BUREAU OF WATER
South Carolina Department of Health and Environmental Control

Big Wateree Creek Study 2019

Technical Report No. 006-2020

S.C. Department of Health and Environmental Control

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Bureau of Water

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Executive Summary

During 2019 sample collection was conducted at 11 locations in the Big Wateree Creek, Little Wateree Creek and Dutchmans Creek watersheds in Fairfield County, SC. Samples were collected for turbidity, total suspended solids, total dissolved solids and total solids, along with the measurement of streamflow (discharge), under a range of different rain amounts to evaluate the total loading of solids as an estimate of sedimentation. This effort was an expansion of a previous study conducted in this area in 2016 and 2017.

Addressing the study scope questions:

- What are the solids loads entering Carolina Adventure World (CAW) from upstream (via Big Wateree Creek and Hogfork Branch)?
- What is the solids load exiting downstream from CAW?
- What is the net solids load to Big Wateree Creek from CAW?

During dry weather only 38% of the total loading leaving CAW originates from CAW, with the rest coming from the upstream watershed activities. However following rain events contributing over 1 inch of rain in the previous 48 hours this value increases up to almost 54%. It is expected that loadings leaving CAW would be greater than loading entering CAW just because of the additional land surface being drained. It is obvious that both the loadings entering and leaving CAW are highly variable and dependent on the magnitude and intensity of the rain event and with loading values varying as much as 3 orders of magnitude.

Modeling analysis suggests that during high intensity rain events the majority of sediment passing through CAW actually originates from the scouring and transport of sediment originating from the watershed upstream of CAW.

- How does this load compare to adjacent watersheds Little Wateree Creek and Dutchmans Creek, with no influence from CAW and different upstream land uses?

Neither Little Wateree Creek or Dutchmans Creek are ideal control watersheds. During the dry weather sample loading exiting Little Wateree Creek exceeded Big Wateree Creek by an order of magnitude. Following rainfall of greater than one inch in the previous 48 hours Big Wateree Creek loading is greater than either of the controls by an order of magnitude.

Introduction and Background

In 2007 Carolina Adventure World (CAW) opened in Fairfield County, at latitude 34.48^{o} N, and longitude -80.96 ^{o} W. Located on 2,600 acres of private land, it is the Southeast's largest All Terrain Vehicle (ATV), Utility Vehicle (UTV) and dirt bike riding park. CAW is located near the downstream end of the Big Wateree Creek watershed. CAW's Park Rules and Regulations state "Federal Law: No riding in creek beds. Crossings allowed only at marked areas." Since CAW's opening there have been frequent complaints from residents along the shore of the Big Wateree Creek cove and the Lake Wateree Association about sedimentation filling the cove and the generally "muddy looking" condition of Big Wateree Creek, especially after rain. From site visits it is clear that riding in creek beds and along and across banks does occur. Historically the ambient surface water quality monitoring site at the downstream end of the watershed, CW-072, has shown frequent exceedances of State Standards for bacteria and turbidity before the opening of CAW and continuing since. Bacteria and turbidity Total Maximum Daily Loads (TMDL) have been developed and were approved in 2004.

A special study was conducted in 2016/2017 to characterize turbidity, *Escherichia coli*, and Residue Suspended (a.k.a. Total Suspended Solids, TSS) in the Big Wateree Creek watershed. While there are State Water Quality Standards for turbidity and *E. coli*, there are no State Standards for TSS. Nevertheless, TSS is a widely-used and meaningful parameter in water quality assessments. TSS was included because it is an indicator of solid materials suspended in the water column that have the potential to eventually settle out when water velocity slows and particulates have the opportunity to settle out. A total of ten sites were included in the special study, nine in the Big Wateree Creek watershed and one site in the Little Wateree Creek watershed that provided a less impacted reference area. In general, the study indicated that several sites in the Big Wateree Creek watershed exceeded *E. coli* standards even during some of the dry weather samples, but especially during wet weather events. The Little Wateree Creek samples only exceeded *E. coli* standards during the rain events. For turbidity, in the Big Wateree Creek watershed every site exceeded the State Standard following a 1.7" rain event. The Little Wateree Creek site never exceeded the turbidity standard, even after this major rainfall event.

The 2016/2017 study was not designed to quantify the contributions to sedimentation from various parts of the Big Wateree Creek watershed. The ongoing concern revolves around the continuing sediment deposition in the Lake Wateree cove at the inflow of Big Wateree Creek and the resulting impediment to boat access for shoreline homeowner's docks. Sediment is not a pollutant, and sedimentation of a cove is not a water quality issue. Erosion and subsequent sedimentation is a natural process, like rainfall and changing of the seasons but it can be accelerated by man-made contributions. Total loading of a substance normally increases from upstream to downstream throughout a watershed due to increasing land surface area draining to the stream, unless there is an impediment to flow that allows settling to occur, e.g. an impoundment, a beaver dam, etc. In a reservoir, generally a cove formed by the input of a stream tributary to the reservoir will fill in with sediment more quickly than the true deep reservoir shoreline. This is because the stream will be carrying runoff and sediment from a relatively large watershed upstream on a more or less continuous basis. As such, these are areas that will fill in and become non-navigable relatively quickly and will usually require repeated dredging to maintain a navigable channel. SCDHEC staff familiar with the Big Wateree

Creek area and CAW have also reported anecdotal observations that extensive timber harvesting has been and is taking place widely within the watershed since the 2016/2017 study time period.

Purpose of Study

The purpose of this study was to determine if CAW is source of sediment loading to Big Wateree Creek that is significantly greater than what would be expected to occur naturally. Specifically, study scope questions to be answered are:

- What are the solids loads entering CAW from upstream (via Big Wateree Creek and Hogfork Branch)?
- What is the solids load exiting downstream from CAW?
- What is the net solids load to Big Wateree Creek from CAW?
- How does this load compare to an adjacent watersheds Little Wateree Creek and Dutchmans Creek, with no influence from CAW and different upstream land uses?

General Study Design

The Bureau of Water was committed to repeat the 2016/2017 study in terms of sampling locations (Table 1 and Figure 1) throughout the Big Wateree Creek watershed and at a nearby, similar, less impacted site in Little Wateree Creek during typical and precipitation impacted stream discharge (See more discussion about changes in Little Wateree Creek and its current suitability as a control watershed below). Accessibility was originally evaluated during the initial reconnaissance in July 2015.

The original 2016/2017 study involved sampling from bridges or instream collection at the bridge location if water depth was too shallow to allow sample collection off the bridges. Since this study will require direct instream access to suitable cross-section transects, verification of the safety of access to the stream and location of a cross section suitable for discharge measurement was confirmed on May 2, 2019. When the Aquatic Science Programs macroinvertebrate taxonomists conducted the macroinvertebrate community sample collection on July 1, 2019, they discovered two beaver dams upstream of the Little Wateree Creek sample collection and flow measurement site BW-17 at US 21.

The Little Wateree Creek watershed has only a very small portion of drainage area within Carolina Adventure World property. It was intended to represent the sedimentation characteristics of an adjacent watershed as a control for comparison to sediment loading in Big Wateree Creek. The beaver dams in essence created two artificial sediment settling basins upstream of the sample collection and flow measurement location, compromising its representation of control conditions. Because of the commitment to repeat the original study this site was maintained for the duration of the study. In order to have a more representative control site another site was added for the rain event sampling. LCT-03, Dutchmans Creek at US-21, Table 1, was evaluated by Aquatic Science Programs staff and verified that beaver dams are not present upstream of this location. This location is also a tributary of Lake Wateree and is part of the **Lower Catawba River Basin – Stream and Lake Nutrient Water Quality Study**. An advantage of this location is that it has a USGS gage. This means that it will not be necessary for SCDHEC staff to measure flow at the time of sample collection at this site. We will be able to get the corresponding discharge value from the USGS site. The USGS gage reports a gage height value every 15 minutes. Using limited field flow measurements an estimated rating curve was developed that allowed a flow measurement to be approximated at this site at a given time.

Minor changes in parameter coverage from the 2016/2017 study were incorporated into this study. *Escherichia coli* was not included in this study because the focus was changed to sediment deposition. This study collected samples for Residue Total (a.k.a. Total Solids or TS), Residue Suspended (a.k.a. Total Suspended Solids or TSS), Residue Dissolved (a.k.a. Dissolved Solids or DS) and turbidity throughout the Big Wateree Creek watershed, the Little Wateree Creek watershed previously considered a similar less impacted site, and Dutchmans Creek a new control location (see further discussion below), during typical and precipitation impacted streamflow. TS, TSS and DS were chosen because they are solids fractions that characterize soil loading in the waters and which the EA BEHS Central Laboratory has the capability to analyze. There are no State Water Quality Standards for any of these analytes and the resulting data are being used for informational purposes only. There is no applicability to any SCDHEC regulatory authority. Sampling was repeated four times total, one (1) dry weather sample and three (3) wet weather sampling events. Wet weather events must be sampled within 24-48 hours following a rain event that is 0.5 inches or greater. Also, at least three (3) days of dry weather must occur between each wet weather sampling event.

Materials and Methods

For each sampling event, streamflow (discharge) was measured onsite following USGS methods, Discharge measurements at gaging stations: U.S. Geological Survey Techniques and Methods (Turnipseed, D.P. and Sauer, V.B. 2010) and SonTek FlowTracker2 User's Manual 1.6, Software Version 1.6, Firmware Version 1.3, 2019. Not all of the original monitoring locations were ideal for discharge measurement, but because of the commitment to include all of the original study locations, every effort was made to measure discharge at all locations for each sample event.

No sample was collected at any of the proposed sites if there is no flowing water. All sample collection, sample handling, sample preservation, and chain of custody will follow all protocols given in the most current EQC Environmental Investigations SOP and QA Manual (SCDHEC 2010). All sample analysis and quality control for chemical analyses were done according to the ARESD Procedures and QC Manual for Chemistry Laboratories. Additionally, independent of the water quality sampling events, one macroinvertebrate community composition assessment was attempted at each monitoring location to characterize biological community health following Standard Operating and Quality Control Procedures for Macroinvertebrate Sampling (SCDHEC 2017).

Standard operating procedures (SOPs) for grab sample collection, field measurements, sample containers, holding times, and chain of custody are detailed in sections within the BEHSPROC 200 – Ambient Surface Water Sampling, Sections 4.3, 4.4, and 4.5 (SCDHEC 2018a) if

Table 1. General Sampling Location Descriptions

Site Number	Site Description	Latitude	Longitude	HUC-12
RS-12060	Old stream statistical survey site originally sampled in 2012. Site is on S-20-44 Bull Run Road at second bridge north of White Oak. Upstream of Bull Run Road there is a Wateree Creek Watershed Structure/Conservation District reservoir	34.50184	-81.10501	30501040104
BW-02	The first bridge on Bull Run Road north of White Oak is an unnamed tributary that flows into Big Wateree Creek. Lots of cattle in this part of the watershed	34.49597	-81.10798	30501040104
BW-06	Unnamed tributary at Fairfield Hill Road approximately 0.6 miles NW of SC 901	34.50969	-81.02876	30501040104
BW-11	Scabber Branch at SC 200	34.50460	-81.00580	30501040105
BW-12A	Hogfork Branch at SC 200	34.51597	-80.98481	30501040105
CW-251	Current ambient monitoring site. Hogfork Branch at Camp Welfare Road S-20-20	34.48412	-80.97124	30501040105
CW-252	Current ambient monitoring site. Big Wateree Creek at Camp Welfare Road S-20-20	34.48178	-80.97868	30501040105
BW-15	Unnamed creek at US 21 N of Big Wateree Creek. In same HUC-12 as Big Wateree Creek also potentially impacted by Carolina Adventure World	34.48168	-80.93638	30501040105
CW-072	Current ambient monitoring site. Big Wateree Creek at US 21	34.46825	-80.93886	30501040105
BW-17	Little Wateree Creek at US 21. Small portion of drainage area within Carolina Adventure World property	34.45523	-80.94147	Drains 30501040102 & 30501040103
LCT-03	Dutchmans Creek at US-21 (tributary of Lake Wateree)	34.3679	-80.9547	30501040108

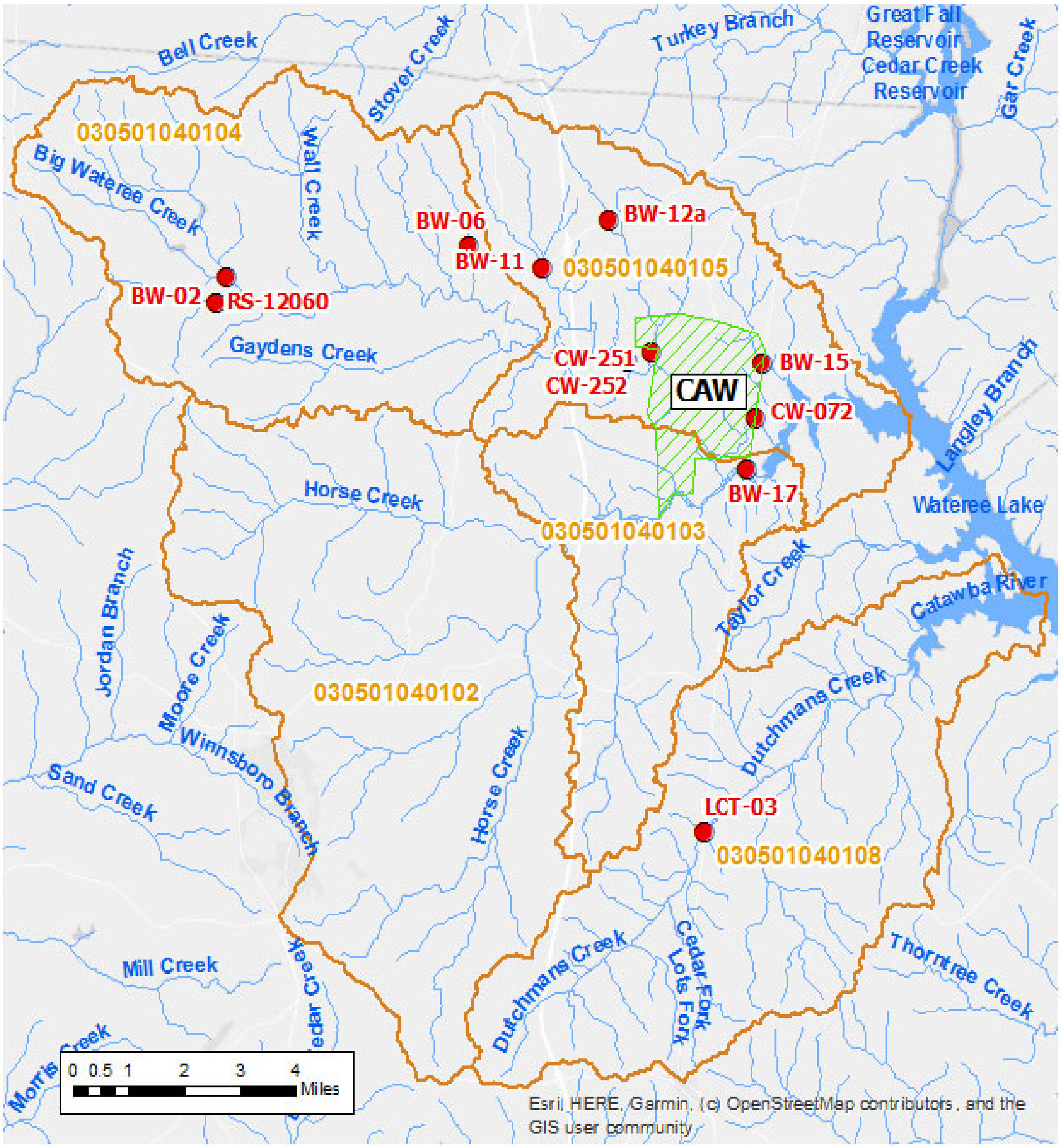

Figure 1. General Sampling Locations and Location of Carolina Adventure World (CAW, not a sampling location)

required and the lab analytical methods are detailed within IX-B-14(b) Turbidity (SCDHEC 2018c), IX-B-10(a) Total Solids (SCDHEC 2015), IX-B-10(b) Total Dissolved Solids (SCDHEC 2018e), IX-B-10(c) Total Suspended Solids (SCDHEC 2014b). Samples were collected in Big Wateree Creek upstream and downstream of CAW. The upstream sites on Big Wateree Creek and Hogfork Branch may potentially identify other activities within the watershed that may be unrelated to CAW and may need to be addressed.

Preferred cross section transect locations were identified and prepared, e.g. removal of large rocks and logs, under dry weather conditions. In terms of stream discharge, the intent of this effort was to get the most accurate measurement for each sampling event, not to develop rating curves. Due to changes in water level, flow velocity, and modification of stream channel characteristics in response to runoff under different magnitude rain events, the cross section location at each site was not always the same exact location. With every analysis and sample collection variability does exist, but this was especially true with the intent to collect each round of samples under different meteorological conditions. The goal was to calculate loadings of the different solids parameters under different runoff conditions.

Results

Table 2. Summary of Rainfall Prior to Sampling Events in the 12-digit Hydrologic Unit Codes Included in the Study.

HUC_12	Date	Rain Total for 24 Hours Prior to Sample Collection (in.)	Rain Total for 48 Hours Prior to Sample Collection (in.)
30501040102	8/21/2019	1.8	1.97
30501040103	8/21/2019	1.6	1.6
30501040104	8/21/2019	1.9	1.93
30501040105	8/21/2019	1.48	1.55
Average		**1.695**	**1.7625**
30501040108	8/21/2019	1.33	1.37
30501040102	10/21/2019	0	1.11
30501040103	10/21/2019	0	1.08
30501040104	10/21/2019	0	1.28
30501040105	10/21/2019	0	1.15
Average		**0**	**1.155**
30501040108	10/21/2019	0	1.15
30501040102	11/14/2019	0	0.4
30501040103	11/14/2019	0	0.43
30501040104	11/14/2019	0	0.37
30501040105	11/14/2019	0	0.48
Average		**0**	**0.42**

HUC_12	Date	Rain Total for 24 Hours Prior to Sample Collection (in.)	Rain Total for 48 Hours Prior to Sample Collection (in.)
30501040108	11/14/2019	0	0.4

Table 3. Areas of 12-digit HUCS included in the study.

Dutchmans Creek	12-digit 030501040108	**27,289.07** acres
Big Wateree Creek	12-digit 030501040105	18,639.00 acres
	12-digit 030501040104	24,480.26 acres
Total		**43,119.26** acres
Little Wateree Creek	12-digit 030501040103	13376.70 acres
	12-digit 030501040102	34055.81 acres
Total		**47,432.51** acres

Macroinvertebrate Results

In keeping with SCDHEC macroinvertebrate protocols (SCDHEC 2017), sampling was conducted in the summer and avoided rain events. Scoring and bioclassification (Table 4) likewise followed SCDHEC criteria:

Table 4. Macroinvertebrate Bioclassification Score

Bioclassification Score	Bioclassification	Aquatic Life Use Support
4.5 - 5.0	Excellent	Fully Supporting
3.5 - 4.4	Good	Fully Supporting
2.5 - 3.4	Good-Fair	Partially Supporting
1.5 - 2.4	Fair	Partially Supporting
1.0 - 1.4	Poor	Not Supporting

Multiple sites were unsampleable by stream macroinvertebrate methods. RS-12060, BW-02, BW-06, BW-12A, CW-251, and BW-15 had no flow (and in some cases were almost completely dry) under normal water conditions. The sites that were sampled yielded the following results: BW-11 (Scabber Branch at SC 200) was the most upstream site and was sampled 6/19/19. It had a bioclassification score of 2.6 which corresponds to a bioclassification of good-fair and an aquatic life use support (ALUS) of partially supporting. Sedimentation was severe, though it was the only site sampled that had a significant amount of rocks in the stream. Looking at the two sites along Big Wateree Creek itself, CW-252 (at S-20-20, upstream of Carolina Adventure World, sampled 6/19/19) had a score of 2.9 (bioclassification of good-fair and ALUS of partially supporting), while CW-072 (at US 21, downstream of Carolina Adventure World, sampled 6/19/19), had a score of 2.4 (bioclassification of fair and ALUS of partially supporting). Sedimentation was severe at both sites. The control site, LCT-03 (Dutchmans Creek at US 21, sampled 7/26/19), had a score of 2.8 (bioclassification of good-fair and ALUS of partially supporting). Sedimentation was severe. BW-17 (Little Wateree Creek at US 21, sampled 6/28/19), was initially going to be used as a control site but beaver dams blocking flow immediately upstream of the site likely affected macroinvertebrate colonization. It scored a 2.4 (bioclassification of fair and ALUS of partially supporting). Sedimentation was severe.

