/17	A1	0.069	0.032	
	A2	0.060			A2	0.500		
	A3	0.000			A3	0.426		
	A4	0.002			A4	0.439		
	R1 *	0.002	0.002		R1 *	0.075	0.075	
	R2	not analyzed	not analyzed		R2	0.100	0.112	
	C2	0.117	0.119		C2	0.056	0.045	
	D1	0.006	0.002		D1	0.088	0.050	
	D2	0.000			D2	0.088		
11/14/16	A1	0.096	0.025	8/28/17	A1	0.075	0.032	0.0398
	A2	0.060			A2	0.105		
	A3	0.022			A3	0.055		
	A4	0.030			A4	0.385		
	R1 *	0.033	0.033		R1 *	0.075	0.075	
	R2	0.030	0.020		R2	0.110	0.112	0.0979

Date	Site	Drainage area ratio loading (g/day*ha)	Concurrent flow loading (g/day*ha)	Date	Site	Drainage area ratio loading (g/day*ha)	Concurrent flow loading (g/day*ha)	Field measured loading (g/day*ha)
	C2	0.019	0.022		P1	-		0.0169
	D1	0.063	0.015		C2	0.045	0.040	0.0619
	D2	0.022			D1	0.090	0.045	0.0778
12/7/16	A1	0.057	0.023		D2	0.334		
	A2	0.108		9/20/17	A1	0.123	0.061	0.0569
	A3	0.493			A2	0.066		0.1089
	A4	0.205			A3	0.041		0.0165
	R1*	0.113	0.113		A4	0.175		0.0340
	R2	0.046	0.045		R1	0.124	0.124	0.1128
	C2	0.008	0.007		R2	0.025	0.029	0.0297
	D1	0.077	0.036		P1	-		0.0191
	D2	0.036			C1	-		0.0044
1/19/17	A1	0.046	0.017		C2	0.004	0.003	0.0026
	A2	0.078			D1	0.066	0.040	0.0333
	A3	0.037			D2	0.017		0.0028
	A4	0.037		10/18/17	A1	0.040	0.013	0.0098
	R1*	0.050	0.050		A2	0.061		0.0724
	R2	0.037	0.033		A3	0.035		0.0016
	C2	0.023	0.022		A4	0.035		no flow
	D1	0.041	0.017		R1	0.048	0.048	0.0308
	D2	0.023			R2	0.044	0.036	0.0410
				10/20/17	P1	-		no flow
					C1	-		0.0378
					C2	0.021	0.023	0.0143
					D1	0.051	0.017	0.0031
					D2	0.034		no flow

Appendix F: Concurrentflow loading and percentages of contributing loading variable

Date	Site	% discharge	% concentration	Ammonium concurrent flow Loading (g/day*hectare)
5/31/16	A1	99.45	0.55	0.209
	R1	99.95	0.05	0.149
	R2	99.95	0.05	0.191
	C2	N/A	N/A	N/A
	D1	99.72	0.28	0.110
6/20/16	A1	99.78	0.22	0.040
	R1	99.93	0.07	0.104
	R2	99.94	0.06	0.118
	C2	99.10	0.90	0.059
	D1	99.66	0.34	0.062
7/28/16	A1	99.93	0.07	0.023
	R1	100.00	0.00	0.000
	R2	100.00	0.00	0.000
	C2	100.00	0.00	0.000
	D1	100.00	0.00	0.000
8/4/16	A1	99.99	0.01	0.009
	R1	100.00	0.00	0.000
	R2	99.99	0.01	0.081
	C2	100.00	0.00	0.000
	D1	100.00	0.00	0.000
9/20/16	A1	99.82	0.18	0.004
	R1	99.96	0.04	0.012
	R2	100.00	0.00	0.000
	C2	99.25	0.75	0.018
	D1	100.00	0.00	0.000
10/25/16	A1	99.98	0.02	0.000
	R1	99.92	0.08	0.009
	R2	100.00	0.00	0.000
	C2	100.00	0.00	0.000
	D1	100.00	0.00	0.000
11/14/16	A1	100.00	0.00	0.000
	R1	100.00	0.00	0.000
	R2	100.00	0.00	0.000
	C2	99.91	0.09	0.001

