The importance of lake and impoundment ecosystems to global organic carbon cycling and climate change Falls Lakes, NC

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Study Objectives and Rationale

Very little has been documented regarding sediment input into Falls Lake. The four major inputs (Flat River, Eno River, Little River and Ellerbe Creek) make up approximately 80% of the freshwater input to Falls Lake. However, no rating curves have been constructed as a means to predict suspended sediment concentration loads as a function of water discharge, a parameter which is readily available daily via USGS reporting stations online. Even less is known about deposition rates (spatially and temporally) with Falls Lake. Based on sediment thickness there is a general impression that sediment deposition rates are higher in the upper lake than in the lower lake. However, no quantitative measures of sedimentation rates currently exist. Seasonal deposition in Falls Lake is likely to vary based on seasonal factors such as water discharge rates and interannual factors such as flood/drought conditions in the drainage basin. Both seasonal deposition rates and decadal sediment accumulations rates provide critical information needed to evaluate the flux of particle associated materials such as carbon, nutrients (N and P) and contaminants.

The overall objective of this study was to better understand sediment fluxes associated with Falls Lake, ranging from rates of sediment inputs to the fate of particulate materials within the lake on time scales from seasonal to decadal.

2019-2020 Objectives:

1. **To quantify the temporal and spatial inputs of suspended sediments to Falls Lake.**
2. **To characterize the spatial and temporal variability in seasonal sediment and organic carbon inputs to Falls Lake bottom sediments.**
3. **To collect cores within the lake for future quantification of bottom sediment mixing and accumulation rates, which are important processes parameters needed to quantify carbon and nutrient fluxes in bottom sediments.**

For the 2019-2020 study period:

We collected and processed water samples at the four major inputs to Falls Lake to quantify total suspended sediment concentrations, calculate suspended sediment loads (*Objective 1*) and characterize spatial and temporal variability in sediment and carbon inputs to Falls Lake (*Objective 2*). These sites are inputs from the Flat, Eno, and Little Rivers and from Ellerbe Creek. We closely monitored water discharge at these four sites and strategically collected samples to completely cover the spectrum of water discharge rates over the course of the year. ***Because of the restriction resulting from the Covid-19 pandemic, we were only able to collect samples over an eight month period ending in March 2020***. A sediment rating curve was constructed (plotting suspended sediment concentrations v. water discharge). The sediment rating curve was used to help predict sediment inputs to Falls Lake. We will continue to add more points to the rating curve over the duration of this project to create a robust relationship between sediment and water fluxes.

During this study period we began collecting short cores to quantify sediment deposition within the lake (*Objective 3*). Short cores were dissected at 1 cm intervals and will be analyzed for the natural radiotracer ^{7}Be and ^{210}Pb, which has a 53-day and 22.2-year half-lives and therefore is useful for quantifying sediment deposition of the lake bed on seasonal to decadal time scales. Comparing deposition rates in the upper, middle and lower lake, seasonally, will greatly improve our understanding of sediment suspension and redistribution throughout the year. We began to collect deeper sediment cores in the lake to determine the historic rate of sediment accumulation since the dam was constructed (*Objective 3*). These cores will also be used to determine nutrient and carbon accumulation in lake bottom sediments.

Overarching Research Question

During the past decade, many environmental and climate scientists have raised (and examined) a central question regarding the importance of inland waters to global organic carbon cycling and climate change (see list "Recent Global Lake Literature"). One of the seminal papers for this research focus (Downing et al., 2008) examined carbon cycling in 40 lakes and impoundments throughout the world. Downing et al (2008) postulated that the extrapolation of their study suggested that lakes and impoundments may bury 4 times as much carbon (C) as the world's oceans, and that agriculturally impacted impoundments alone may bury more organic carbon (OC) than the oceans and 33% as much as the world's rivers deliver to the sea. The ramifications this had on global carbon sequestration and it impact on global climate was significant. This assertion galvanized the research community and generated world-wide interest in inland water ecosystems and their influence on global organic carbon and climate change. A special issue of *Limnology and Oceanography* was dedicated to this issue in 2009 and over a dozen of highly cited papers published during the last decade (see list "Recent Global Lake Literature") have examined ponds, lakes and impoundments to verify or refute the original assertions made by Downing et al. (2008).

This study is the first of a two-part research project that examines carbon cycling in North Carolina's Falls Lake. The focus of this study is on the supply of sediments and associated particulate organic carbon (POC). A second related study will examine organic carbon burial in Falls Lake during 2020-2021.

Central Study Objective

The central objective of this study is to quantify the spatial and temporal flux of sediments and POC to Falls Lake. The spatial aspects of this study was addressed by examining four (4) rivers and creeks that supply most of the particulate materials to the lake. These input waters vary in terms of the size of their watersheds, the nature of land use within their watersheds (urban, forest, agriculture etc.) and their water discharge rates. The temporal aspect of this study was addressed by collecting river/creek water samples frequently (approximately every month) during the period of August 2019 to March 2020. Samples were collected at/near USGS stations on each river/creek where continuous water discharge measurements are made and reported online (https://m.waterdata.usgs.gov/) for each station. For sampling location information see ***Site Information*** at the end of this report.

Focused Questions

1) ***How do total suspended matter (TSM) concentrations vary during the 8 months study period and what is the relationship between TSM concentrations and water discharge rates.***

In most rivers and creeks, TSM concentrations increase with increasing water discharge. This relationship is controlled by the supply of particulate matter from the watershed to the river/creek resulting from landscape erosion and transport. The relationship between TSM concentrations and water discharge is referred to as the sediment rating curve. Water discharge values for each sample were obtained online from the appropriate USGS location and time.

Approach: Five rivers and creeks will be sampled approximately every two weeks to collect water samples (see "USGS Water Discharge Site Locations").
The five input sources are: Eno River, Flat River, Little River and Ellerbe Creek for Falls Lake. Collectively these fourrivers/creeks supply approximately 80% of the water and suspended sediments to the two lakes. Water sampling dates/times were chosen to cover a wide range in water discharge rates observed. Samples were collected during low, medium and high water-discharge stages so that sediment rating curves represent a wide range of conditions. A sediment rating curve was constructed for each of the 4 water inputs.

Method: One to two liters of river/creek water were collected from surface waters and returned to the McKee Lab for subsequent filtration. Triplicate samples will be collected at each site for TSM determination. Pre-weighed polycarbonate filters (0.2-micron pore size) will be utilized (under vacuum) to collect the suspended matter from each water samples. Each filtered sample will be dried and then reweighed to determine the particulate mass collected. TSM concentrations (mass per water volume collected) will then be calculated, using a standard measurement unit of mg/L (milligram per liter).

Product: A water discharge vs TSM concentration rating curve relationship will be established for each of the five rivers/creeks. These rating curves will be used in the future to predict TSM concentrations and sediment discharge rates based on USGS water discharge data readily available online.

2) ***What is the relationship between TSM and POC concentrations and between POC concentration and water discharge?***

The organic carbon fraction of TSM can vary mainly as a function of watershed land use/land cover and water discharge. Understanding the relationship between TSM and POC concentrations provides insight into the watershed processes that control organic carbon inputs to lakes and can also be useful in predicting organic carbon fluxes to lakes.

Approach: A separate water sample was collected for POC determination at each of the four sites during each sampling time. As above, sampling dates/time were chosen to optimize the establishment of sediment rating curves.

Method: One to two liters of river/creek water were collected from surface waters at each location/date and returned to the McKee Lab for subsequent filtration. Pre-combusted glass Microfiber Filters (GF/F 0.7-micron pore size) were used to filter the samples for POC determination. Filters were frozen, freeze dried and the transported under cold, dark conditions to the UNC Institute of Marine Sciences where samples were run on a CHN analyzer to determine particulate carbon and nitrogen concentrations on each filter.

Product: A TSM vs POC concentration relationship was established for each of the four input rivers/creeks. This relationship yielded insight into how the organic carbon fraction of suspended matter varies over time and space. Water discharge vs POC concentration rating curve relationship was also established for each of the four rivers/creeks. These rating curves were used to predict POC concentrations and the particulate organic carbon flux from each river/creek based on USGS water discharge data readily available online.

Introduction

Environmental and climate scientists have examined the importance of inland waters to global organic carbon cycling and climate change over the last decade. Downing et al. "Sediment Organic Carbon Burial in Agriculturally Eutrophic Impoundments Over the Last Century", examined carbon cycling in 40 different lakes and impoundments across the world. Their study found that lakes and impoundments could store 4 times as much carbon as the world's oceans. They also found that agriculturally impacted impoundments can bury more organic carbon than the oceans and 33% as much as the world's rivers deliver to the ocean.

This study completed over a eight-month period, addresses one aspect of the research question proposed by earlier researchers, focusing on one local North Carolina impoundment, Falls lake. This is the first part of a two-part research project that looks at carbon cycling in North Carolina lakes and impoundments, focusing primarily on the supply of sediments and associated particulate organic carbon to Falls Lake.

The objective of this research is to quantify the spatial and temporal flux of sediments and particulate organic carbon to Falls lake. 4 rivers will be examined in this study, as they supply 80% of the particulate materials to the lake. These rivers are Ellerbe Creek, Falls River, Little River, and Eno River.

The questions being addressed by this research are:

1. **how does total suspended matter (TSM) concentrations vary during the 8 months study period and what is the relationship between TSM concentrations and water discharge rates?**
2. **What is the relationship between TSM and POC concentrations and between POC concentration and water discharge?**

Methods

The 4 rivers sampled were the Little River, Falls River, Ellerbe Creek, and the Eno River. These rivers were sampled approximately every two weeks and water samples were collected. While collecting samples, one to two liters of surface water was gathered and returned to the McKee Lab to be filtered. Triplicate samples were collected at each site for TSM determination. Pre-weighed polycarbonate filters were used to collect suspended matter from each water sample. The samples were then dried and reweighed to determine the particulate mass accumulated.