Table 5. Turbidity Results for This Study

Date		6/27/2019	8/21/2019	10/21/2019	11/14/2019
HUC 030501040104					
	Rain Prior 48 Hr. (in.)	Dry	1.93	1.28	0.37
	Rain Prior 24 Hr. (in.)	Dry	1.90	0.00	0.00
RS-12060	Turbidity (NTU)	NA	37	40	65
BW-02	Turbidity (NTU)	NA	110	NA	85
BW-06	Turbidity (NTU)	NA	180	140	55
HUC 030501040105					
	Rain Prior 48 Hr. (in.)	Dry	1.55	1.15	0.42
	Rain Prior 24 Hr. (in.)	Dry	1.48	0.00	0.00
BW-11	Turbidity (NTU)	6.4	140	50	8.5
BW-12A	Turbidity (NTU)	NA	140	NA	NA
CW-251	Turbidity (NTU)	1.8	190	24	3.7
CW-252	Turbidity (NTU)	1.8	260	16	4.9
CW-072	Turbidity (NTU)	34	500	44	25
BW-15	Turbidity (NTU)	NA	850	900	500
HUC 030501040102 **HUC 030501040103**					
	Rain Prior 48 Hr. (in.)	Dry	1.60	1.08	0.43
	Rain Prior 24 Hr. (in.)	Dry	1.60	0.00	0.00
BW-17	Turbidity (NTU)	8.1	NA	26	18
HUC 030501040108					
	Rain Prior 48 Hr. (in.)	Dry	1.37	1.15	0.40
	Rain Prior 24 Hr. (in.)	Dry	1.33	0.00	0.00
LCT-03	Turbidity (NTU)	NA	7.4	7.6	4.2

In Table 6 the total loading for each parameter entering CAW is the sum of the loadings from CW-251 and CW-252. The total load leaving CAW is represented by CW-072.

Table 6. Total Loading Entering and Leaving CAW.

STAT	DATE	PARAMETER	RESULT (mg/L)	Flow Cubic Feet per Second	Loading (lbs/day)	Total Load Out Below CAW vs. Total Load Into CAW CW-251+CW-252	Load In vs. Load Out	Percent of Total Load Out CW-072 By CW-251+CW-252	Rain Prior 24 Hours (Inches)	Rain Prior 48 Hours (Inches)
CW-252	6/27/2019	TotDissSolid	140	0.25	186.42				Dry	Dry
CW-251	6/27/2019	TotDissSolid	130	0.02	16.54	Total In Abv CAW	202.96	70.32%	Dry	Dry
CW-072	6/27/2019	TotDissSolid	150	0.36	288.61	Total Out Blw CAW	288.61	29.68%	Dry	Dry
CW-252	6/27/2019	TotSolid	140	0.25	186.42				Dry	Dry
CW-251	6/27/2019	TotSolid	130	0.02	16.54	Total In Abv CAW	202.96	62.05%	Dry	Dry
CW-072	6/27/2019	TotSolid	170	0.36	327.09	Total Out Blw CAW	327.09	37.95%	Dry	Dry
CW-252	6/27/2019	TSS	1	0.25	1.33				Dry	Dry
CW-251	6/27/2019	TSS	1	0.02	0.13	Total In Abv CAW	1.46	2.92%	Dry	Dry
CW-072	6/27/2019	TSS	26	0.36	50.03	Total Out Blw CAW	50.03	97.08%	Dry	Dry
CW-252	8/21/2019	TotDissSolid	160	116.92	100,853.56				1.48	1.55
CW-251	8/21/2019	TotDissSolid	220	3.54	4,192.88	Total In Abv CAW	105,046.43	95.20%	1.48	1.55
CW-072	8/21/2019	TotDissSolid	170	120.39	110,339.85	Total Out Blw CAW	110,339.85	4.80%	1.48	1.55
CW-252	8/21/2019	TotSolid	430	116.92	271,043.93				1.48	1.55
CW-251	8/21/2019	TotSolid	270	3.54	5,145.81	Total In Abv CAW	276,189.74	47.81%	1.48	1.55
CW-072	8/21/2019	TotSolid	890	120.39	577,661.57	Total Out Blw CAW	577,661.57	52.19%	1.48	1.55
CW-252	8/21/2019	TSS	310	116.92	195,403.76				1.48	1.55
CW-251	8/21/2019	TSS	46	3.54	876.69	Total In Abv CAW	196,280.46	46.52%	1.48	1.55
CW-072	8/21/2019	TSS	650	120.39	421,887.66	Total Out Blw CAW	421,887.66	53.48%	1.48	1.55
CW-252	10/21/2019	TotDissSolid	120	0.71	460.61				0	1.15
CW-251	10/21/2019	TotDissSolid	130	0.23	158.88	Total In Abv CAW	619.49	53.34%	0	1.15
CW-072	10/21/2019	TotDissSolid	130	1.66	1,161.43	Total Out Blw CAW	1,161.43	46.66%	0	1.15
CW-252	10/21/2019	TotSolid	120	0.71	460.61				0	1.15
CW-251	10/21/2019	TotSolid	130	0.23	158.88	Total In Abv CAW	619.49	46.23%	0	1.15
CW-072	10/21/2019	TotSolid	150	1.66	1,340.11	Total Out Blw CAW	1,340.11	53.77%	0	1.15
CW-252	10/21/2019	TSS	1	0.71	3.84				0	1.15
CW-251	10/21/2019	TSS	2.2	0.23	2.69	Total In Abv CAW	6.53	3.65%	0	1.15
CW-072	10/21/2019	TSS	20	1.66	178.68	Total Out Blw CAW	178.68	96.35%	0	1.15
CW-252	11/14/2019	TotDissSolid	120	2.87	1,858.37				0	0.48
CW-251	11/14/2019	TotDissSolid	120	0.09	54.99	Total In Abv CAW	1,913.36	258.42%	0	0.48
CW-072	11/14/2019	TotDissSolid	120	1.14	740.41	Total Out Blw CAW	740.41	-158.42%	0	0.48

STAT	DATE	PARAMETER	RESULT (mg/L)	Flow Cubic Feet per Second	Loading (lbs/day)	Total Load Out Below CAW vs. Total Load Into CAW CW-251+CW-252	Load In vs. Load Out	Percent of Total Load Out CW-072 By CW-251+CW-252	Rain Prior 24 Hours (Inches)	Rain Prior 48 Hours (Inches)
CW-252	11/14/2019	TotSolid	140	2.87	2,168.10				0	0.48
CW-251	11/14/2019	TotSolid	130	0.09	59.57	Total In Abv CAW	2,227.67	257.89%	0	0.48
CW-072	11/14/2019	TotSolid	140	1.14	863.81	Total Out Blw CAW	863.81	-157.89%	0	0.48
CW-252	11/14/2019	TSS	1.1	2.87	17.04				0	0.48
CW-251	11/14/2019	TSS	1	0.09	0.46	Total In Abv CAW	17.49	70.88%	0	0.48
CW-072	11/14/2019	TSS	4	1.14	24.68	Total Out Blw CAW	24.68	29.12%	0	0.48

Key: TotDissSolid = Total Dissolved Solids, TotSolid = Total Solids, TSS = Total Suspended Solids. Orange shaded cells indicate impossible loading values due to very poor flow measurements.

Discussion

Turbidity

Regulation 61-68, Water Classifications and Standards (SCDHEC, 2014a) establishes the Class Freshwater (FW) standard for streams as 50 NTUs. Table 5 indicates that under dry weather conditions all sites either met the standard or didn’t exhibit any flow (NA). On August 21, 2019, following nearly 2 inches of rain, with the exception of RS-12060, all sites in the Big Wateree Creek watershed (HUCs 030501040104 and 030501040105) greatly exceeded the water quality standard. RS-12060 was the only exception. This location is just a short distance downstream of a Wateree Creek Watershed Structure/Conservation District firefighting reservoir. This reservoir acts as a settling basin and discharges relatively clean water. The two monitoring sites in the “control” watersheds, Little Wateree Creek and Dutchmans Creek, never exceeded the water quality standard. Subsequent smaller rain events only resulted in standards exceedances at the most upstream sites and BW-15. BW-15 represents the overflow discharge from a stormwater retention pond on CAW and does not connect to Big Wateree Creek.

Solids Parameters Loadings Into and Leaving Carolina Adventure World

When you have a measurement of discharge volume, also referred to as flow, and the concentration of a material in the water column, it is possible to calculate an estimate of the loading of that material. This is generally expressed as total pounds per day (lbs/day, Table 6). Although Table 6 expresses estimated loadings as lbs/day, discharge was only measured at the time samples were collected and it is unlikely that the flow and material concentrations were constant throughout a 24-hour period.

Study Objective Questions

- What are the solids loads entering CAW from upstream (via Big Wateree Creek and Hogfork Branch)?
- What is the solids load exiting downstream from CAW?
- What is the net solids load to Big Wateree Creek from CAW?

Total Solids for the dry event on June 27, 2019, 62.05% (202.96 lbs/day) of the total load being discharged from CW-072 originates from the upstream locations, with only 37.95% (327.09 lbs/day) of the discharged load originating within CAW, creating a net solids load of 124.13 lbs/day to Big Wateree Creek. However, Total Solids increase when there is more than an inch of rain in the preceding 48-hour period.

On August 21, 2019, following 1.55 inches of rain in the previous 48 hours, only 47.81% (276,189.74 lbs/day) of the total load being discharged from CW-072 originates from the upstream locations, with 52.19% (577,661.57 lbs/day) of the discharged load originating within CAW, creating a net solids load of 301,471.83 lbs/day to Big Wateree Creek. The magnitudes of the loadings on August 21, 2019 are several orders of magnitude greater than those observed on the June 27, 2019 measurements.

Another way to look at loadings is in terms of pounds per acre of watershed area per day (lbs/acre/day). For the August 21 sampling event, Appendix 4 page 55 shows that because CAW drainage area is so small the yield is very large compared to the overall yield at CW-252 (orange area only) because of its much larger drainage area. So relatively speaking the sediment yield from CAW (brown watershed areas) is much higher per acre than that from the orange area representing the yields calculated for CW-252.

Similarly on October 21, 2019, following 1.15 inches of rain in the previous 48 hours, 46.23% (619.49 lbs/day) of the total load being discharged from CW-072 originates from the upstream locations, with 53.77% (1340.11 lbs/day) of the discharged load originating within CAW, creating a net solids load of 720.62 lbs/day to Big Wateree Creek. Loading magnitudes following this event were not as large as those following the August sample event, but still larger than the dry weather June samples.

Comparison to Adjacent Watersheds

Study Objective Question

- How does this load compare to an adjacent watersheds Little Wateree Creek and Dutchmans Creek, with no influence from CAW and different upstream land uses?

Neither Little Wateree Creek or Dutchmans Creek are ideal control watersheds. The discovery of two beaver dams upstream of the Little Wateree sampling location, BW-17, call into question its comparability to the Big Wateree Creek site, CW-072. Dutchmans Creek is a much smaller watershed being only roughly half the drainage area of Big Wateree Creek, Table 3, and the monitoring location is in located in the upper end of the watershed rather than near the downstream pour point (Figure 1).

The loadings coming out of CAW (CW-072) are drastically lower than the Little Wateree Creek site (BW-17) during the dry sample, June 27, Table 7. No sample was taken from Dutchmans Creek (LCT-03) that day. Conversely, following rain events over an inch loadings during the previous 48 hours, CW-072 is shown to be much higher than the Dutchmans Creek site (LCT-03) and Little Wateree Creek site (BW-17), with the exception of August 21 when no flow/sample was collected at BW-17. The November 14th rain event of 0.42 inches where the loadings at LCT-03 and CW-072 are much closer at 708.60 lbs/day and 863.81 lbs/day respectively is the exception, keeping in mind that the measurements were not taken with a rain event above 0.5 inches which would classify it as a true rain event.

Conclusions

The modeling analyses, Appendix 4, slide 57, suggests that for the August 21, 2019 sampling event the majority of the sediment loading occurring at CW-072 was due to transport of previously deposited upstream streambed sediments being moved by scouring due to the high discharge volume and flow rate. Depending on rainfall intensity, discharge volume and flow rate, load contributions from CAW likely represent both fresh land surface erosion and resuspension of, or movement of, previously deposited bottom sediments being scoured from upstream. On November 14, 2019, the discharge measurements at these sites were very poor. There was not quite 0.5 inches of rainfall within the 48-hour window prior to sample collection. This was also following a period of drought, so the rainfall amount was insufficient to result in adequate discharge for measurement. The measured discharge entering CAW was greater than the discharge leaving CAW which is not possible unless water volume is being diverted between the measurement locations. At CW-072 there is evidence that at times this location may have a braided channel. It is possible that a side channel may have been missed on this date. There is also a large area of riparian wetlands that can hold and store water under certain flow regimes.

During the June dry condition sampling Little Wateree Creek (BW-17) had almost 4 times more total solids loading than Big Wateree Creek (CW-072) (Table 7). Little Wateree Creek never showed loading anywhere close to the June value following any of the rain events. Big Wateree Creek had significantly more total solids loading than the other creeks in August and October samples following significant rain events.

As noted earlier, the November rain event did not really have the amount of rain to qualify as a true rain event (Table 2). This rain event followed a period of drought and the rain amount was insufficient to produce normal flows at all sites. RS-12060 had a blockage that resulted in an eddy and backflow that resulted in an erroneous discharge measurement. During this sampling event loading of total solids at Dutchmans Creek (LCT-03) was very close to the loading at Big Wateree Creek, which is surprising given the large difference in drainage area. The drainage area of Big Wateree Creek is almost twice that of Dutchmans Creek (Table 3) and LCT-03 is located almost in the center of the watershed. The contribution of total solids loading contributed by CAW is highly variable depending on the magnitude of rain.

Table 7. Comparison of Solids Loading for Three Creeks: Big Wateree Creek (CW-072), Little Wateree Creek (BW-17) and Dutchmans Creek (LCT-03).

Key: TotDissSolid = Total Dissolved Solids, TotSolid = Total Solids, TSS = Total Suspended Solids

Station	Parameter	Result	Loading (lbs/day)	Result	Loading (lbs/day)	Result	Loading (lbs/day)	Result	Loading (lbs/day)
		6/27/2019	6/27/2019	8/21/2019	8/21/2019	10/21/2019	10/21/2019	11/14/2019	11/14/2019
CW-072	Rain Prior 48 Hr. (in.)	Dry	Dry	1.55	1.55	1.15	1.15	0.42	0.42
CW-072	Rain Prior 24 Hr. (in.)	Dry	Dry	1.48	1.48	0.00	0.00	0.00	0.00
CW-072	TotDissSolid (mg/L)	150	288.61	170	110,339.85	130	1,161.43	120	740.41
CW-072	TotSolid (mg/L)	170	327.09	890	577,661.57	150	1,340.11	140	863.81
CW-072	TSS (mg/L)	26	50.03	650	421,887.66	20	178.68	4	24.68
CW-072	Turbidity (NTU)	34		500		44		25	
		6/27/2019	6/27/2019	8/21/2019	8/21/2019	10/21/2019	10/21/2019	11/14/2019	11/14/2019
BW-17	Rain Prior 48 Hr. (in.)	Dry	Dry	1.60	1.60	1.08	1.08	0.43	0.43
BW-17	Rain Prior 24 Hr. (in.)	Dry	Dry	1.60	1.60	0.00	0.00	0.00	0.00
BW-17	TotDissSolid (mg/L)	110	1,063.34	NA	NA	94	43.89	93	200.90
BW-17	TotSolid (mg/L)	120	1,160.01	NA	NA	110	51.36	130	280.83
BW-17	TSS (mg/L)	3.2	30.93	NA	NA	14	6.54	20	43.20
BW-17	Turbidity (NTU)	8.1		NA		26		18	
		6/27/2019	6/27/2019	8/21/2019	8/21/2019	10/21/2019	10/21/2019	11/14/2019	11/14/2019
LCT-03	Rain Prior 48 Hr. (in.)	Dry	Dry	1.37	1.37	1.15	1.15	0.40	0.40
LCT-03	Rain Prior 24 Hr. (in.)	Dry	Dry	1.33	1.33	0.00	0.00	0.00	0.00
LCT-03	TotDissSolid (mg/L)	NA	NA	190	552.41	180	637.74	180	637.74
LCT-03	TotSolid (mg/L)	NA	NA	210	610.56	190	673.17	200	708.60
LCT-03	TSS (mg/L)	NA	NA	1.3	3.78	<1	3.54	<1	3.54
LCT-03	Turbidity (NTU)	NA		7.4		7.6		4.2	

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Appendices

Appendix 1.

Analytical Results, Rainfall Data, Discharge Measurement, and Calculated Loading

Appendix 1. Analytical Results, Rainfall Data, Discharge Measurement, and Calculated Loading

Station	Parameter	Result	Discharge (cfs)	Loading (lbs/day)	Result	Discharge (cfs)	Loading (lbs/day)	Result	Discharge (cfs)	Loading (lbs/day)	Result	Discharge (cfs)	Loading (lbs/day)
	Legend	Loading entering and leaving CAW											
		Turbity exceeds water quality standard of 50 NT											
		6/27/2019	6/27/2019	6/27/2019	8/21/2019	8/21/2019	8/21/2019	10/21/2019	10/21/2019	10/21/2019	11/14/2019	11/14/2019	11/14/2019
RS-12060	Rain Prior 48 Hr. (in.)	Dry	No Flow	Dry	1.93	--	1.93	1.28	--	1.28	0.37	--	0.37
RS-12060	Rain Prior 24 Hr. (in.)	Dry	No Flow	Dry	1.90	--	1.90	0.00	--	0.00	0.00	--	0.00
RS-12060	TotDissSolid (mg/L)	NA	No Flow	NA	100	27.1359	14,629.18	190	Invalid	NA	180	Invalid	NA
RS-12060	TotSolid (mg/L)	NA	No Flow	NA	140	27.1359	20,480.85	200	Invalid	NA	200	Invalid	NA
RS-12060	TSS (mg/L)	NA	No Flow	NA	34	27.1359	4,973.92	5.6	Invalid	NA	NA	NA	NA
RS-12060	Turbidity (NTU)	NA	No Flow	NA	37	--	--	40	--	--	65	--	--
		6/27/2019	6/27/2019	6/27/2019	8/21/2019	8/21/2019	8/21/2019	10/21/2019	10/21/2019	10/21/2019	11/14/2019	11/14/2019	11/14/2019
BW-02	Rain Prior 48 Hr. (in.)	Dry	No Flow	Dry	1.93	--	1.93	1.28	No Flow	1.28	0.37	--	0.37
BW-02	Rain Prior 24 Hr. (in.)	Dry	No Flow	Dry	1.90	--	1.90	0.00	No Flow	0.00	0.00	--	0.00
BW-02	TotDissSolid (mg/L)	NA	No Flow	NA	170	3.5998	3,299.16	NA	No Flow	NA	190	0.1169	119.74
BW-02	TotSolid (mg/L)	NA	No Flow	NA	200	3.5998	3,881.36	NA	No Flow	NA	220	0.1169	138.65
BW-02	TSS (mg/L)	NA	No Flow	NA	28	3.5998	543.39	NA	No Flow	NA	1.2	0.1169	0.76
BW-02	Turbidity (NTU)	NA	No Flow	--	110	--	--	NA	No Flow	--	85	--	--
		6/27/2019	6/27/2019	6/27/2019	8/21/2019	8/21/2019	8/21/2019	10/21/2019	10/21/2019	10/21/2019	11/14/2019	11/14/2019	11/14/2019
BW-06	Rain Prior 48 Hr. (in.)	Dry	No Flow	Dry	1.93	--	1.93	1.28	--	1.28	0.37	--	0.37
BW-06	Rain Prior 24 Hr. (in.)	Dry	No Flow	Dry	1.90	--	1.90	0.00	--	0.00	0.00	--	0.00
BW-06	TotDissSolid (mg/L)	NA	No Flow	NA	230	1.09	1,351.54	200	0.0871	93.91	140	0.0194	14.64
BW-06	TotSolid (mg/L)	NA	No Flow	NA	270	1.09	1,586.59	260	0.0871	122.09	160	0.0194	16.73
BW-06	TSS (mg/L)	NA	No Flow	NA	42	1.09	246.80	54	0.0871	25.36	4.3	0.0194	0.45
BW-06	Turbidity (NTU)	NA	No Flow	--	180	--	--	140	--	--	55	--	--
		6/27/2019	6/27/2019	6/27/2019	8/21/2019	8/21/2019	8/21/2019	10/21/2019	10/21/2019	10/21/2019	11/14/2019	11/14/2019	11/14/2019
BW-11	Rain Prior 48 Hr. (in.)	Dry	--	Dry	1.55	--	1.55	1.15	--	1.15	0.42	--	0.42
BW-11	Rain Prior 24 Hr. (in.)	Dry	--	Dry	1.48	--	1.48	0.00	--	0.00	0.00	--	0.00
BW-11	TotDissSolid (mg/L)	140	0.0326	24.60	200	5.7826	6,234.89	130	0.127	89.01	120	0.3113	201.39
BW-11	TotSolid (mg/L)	150	0.0326	26.36	240	5.7826	7,481.87	140	0.127	95.85	130	0.3113	218.17
BW-11	TSS (mg/L)	7.2	0.0326	1.27	39	5.7826	1,215.80	6.2	0.127	4.24	<1	0.3113	1.68
BW-11	Turbidity (NTU)	6.4	0.0326	--	140	--	--	50	--	--	8.5	--	--

Appendix 1. Analytical Results, Rainfall Data, Discharge Measurement, and Calculated Loading