Date	Site	% discharge	% concentration	Ammonium concurrent flow Loading (g/day*hectare)
	D1	100.00	0.00	0.000
12/7/16	A1	99.51	0.49	0.005
	R1	99.99	0.01	0.002
	R2	100.00	0.00	0.000
	C2	99.93	0.07	0.001
	D1	99.93	0.07	0.001
1/19/17	A1	99.43	0.57	0.004
	R1	99.89	0.11	0.015
	R2	100.00	0.00	0.000
	C2	100.00	0.00	0.000
	D1	100.00	0.00	0.000
2/17/17	A1	99.93	0.07	0.017
	R1	100.00	0.00	0.004
	R2	100.00	0.00	0.000
	C2	100.00	0.00	0.000
	D1	99.99	0.01	0.002
3/16/17	A1	99.99	0.01	0.009
	R1	100.00	0.00	0.000
	R2	100.00	0.00	0.000
	C2	100.00	0.00	0.000
	D1	100.00	0.00	0.000
4/28/17	A1	99.82	0.18	0.025
	R1	99.97	0.03	0.034
	R2	99.98	0.02	0.024
	C2	99.91	0.09	0.005
	D1	99.85	0.15	0.021
5/26/17	A1	99.95	0.05	0.185
	R1	100.00	0.00	0.111
	R2	100.00	0.00	0.047
	C2	99.83	0.17	0.119
	D1	99.98	0.02	0.084
6/20/17	A1	100.00	0.00	0.000
	R1	100.00	0.00	0.014
	R2	100.00	0.00	0.004
	C2	99.68	0.32	0.041

Date	Site	% discharge	% concentration	Ammonium concurrent flow Loading (g/day*hectare)
	D1	99.93	0.07	0.037
7/25/17	A1	99.55	0.45	0.010
	R1	99.83	0.17	0.053
	R2	99.90	0.10	0.025
	C2	100.00	0.00	0.000
	D1	99.75	0.25	0.005
8/28/17	A1	99.12	0.88	0.010
	R1	100.00	0.00	0.000
	R2	100.00	0.00	0.000
	C2	99.66	0.34	0.006
	D1	100.00	0.00	0.000
9/20/17	A1	100.00	0.00	0.000
	R1	100.00	0.00	0.000
	R2	100.00	0.00	0.000
	C2	100.00	0.00	0.000
	D1	100.00	0.00	0.000
10/18/17	A1	99.19	0.81	0.003
	R1	99.92	0.08	0.008
	R2	100.00	0.00	0.000
10/20/17	C2	100.00	0.00	0.000
	D1	100.00	0.00	0.000

Date	Site	% discharge	% concentration	Phosphate concurrent flow Loading (g/day*hectare)
	A1	99.95	0.048444836	0.018
	R1	99.93	0.074567582	0.230
	R2	99.96	0.040408683	0.162
	C2	N/A	N/A	not collected
	D1	99.70	0.303078641	0.120
6/20/16	A1	99.44	0.557706858	0.099
	R1	99.90	0.095412753	0.151
	R2	99.92	0.078321737	0.148
	C2	97.90	2.10432387	0.140
	D1	99.24	0.759232215	0.139
7/28/16	A1	99.54	0.464891683	0.150
	R1	99.94	0.061164752	0.164
	R2	99.90	0.104413804	0.360
	C2	98.86	1.138341846	0.112
	D1	99.09	0.913078586	0.310
8/4/16	A1	99.81	0.185537472	0.120
	R1	99.96	0.044441992	0.225
	R2	99.97	0.032491748	0.223
	C2	99.87	0.133780928	0.022
	D1	99.52	0.475425246	0.326
9/20/16	A1	99.35	0.646879922	0.016
	R1	99.97	0.031777201	0.010
	R2	99.75	0.252655703	0.067
	C2	98.54	1.456572559	0.035
	D1	96.67	3.326473847	0.075
10/25/16	A1	97.98	2.024216656	0.011
	R1	99.83	0.17477742	0.021
	R2	99.44	0.557273103	0.033
	C2	98.82	1.182187409	0.018
	D1	95.99	4.013602644	0.015
11/14/16	A1	96.53	3.47032108	0.006
	R1	99.80	0.196461407	0.015
	R2	99.36	0.637956958	0.014
	C2	98.15	1.84589806	0.023
	D1	92.49	7.505644876	0.007
12/7/16	A1	98.32	1.676282817	0.016