To observe the relationship between TSM and POC concentrations and between POC concentration and water discharge, one to two liters of surface water was collected at each site and returned to the McKee lab for filtration. This water was filtered using pre-combusted glass microfiber filters. After completion of filtration, the filters were frozen to dry and transported under cold, dark conditions to the UNC Institute of Marine Sciences where samples were run on a CHN analyzer to determine the particulate carbon and nitrogen concentrations on the filters.

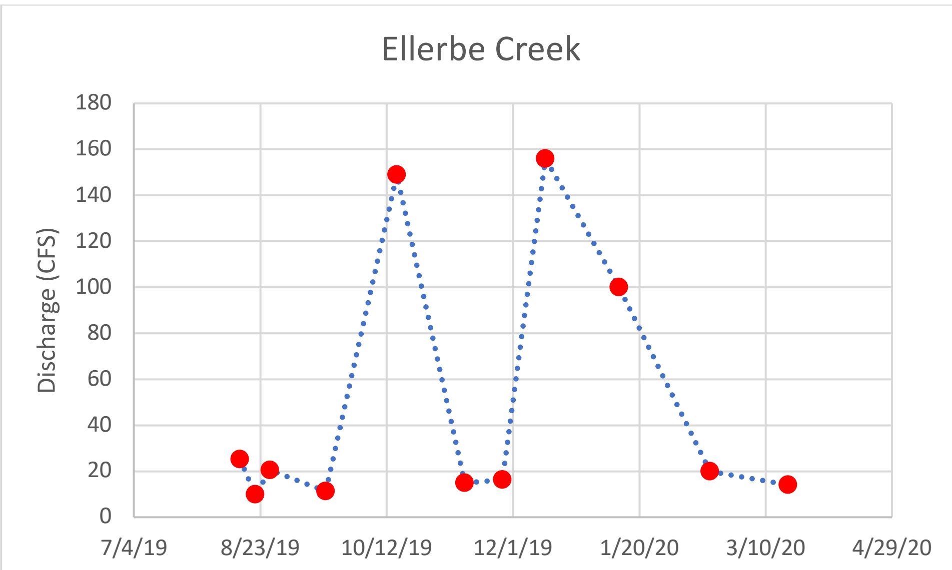
The locations of these top 4 freshwar inputs to Falls Lake are shown in Figure 1. The list of USGS station used for this location are:

Discharge data was retrieved from the USGS site for each of the 4 rivers and used to examine the relationship between discharge and the date the water samples were collected. This data can be observed in figures 1 through 4 for each of the rivers

Results

<u>**Water Discharge**</u>

Ellerbe Creek. Discharge for Ellerbe Creek (near Gorman) remained steady across seven of the ten sampling dates and showed a significant increase in discharge for 10/16 19, 12/14/19 and 1/12/20.



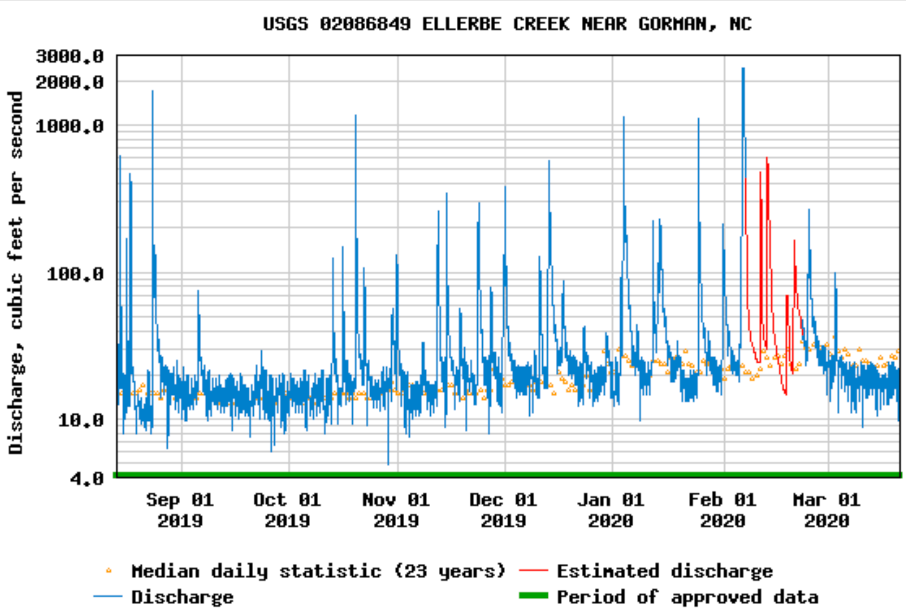
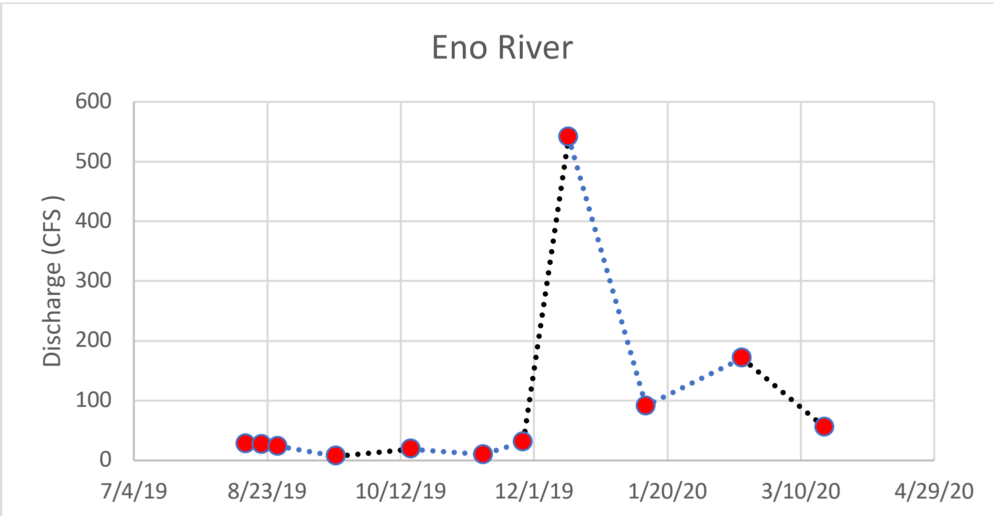


Figure 1 shows the relationship between Discharge and the dates the samples were collected for Ellerbe Creek. Discharge (cubic meters per second (CMS) for the 10 dates sampled.

Discharge for Eno River. Flat River and Little River remained steady and relatively low throughout all sampling dates except for the 14 December 2019 date. The Flat River had an additional high discharge during the 2/17 /20 sampling period.



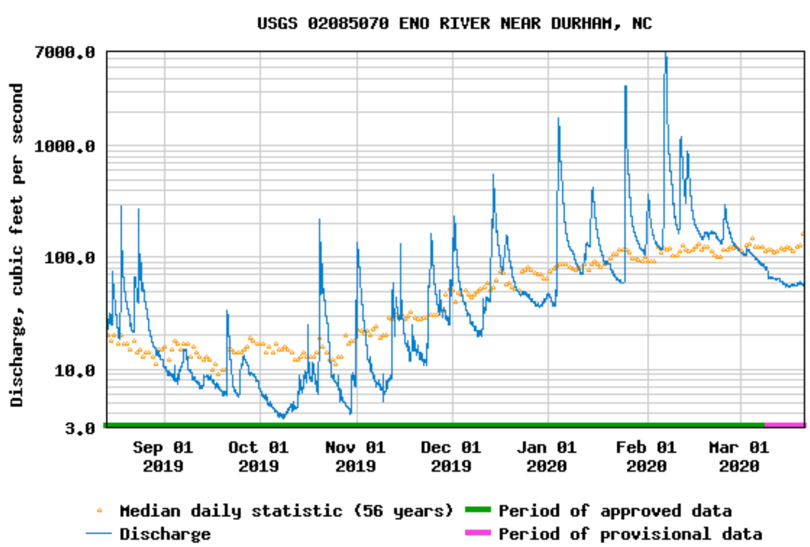
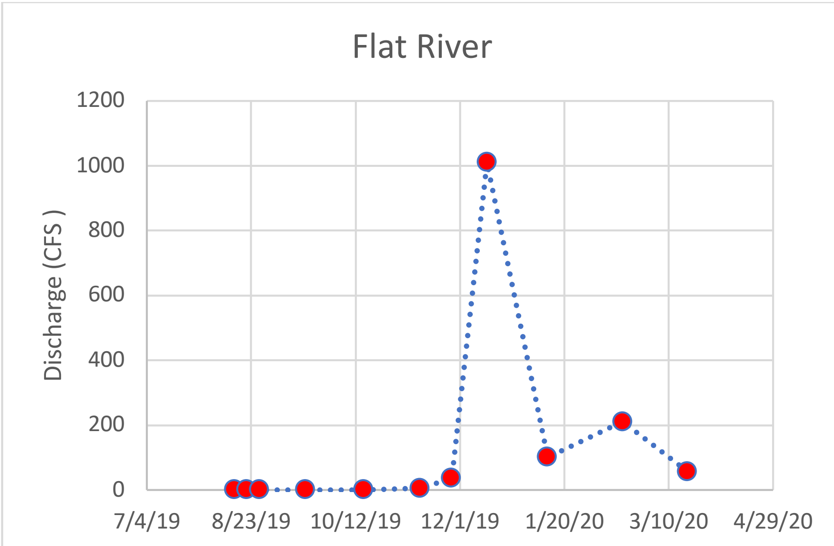


Figure 2 Shows the relationship between discharge and the dates the samples were collected for Eno River. Discharge (cubic meters per second (CMS) for the 10 dates sampled.