Station	Parameter	Result	Discharge (cfs)	Loading (lbs/day)	Result	Discharge (cfs)	Loading (lbs/day)	Result	Discharge (cfs)	Loading (lbs/day)	Result	Discharge (cfs)	Loading (lbs/day)
	Legend	Loading entering and leaving CAW											
		Turbity exceeds water quality standard of 50 NT											
		6/27/2019	6/27/2019	6/27/2019	8/21/2019	8/21/2019	8/21/2019	10/21/2019	10/21/2019	10/21/2019	11/14/2019	11/14/2019	11/14/2019
BW-12A	Rain Prior 48 Hr. (in.)	Dry	No Flow	Dry	1.55	--	1.55	1.15	No Flow	1.15	0.42	No Flow	0.42
BW-12A	Rain Prior 24 Hr. (in.)	Dry	No Flow	Dry	1.48	--	1.48	0.00	No Flow	0.00	0.00	No Flow	0.00
BW-12A	TotDissSolid (mg/L)	NA	No Flow	NA	220	0.9567	1,134.68	NA	No Flow	NA	NA	No Flow	NA
BW-12A	TotSolid (mg/L)	NA	No Flow	NA	240	0.9567	1,237.83	NA	No Flow	NA	NA	No Flow	NA
BW-12A	TSS (mg/L)	NA	No Flow	NA	24	0.9567	123.78	NA	No Flow	NA	NA	No Flow	NA
BW-12A	Turbidity (NTU)	NA	No Flow	--	140	--	--	NA	No Flow	--	NA	No Flow	--
		6/27/2019	6/27/2019	6/27/2019	8/21/2019	8/21/2019	8/21/2019	10/21/2019	10/21/2019	10/21/2019	11/14/2019	11/14/2019	11/14/2019
CW-251	Rain Prior 48 Hr. (in.)	Dry	--	Dry	1.55	--	1.55	1.15	--	1.15	0.42	--	0.42
CW-251	Rain Prior 24 Hr. (in.)	Dry	--	Dry	1.48	--	1.48	0.00	--	0.00	0.00	--	0.00
CW-251	TotDissSolid (mg/L)	130	0.0236	16.54	220	3.5352	4,192.88	130	0.2267	158.88	120	0.085	54.99
CW-251	TotSolid (mg/L)	130	0.0236	16.54	270	3.5352	5,145.81	130	0.2267	158.88	130	0.085	59.57
CW-251	TSS (mg/L)	<1	0.0236	0.13	46	3.5352	876.69	2.2	0.2267	2.69	<1	0.085	0.46
CW-251	Turbidity (NTU)	1.8	0.0236	--	190	--	--	24	--	--	3.7	--	--
		6/27/2019	6/27/2019	6/27/2019	8/21/2019	8/21/2019	8/21/2019	10/21/2019	10/21/2019	10/21/2019	11/14/2019	11/14/2019	11/14/2019
CW-252	Rain Prior 48 Hr. (in.)	Dry	--	Dry	1.55	--	1.55	1.15	--	1.15	0.42	--	0.42
CW-252	Rain Prior 24 Hr. (in.)	Dry	--	Dry	1.48	--	1.48	0.00	--	0.00	0.00	--	0.00
CW-252	TotDissSolid (mg/L)	140	0.247	186.42	160	116.9218	100,853.56	120	0.712	460.61	120	2.8726	1,858.37
CW-252	TotSolid (mg/L)	140	0.247	186.42	430	116.9218	271,043.93	120	0.712	460.61	140	2.8726	2,168.10
CW-252	TSS (mg/L)	<1	0.247	1.33	310	116.9218	195,403.76	<1	0.712	3.84	1.1	2.8726	17.04
CW-252	Turbidity (NTU)	1.8	0.247	--	260	--	--	16	--	--	4.9	--	--
		6/27/2019	6/27/2019	6/27/2019	8/21/2019	8/21/2019	8/21/2019	10/21/2019	10/21/2019	10/21/2019	11/14/2019	11/14/2019	11/14/2019
CW-072	Rain Prior 48 Hr. (in.)	Dry	--	Dry	1.55	--	1.55	1.15	--	1.15	0.42	--	0.42
CW-072	Rain Prior 24 Hr. (in.)	Dry	--	Dry	1.48	--	1.48	0.00	--	0.00	0.00	--	0.00
CW-072	TotDissSolid (mg/L)	150	0.3569	288.61	170	120.3948	110,339.85	130	1.6572	1,161.43	120	1.1445	740.41
CW-072	TotSolid (mg/L)	170	0.3569	327.09	890	120.3948	577,661.57	150	1.6572	1,340.11	140	1.1445	863.81
CW-072	TSS (mg/L)	26	0.3569	50.03	650	120.3948	421,887.66	20	1.6572	178.68	4	1.1445	24.68
CW-072	Turbidity (NTU)	34	0.3569	--	500	--	--	44	--	--	25	--	--

Appendix 1. Analytical Results, Rainfall Data, Discharge Measurement, and Calculated Loading

Station	Parameter	Result	Discharge (cfs)	Loading (lbs/day)	Result	Discharge (cfs)	Loading (lbs/day)	Result	Discharge (cfs)	Loading (lbs/day)	Result	Discharge (cfs)	Loading (lbs/day)
	Legend	Loading entering and leaving CAW											
		Turbidity exceeds water quality standard of 50 NT											
		6/27/2019	6/27/2019	6/27/2019	8/21/2019	8/21/2019	8/21/2019	10/21/2019	10/21/2019	10/21/2019	11/14/2019	11/14/2019	11/14/2019
BW-15	Rain Prior 48 Hr. (in.)	Dry	No Flow	Dry	1.55	--	1.55	1.15	--	1.15	0.42	--	0.42
BW-15	Rain Prior 24 Hr. (in.)	Dry	No Flow	Dry	1.48	--	1.48	0.00	--	0.00	0.00	--	0.00
BW-15	TotDissSolid (mg/L)	NA	No Flow	NA	520	0.125	350.42	790	Invalid	NA	540	0.0649	188.94
BW-15	TotSolid (mg/L)	NA	No Flow	NA	770	0.125	518.89	920	Invalid	NA	610	0.0649	213.43
BW-15	TSS (mg/L)	NA	No Flow	NA	470	0.125	316.73	270	Invalid	NA	23	0.0649	8.05
BW-15	Turbidity (NTU)	NA	No Flow	--	850	--	--	900	--	--	500	--	--
		6/27/2019	6/27/2019	6/27/2019	8/21/2019	8/21/2019	8/21/2019	10/21/2019	10/21/2019	10/21/2019	11/14/2019	11/14/2019	11/14/2019
BW-17	Rain Prior 48 Hr. (in.)	Dry	--	Dry	1.60	--	1.60	1.08	--	1.08	0.43	--	0.43
BW-17	Rain Prior 24 Hr. (in.)	Dry	--	Dry	1.60	--	1.60	0.00	--	0.00	0.00	--	0.00
BW-17	TotDissSolid (mg/L)	110	1.7931	1,063.34	NA	NA	NA	94	0.0866	43.89	93	0.4007	200.90
BW-17	TotSolid (mg/L)	120	1.7931	1,160.01	NA	NA	NA	110	0.0866	51.36	130	0.4007	280.83
BW-17	TSS (mg/L)	3.2	1.7931	30.93	NA	NA	NA	14	0.0866	6.54	20	0.4007	43.20
BW-17	Turbidity (NTU)	8.1	1.7931	--	NA	--	--	26	--	--	18	--	--
		6/27/2019		6/27/2019	8/21/2019	8/21/2019	8/21/2019	10/21/2019	10/21/2019	10/21/2019	11/14/2019	11/14/2019	11/14/2019
LCT-03	Rain Prior 48 Hr. (in.)	Dry	NA	Dry	1.37	--	1.37	1.15	--	1.15	0.40	--	0.40
LCT-03	Rain Prior 24 Hr. (in.)	Dry	NA	Dry	1.33	--	1.33	0.00	--	0.00	0.00	--	0.00
LCT-03	TotDissSolid (mg/L)	NA	NA	NA	190	0.5393	552.41	180	0.6572	637.74	180	0.6572	637.74
LCT-03	TotSolid (mg/L)	NA	NA	NA	210	0.5393	610.56	190	0.6572	673.17	200	0.6572	708.60
LCT-03	TSS (mg/L)	NA	NA	NA	1.3	0.5393	3.78	<1	0.6572	3.54	<1	0.6572	3.54
LCT-03	Turbidity (NTU)	NA	NA	--	7.4	--	--	7.6	--	--	4.2	--	--

Appendix 2.

Appendix 2. SC Big Wateree Creek QAPP Final

South Carolina Department of Health and Environmental Control
Bureau of Water
Aquatic Science Programs

Class 1 QAPP

Section A. Project Management

A1. Title and Approval Sheet

Project: Big Wateree Creek Watershed Solids Study

Date: June 6, 2019

Date of Initiation: June, 2019

Quality Assurance Manager
David Graves, EA — 6-17-2019

Manager, Aquatic Science Programs
Bryan Rabon, BOW — 6/18/19

Project Manager:
David Chestnut, BOW — 6/18/19

Quality Assurance Liaison
Rusty Wenerick, BOW — 6/17/19

Quality Assurance Liaison
Paul Miller, BEHS — for 6/18/19

EA BEHS ARESD
Susan Jackson, Director, BEHS — 6/19/19

EPA Region 4 Quality Assurance Manager
Liza Montalvo, USEPA Region 4 — signed for 7/16/19

A2. Table of Contents

A3. Distribution List

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Elizabeth Smith	EPA Region 4 – Atlanta, GA	404-562-8721	smith.elizabeth@epa.gov

A4. Project/Task Organization

David Chestnut will be the project manager and will distribute and maintain the QAPP.

Bureau of Water staff, Aquatic Science Programs and Water Pollution Compliance Section, will collect all grab samples and conduct all stream discharge measurements under the direction of the project manager.

The Analytical and Radiological Environmental Services Division (ARESD) Lab, will be responsible for analysis of samples and verification of results for Residue Total (a.k.a. Total Solids or TS), Residue Suspended (a.k.a. Total Suspended Solids or TSS), Residue Dissolved (a.k.a. Dissolved Solids or DS) and turbidity.

Emily Bores will verify the samples for completeness (results and documentation) only.

Rusty Wenerick (Bureau of Water, BOW) and Paul Miller (Bureau of Environmental Health Services, BEHS) will serve as Quality Assurance Liaisons for their respective bureaus. They will review the draft QAPP and submit comments to the Project Manager. David Graves (Quality Assurance Manager, QAM) will review the QAPP for completeness and forward additional comments to the Project Manager.

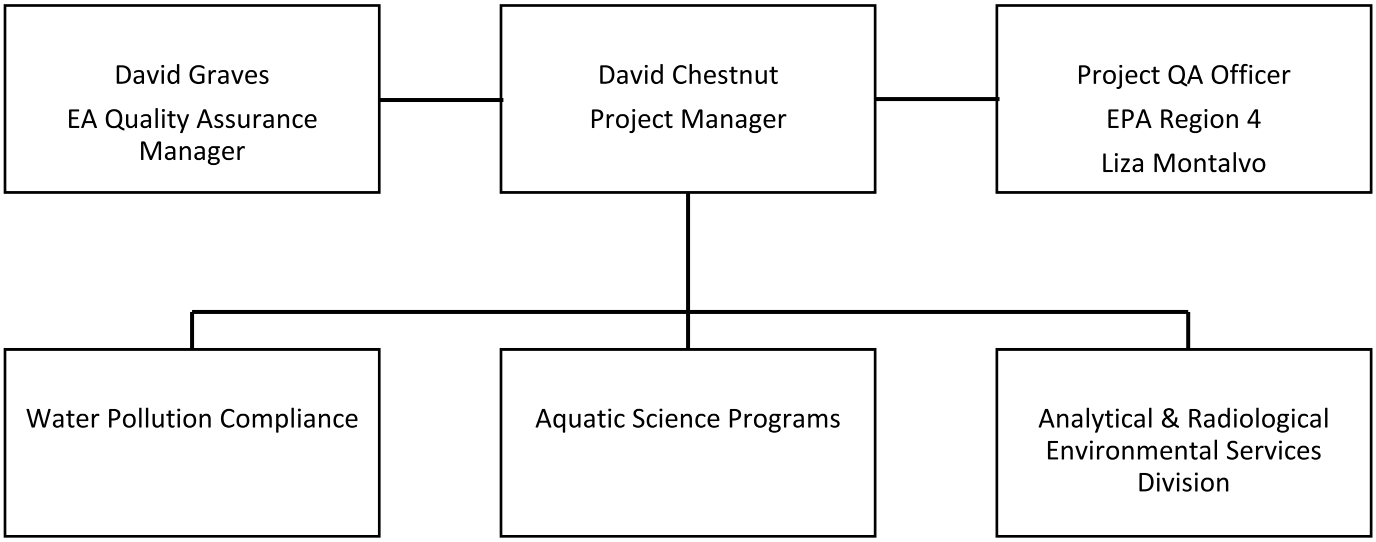

Figure 1 Organization Chart

A5. Project Definition/Background

In 2007 Carolina Adventure World (CAW) opened in Fairfield County, at latitude 34.48° N, and longitude -80.96 ° W. Located on 2,600 acres of private land, it is the Southeast's largest All Terrain Vehicle (ATV), Utility Vehicle (UTV) and dirt bike riding park. CAW is located near the downstream end of the Big Wateree Creek watershed.

CAW's Park Rules and Regulations state "Federal Law: No riding in creek beds. Crossings allowed only at marked areas." Since CAW's opening there have been frequent complaints from residents along the shore of the Big Wateree Creek cove and the Lake Wateree Association about sedimentation filling the cove and the generally "muddy looking" condition of Big Wateree Creek, especially after rain. From site visits it is clear that riding in creek beds and along and across banks does occur.

Historically the ambient surface water quality monitoring site at the downstream end of the watershed, CW-072, has shown frequent exceedances of State Standards for bacteria and turbidity before the opening of CAW, and continuing since. Bacteria and turbidity Total Maximum Daily Loads (TMDL) have been developed and were approved in 2004.

A special study was conducted in 2016/2017 to characterize turbidity, *Escherichia coli*, and Residue Suspended (a.k.a. Total Suspended Solids, TSS) in the Big Wateree Creek watershed. While there are State Water Quality Standards for turbidity and *E. coli*, there are no State Standards for TSS. Nevertheless, TSS is a widely-used and meaningful parameter in water quality assessments.

TSS was included because it is an indicator of solid materials suspended in the water column that have the potential to eventually settle out when water velocity slows and particulates have the opportunity to settle out.

A total of ten sites were included in the special study, nine in the Big Wateree Creek watershed and one site in the Little Wateree Creek watershed that provided a less impacted reference area.

In general, the study indicated that several sites in the Big Wateree Creek watershed exceeded *E. coli* standards even during some of the dry weather samples, but especially during wet weather events. The Little Wateree Creek samples only exceeded *E. coli* standards during the rain events.

For turbidity, in the Big Wateree Creek watershed every site exceeded the State Standard following a 1.7" rain event. The Little Wateree Creek site never exceeded the turbidity standard, even after this major rainfall event.

The 2016/2017 study was not designed to quantify the contributions to sedimentation from various parts of the Big Wateree Creek watershed.

The ongoing concern revolves around the continuing sediment deposition in the Lake Wateree cove at the inflow of Big Wateree Creek and the resulting impediment to boat access for shoreline homeowner's docks.

SCDHEC staff familiar with the Big Wateree Creek area and CAW have also reported anecdotal observations that extensive timber harvesting has been and is taking place widely within the watershed since the 2016/2017 study time period.

A6. Project/Task Description

The purpose of this study is to determine if CAW is source of sediment loading to Big Wateree Creek that is significantly greater than what would be expected to occur naturally. Specifically, study scope questions to be answered are:

- What are the solids loads entering CAW from upstream (via Big Wateree Creek and Hogfork Branch)?
- What is the solids load exiting downstream from CAW?
- What is the net solids load to Big Wateree Creek from CAW?
- How does this load compare to an adjacent watershed, Little Wateree Creek, with minimal influence from CAW and different upstream land uses?

The 2016/17 study design will be replicated in terms of monitoring locations, Table 3 and Figure 1.

This study will collect samples for Residue Total (a.k.a. Total Solids or TS), Residue Suspended (a.k.a. Total Suspended Solids or TSS), Residue Dissolved (a.k.a. Dissolved Solids or DS) and turbidity throughout the Big Wateree Creek watershed and at a nearby, similar, less impacted site in Little Wateree Creek during typical and precipitation impacted streamflow.

TS, TSS and DS were chosen because they are solids fractions that characterize soil loading in the waters and which the EA BEHS Central Laboratory has the capability to analyze. There are no State Water Quality Standards for any of these analytes and the resulting data will be used for informational purposes only. There is no applicability to any SCDHEC regulatory authority.

It is planned to repeat the sampling four times total, one (1) dry weather and three (3) wet weather sampling events. At least three (3) days of dry weather must occur between each wet weather sampling event.

For each sampling event streamflow (discharge) will be measured onsite following USGS methods, *Turnipseed, D.P., and Sauer, V.B., 2010, Discharge measurements at gaging stations: U.S. Geological Survey Techniques and Methods book 3, chap. A8, 87 p.* (Also available at http://pubs.usgs.gov/tm/tm3-a8/.) and SonTek FlowTracker2 User's Manual 1.6, Software Version 1.6, Firmware Version 1.3, 2019, http://info.xylem.com/rs/240-UTB-146/images/FlowTracker2%20User%27s%20Manual%20v1.6%20Rev%20H.pdf?aliId=eyJpIjoicnBGWkRrRExBT1lBaG5HRCIsInQiOiJBQk43MkFWaHZIb3NuWW9pNnBjQlJRPT0ifQ%253D%253D.

It is planned to repeat this effort four times. The exact dates of sampling are weather dependent and cannot be predicted. The first set of samples will be planned for June 2019, as weather allows, with the exact date to be determined after the QAPP is approved. Other rounds of sampling will be scheduled contingent upon rainfall being normal to above normal. The goal is to collect at least one round of samples during a relatively dry period and at least three rounds following a significant rain event.

One round of background data will be collected following at least 3 days with no precipitation. Other sample events will be within 24-48 hours after a rain event of 0.5 inches or greater. It is desirable to capture a range of rainfall totals.

For total precipitation from the previous 24 hours, Weather Underground Station ID: KSCRIDGE6, Old Brick Store Road, will be used to help decide when to collect a wet weather event. https://www.wunderground.com/dashboard/pws/KSCRIDGE6

Additionally, the National Weather Service Forecast for latitude 34.47° N, longitude -80.96° W will be used to help anticipate when a wet weather event may be coming. https://forecast.weather.gov/MapClick.php?w3u=1&w5=pop&w7=rain&w10u=0&w13u=1&AheadHour=48&Submit=Submit&FcstType=graphical&textField1=34.48&textField2=-80.96&site=cae&unit=0&dd=&bw=

Waiting for and chasing rain events would involve coordination and cooperation with the

ARESD Central Laboratory. It would be ideal to sample on a Monday after a busy weekend at Carolina Adventure World, but rainfall is the more important factor.

No sample will be collected at any of the proposed sites if there is no flowing water.

Additionally, independent of the water quality sampling events, one macroinvertebrate community composition assessment will also be conducted at each monitoring location to characterize biological community health.

A7. Data Quality Objectives (DQOs) and Data Quality Indicators (DQIs)

Data Quality Objectives

The DQOs for flow are in the SonTek FlowTracker2 User's Manual 1.6, Software Version 1.6, Firmware Version 1.3, 2019, http://info.xylem.com/rs/240-UTB-146/images/FlowTracker2%20User%27s%20Manual%20v1.6%20Rev%20H.pdf?aliId=eyJpIjoicnBGWkRrRExBT1lBaG5HRCIsInQiOiJBQk43MkFWaHZIb3NuWW9pNnBjQlJRPT0ifQ%253D%253D.

The data collected during this study will be used to address the questions outlined in Section A-6. Stations were selected to represent the solids loading throughout the Big Wateree Creek watershed and in an adjacent, control, watershed. Any samples that are missed or invalid will be omitted from the data set for this period and will not be repeated unless the number of valid samples falls below 60%.

These data quality objectives are listed in Table 1 along with DQO's for Residue Total (a.k.a. Total Solids or TS), Residue Suspended (a.k.a. Total Suspended Solids or TSS), Residue Dissolved (a.k.a. Dissolved Solids or DS) and turbidity.

Table 1: Analytical Data Quality Objectives.

Parameter	Units	Potential Range of Results	Method Detection Limit Objective	Precision Objective[a]	Method Derived From
Turbidity	NTU	0 – 100	0.5	≤20% RPD	EPA180.1 Rev 2
Residue Suspended (Total Suspended Solids - TSS)	mg/L	0-20,000 mg/L	1 mg/L	≤10% RPD	SM2540 D-2011
Residue Total (Total Solids - TS)	mg/L	0-20,000 mg/L	10 mg/L	≤10% RPD	SM2540 B-2011
Residue Dissolved (Dissolved Solids - DS)	mg/L	0-20,000 mg/L	10 mg/L	≤10% RPD	SM2540 C-2011

[a]Relative Percent Difference: ($\%RPD = \left(\frac{|R1-R2|}{\bar{R}}\right) \times 100\%$; *R1* and *R2* and replicate measurements and $\overline{R}$ is the mean value of the two measurements.

Sampling Protocols and Standard Operating Procedures

Standard operating procedures (SOPs) for grab sample collection, field measurements, sample containers, holding times, and chain of custody are detailed in sections within the BEHSPROC 200 – Ambient Surface Water Sampling, Sections 4.3, 4.4, and 4.5 (SCDHEC 2018a) if required and the lab analytical methods are detailed within IX-B-14(b) Turbidity (SCDHEC 2018c), IX-B-10(a) Total Solids (SCDHEC 2015), IX-B-10(b) Total Dissolved Solids (SCDHEC 2018e), IX-B-10(c) Total Suspended Solids (SCDHEC 2014).

Samples will be collected in Big Wateree Creek upstream and downstream of CAW. The upstream sites on Big Wateree Creek and Hogfork Branch may potentially identify other activities within the watershed that may be unrelated to CAW and may need to be addressed.

Any samples that are missed or invalid will be omitted from the data set for this period. Inclement weather prior to or during the sampling period may postpone the sampling to the following day. If sampling cannot be conducted on the following day a new date will be selected for that round of sample collection.