Date	Site	% discharge	% concentration	Phosphate concurrent flow Loading (g/day*hectare)
	R1	99.68	0.321001741	0.056
	R2	99.84	0.158684277	0.017
	C2	98.57	1.430521155	0.025
	D1	98.70	1.297787507	0.010
1/19/17	A1	98.53	1.469605878	0.009
	R1	99.52	0.475425246	0.066
	R2	99.20	0.801910272	0.059
	C2	98.60	1.39994315	0.022
	D1	99.51	0.489057102	0.002
2/17/17	A1	99.97	0.029045705	0.007
	R1	99.97	0.029909193	0.065
	R2	100.00	0	0.000
	C2	99.60	0.403463616	0.034
	D1	99.96	0.042052006	0.011
3/16/17	A1	99.97	0.029046836	0.021
	R1	100.00	0.004703965	0.027
	R2	100.00	0.004622986	0.036
	C2	99.90	0.09534577	0.017
	D1	99.97	0.031673788	0.025
4/28/17	A1	99.95	0.053931349	0.008
	R1	99.95	0.049513302	0.064
	R2	99.98	0.015843848	0.024
	C2	99.91	0.093952641	0.005
	D1	99.89	0.114188454	0.016
5/26/17	A1	99.92	0.079506629	0.301
	R1	100.00	0.002632445	0.072
	R2	100.00	0.001661351	0.067
	C2	99.94	0.057983162	0.041
	D1	99.95	0.0484782	0.198
6/20/17	A1	99.76	0.2364765	0.114
	R1	99.97	0.033500678	0.129
	R2	99.96	0.039432219	0.201
	C2	99.92	0.084069201	0.011
	D1	99.72	0.281301469	0.142
7/25/17	A1	99.82	0.179364091	0.004
	R1	99.97	0.034898648	0.011

Date	Site	% discharge	% concentration	Phosphate concurrent flow Loading (g/day*hectare)
	R2	99.99	0.008762899	0.002
	C2	98.74	1.255878932	0.030
	D1	98.72	1.279815565	0.027
8/28/17	A1	98.27	1.727400354	0.021
	R1	99.75	0.254537897	0.051
	R2	99.84	0.1587661	0.021
	C2	99.83	0.169335084	0.003
	D1	99.68	0.32414415	0.003
9/20/17	A1	99.37	0.629975613	0.020
	R1	99.90	0.101831279	0.040
	R2	99.80	0.202148289	0.070
	C2	99.82	0.1806671	0.005
	D1	98.29	1.712095865	0.051
10/18/17	A1	97.28	2.716762414	0.011
	R1	99.69	0.306918957	0.034
	R2	99.58	0.415986612	0.020
10/20/17	C2	99.96	0.038398711	0.001
	D1	92.42	7.583217112	0.019