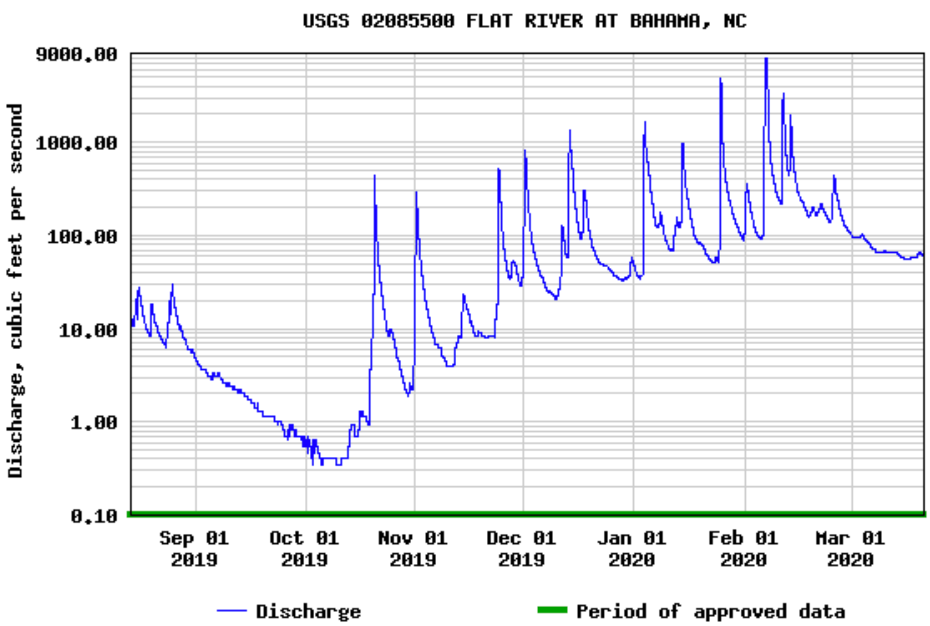
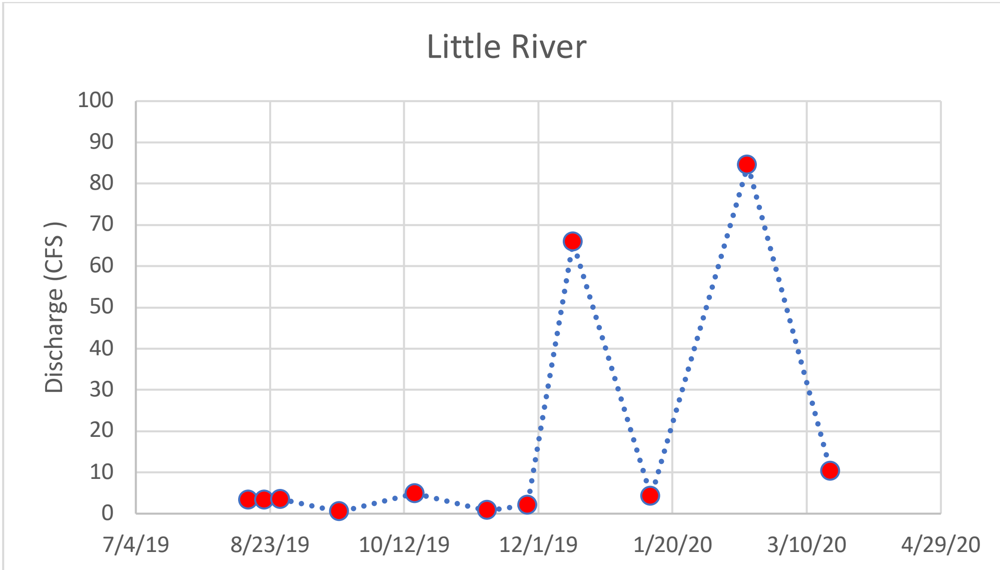


Figure 3 Shows the relationship between discharge and the date the samples were collected for Flat River. Discharge (cubic meters per second (CMS) for the 10 dates sampled.



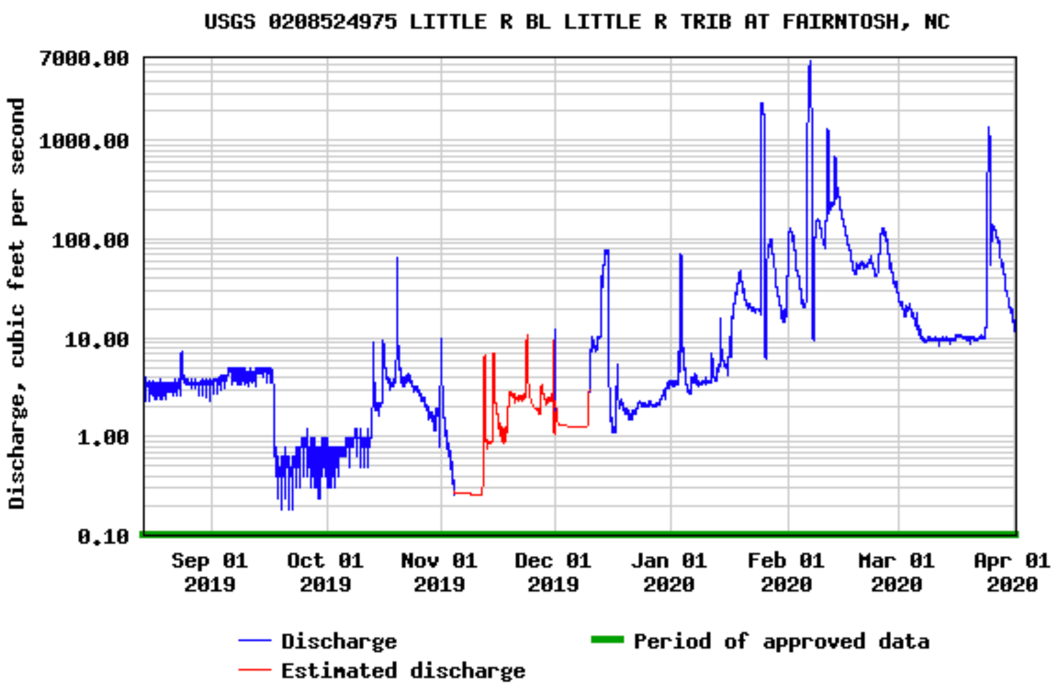


Figure 4 Shows the relationship between discharge and the date the samples were collected for Little River. Discharge (cubic meters per second (CMS) for the 10 dates sampled

Relationship between Suspended Sediment Concentration and Water Discharge

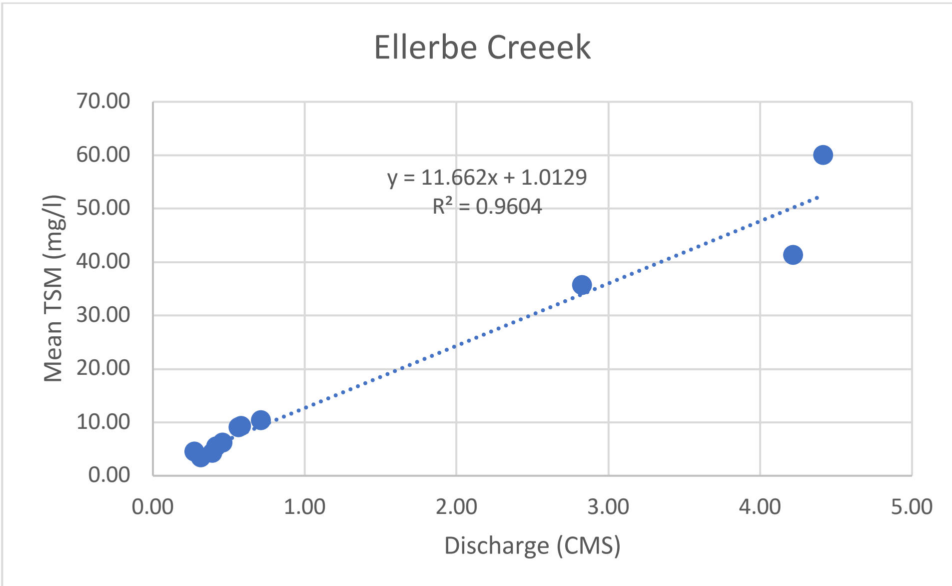


Figure 5 Shows mean TSM in relation to discharge for Ellerbe Creek.

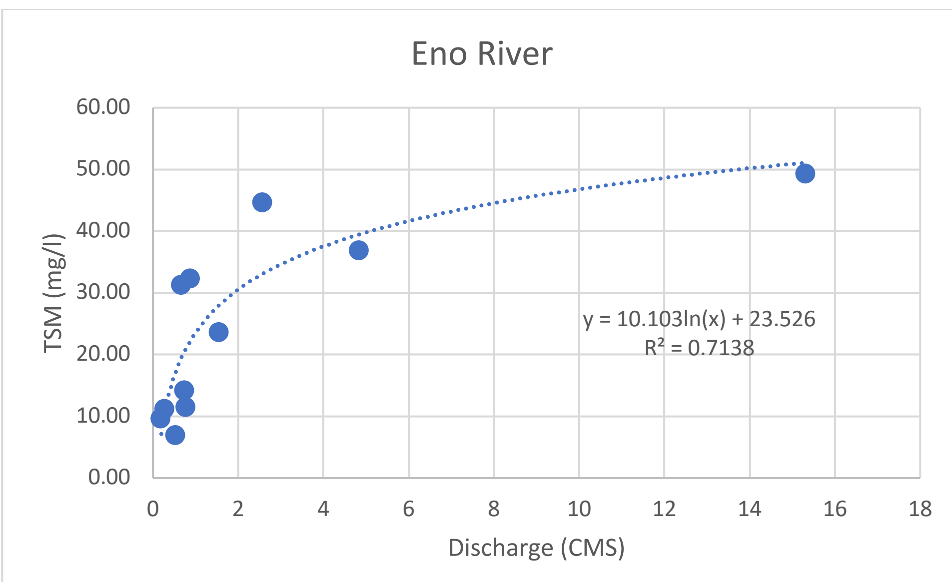


Figure 6 Shows mean TSM in relation to discharge for Eno River.