A8. Special Training Requirements/Certifications

Justin Lewandowski, Scott Castleberry, Matt Krofchick, and Ronnie Martin received training in the operation of the SonTek FlowTracker2 for the measurement of stream discharge from Kendra Smith, USGS, Columbia, on May 14, 2019, with Bryan Rabon observing.

Justin Lewandowski, Scott Castleberry, Matt Krofchick, and David Chestnut received training in the operation of the SonTek FlowTracker2 for the measurement of stream discharge from SonTek sales representative Brad Kingsmore on May 29, 2019, with David Graves and Scott Reynolds observing.

Justin Lewandowski and Scott Castleberry participated in another training that took place with SonTek sales representative Brad Kingsmore on June 7, 2019.

A9. Documentation and Records

The fully executed QAPP and any subsequent revisions will be sent to the Distribution List via e-mail by the project manager, David Chestnut.

Discharge summary data and documentation will be stored in PDF format files for each measurement event at each location on a BOW server backed up nightly.

Laboratory results for Total Solids, Total Suspended Solids, Dissolved Solids and turbidity will be stored in an Excel spreadsheet on a BOW server that is backed up nightly.

A brief discussion and comparison of the results from each station will be prepared in a summary report and made available to all interested parties.

Section B. Measurement/Data Acquisition

B1. Sampling Process Design

The Bureau of Water has been committed to repeat the 2016/2017 study in terms of sampling locations (Table 3, Figure 1) throughout the Big Wateree Creek watershed and at a nearby, similar, less impacted site in Little Wateree Creek during typical and precipitation impacted stream discharge.

Accessibility was originally evaluated during the initial reconnaissance in July 2015. The original 2016/2017 study involved sampling from bridges or instream collection at the bridge location if water depth was too shallow to allow sampling collection off the bridges. Since this study will require direct instream access to suitable cross-section transects, verification of the safety of access to the stream and location of a cross section suitable for discharge measurement was confirmed on May 2, 2019.

Table 3. General Sampling Location Descriptions

Site Number	Site Description	Latitude	Longitude
RS-12060	Old stream statistical survey site originally sampled in 2012. Site is on S-20-44 Bull Run Road at second bridge north of White Oak. Upstream of Bull Run Road there is a Wateree Creek Watershed Structure/Conservation District reservoir	34.50184	-81.10501
BW-02	The first bridge on Bull Run Road north of White Oak is an unnamed tributary that flows into Big Wateree Creek. Lots of cattle in this part of the watershed	34.49597	-81.10798
BW-06	Unnamed tributary at Fairfield Hill Road approximately 0.6 miles NW of SC 901	34.50969	-81.02876
BW-11	Scabber Branch at SC 200	34.50460	-81.00580
BW-12A	Hogfork Branch at SC 200	34.51597	-80.98481
CW-251	Current ambient monitoring site. Hogfork Branch at Camp Welfare Road S-20-20	34.48412	-80.97124
CW-252	Current ambient monitoring site. Big Wateree Creek at Camp Welfare Road S-20-20	34.48178	-80.97868
BW-15	Unnamed creek at US 21 N of Big Wateree Creek. In same HUC-12 as Big Wateree Creek also potentially impacted by Carolina Adventure World	34.48168	-80.93638
CW-072	Current ambient monitoring site. Big Wateree Creek at US 21	34.46825	-80.93886
BW-17	Little Wateree Creek at US 21. Small portion of drainage area within Carolina Adventure World property	34.45523	-80.94147

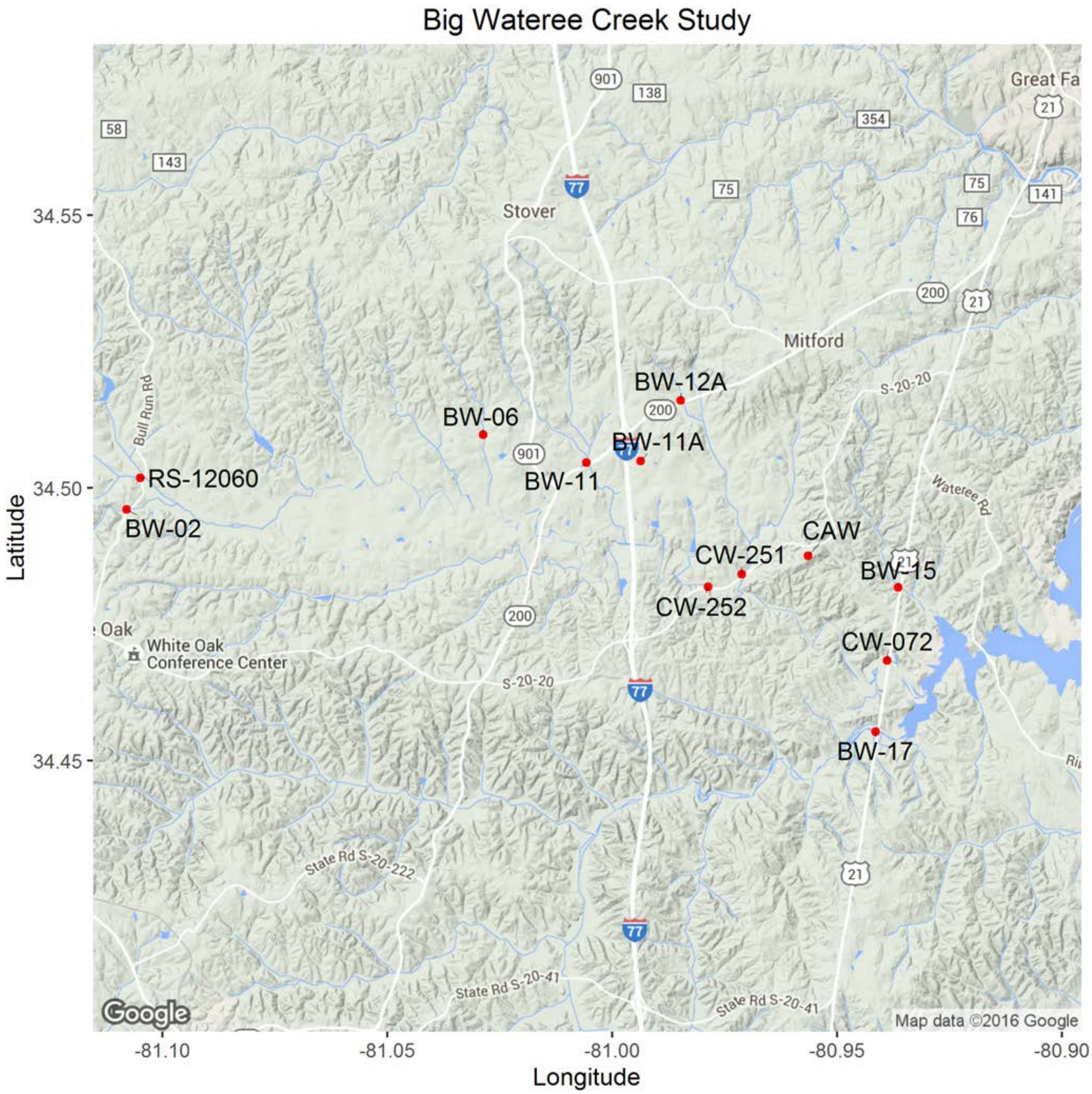

Figure 1. General Sampling Locations and Location of Carolina Adventure World (CAW, not a sampling location)

Although the map depicts a site numbered BW-11A, during the 2016/2017 study it never contained enough water to sample. Therefore, it is not intended to be included in the 2019 study. CAW represents the location of Carolina Adventure World relative to the actual sampling locations.

Minor changes in parameter coverage from the 2016/2017 study will be incorporated into this study with the addition of Residue Total (a.k.a. Total Solids or TS) and Residue Dissolved (a.k.a. Dissolved Solids or DS) and dropping *Escherichia coli*. Residue Suspended (a.k.a. Total Suspended Solids or TSS) and turbidity will be maintained in this study.

For each sampling event, the total number of samples collected will be:

Number of Samples	Parameter	Processing Lab
10	Residue Suspended (non-filterable) (Total Suspended Solids - TSS), mg/L, Standard Method SM2540 D-2011	Central Lab
10	Residue Total (Total Solids - TS), mg/L, Standard Method SM2540 B-2011	Central Lab
10	Residue Dissolved (Dissolved Solids - DS), mg/L, Standard Method SM2540 C-2011	Central Lab
10	Turbidity USEPA Method 180.1 revision 2	Central Lab

For each sampling event streamflow (discharge) will be measured onsite following USGS methods Turnipseed, D.P., and Sauer, V.B., 2010, Discharge measurements at gaging stations: U.S. Geological Survey Techniques and Methods book 3, chap. A8, 87 p. (Also available at *http://pubs.usgs.gov/tm/tm3-a8/*.) and SonTek FlowTracker2 User's Manual 1.6, Software Version 1.6, Firmware Version 1.3, 2019, http://info.xylem.com/rs/240-UTB-146/images/FlowTracker2%20User%27s%20Manual%20v1.6%20Rev%20H.pdf?aliId=eyJpIjoicnBGWkRrRExBT1lBaG5HRCIsInQiOiJBQk43MkFWaHZIb3NuWW9pNnBjQlJRPT0ifQ%253D%253D.

It is planned to repeat this effort four times. The first set of samples will be planned for June 2019, as weather allows, with the exact date to be determined after the QAPP is approved. Other rounds of sampling will be scheduled contingent upon rainfall being normal to above normal. The goal is to collect at least one round of samples during a relatively dry period and at least three rounds following a significant rain event.

Preferred cross section transect locations will be identified and prepared, e.g. removal of large rocks and logs, under dry weather conditions. In terms of stream discharge, the intent of this effort is to get the most accurate measurement for each sampling event, not to develop rating curves. Due to changes in water level, flow velocity, and modification of stream channel characteristics in response to runoff under different magnitude rain events, the cross section location may be moved up to 100 yards from the identified preferred location if that will result in a more accurate measurement of discharge.

With every analysis and sample collection variability does exist, but this will be especially true when the intent is to collect each round of samples under different meteorological conditions. The goal is to calculate loadings of the different solids parameters under different runoff conditions.

For each round of sampling, personnel will collect all samples and measure stream discharge on the same day. Weather conditions will be recorded. If problems occur in the field, David Chestnut will be responsible for the identification of the problem and corrective action. Corrective actions will be documented in the Ambient Water Field Logbook.

Because of the variability in water depth and current velocity, each sampling team will have the authority to abort sampling at specific individual sampling locations if they determine that wading in the stream is unsafe. Missed samples and measurements under such conditions will not be resampled.

Data are to be used for comparison of individual sites against one another and historic data where it exists. No historic data exists for TS and DS.

No particular data point is critical and up to 40% of the samples could be lost before recollection would be required.

B2. Sampling Methods

Sampling will be conducted by Aquatic Science Programs staff with assistance from Water Pollution Compliance staff, Bureau of Water, following the most current EQC Environmental Investigations SOP and QA Manual (SCDHEC, 2010).

Additionally, independent of the water quality sampling events, one macroinvertebrate community composition assessment will also be conducted by ASP biologists at each monitoring location to evaluate the biological community health at each location.

All sample collection, sample handling, sample preservation, and chain of custody will follow all protocols given in the most current EQC Environmental Investigations SOP and QA Manual (SCDHEC 2010). All sample analysis and quality control for chemical analyses will be done according to the ARESD Procedures and QC Manual for Chemistry Laboratories.

Sample bottles will generally be labeled with the site number in the office before the sampling event. Sample collection date and time will be recorded in the field logbook and transferred to the chain-of-custody and sample request form DHEC 2186.

Sample Containers

The ARESD central laboratory will supply all sample containers (Table 2). Arrangements will be made with the lab to obtain these sample containers prior to the week of sampling.

Table 2. (from Table A-3a, SCDHEC 2018b)

Parameter(s)	Bottle Label	Number, Size, and Type of Containers	Preservation and Temperature	Maximum Holding Time
Turbidity, Color, pH, TDS, TSS, TS, Specific Conductance	pH, ALKALINITY, COLOR, TURBIDITY, TDS, TS	1-1 Liter plastic (Do not use the bottle to measure pH)	Cool, ≤ 6°C	pH = field analysis Turbidity, Color = 48 hours TDS, TS, TSS = 7 days Specific Conductance = 28 days

B3. Sample Handling and Custody

All sample collection, sample handling, sample preservation, and chain of custody will follow all protocols given in the most current EQC Environmental Investigations SOP and QA Manual (SCDHEC 2010). All sample analysis and quality control for chemical analyses will be done according to the ARESD Procedures and QC Manual for Chemistry Laboratories.

B4. Analytical Methods

See Section A7. Table 1: Analytical Data Quality Objectives.

B5. Quality Control

For the laboratory analyses, QC will follow the current ARESD Chemistry Laboratory SOP.

B6. Instrument/Equipment Testing, Inspection, and Maintenance

The SonTek FlowTracker2 will be inspected in the office for functionality before each sample event.

For the laboratory analyses, testing, inspection, and maintenance will follow the current ARESD Chemistry Laboratory SOP.

B7. Instrument/Equipment Calibration and Frequency

The SonTek FlowTracker2 can only be calibrated by the factory.

For the laboratory analyses, calibration will follow the current ARESD Chemistry Laboratory SOP.

B8. Inspection/Acceptance for Supplies and Consumables

There are no consumables for the SonTek FlowTracker2 with exception of alkaline AA/LR6 batteries.

For the laboratory analyses, acceptance for supplies and consumables will follow the current ARESD Chemistry Laboratory SOP.

B9. Non-direct Measurements

Three sample events will be within 24-48 hours after a rain event of 0.5 inches or greater. It is desirable to capture a range of rainfall totals.

For total precipitation from the previous 24 hours, Weather Underground Station ID: KSCRIDGE6, Old Brick Store Road, will be used to help decide when to collect a wet weather event. https://www.wunderground.com/dashboard/pws/KSCRIDGE6

Additionally, the National Weather Service Forecast for 34.47N 80.96W will be used to help anticipate when a wet weather event may be coming.
https://forecast.weather.gov/MapClick.php?w3u=1&w5=pop&w7=rain&w10u=0&w13u=1&AheadHour=48&Submit=Submit&FcstType=graphical&textField1=34.48&textField2=-80.96&site=cae&unit=0&dd=&bw=

B10. Data Management

Analytical results produced by SC DHEC Central Lab are uploaded to the SC DHEC Laboratory Information Management System (LIMS), and paper copies of the results are forwarded to the project manager. Electronic data files can be provided from LIMS by ARESD staff upon request by the project manager.

The Project Manager is responsible for storing all data in a folder that is maintained indefinitely on SC DHEC internal server which is backed up daily.

All processes which involve data handling have been reviewed to ensure that data integrity is maintained by the Agency's IT Department.

All laboratory data are backed up daily. As per the Agency's QMP, the IT Department processes ensure that both software and hardware configurations are acceptable.

The laboratory and ASP do not employ checklists/standard forms (other than the chain of custody form) for inorganic analysis.

Section C. Assessments and Oversight

C1. Assessments and Response Actions

The ARESD Laboratory is evaluated and certified by EPA Region 4 under the Safe Drinking Water Act. The laboratory is evaluated every three years and the Laboratory Director is responsible for corrective action. The laboratory also participates in both WP and WS Proficiency Testing. These results are sent to the Laboratory Director and EPA Region 4.

Senior analysts are assigned internal evaluations of sections other than their own. The Laboratory Director and the Section Manager receive the evaluation results, and corrective action is overseen by the Section Manager and reviewed by the Laboratory Director.

The ASP participates in annual proficiency testing (PTs) and each new analyst is required to perform an initial demonstration of capability.

C2. Reports to Management

Corrective action for field issues are included in the field logbooks along with a narrative about the issues.

The Project Manager is responsible for collating data and ensuring validation is performed on data received from all sources. Bryan Rabon, manager of the ASP, reviews the project for completeness. The Project Manager is responsible for contacting the analytical labs if there are problems with data quality or completeness in the data received (missing values, a high percentage of data not meeting QC criteria) and resolving any recurring data problems. The Project Manager is responsible for correcting problems that arise in the field.

A brief discussion and comparison of the results from each station will be prepared in a summary report and made available to all interested parties.

Section D. Data Validation and Usability

D1. Data Review, Verification, and Validation

Item	Criteria	If the criteria are not met are samples flagged or rejected
Holding Times	Samples must be analyzed within holding time	Flagged. Used for informational purposes.
Temperature	The temperature at receipt must be <6°C for chemical analysis and not frozen	Rejected

D2. Verification and Validation Methods

Verification:

Verification is done by the laboratories as per the ARESD Laboratory Manuals. Verification by Emily Bores will consist only of a completeness check. This check will ensure that all sample data was received. Any problems will be noted in an email to Bryan Rabon who will validate the data.

Validation:

The Project Manager will note the problems seen by the verifiers. He will then examine the data and ensure that sample results match what was expected at the site and compare the data against historical data, where available, and determine if the data agrees with the project data. After these assessments, the Validator researches the data and/or documentation that are inconsistent. This is done by contacting Lab and Field Personnel to correct and/or explain inconsistencies. After all of the Validation steps have been completed, the Validator will include this information in the final report.

D3. Reconciliation with User Requirements

Any issues with the data found during the verification or validation will be transmitted to data users in the final report. This includes the process for reconciling project results with DQOs and reporting limits of data use.

References

South Carolina Department of Health and Environmental Control. 2014. Bureau of Environmental Health Services. Standard Operating Procedures for Solids, Total Suspended (TSS Dried at 103-105^oC), SM2540 D, Section IX-B-10(c).

South Carolina Department of Health and Environmental Control. 2015. Bureau of Environmental Health Services. Standard Operating Procedures for Solids, Total (TS Dried at 103-105^oC), SM2540 B, Section IX-B-10(a).

South Carolina Department of Health and Environmental Control. 2018a. Bureau of Environmental Health Services. BEHSPROC 200 Standard Operating Procedures, Ambient Surface Water Sampling.

South Carolina Department of Health and Environmental Control. 2018b. Bureau of Environmental Health Services. BEHSPROC 108 Standard Operating Procedures, Sample Containers, Preservation, and Maximum Holding Times for Chemistry and Microbiological Analyses.

South Carolina Department of Health and Environmental Control. 2018c. Bureau of Environmental Health Services. Standard Operating Procedures for Turbidity IX-B-14(b), Hach 2100N, EPA Method 180.1 Revision 2.

South Carolina Department of Health and Environmental Control. 2018d. Bureau of Environmental Health Services. Standard Operating Procedures for Solids, Total (TS Dried at 103-105^oC), SM2540 B, Section IX-B-10(a).

South Carolina Department of Health and Environmental Control. 2018e. Bureau of Environmental Health Services. Standard Operating Procedures for Solids, Total Dissolved (TDS Dried at 108^oC), SM2540 C, IX-B-10(b).

Appendix 3.

SC Big Wateree Creek QAPP Amendment Final

South Carolina Department of Health and Environmental Control
Bureau of Water
Aquatic Science Programs

Date: July 11, 2019
Amendment to Big Wateree Creek Watershed Solids Study QAPP

<u>Approved by:</u>

Quality Assurance Manager	David Graves, EA	Date 7-11-19
Manager, Aquatic Science Programs	Bryan Rabon, BOW	Date 7/11/19
Project Manager:	David Chestnut, BOW	Date 7/11/19
Quality Assurance Liaison	Rusty Wenerick, BOW	Date 7/11/19
Quality Assurance Liaison	Paul Miller, BEHS	Date 07-11-2019
EA BEHS ARESD	Susan Jackson, Director, BEHS	Date 7-11-19
EPA Region 4 Quality Assurance Manager	Liza Montalvo, USEPA Region 4 (Signed for)	Date 7/16/19

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Paul Miller	BEHS - Columbia	803-896-0971	millerpm@dhec.sc.gov
Elizabeth Smith	EPA Region 4 – Atlanta, GA	404-562-8721	smith.elizabeth@epa.gov

Issue Identified

When the Aquatic Science Programs macroinvertebrate taxonomists conducted the macroinvertebrate community sample collection on July 1, 2019, they discovered two beaver dams upstream of sample collection and flow measurement site BW-17, Little Wateree Creek at US 21.

This watershed has only a very small portion of drainage area within Carolina Adventure World property. It was intended to represent the sedimentation characteristics of an adjacent watershed as a control for comparison to sediment loading in Big Wateree Creek.

The beaver dams in essence created two artificial sediment settling basins upstream of the sample collection and flow measurement location, compromising its representation of control conditions.

Because of the commitment to repeat the original study this site must be maintained for the duration of the study.

New Site to be Added

The proposed change is the addition of one more monitoring site, LCT-03, Dutchmans Creek at US-21, Table 1, to serve as a control site. Reconnaissance by Aquatic Science Programs staff has verified that beaver dams are not present upstream of this location. This location is also a tributary of Lake Wateree and is part of the **Lower Catawba River Basin – Stream and Lake Nutrient Water Quality Study**.

Table 1. New Monitoring Site to be Added to Big Wateree Creek Study

Station ID	Lat./Long.	County	Site Description
LCT-03	34.3679 / -80.9547	Fairfield	Dutchmans Creek at US-21 (tributary of Lake Wateree)

An advantage of this location is that it has a USGS gage. This means that it will not be necessary for SCDHEC staff to measure flow at the time of sample collection at this site. We will be able to get the corresponding discharge value from the USGS site. The USGS gage reports a discharge value every 15 minutes.

Parameter coverage and sampling frequency will follow those for all other sites identified in the original approved QAPP.