Date	Site	% discharge	% concentration	Nitrate concurrent flow Loading (g/day*hectare)
5/31/16	A1	96.85	3.15	1.22
	R1	98.82	1.18	3.69
	R2	98.81	1.19	4.84
	C2	N/A	N/A	not collected
	D1	94.97	5.03	2.08
6/20/16	A1	92.02	7.98	1.53
	R1	98.41	1.59	2.55
	R2	99.14	0.86	1.64
	C2	93.35	6.65	0.46
	D1	90.10	9.90	1.99
7/28/16	A1	93.19	6.81	2.35
	R1	99.37	0.63	1.72
	R2	99.40	0.60	2.08
	C2	96.46	3.54	0.36
	D1	97.99	2.01	0.69
8/16/16	A1	96.32	3.68	2.47
	R1	99.59	0.41	2.09
	R2	99.56	0.44	3.05
	C2	97.70	2.30	0.38
	D1	96.13	3.87	2.75
9/20/16	A1	100.00	0.00	0.00
	R1	100.00	0.00	0.00
	R2	99.97	0.03	0.01
	C2	98.99	1.01	0.02
	D1	95.92	4.08	0.09
10/25/16	A1	72.67	27.33	0.19
	R1	98.96	1.04	0.13
	R2	99.02	0.98	0.06
	C2	98.47	1.53	0.02
	D1	74.41	25.59	0.13
11/14/16	A1	45.23	54.77	0.21
	R1	98.38	1.62	0.12
	R2	99.97	0.03	0.00
	C2	99.78	0.22	0.00
	D1	88.46	11.54	0.01
12/7/16	A1	93.82	6.18	0.06

Date	Site	% discharge	% concentration	Nitrate concurrent flow Loading (g/day*hectare)
	R1	97.94	2.06	0.37
	R2	83.81	16.19	2.07
	C2	85.49	14.51	0.30
	D1	78.54	21.46	0.21
1/19/17	A1	83.04	16.96	0.13
	R1	96.13	3.87	0.56
	R2	92.39	7.61	0.60
	C2	63.74	36.26	0.89
	D1	79.56	20.44	0.12
2/17/17	A1	98.03	1.97	0.51
	R1	99.15	0.85	1.87
	R2	99.44	0.56	1.54
	C2	82.09	17.91	1.81
	D1	98.24	1.76	0.47
3/16/17	A1	92.64	7.36	5.84
	R1	99.56	0.44	2.53
	R2	99.84	0.16	1.28
	C2	98.28	1.72	0.31
	D1	97.82	2.18	1.73
4/28/17	A1	94.92	5.08	0.75
	R1	98.73	1.27	1.67
	R2	99.26	0.74	1.13
	C2	95.62	4.38	0.26
	D1	95.26	4.74	0.71
5/26/17	A1	97.23	2.77	10.79
	R1	99.84	0.16	4.43
	R2	99.89	0.11	4.60
	C2	98.11	1.89	1.35
	D1	98.62	1.38	5.70
6/20/17	A1	94.13	5.87	2.99
	R1	99.30	0.70	2.73
	R2	99.48	0.52	2.69
	C2	97.94	2.06	0.27
	D1	96.75	3.25	1.70
7/25/17	A1	92.19	7.81	0.19
	R1	98.50	1.50	0.47

Date	Site	% discharge	% concentration	Nitrate concurrent flow Loading (g/day*hectare)
	R2	96.67	3.33	0.87
	C2	91.78	8.22	0.21
	D1	91.94	8.06	0.18
8/28/17	A1	97.00	3.00	0.04
	R1	97.94	2.06	0.42
	R2	88.57	11.43	1.72
	P1	0.00	100.00	
	C2	85.14	14.86	0.33
	D1	74.70	25.30	0.34
9/20/17	A1	85.82	14.18	0.52
	R1	99.04	0.96	0.38
	R2	99.22	0.78	0.27
	C1	0.00	100.00	
	C2	96.64	3.36	0.09
	D1	89.79	10.21	0.33
10/18/17	A1	79.01	20.99	0.11
	R1	98.86	1.14	0.13
	R2	97.74	2.26	0.11
10/20/17	C1	0.00	100.00	
	C2	97.71	2.29	0.03
	D1	62.60	37.40	0.14