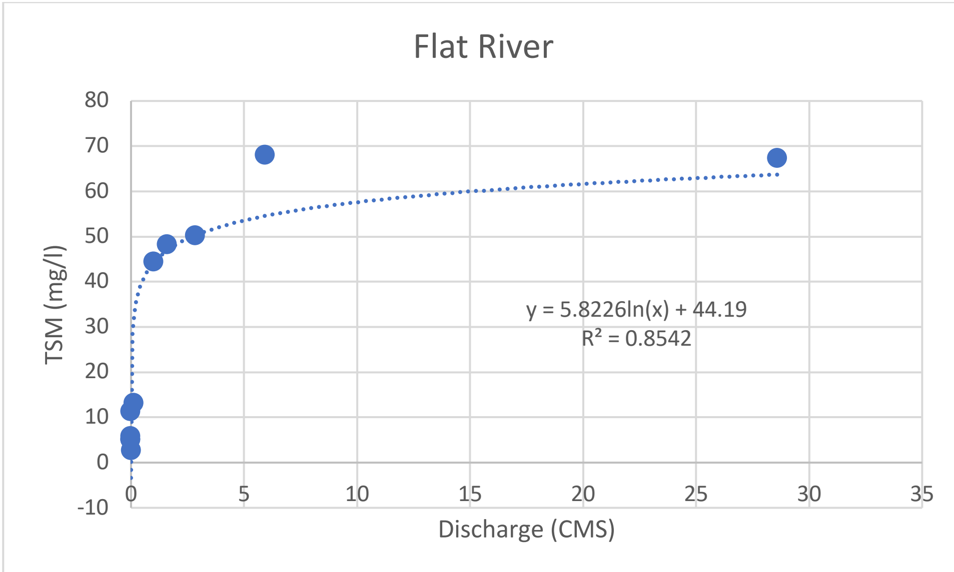


Figure 7 Shows the relationship between TSM and discharge for the Flat River

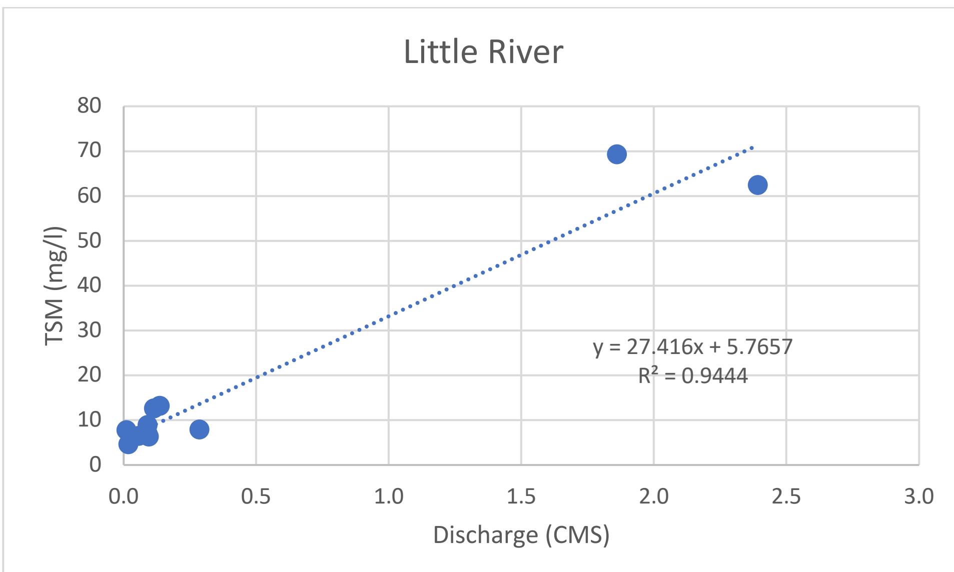


Figure 8 Shows mean TSM in relation to discharge for Little River

Relationship between Organic Carbon concentrations and Discharge

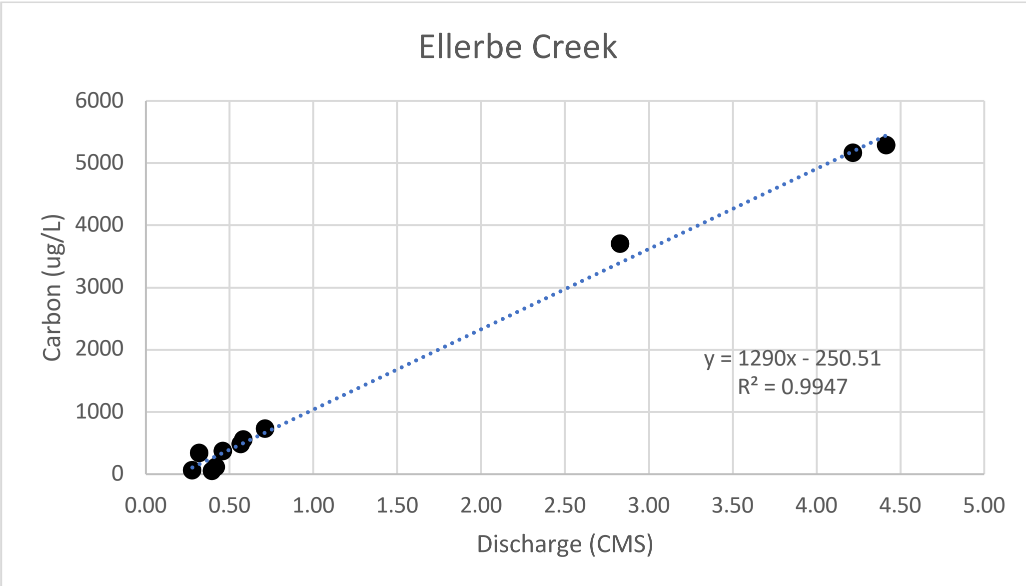


Figure 9 Shows the relationship between carbon (ug/L) and discharge for Ellerbe Creek.

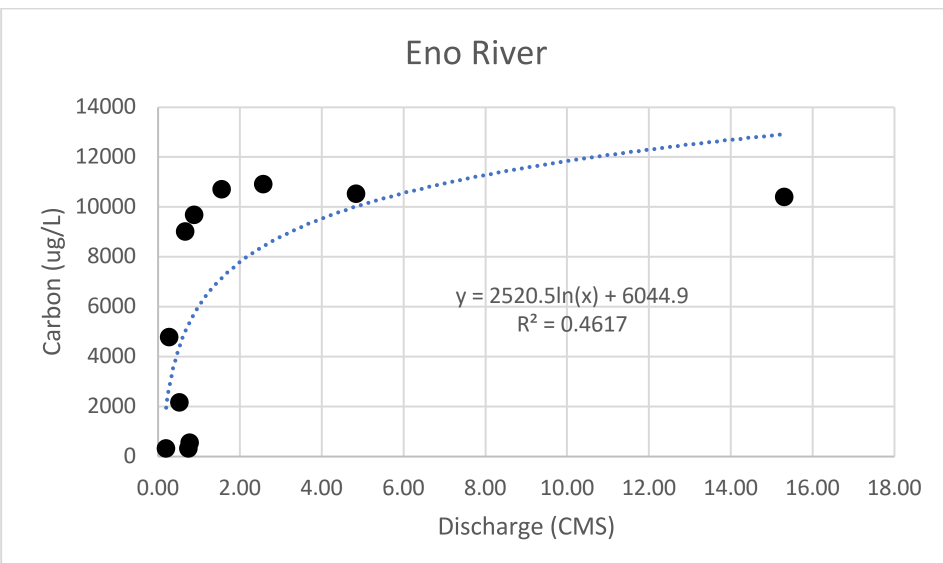


Figure 10 Shows the relationship between carbon (ug/L) and discharge for Eno River.

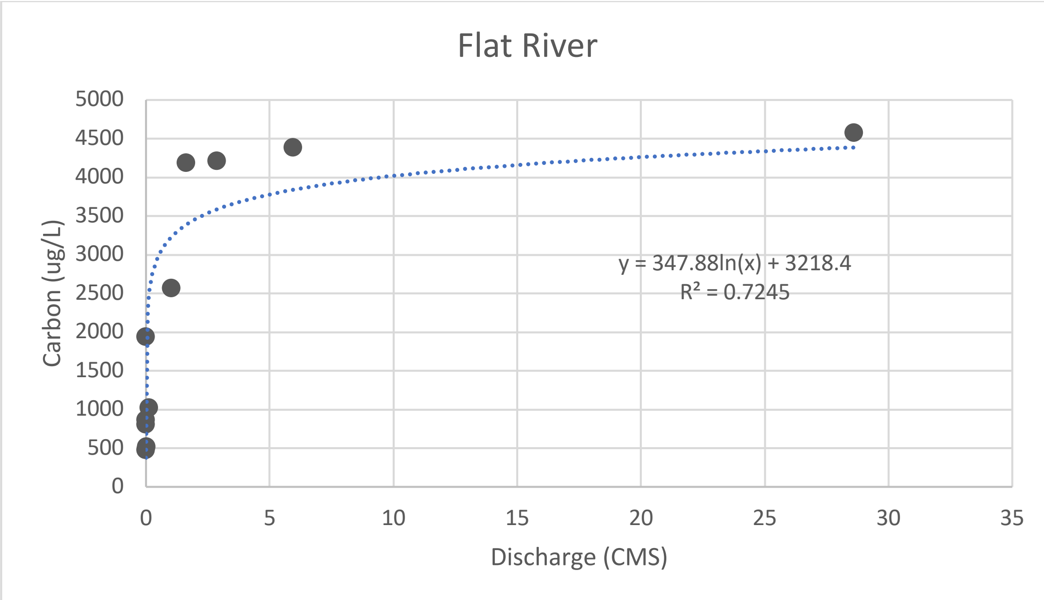


Figure 11 Shows the relationship between carbon (ug/L) and discharge for Flat River.