The only exception to sampling frequency is that the new site will require a separate establishing background sample because the background samples for all other sites were collected on June 27, 2019.

Appendix 4.

A part of Lake Wateree Basin Sediment Source Review - preliminary

A part of Lake Wateree Basin Sediment Source Review-preliminary

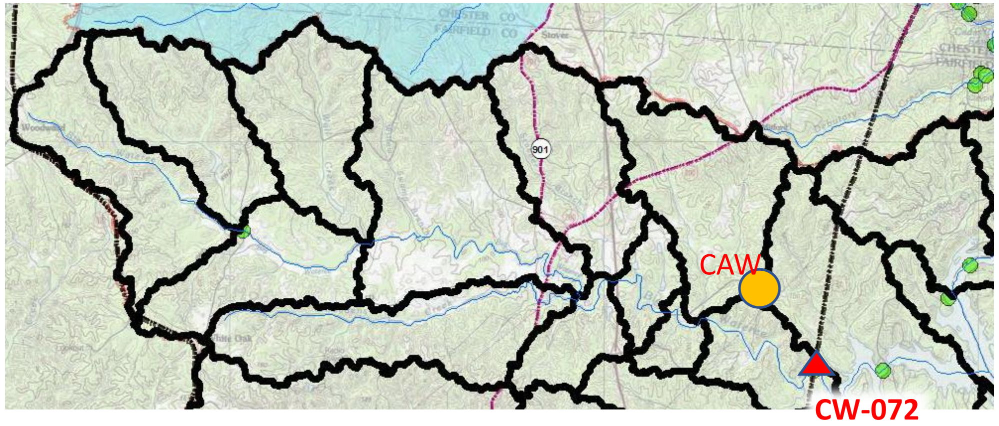
This preliminary analysis was conducted as a part of an evaluation for potential sediment sources within the lower Lake Wateree basin. Big Wateree Creek watershed was selected as it has more TSS data than anywhere else at the lower basin. Erosion/Sediment transport is important for modeling as particle sizes of clay and organic particulates can adsorb nutrients, especially phosphorus and ammonia, to influence sediment delivery, enrichment, and biological availability of the nutrients

This analysis includes;

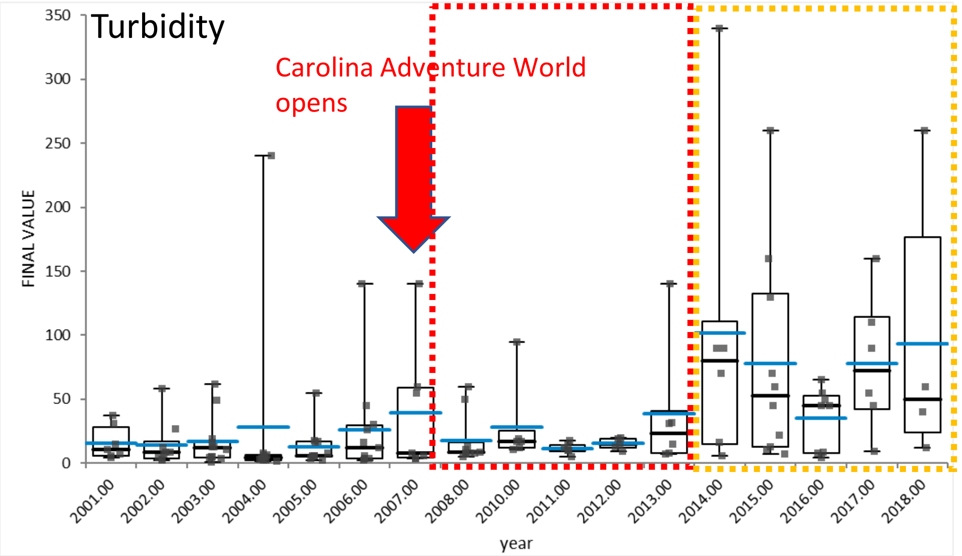
- A Long-term trend analysis of turbidity and related data.
- Analysis of 2016-2017 special study at Big Wateree Creek watershed
- Forest logging
- Summary
- Additional information on Cs137 analysis

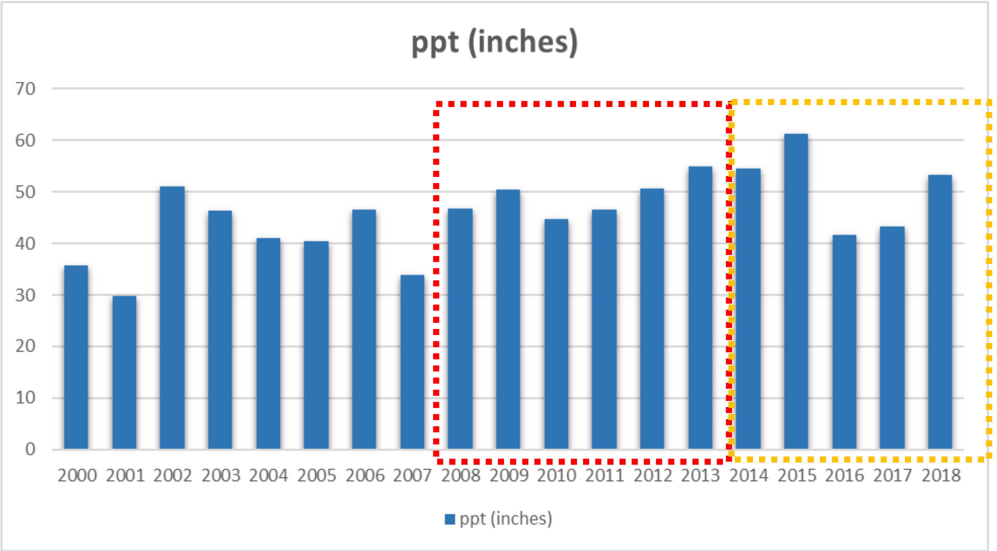
CW-072 at Big Wateree Creek

There is no long term TSS observed data available at station CW-072 in Big Wateree Creek; thus, turbidity was used as surrogate for TSS. Although colored organic matter could disrupt correlation between TSS and turbidity, there usually is reasonable relationship between the two parameters. The next few slides show the data from 2002 through 2019 of turbidity and related datasets. The plot below shows annual average turbidity (on the left) from STORET and rainfall data retrieved from 4km by 4km PRISM data (on the right).



Carolina Adventure World (CAW) opened in 2007. However, the turbidity data indicate the constant lower value in the next five years after the facility opened. Then, turbidity increased drastically from 2014. Although Levene test on turbidity indicates equal variance between the data of 2008-2013 and 2014-2018, T-test shows the mean is not equal between the two groups based on p-value of 0.007. The annual precipitation between the year groups, both Levene and T-test indicated the variance and mean are equal. If the annual rainfall is almost the same, what is causing the turbidity jump?





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Following bullets show what turbidity implicitly measures. The four plots on the right were intended to evaluate some of the elements that turbidity evaluates.

- clay
- silt

Small colloidal inorganic and organic matter & dissolved colored organic compounds

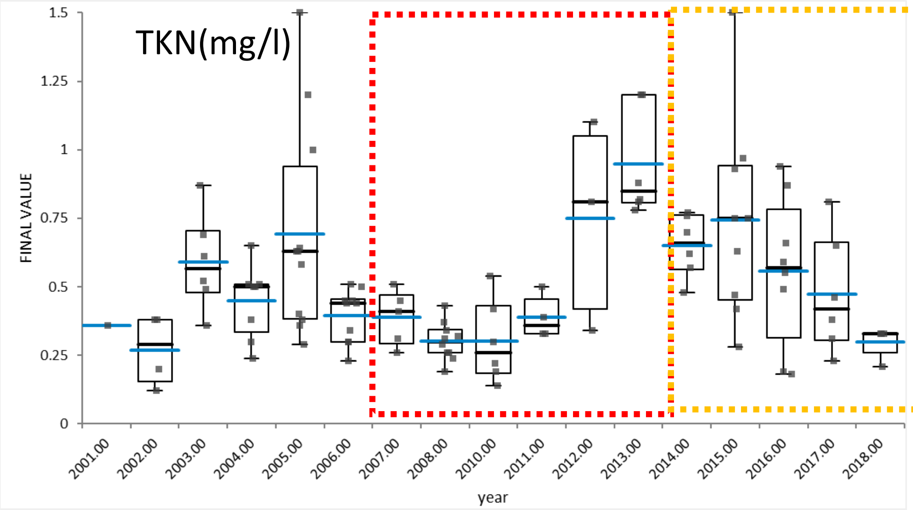
TKN is included here (see the plot on the right) to represent organic matter because organic N is much higher than P concentrations. Although TKN shows some fluctuation, it doesn't support the higher turbidity from 2014

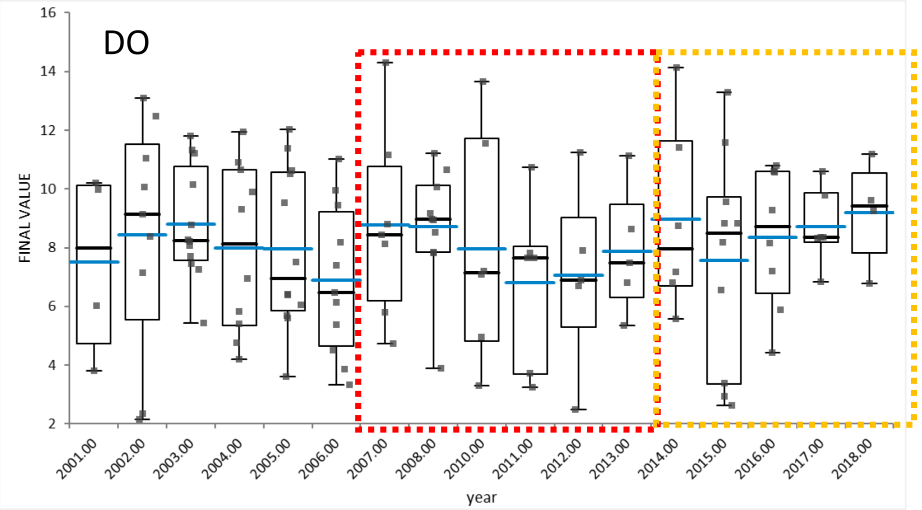
- Algae

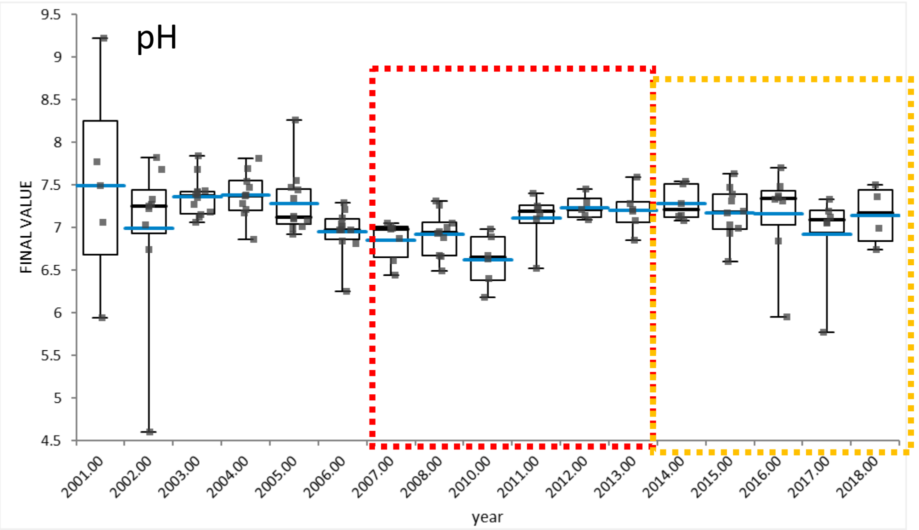
As there is not enough Chl-a (only three observed data at CW-072), DO and pH were evaluated for potential biological production changes due to algal activity. DO and pH are related to photosynthesis and respiration. These two parameters were relatively constant, thus no clear indication of productivity changes to support any of the increased turbidity from 2014.

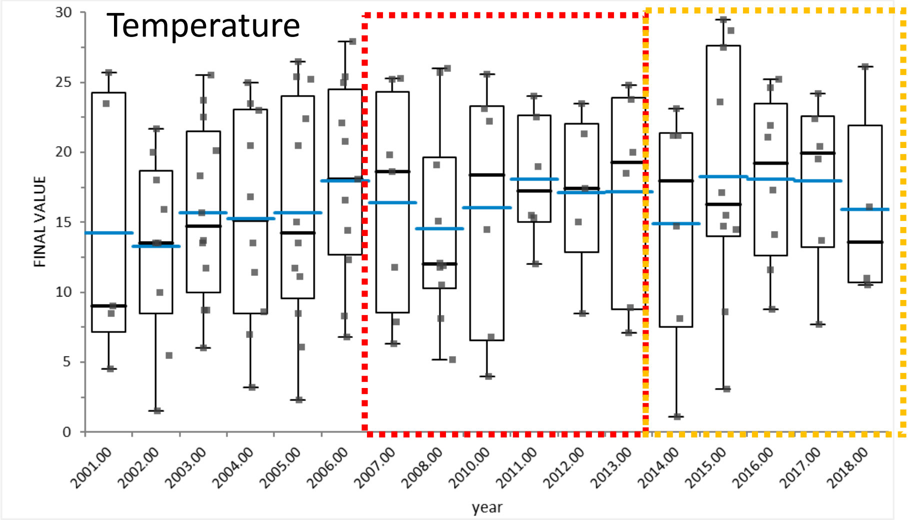
Temperature was included for physical/biological/chemical reactions. Temperature is also relatively constant.

- microscopic organisms.









Since organic matter and algal activity was evaluated to be not significant causes for the increase, the increase of turbidity from 2014 can be attributed to clay, silt increases, detritus from watersheds. If CAW and algal activity are not a cause of the turbidity jump and the annual rainfall patterns are the same, land-use changes can be a potential cause.

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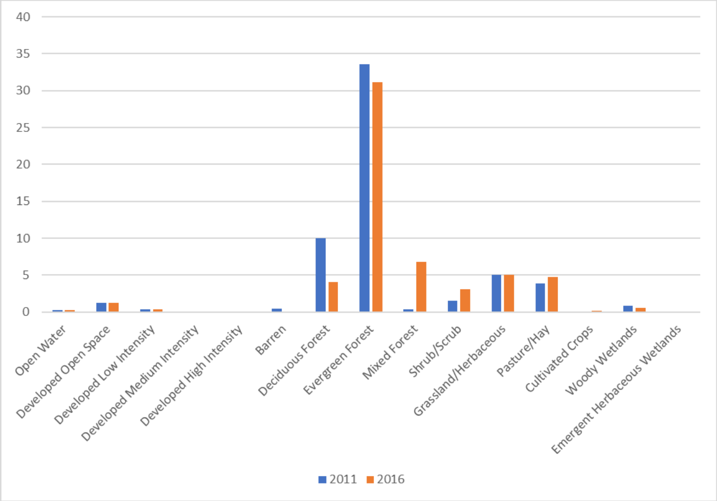
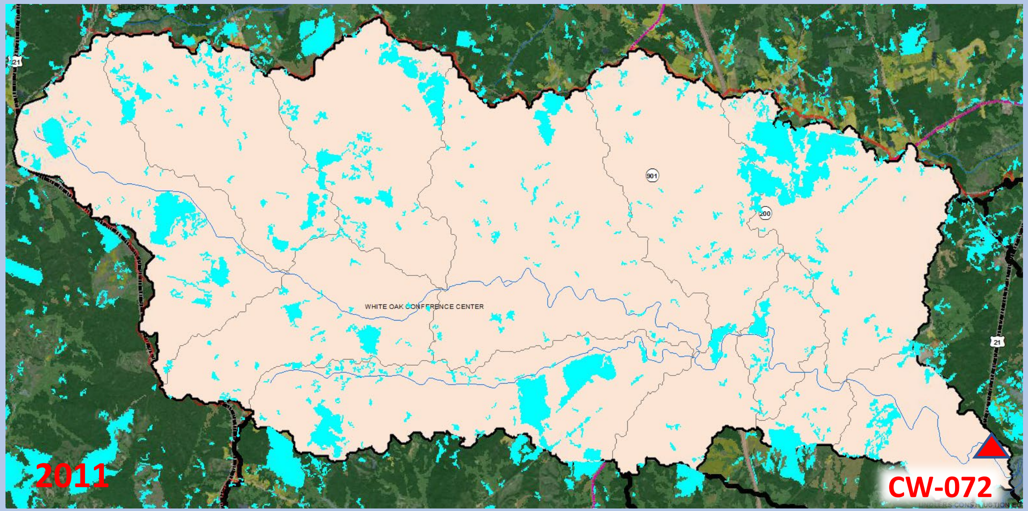
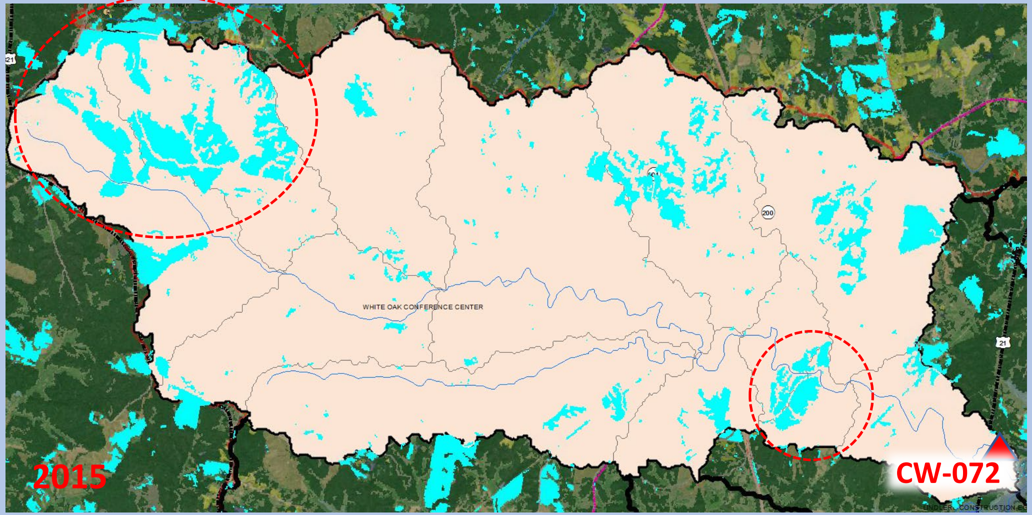
Land use comparison between 2011 and 2016 using NLCD data indicate that land use distribution hadn't changed much. It appears that a small portion of deciduous and evergreen category moved to mixed forest category.

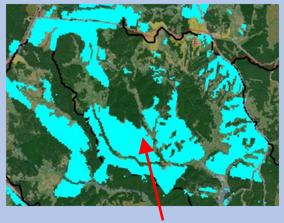


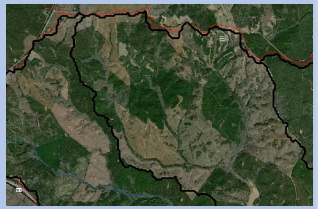
A comparison of CAW between 2011 and 2015 also show no significant change to CAW outer extent.





- Forest logging area was indicated as herbaceous land in NLCD category (see the herbaceous NLCD category and the logging area verification). Thus, this land use category was used to identify logging locations.
- The data indicated that there are intense logging activities at the northern upper watershed and lower watershed along the mainstem of Big Wateree Creek.