Date	Site	% discharge	% concentration	TSS concurrent flow loading (g/day*hectare)
5/31/16	A1	11.86	88.14	280
	R1	44.00	56.00	393
	R2	77.47	22.53	117
	C2	N/A	N/A	not collected
	D1	32.48	67.52	82
6/20/16	A1	39.26	60.74	27
	R1	67.78	32.22	75
	R2	89.53	10.47	22
	C2	41.87	58.13	9
	D1	58.64	41.36	13
7/28/16	A1	19.09	80.91	136
	R1	57.45	42.55	199
	R2	92.50	7.50	28
	C2	48.42	51.58	10
	D1	86.56	13.44	5
8/4/16	A1	59.97	40.03	43
	R1	92.69	7.31	40
	R2	92.67	7.33	54
	C2	15.02	84.98	91
	D1	73.18	26.82	25
9/20/16	A1	49.89	50.11	2
	R1	90.42	9.58	3
	R2	87.00	13.00	4
	C2	9.26	90.74	23
	D1	92.16	7.84	0
10/25/16	A1	5.91	94.09	8
	R1	47.39	52.61	14
	R2	48.51	51.49	6
	C2	100.00	0.00	0
	D1	100.00	0.00	0
11/14/16	A1	42.07	57.93	0
	R1	48.95	51.05	8
	R2	31.68	68.32	5
	C2	45.04	54.96	1
	D1	1.90	98.10	4
12/7/16	A1	27.38	72.62	3

Date	Site	% discharge	% concentration	TSS concurrent flow loading (g/day*hectare)
	R1	61.10	38.90	11
	R2	79.89	20.11	3
	C2	61.90	38.10	1
	D1	5.93	94.07	12
1/19/17	A1	25.43	74.57	2
	R1	45.45	54.55	17
	R2	73.30	26.70	3
	C2	65.68	34.32	1
	D1	46.51	53.49	1
2/17/17	A1	65.16	34.84	14
	R1	94.98	5.02	11
	R2	58.70	41.30	192
	C2	29.82	70.18	20
	D1	59.76	40.24	18
3/16/17	A1	81.96	18.04	16
	R1	92.30	7.70	48
	R2	98.27	1.73	14
	C2	21.86	78.14	64
	D1	71.53	28.47	31
4/28/17	A1	20.70	79.30	54
	R1	46.52	53.48	149
	R2	66.74	33.26	75
	C2	30.19	69.81	13
	D1	43.83	56.17	18
5/26/17	A1	44.36	55.64	475
	R1	88.58	11.42	350
	R2	91.15	8.85	389
	C2	51.21	48.79	67
	D1	77.92	22.08	116
6/20/17	A1	36.25	63.75	84
	R1	76.11	23.89	121
	R2	91.64	8.36	47
	C2	34.42	65.58	25
	D1	40.50	59.50	74
7/25/17	A1	40.58	59.42	3
	R1	62.08	37.92	19

Date	Site	% discharge	% concentration	TSS concurrent flow loading (g/day*hectare)
	R2	81.24	18.76	6
	C2	30.07	69.93	5
	D1	56.23	43.77	2
8/28/17	A1	11.25	88.75	9
	R1	35.15	64.85	37
	R2	33.69	66.31	26
	C2	13.40	86.60	12
	D1	6.99	93.01	13
9/20/17	A1	50.19	49.81	3
	R1	56.19	43.81	30
	R2	89.70	10.30	4
	C2	37.31	62.69	4
	D1	66.85	33.15	1
10/18/17	A1	40.77	59.23	1
	R1	37.96	62.04	18
	R2	57.28	42.72	4
10/20/17	C2	11.35	88.65	11
	D1	35.48	64.52	0