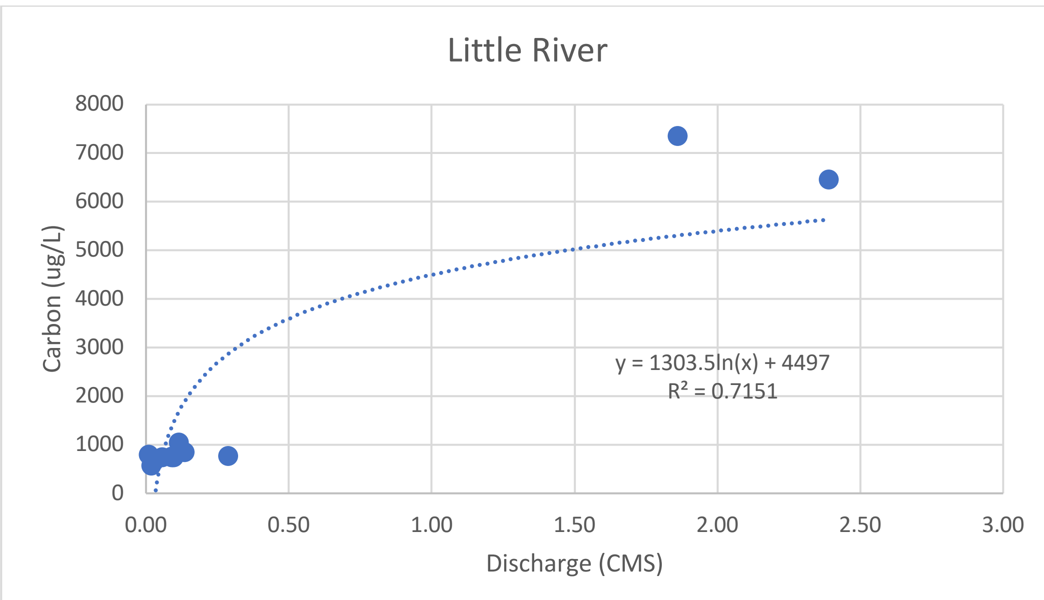


Figure 12 Shows the relationship between carbon (ug/L) and discharge for Little River.

POC as a function of TSM

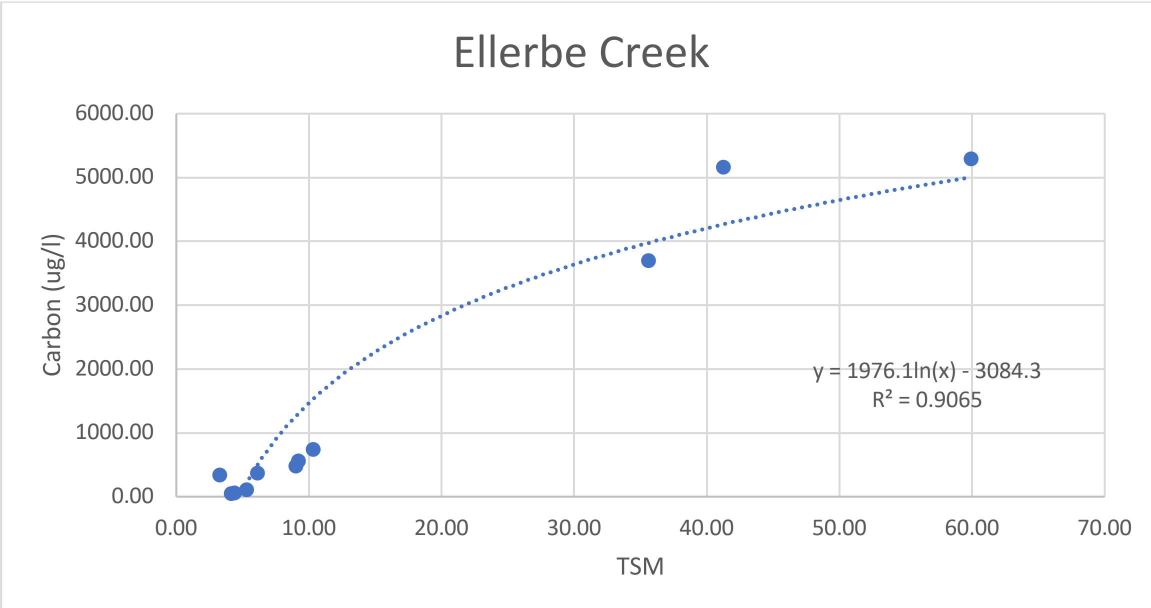


Figure 13 Shows the relationship between TSM and carbon (ug/L) for Ellerbe Creek.

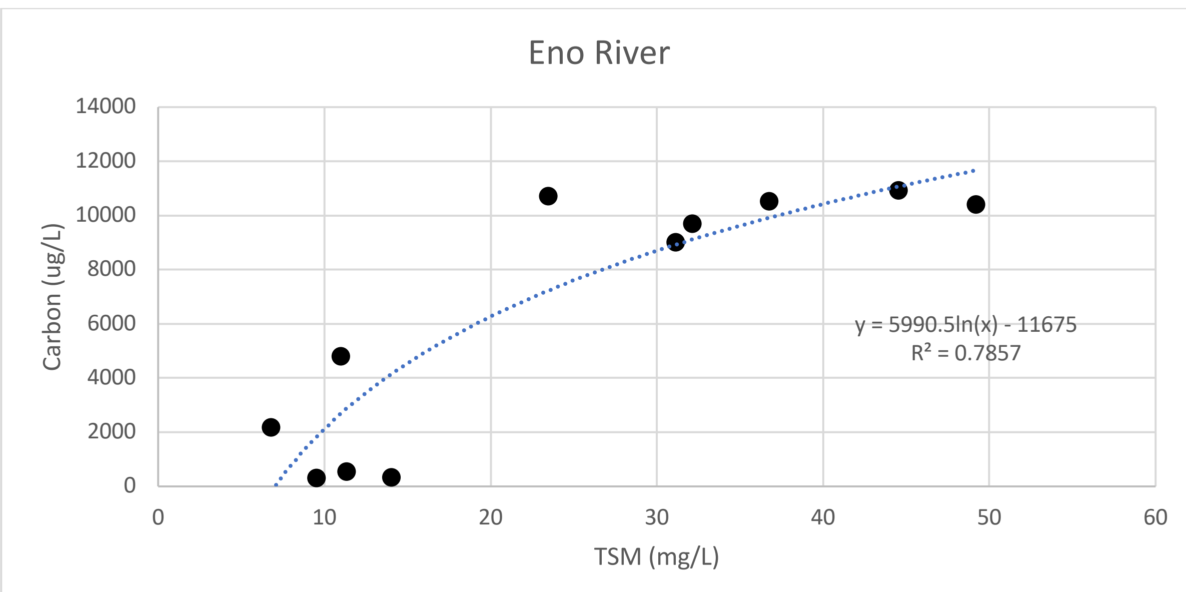


Figure 14 Shows the relationship between TSM and carbon (ug/L) for the Eno River.

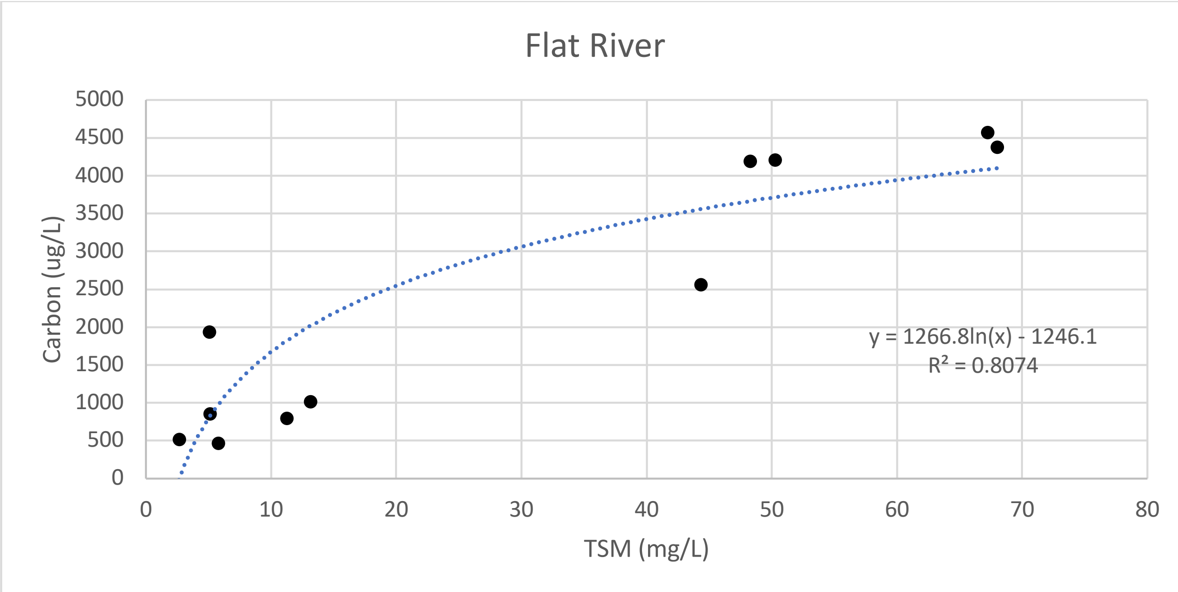


Figure 15 Shows the relationship between TSM and carbon (ug/L) for the Flat River.