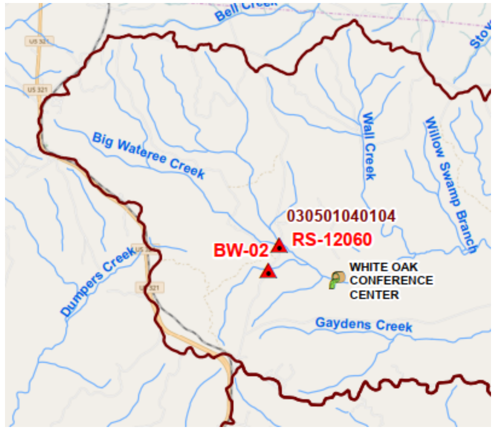


Herbaceous land category

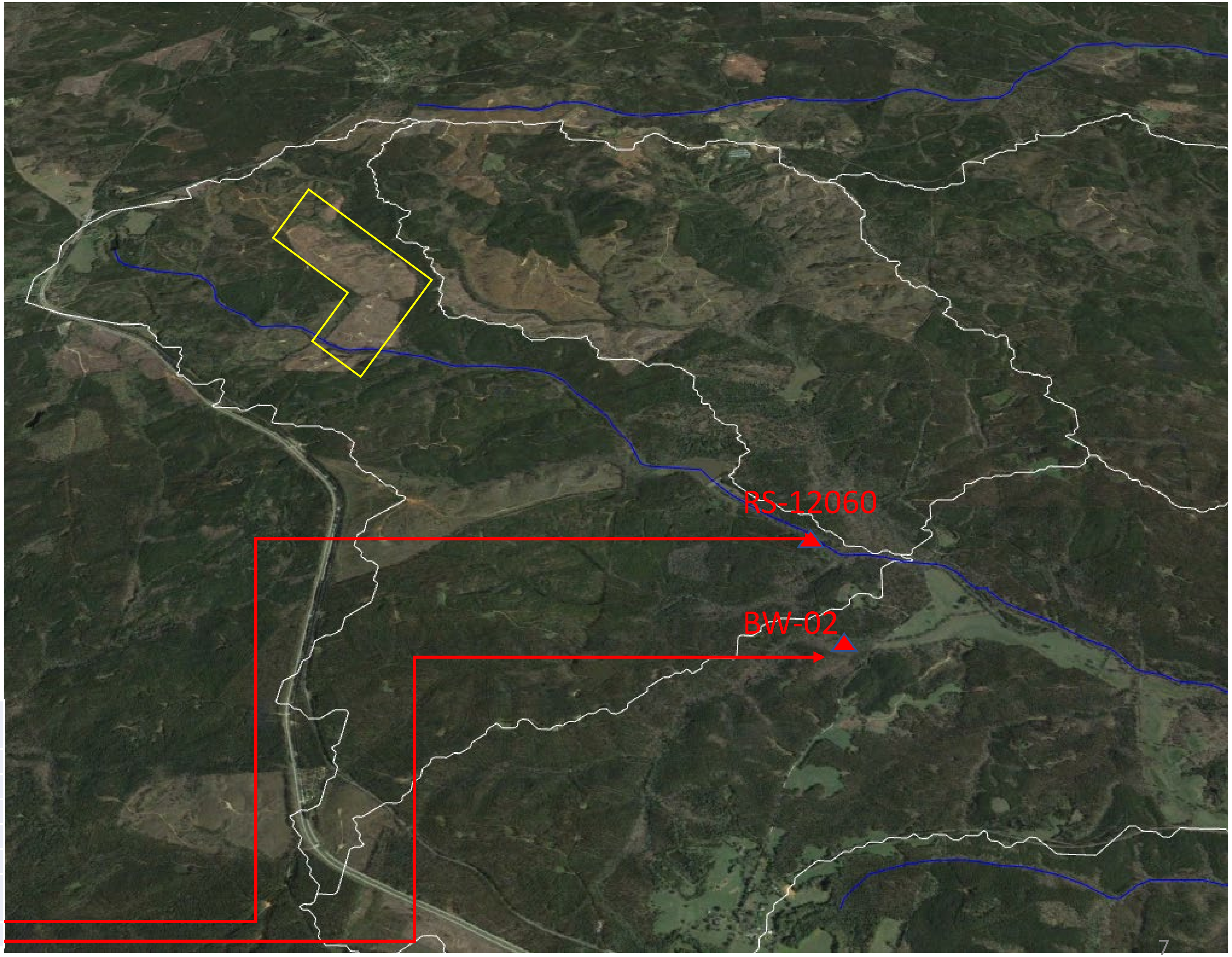
2016-2017 A special study at Big Wateree Creek Watershed

The upper Big Wateree Creek watershed

Both of RS-12060 and BW-02 shows low TSS. However, RS-12060 shows slightly higher TSS. According to the aerial photo, there are some logging activity in RS-12060 watershed. The literature indicates that logging activity, especially unpaved logging roads (access roads) could generate higher erosion.

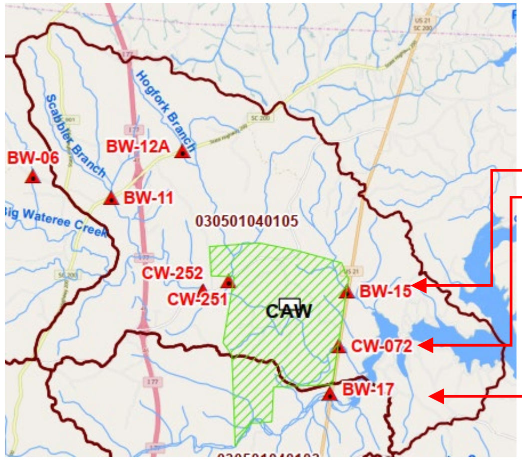


STAT	PARM	4/6 2016	6/16 2016	11/14 2016	5/23 2017	Units
BW-15	TSS	4.5	100	25	270	mg/L
BW-17	TSS	9.7	4.5	3	34	mg/L
CW-072	TSS	8.8	10	6.6	87	mg/L
CW-251	TSS	6	NA	<1.0	26	mg/L
CW-252	TSS	6	8.2	<1.0	39	mg/L
RS-12060	TSS	12	17	No	20	mg/L
BW-02	TSS	2.5	9.5	No	7.7	mg/L



A photo from 4/2017

The lower Big Wateree Creek watershed



STAT	PARM	4/6 2016	6/16 2016	11/14 2016	5/23 2017	Units
BW-15	TSS	4.5	100	25	270	mg/L
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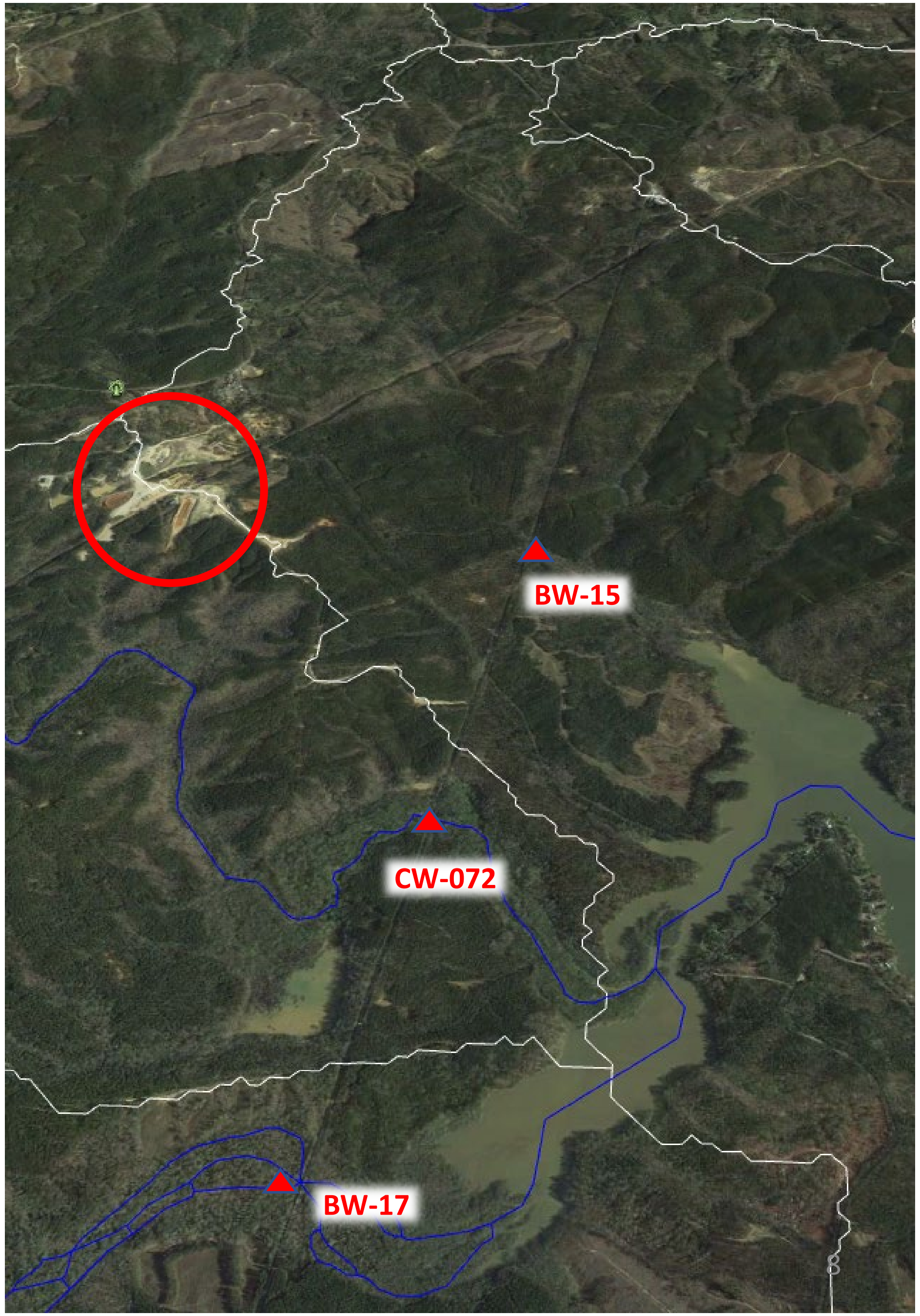
RS-12060	TSS	12	17	No	20	mg/L
BW-02	TSS	2.5	9.5	No	7.7	mg/L

The data from the special study indicates that TSS samples collected at CW-072 and BW-15 were higher than any other locations.



A photo from 4/2017

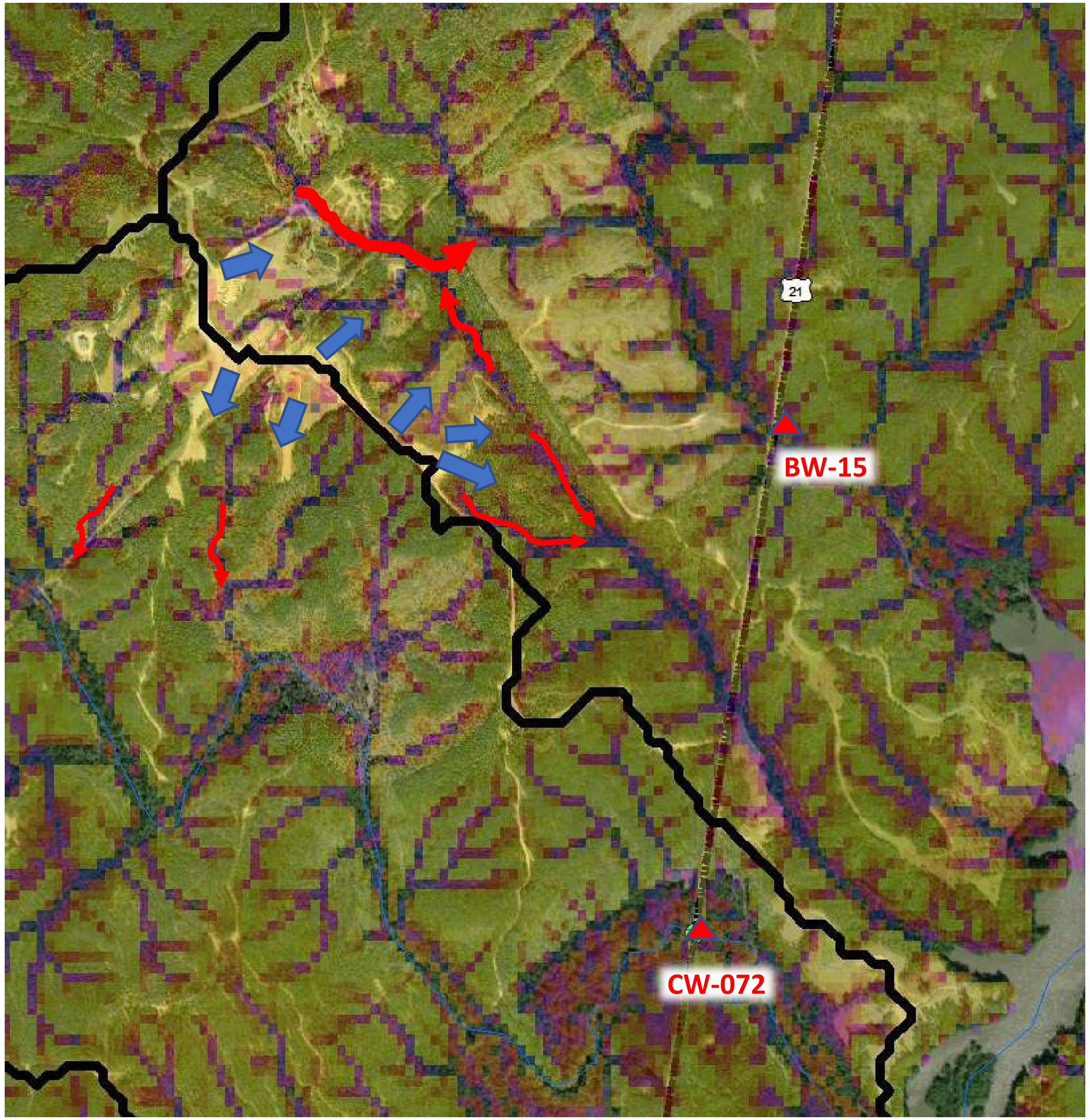
Potential erosion paths from CAW

CAW sediment appears to be distributed to three tributaries based on the wetness topographic index (WTI). The WTI represents a relative likelihood that a rainfall event saturates the soil and generates overland runoff based on the upslope contributing area per contour length and the local slope based on the grid data.

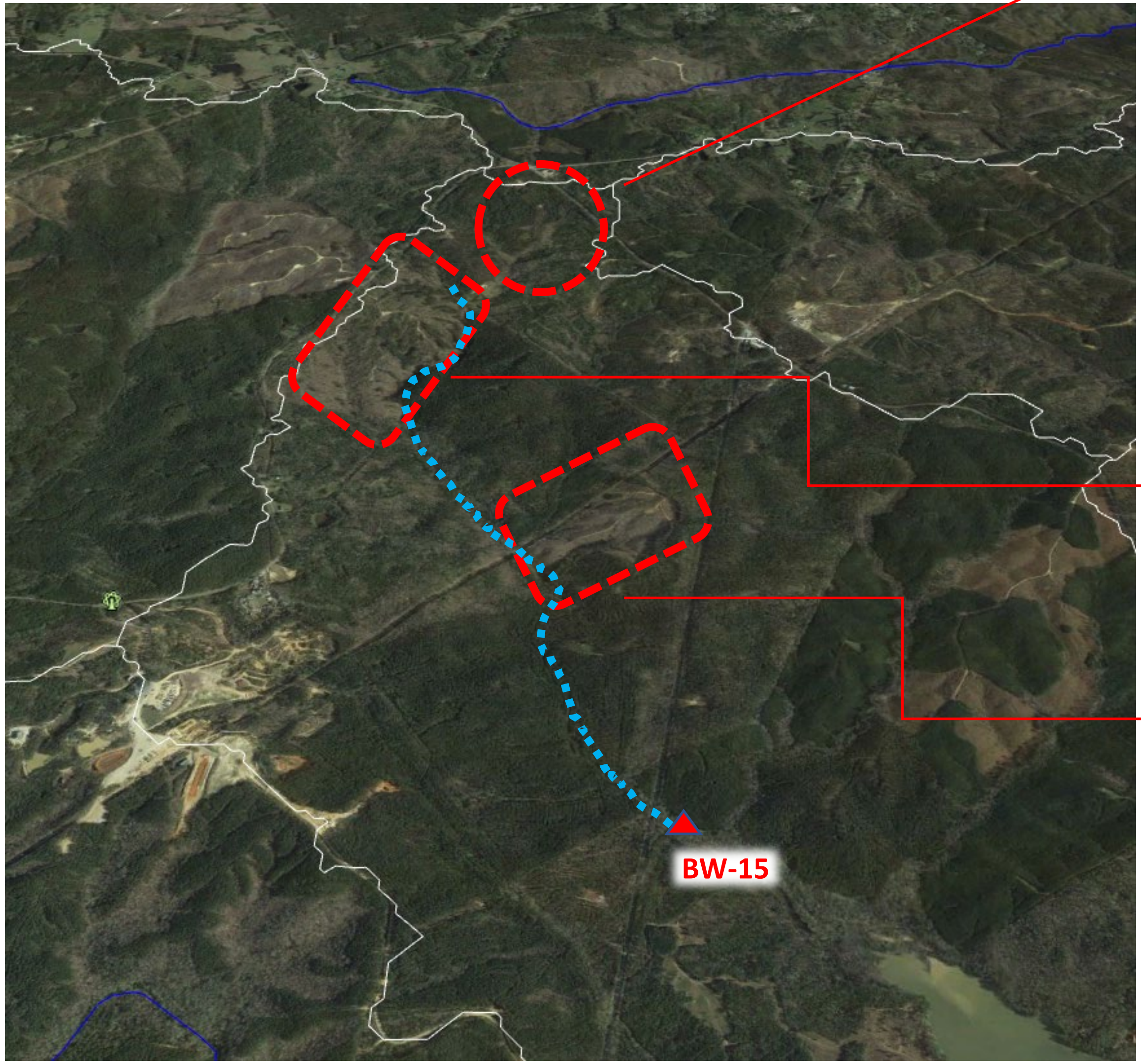
Dark blue to purple color indicates potential runoff concentrated flows. Two sediment paths were captured by the stations BW-15 and CW-072 but the lower sediment source of CAW path appeared to be leading to the unnamed tributary. It is possible that a part of this tributary is intermittent under dry weather.

A possible source causing the high TSS at BW-15 is from CAW. However, during the source assessment, extended forest logging was identified throughout the watershed.

Next, a few slides explore the potential sediment sources including logging area for BW-15.



Logging related sources potentially affecting BW-15

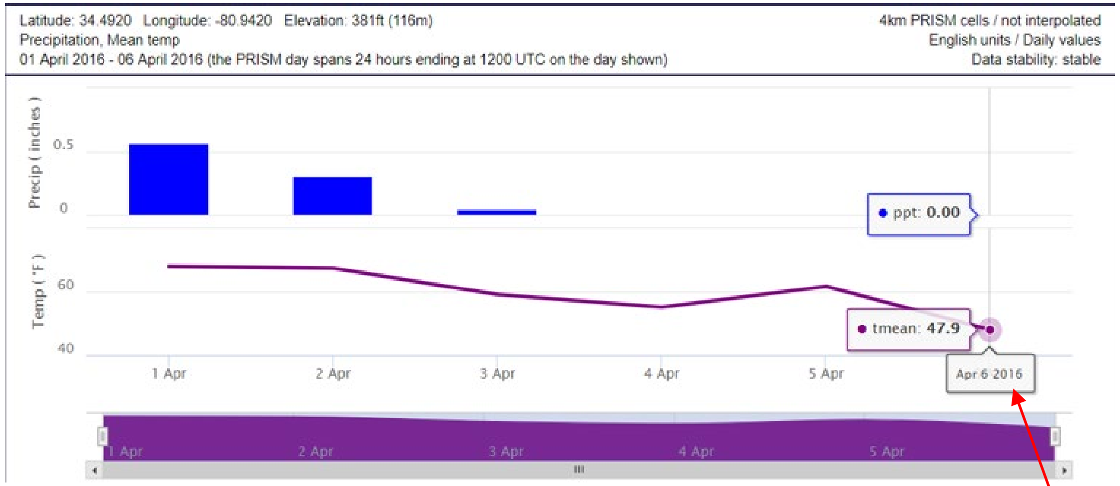


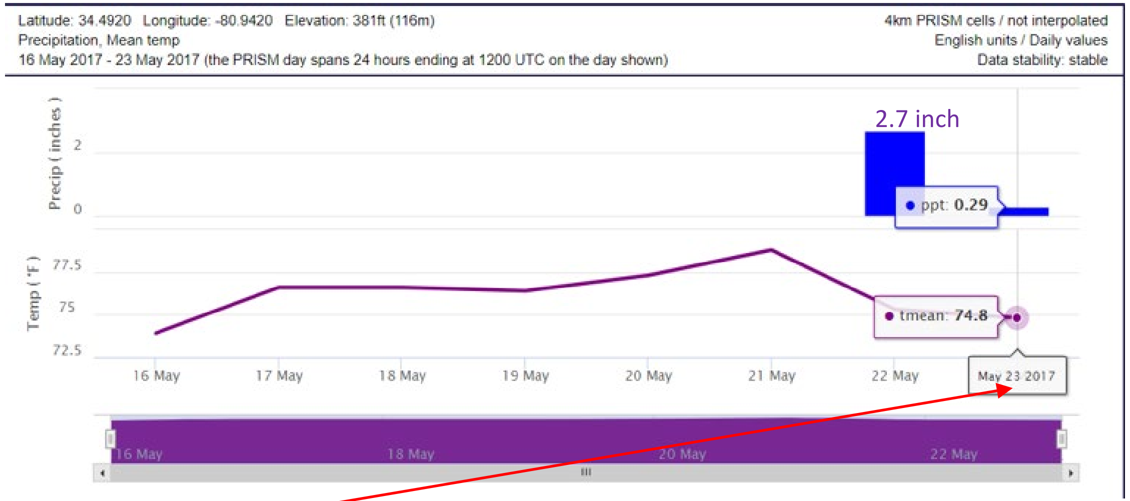
This aerial photo was dated in April 2017. The high observed TSS concentration was sampled in May of 2017. Thus, land surface conditions during the sample period were probably similar to what the picture shows here.

There appear to be three logging related sources. From the north to the south;

- A detention reservoir-possible overflow during wet weather.
- Logging site at the west face – possible erosion and sediment transfer to the stream during the wet weather.
- Logging site at the east face – possible erosion and sediment transfer to the stream during the wet weather.