Date	Site	% discharge	% concentration	TP Concurrent flow Loading (g/day*hectare)
5/31/16	A1	98.91	1.09	0.41
	R1	99.79	0.21	0.64
	R2	99.92	0.08	0.32
	C2	N/A	N/A	N/A
	D1	99.40	0.60	0.24
6/20/16	A1	99.23	0.77	0.14
	R1	99.85	0.15	0.23
	R2	99.83	0.17	0.32
	C2	99.04	0.96	0.06
	D1	99.47	0.53	0.10
7/28/16	A1	98.99	1.01	0.33
	R1	99.70	0.30	0.81
	R2	99.79	0.21	0.71
	C2	98.19	1.81	0.18
	D1	98.83	1.17	0.40
8/4/16	A1	99.96	0.04	0.03
	R1	100.00	0.00	0.00
	R2	100.00	0.00	0.00
	C2	99.03	0.97	0.16
	D1	99.83	0.17	0.11
9/20/16	A1	97.68	2.32	0.06
	R1	99.60	0.40	0.13
	R2	99.67	0.33	0.09
	C2	96.44	3.56	0.09
	D1	96.49	3.51	0.08
10/25/16	A1	98.24	1.76	0.01
	R1	99.98	0.02	0.00
	R2	N/A	N/A	not analyzed
	C2	92.74	7.26	0.12
	D1	99.33	0.67	0.00
11/14/16	A1	86.99	13.01	0.03
	R1	99.55	0.45	0.03
	R2	99.08	0.92	0.02
	C2	98.24	1.76	0.02
	D1	85.08	14.92	0.02

12/7/16	A1	97.64	2.36	0.02
	R1	99.35	0.65	0.11
	R2	99.58	0.42	0.05
	C2	99.60	0.40	0.01
	D1	95.52	4.48	0.04
1/19/17	A1	97.39	2.61	0.02
	R1	99.64	0.36	0.05
	R2	99.55	0.45	0.03
	C2	98.60	1.40	0.02
	D1	96.57	3.43	0.02
2/17/17	A1	99.53	0.47	0.12
	R1	99.86	0.14	0.31
	R2	99.80	0.20	0.54
	C2	98.43	1.57	0.13
	D1			not analyzed
3/16/17	A1	99.89	0.11	0.08
	R1	99.97	0.03	0.16
	R2	99.98	0.02	0.19
	C2	99.53	0.47	0.08
	D1	99.86	0.14	0.11
4/28/17	A1	99.03	0.97	0.14
	R1	99.80	0.20	0.26
	R2	99.79	0.21	0.32
	C2	97.98	2.02	0.12
	D1	99.08	0.92	0.13
5/26/17	A1	99.81	0.19	0.72
	R1	99.97	0.03	0.82
	R2	99.97	0.03	1.15
	C2	99.73	0.27	0.19
	D1	99.75	0.25	1.01
6/20/17	A1	99.68	0.32	0.15
	R1	99.85	0.15	0.56
	R2	99.83	0.17	0.86
	C2	98.90	1.10	0.14
	D1	99.41	0.59	0.30
7/25/17	A1	98.60	1.40	0.03
	R1	99.76	0.24	0.08
	R2	99.56	0.44	0.11
	C2	98.12	1.88	0.04

	D1	97.64	2.36	0.05
8/28/17	A1	97.39	2.61	0.03
	R1	99.62	0.38	0.08
	R2	99.17	0.83	0.11
	C2	97.90	2.10	0.04
	D1	95.68	4.32	0.04
9/20/17	A1	98.10	1.90	0.06
	R1	99.68	0.32	0.12
	R2	99.92	0.08	0.03
	C2	99.88	0.12	0.00
	D1	98.65	1.35	0.04
10/18/17	A1	96.87	3.13	0.01
	R1	99.56	0.44	0.05
	R2	99.26	0.74	0.04
10/20/17	C2	98.39	1.61	0.02
	D1	93.08	6.92	0.02