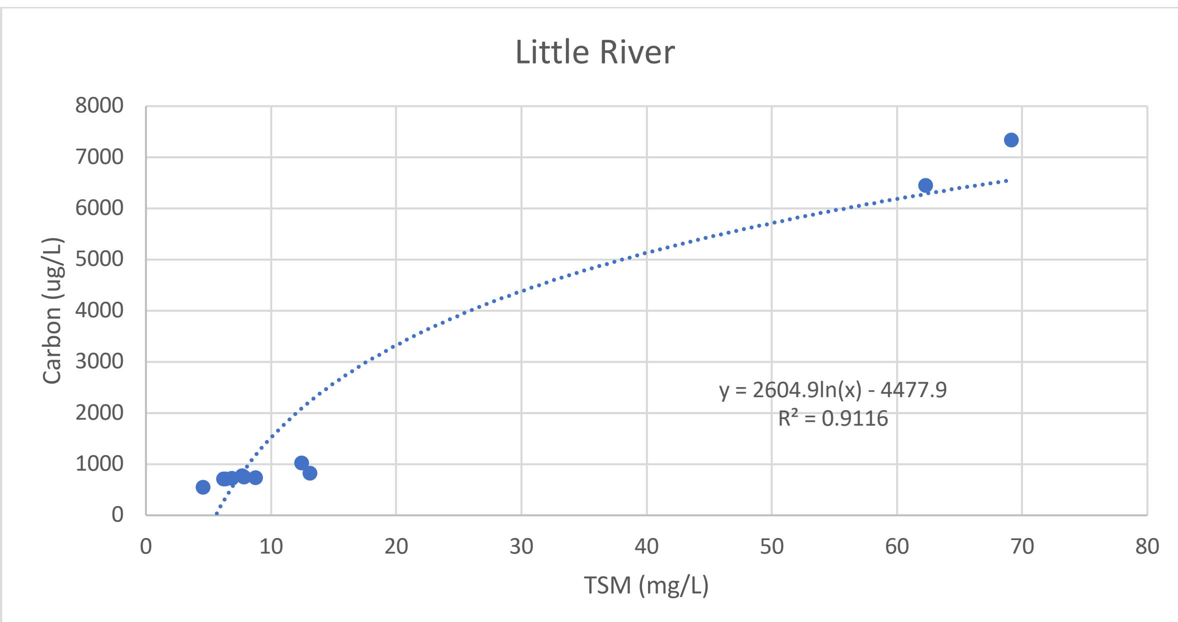


Figure 16 Shows the relationship between TSM and carbon (ug/L) for the Little River.

Percent Carbon as a function of TSM

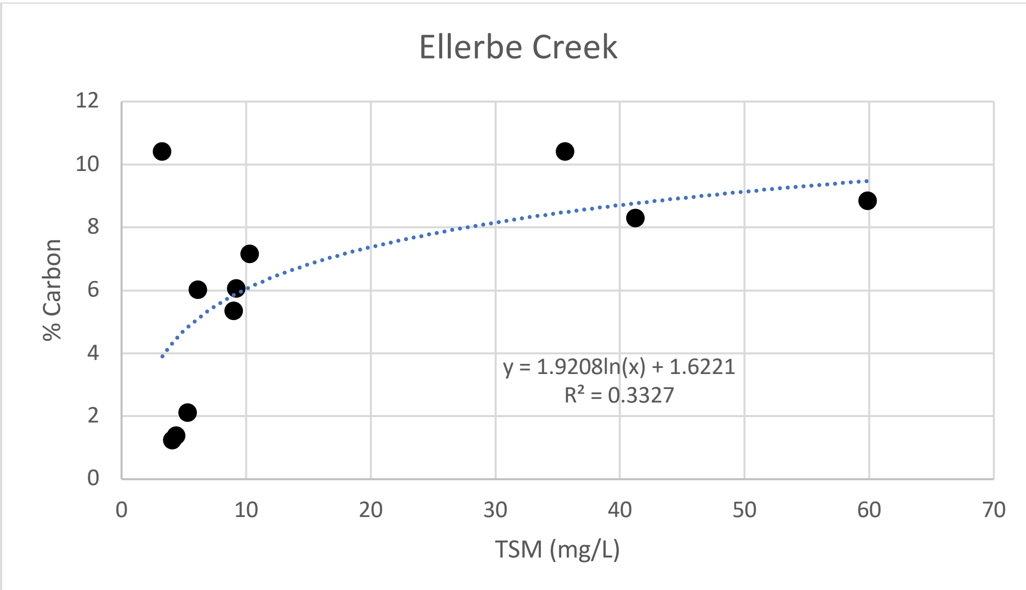


Figure 17 Shows the relationship between TSM and % carbon for Ellerbe Creek

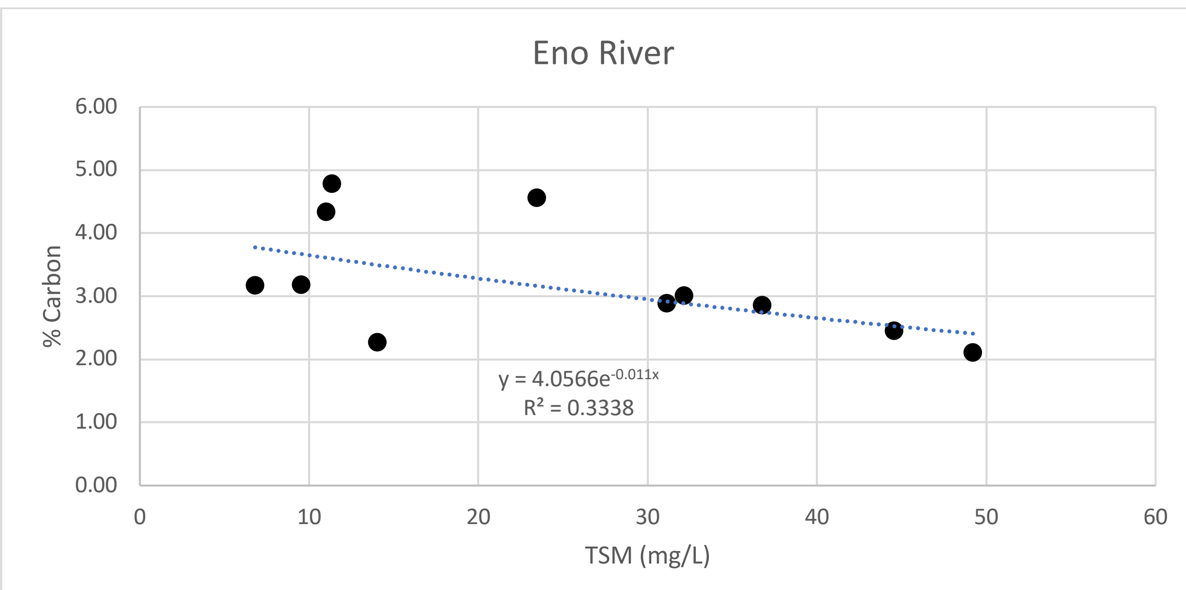


Figure 18 Shows the relationship between TSM and % carbon for the Eno River.