Rainfall analysis during TSS measurement periods





STAT	PARM	4/6 2016	6/16 2016	11/14 2016	5/23 2017	Units
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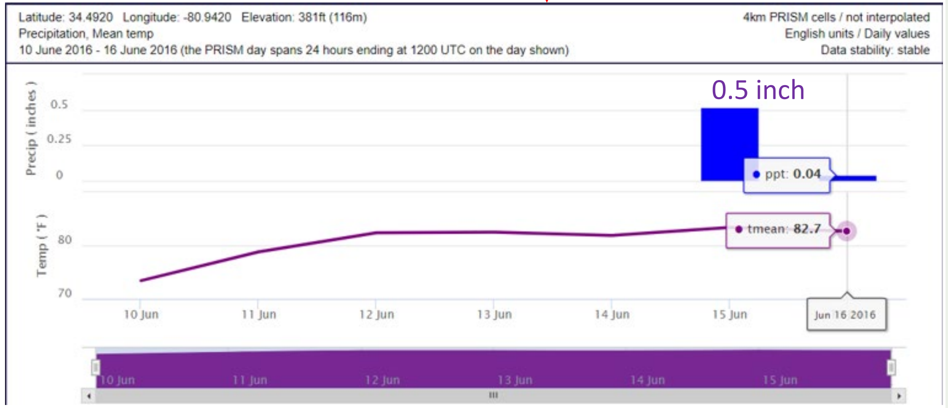
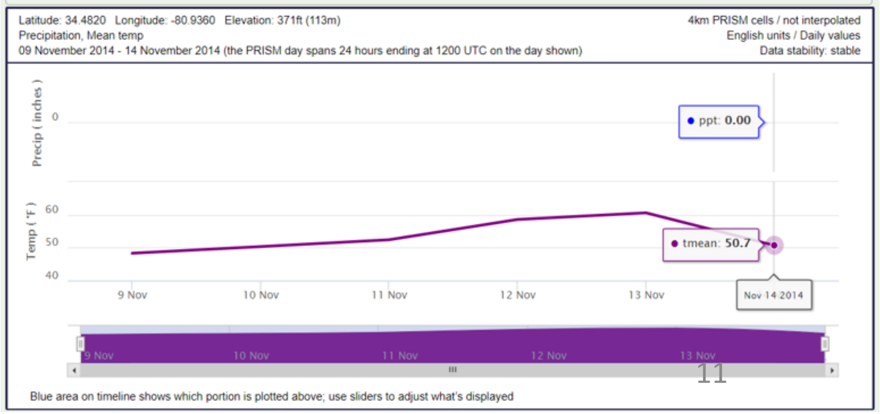
BW-02	TSS	2.5	9.5	No	7.7	mg/L

Rainfall data indicated that 5/22-5/23/2017 had almost 3 inches of precipitation and 0.55 inches of rainfall on 6/15-6/16/2016 whereas 4/6 and 11/14 of 2016 had no rainfall. This analysis indicates wet weather causes the high TSS observed at BW-15. The high rainfall (3inches) transported large amounts of sediment to BW-15. However, without additional data, the sources can be identified as either CAW, logging, or combination of both.

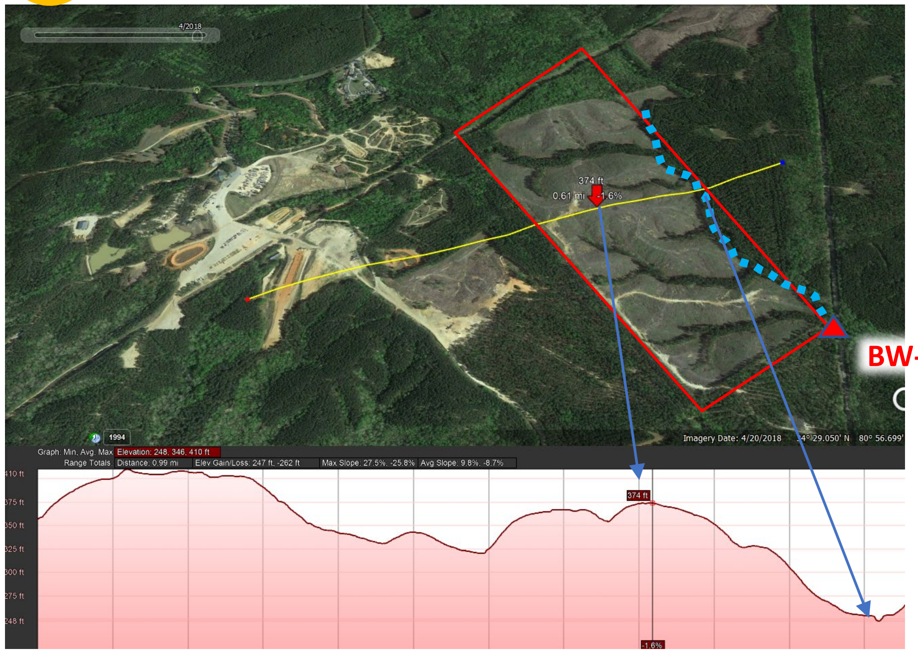




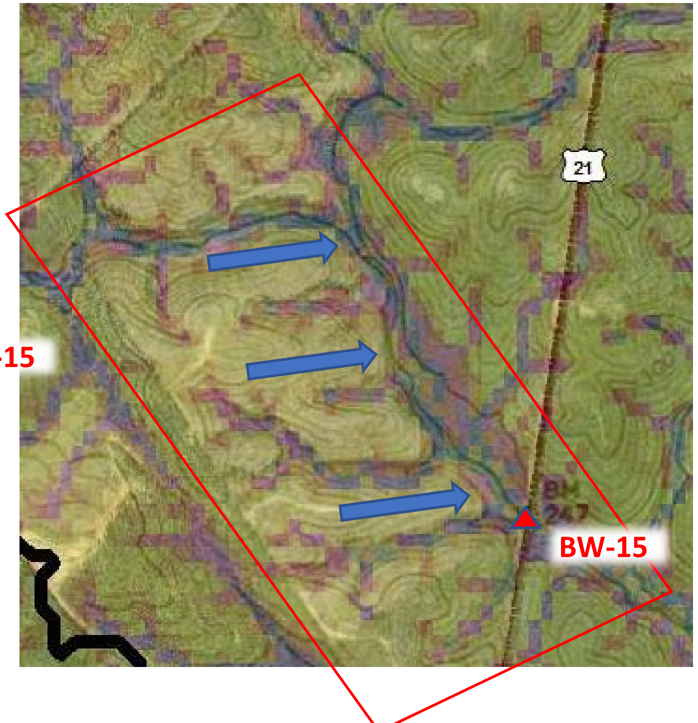
Potential logging sources

The most recent data in google earth in 2018 (Figure 1) indicates the large logging activity that had occurred adjacent to the BW-15 station. The topographic information also indicates that runoff from the logging eventually discharges into the stream around BW-15 (Figure 2). The picture on the right (Figure 3) shows additional large logging operations in the watershed (red circles).

1



2



3

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Generally, harvesting itself does not substantially increase soil erosion. However, skid trails, log decks, and roads commonly cover 2 to 10 percent of logged sites (Kochenderfer 1977) and represent the most significant threat to water quality from forest operations due to an increase in erosion potential resulting from bare soil exposure, compaction, and increased surface runoff .

The picture on the left is from 2004. it shows an example of forest logging effect if the activity becomes severe.

CAW had not been built at that time. The picture shows concentrated logging activities throughout the Big Wateree Creek basin. The cove shows high turbidity indicating potential high TSS concentrations. Although the current conditions are not as severe as 2004 in terms of aerial photos, logging activity in the lower portion of the Lower Catawba basin appeared to still be very active.

SUMMARY

- The annually averaged turbidity data indicated that CAW might not be the only the source for high TSS observed at BW-15 and CW-072.
- The TSS data (a special study 2016-2017) at BW-15 indicates high TSS concentrations. The analysis indicated that CAW is probably one of the sources affecting this stream but may not be the only source. Additionally, the aerial photo shows possible other sources (detention pond and logging activities).
- The precipitation data indicates more TSS being observed during higher precipitation events.
- The analysis recommends a potential benefit of wet weather sampling at the tributaries between CW-072 and BW-15 based on the wetness topographic index and spatial information of the area.
- Forest logging appears to be another major source of high TSS concentrations.

Additional information

Cesium-137 is a fallout product from the atmospheric testing of nuclear weapons carried out during the period between the 1950s and the 1970s. On reaching the earth's surface, Cs-137 in most environments is strongly and rapidly adsorbed by fine-grained particulate matter and its subsequent movement occurs in association with sediment particles in response to erosion, transport and deposition processes.

The basis for using Cs-137 measurements to investigate erosion involves the simple premise that measurements of the Cs-137 inventory at different locations within the landscape can be compared to an estimate of the baseline fallout to the area to provide information on patterns of soil loss and deposition.

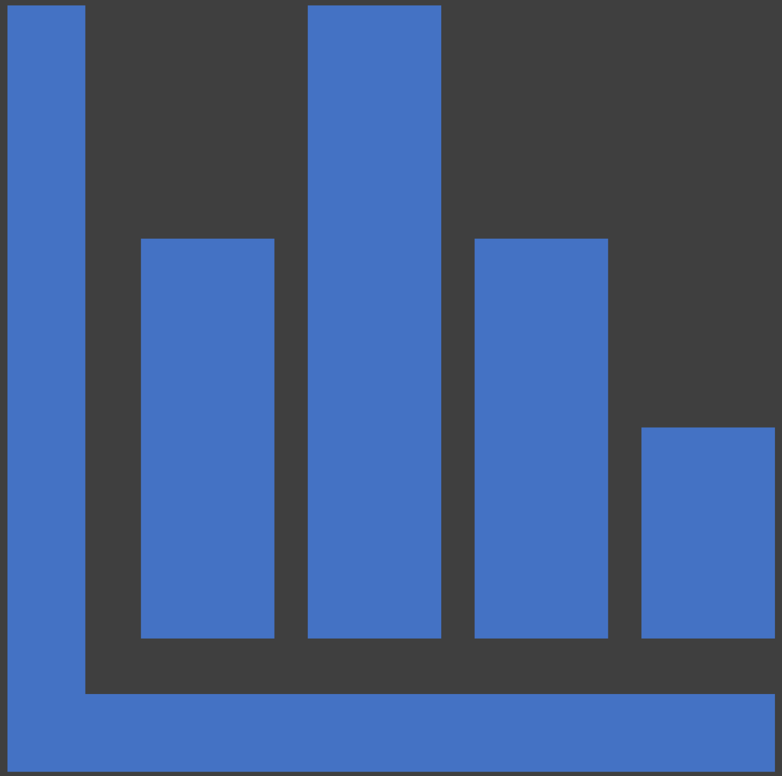
Chesapeake bay watersheds and the other states such as Minnesota have used the method to identify upland erosions and stream bank erosions.

Additional information

The relative contribution from logging fields and banks to the sediments deposited in the river can be evaluated by comparing the Cs-137 concentration of the source soil and the measured sediment samples. The method can estimate a percentage contribution from field (logging area).

$$C_c = \frac{(P_s - P_b)}{(P_f - P_b)} \times 100$$

Cc: Contribution of fields
Ps: Cs-137 on bottom sediments (Bq/kg)
Pb:Cs-137 on bank soils (Bq/kg)
Pf:Cs-137 on field soils (Bq/kg)



Data Analysis based on the 2019 data

The Data Analysis Procedures

1. Data overview
- Introduction of watersheds, data sampling locations
- Rainfall summary during 2019's samplings
- Data analysis of 2019 collected data
- Summary so far version 1

2. TDS analysis
- Evaluation of TDS conditions in general
- Evaluation of TDS at BW-15

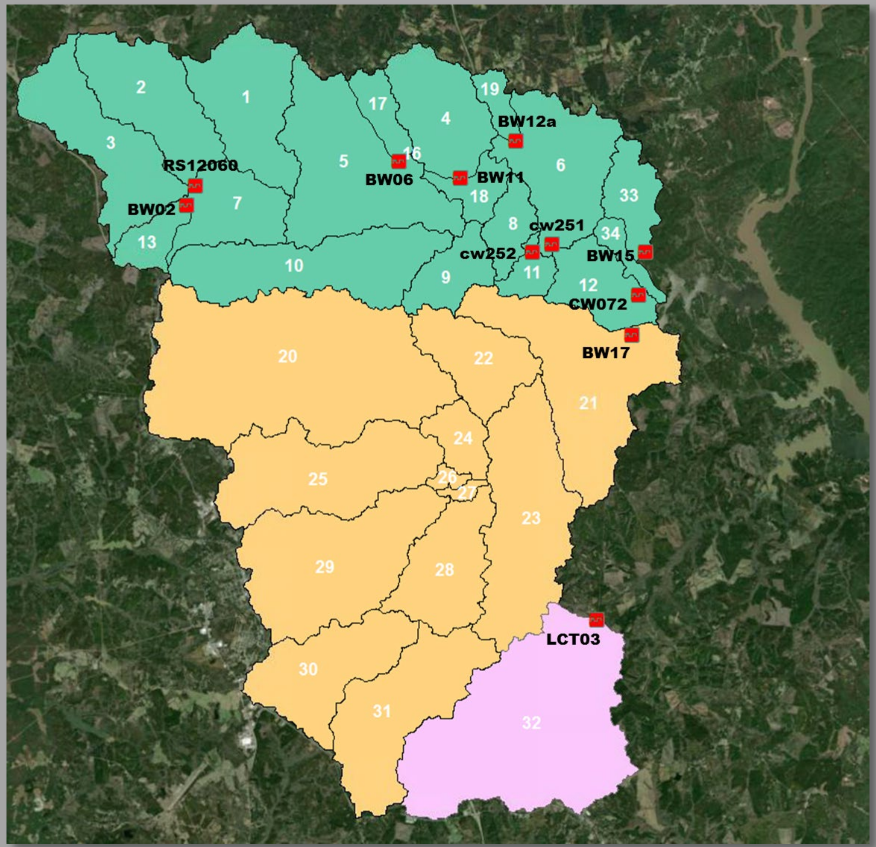
3. TSS analysis
- An overview of TSS data trend
- An introduction of the RUSLE model and application
- Summary so far version 2
- The data revisited
- RUSLE & USPED model application
- Topographical data interpretation
- Hydrologic soil interpretation
- CW-252 analysis
- Additional analysis of TSS between CW252 and CW72

4. Highlights of physical characteristics and loading sources

5. Conclusion

DATA Overview

Sub-delineated watersheds, the sampling locations & dominant land use evaluation of the three basins



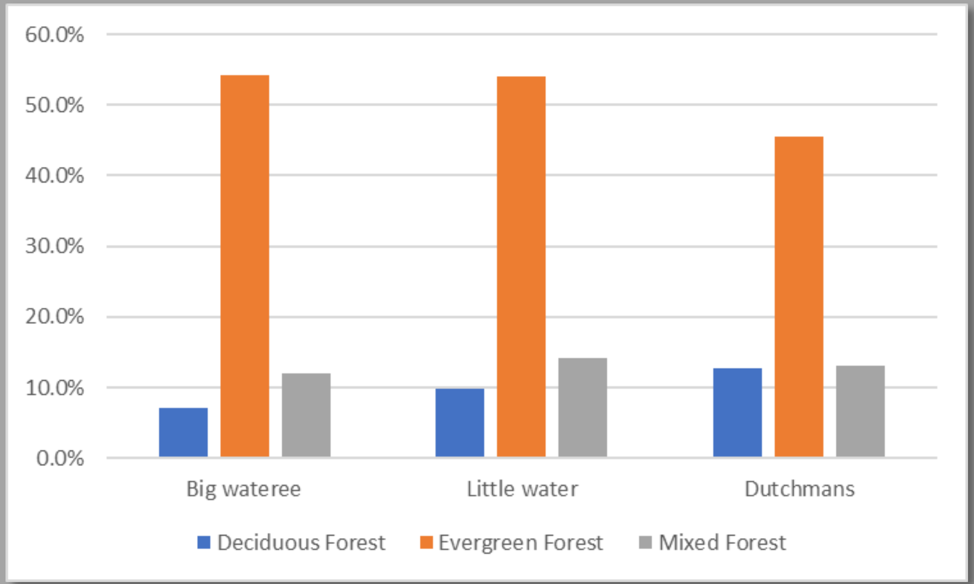
The basin was delineated using USGS $10m(32\ feet) \times 10m(32 feet)$ digital elevation model and NHD flow line data.

Each subwatershed will be identified as sws (e.g., sws33 means subwatershed 33)

Big Wateree creek

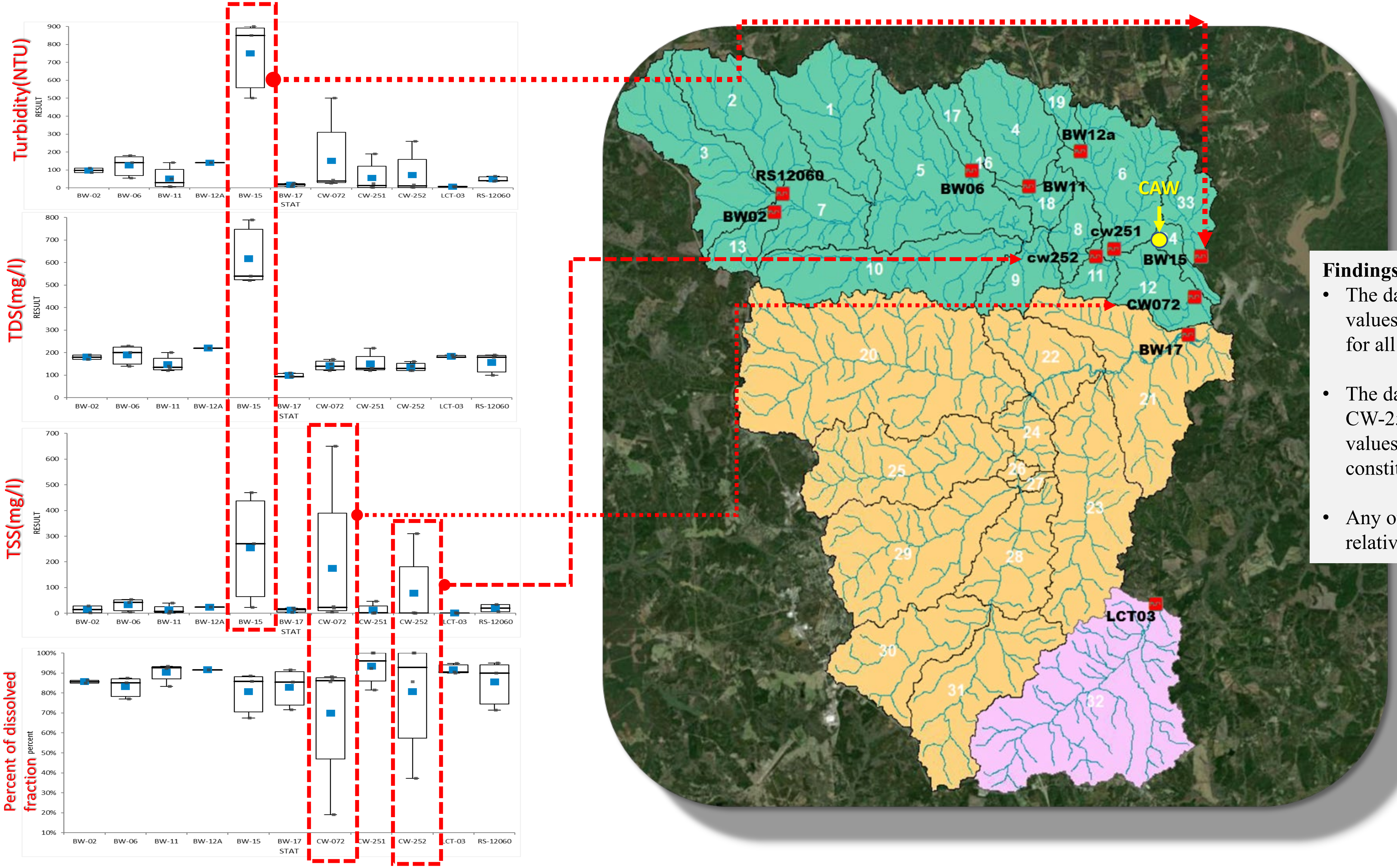
Little Wateree creek

Dutchmans Creek



According to NLCD's most recent available land use data (2016), forest land use is dominant for all of these three basins. More than 70% of each basin consists of three land-use types: deciduous, evergreen and mixed forest. The distribution among these land uses for each basin is almost identical (see the plot above).