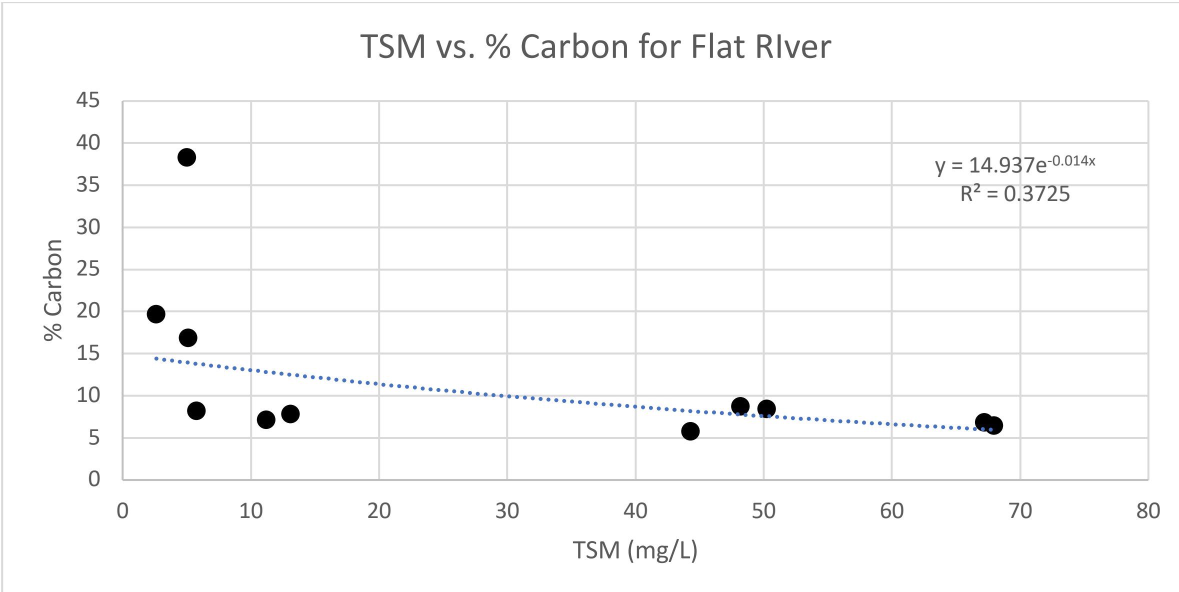


Figure 19 Shows the relationship between TSM and % carbon for the Flat River

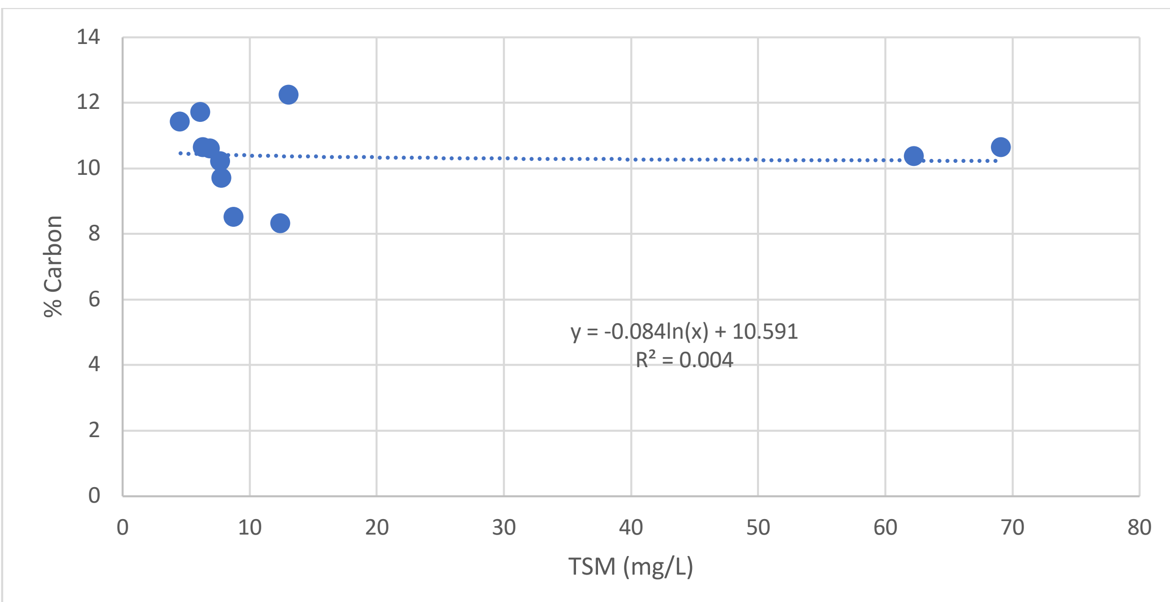


Figure 20 Shows the relationship between TSM and % carbon for the Little River.

C:N ratios as an indicator of Carbon sources within the drainage basins

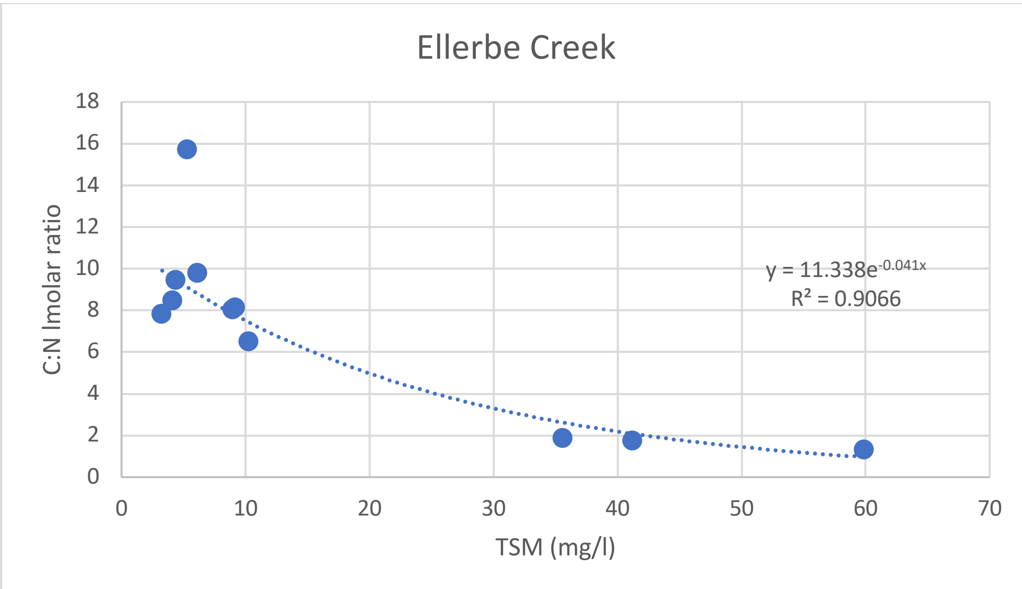


Figure 21 Shows the relationship between the C:N ratio and discharge for Ellerbe Creek. Mean values is 7.16

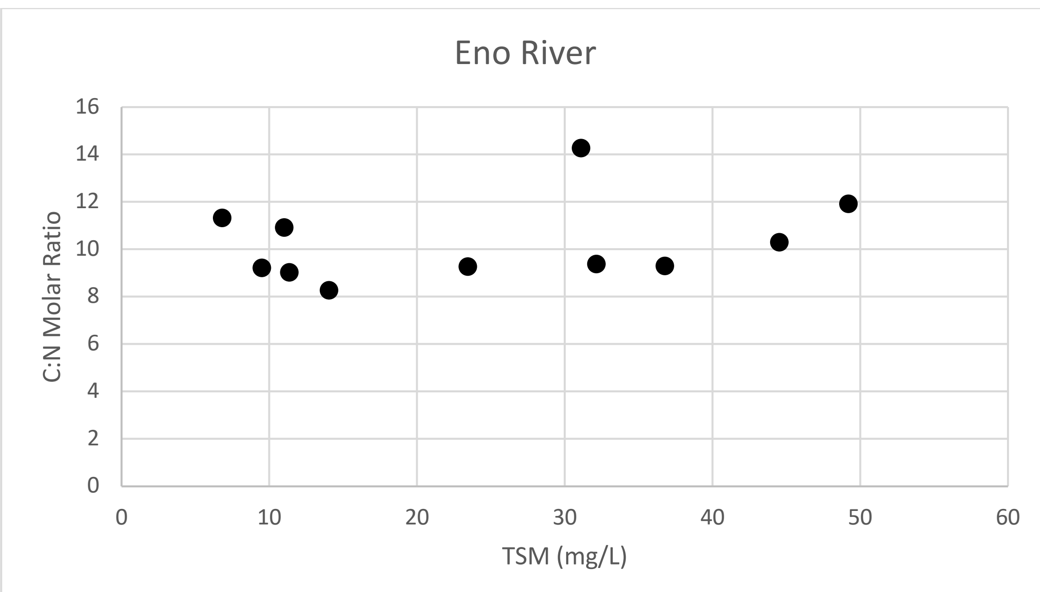


Figure 22 Shows the relationship between the C:N ratio and discharge for Eno River. Mean value is 10.27

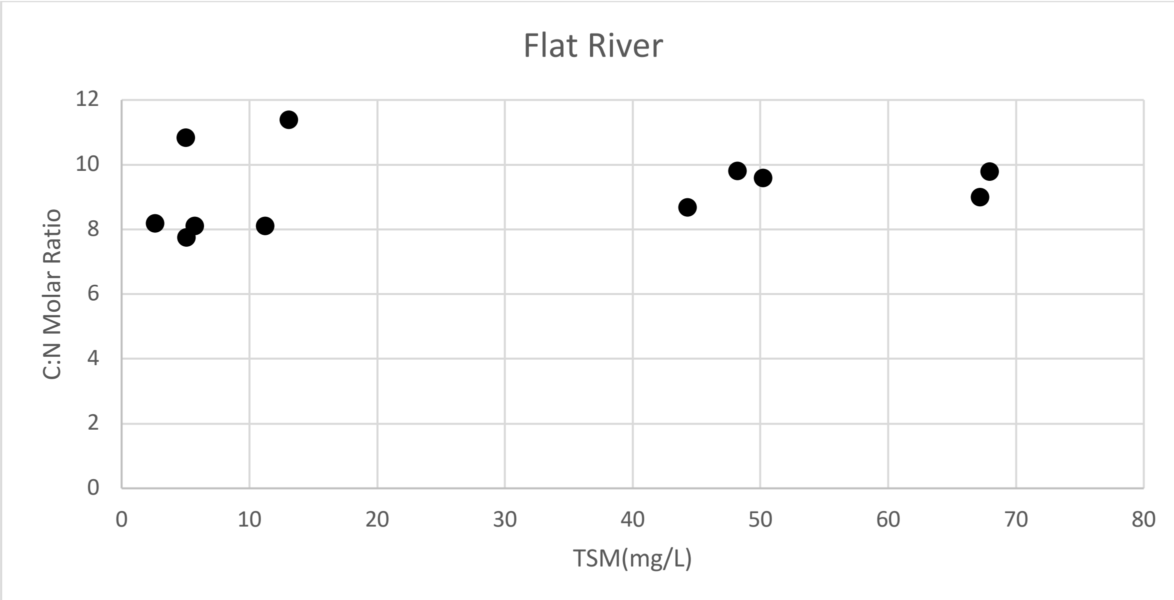


Figure 23 Shows the relationship between the C:N ratio and discharge for Flat River. Mean value is 9.19

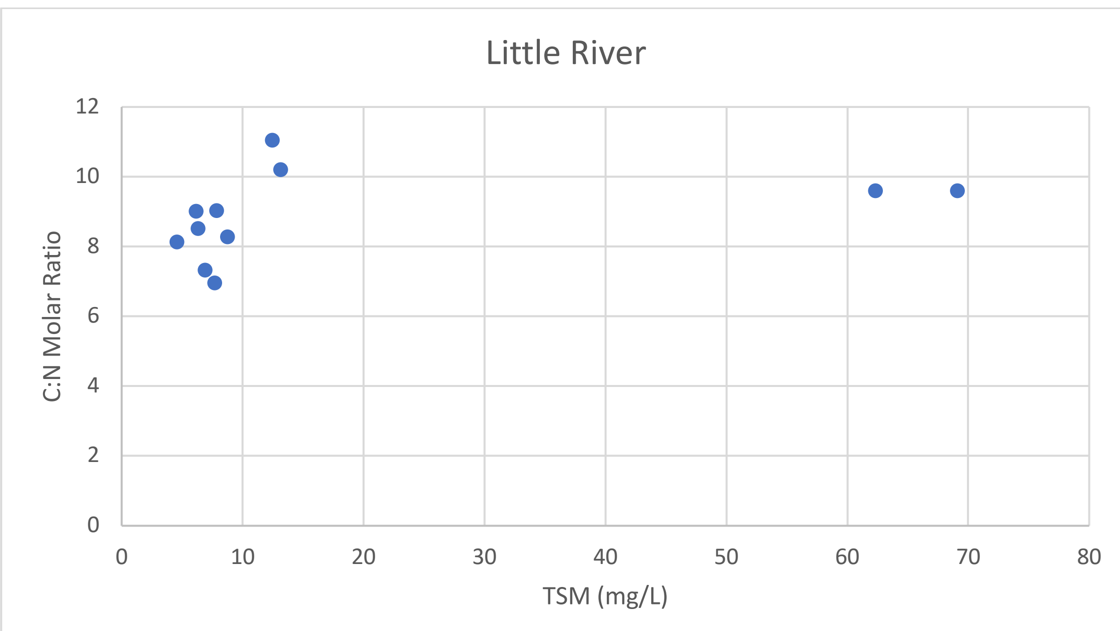
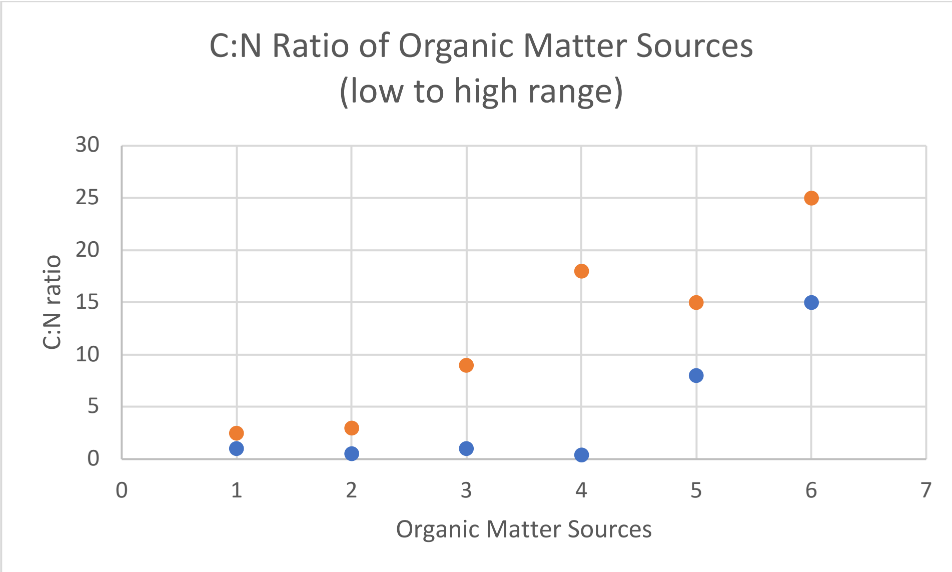


Figure 24 Shows the relationship between the C:N ratio and discharge for Little River. Mean values is 8.89



1 Septic, 2 Sewage, 3 Forest, 4 Fertilizwer, 5 Soil organinc matter, 6 Terrestrial plants

Site	**C:N Range**	**Possible Sources**
Ellerbe Creek	2-16	Include fertilizer, septic, sewage
Eno	8-14	Soil organic matter
Flat	8-12	Soil organic matter
Little	7-11	Soil organic matter

Figure 25 Shows the C:N range for each site and representative ranges for 6 potential organinc matter sources. Given the ovserved ranges for C:N, possible sources of organic matter is suspended sediments collected are suggested.

Discussion and Conclusions

Water Discharge in Cubic Feet per Second (CFS): During the study period the water discharge for the 4 river/creek inputs ranged from 10-2000 CFS for Ellerbe Creek; 1-6000 CFS for The Eno River; 1-8000 CFS for the Flat River; and, 1-6000 CFS for the Little River. We were able to collect water samples at two higher stages (140-160 CFS) for Ellerbe Creek; one higher stage (500 CFS) for the Eno River; one higher stage (1000 CFS)for the Flat River; and, two higher stages (65 and 85 CFS) for the Little River (Figures 1-4). None of these sample collections were near high flow stage but rather represent medium-low discharge. For the remainder of this report, water discharge will be expressed in units of Cubic Meters per Second (CMS) rather than than CFS units used by the US Geological Survey. A unit conversion of CMS = CFS/ 35.314 is used.

One of the major objectives of this study was to examine sediment rating curves that may enable us to predict total suspended matter (TSM) concentrations based on water discharge (in CMS) which is readily available online at https://m.waterdata.usgs.gov/ from the US Geological Survey. The ranges in discharge values were small for Ellerbe Creek (0-5 CMS) and Little River (0-2.5 CMS) and therefore we collected no samples that represent medium to high discharge stages. For this reason the TSM vs Discharge relationship for these two sites is best represented by linear regressions with R^2 values of 0.96 and 0.94 respectively. Typical rating curves that represent the full reange in annual discharge are logarithmic relationship with an initial steep increase in TSM at lower discharge values; reaching an asymptote in TSM values as discharge reaches maximum values. The range in discharge for the Eno and Flat Rivers are wide enough to observe a portion of the asymptote at 50 mg/l TSM for the Eno ($R^2 = 0.713$) and 70 mg/l TSM for the Flat ($R^2 = 0.854$). In all four river/creek inputs good rating curves were established to adequately predict TSM values at a given location and discharge. The weakness of the current rating curves is the uncertainty in predicted values when discharge exceed the values that we sampled in this study.

Particulate Organic Carbon (POC) values in ug/l appear to be strongly correlated with TSM values. Therefore is is possible to predict POC values of Falls Lake inputs based on discharge values. Maximum POC values observed were approximately 5000, 1100, 4500 and 7000 ug/l for Ellerbe Creek, Eno, Flat and Little Rivers, respectively. POC to TSM correlations are best represented by a logarithmic relationship with R^2 values of 0.91, 0.79, 0.81 and 0.91 for Ellerbe Creek, Eno, Flat and Little Rivers, respectively. As long as TSM values are in the range of 0-70 mg/l (as we observed) the POC:TSM curve that we have constructed will do a very good job of predicting POC values of suspended matter entering Falls Lake.

Percent Carbon content and C:N molar ratios for suspended sediments provide a semi-quantitiative approach to identifing sources of organic matter in each of the river/creek inputs. There are many other more quantitative tracers that can be used to better identify the types of soils and vegetation from which suspended sediment originate (e.g., stable isotopes of C, N and S) but %C and C:N ratios are useful for first insights without the high expense of those alternative approaches. For Eno, Flat and Little Rivers, the range in %C values throughout the sampling period are well constrained (2-5, 5-20 and 8-12, respectively). In general an inverse relationship between %C and suspended sediment grain size is observed in world rivers. The correlatins between %C and TSM is poor for all four river/creeks (R^2 ranging from 0.004 to

0.37) while the %C values remain relatively constant across the entire TSM range indicates that the sediment being supplied in each of the four basins are similar in character.

C:N molar ratios of suspended sediments can provide insights as to the source of the organic matter in each sample collected. Figure 25 illustrates some possible sources within the watersheds of Falls Lake. Given the range in C:N observed during this study, a combination of sources are suggested for each river/creek. With the exception of Ellerbe Creek the most likely sources of organic matter discharged into Falls Lake come from soil organic matter. Ellerbe Creek, which has a large proportion of urban environments within its watershed, has lower C:N values which indicate the influence of human inputs such as fertilizer, septic, sewage.

Site Information

USGS Water Discharge Site Locations

Falls Lake

Site Number: 02086849
Site Name: **ELLERBE CREEK NEAR GORMAN, NC**
Site Type: Stream
Agency: USGS
    Latitude 36°03'33" N 78°49'58" W NAD27
    Durham County, North Carolina, Hydrologic Unit 03020201
    Drainage area: 21.9 square miles
    Datum of gage: 252.31 feet above NAVD88.

Site Number: 02086500
Site Name: **FLAT RIVER AT DAM NEAR BAHAMA, NC**
Site Type: Stream
Agency: USGS
    Latitude 36°08'55" N 78°49'44" W NAD83
    Durham County, North Carolina, Hydrologic Unit 03020201
    Drainage area: 168 square miles
    Datum of gage: 256.60 feet above NGVD29.

Site Number: 0208524975
Site Name: **LITTLE R BL LITTLE R TRIB AT FAIRNTOSH, NC**
Site Type: Stream
Agency: USGS
    Latitude 36°06'48" N. 78°51'35" W NAD83
    Durham County, North Carolina, Hydrologic Unit 03020201
    Drainage area: 98.9 square miles
    Datum of gage: 263.6 feet above NAVD88

Site Number: 02085070
Site Name: **ENO RIVER NEAR DURHAM, NC**
Site Type: Stream
Agency: USGS
    Latitude 36°04'20" N 78°54'28" W NAD83
    Durham County, North Carolina, Hydrologic Unit 03020201
    Drainage area: 141 square miles
    Datum of gage: 269.92 feet above NAVD88.

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