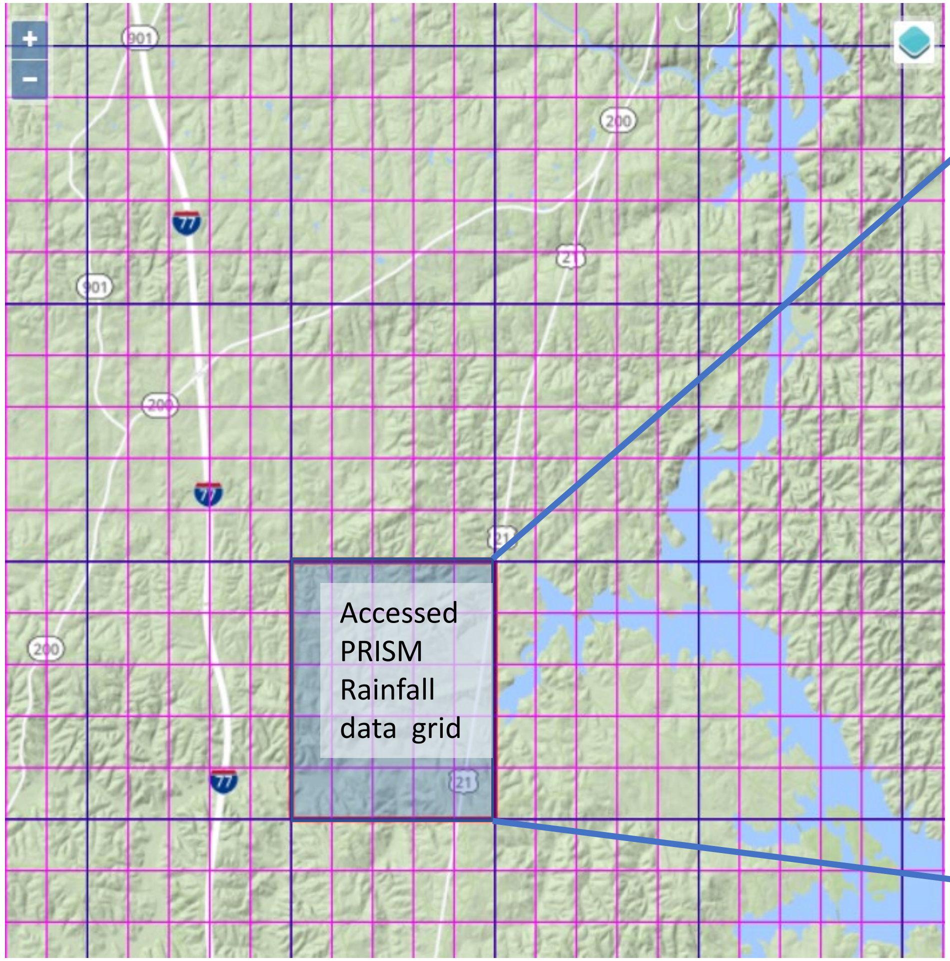
A first look of the collected data set from 2019 data collection efforts



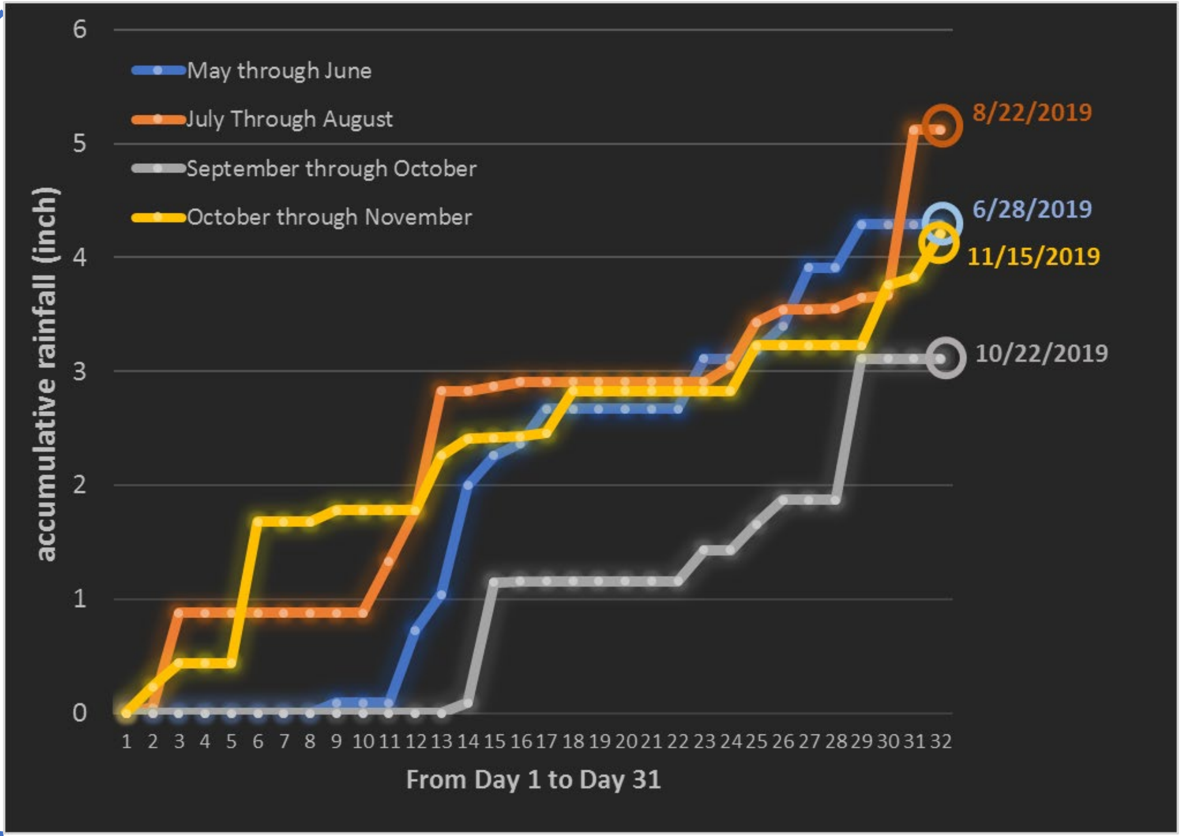
Findings

- The data at BW-15 shows high values (concentrations & NTU) for all turbidity, TDS and TSS.
- The data at CW-072 and CW-252 indicate higher TSS values and lesser dissolved constituents in the data.
- Any other data appears to be relatively constant and low.

Cumulative PRISM rainfall data ($4km \times 4km$ *grid data*) for the month up to the sampling date



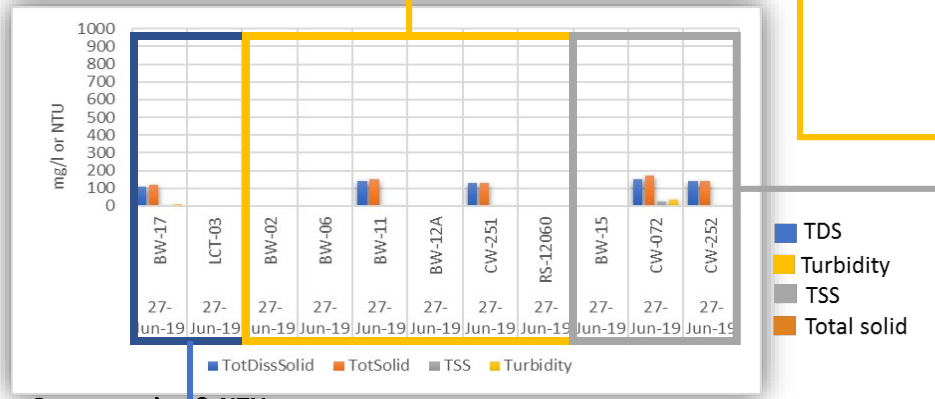
PRISM data is one of the most widely used spatial climate data sets in the United States, developed by Oregon State University's PRISM Climate Group, named for the PRISM climate mapping system. PRISM products are the official spatial climate data sets of the USDA.



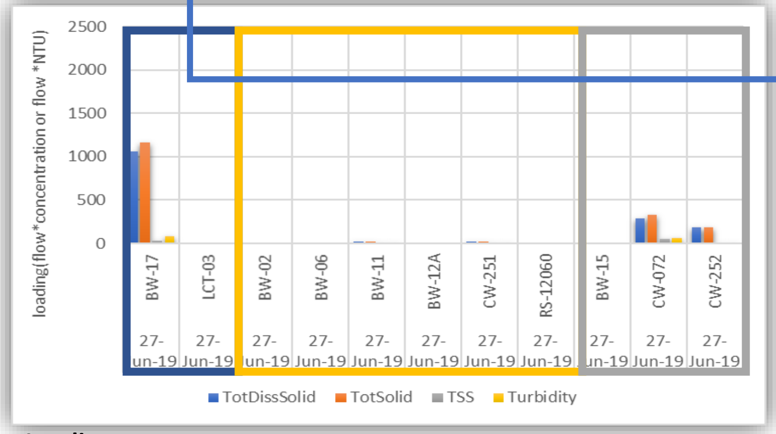
31 day-cumulative rainfall data up to the sampling dates. This cumulative rainfall data can also be considered as a rough representation of antecedent soil moisture (wetness) conditions of the basin.

- The rainfall pattern of June and November is similar.
- The data indicates that the days up to the October sampling was the driest month of the sampling events in 2019
- High-intensity rainfall was observed before the sampling events in August and October

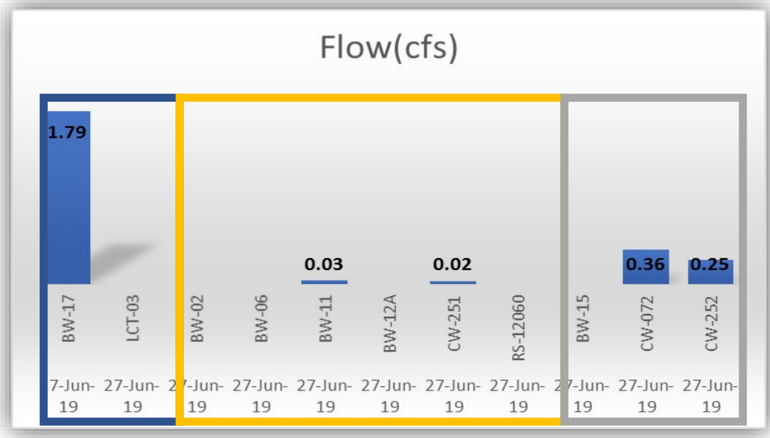
The sampling data from June 19, 2019

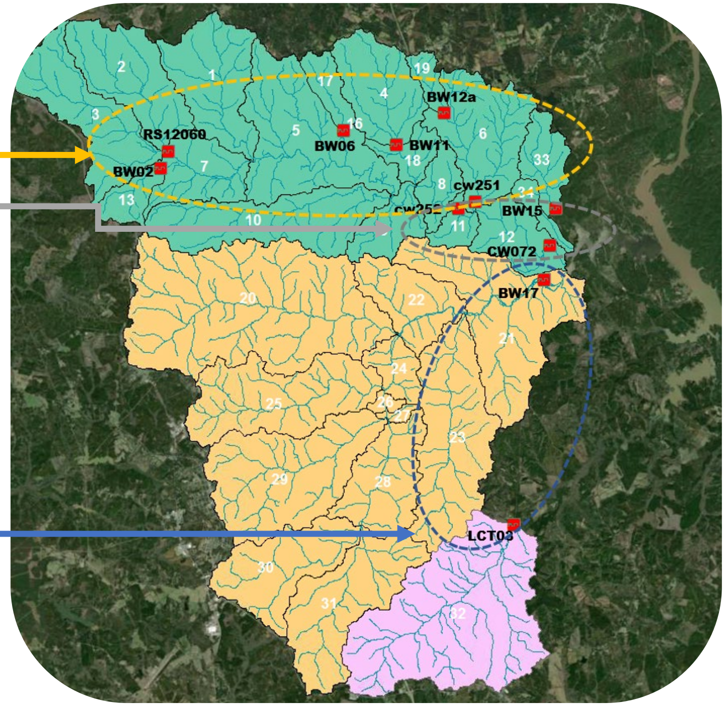


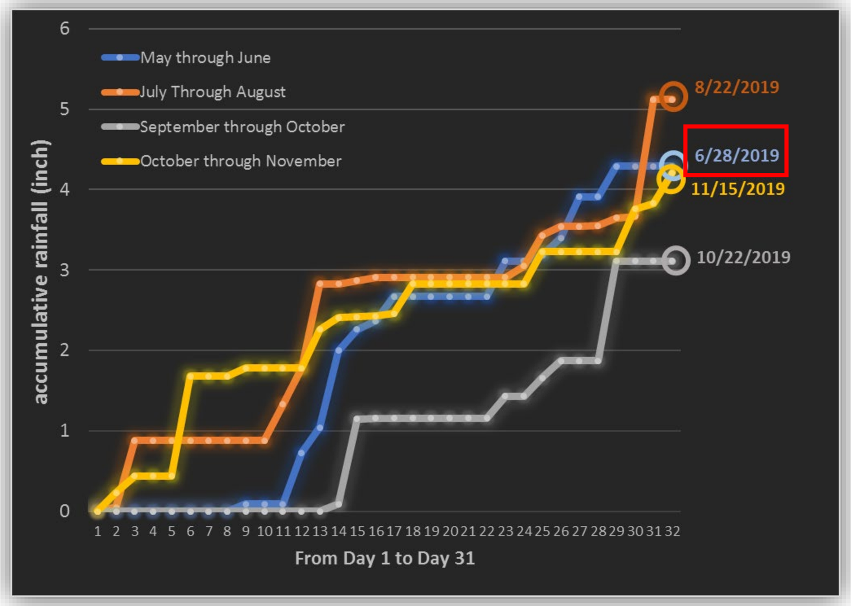
Concentration & NTU



Loadings

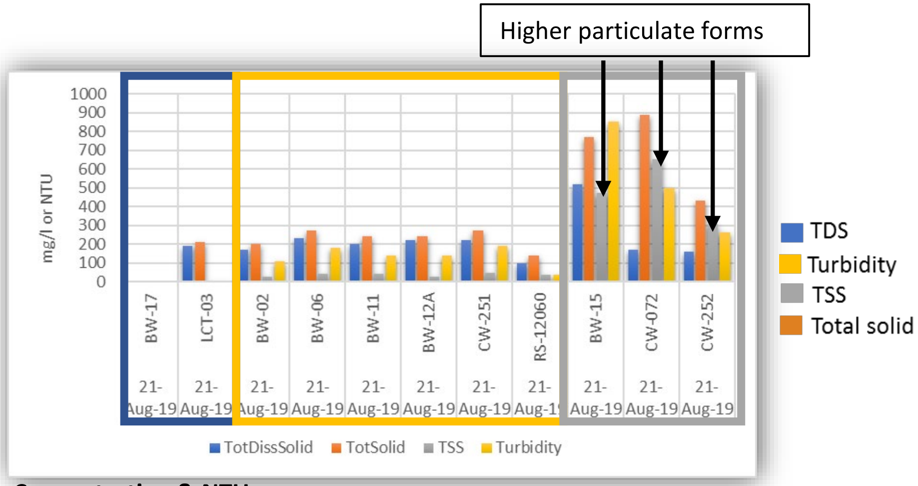




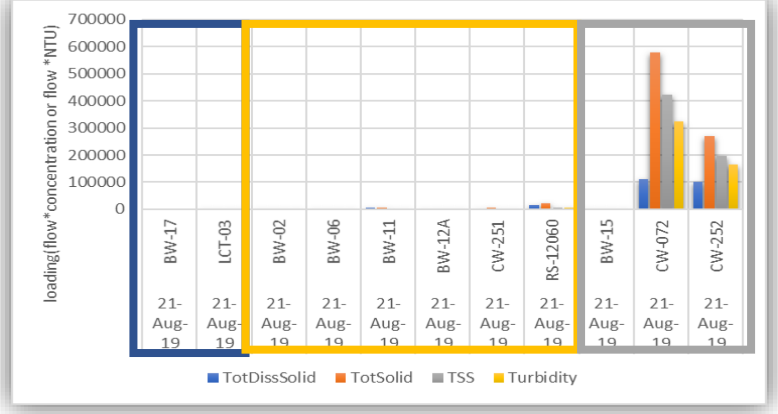


- The data (the plot on the top left) show low values (concentrations & NTU) of all the sampled data. The magnitude of the measured values is almost identical irrespective of the sampled locations.
- The observed constituent is mainly dissolved solids (TDS), with no significant particulate form.
- TDS loading at BW-17 is higher due to the higher flow rate at the watershed.

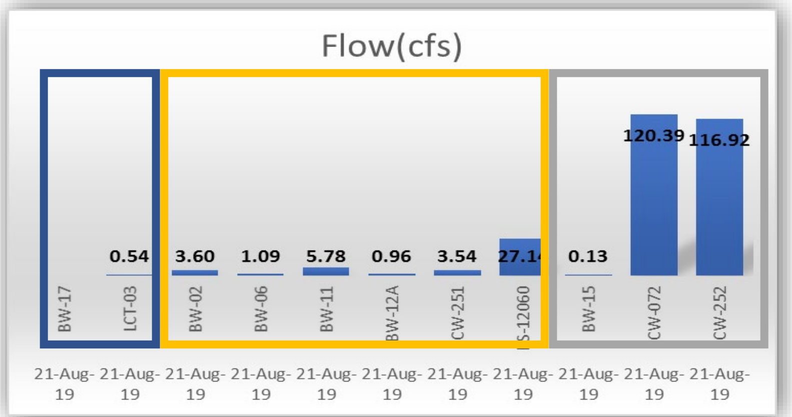
The sampling data from August 22, 2019

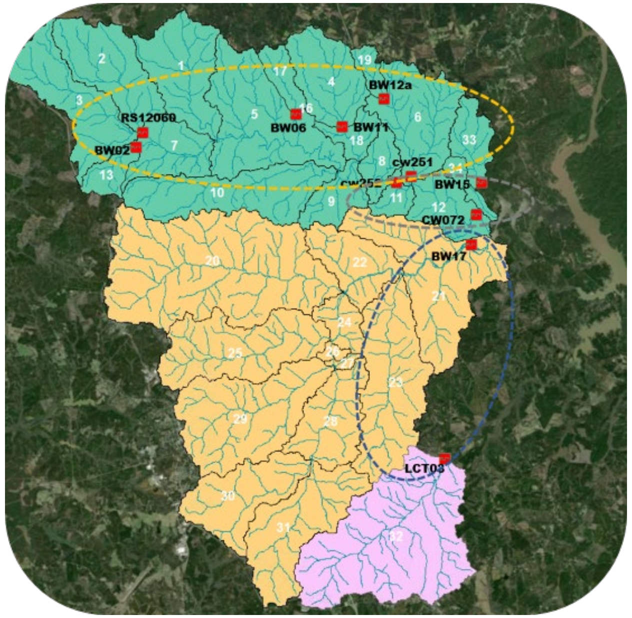


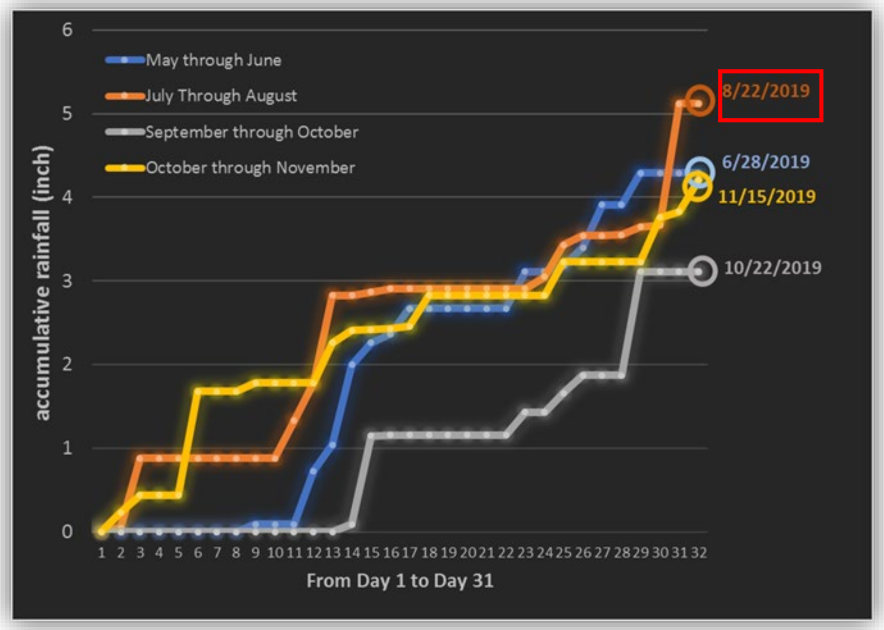
Concentration & NTU



Loadings

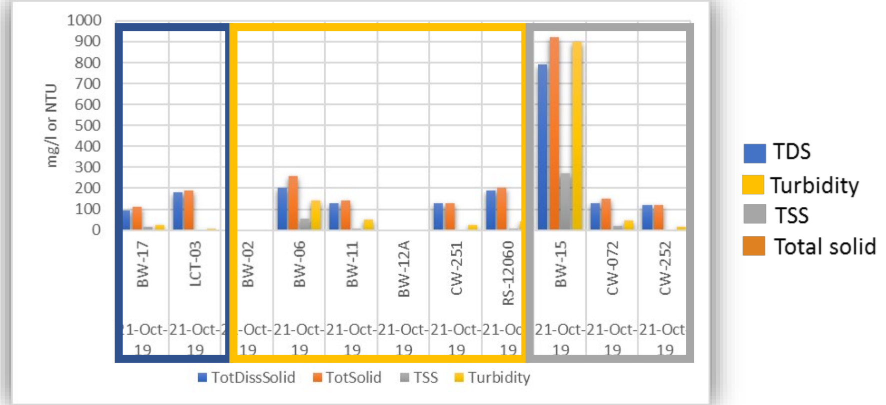




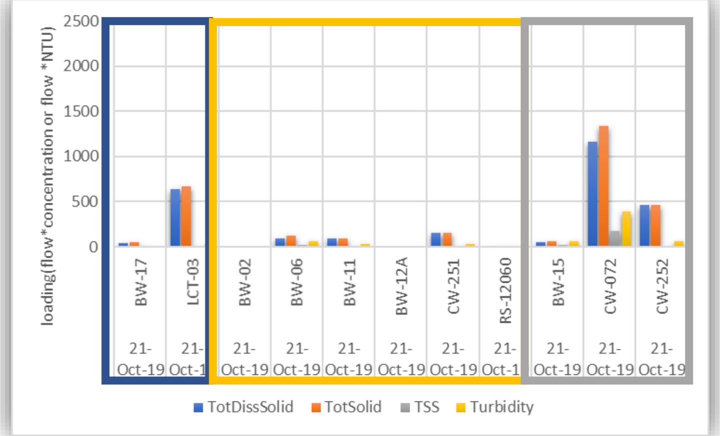


- August rainfall data shows a high spike of the rainfall event before the sampling(see the right bottom plot). The rainfall made the August sample the wettest sampling period among all the sampling events.
- The sampled data shows, especially, a higher value of TSS and turbidity at BW-15, CW-072 and CW-252 whereas any other locations show much lower values of these parameters (the top left plot).
- Loadings at CW-072 and CW-252 are also high due to the higher flow rates at the watersheds.
- TDS concentration at BW-15 is also much higher than any other sampled locations.

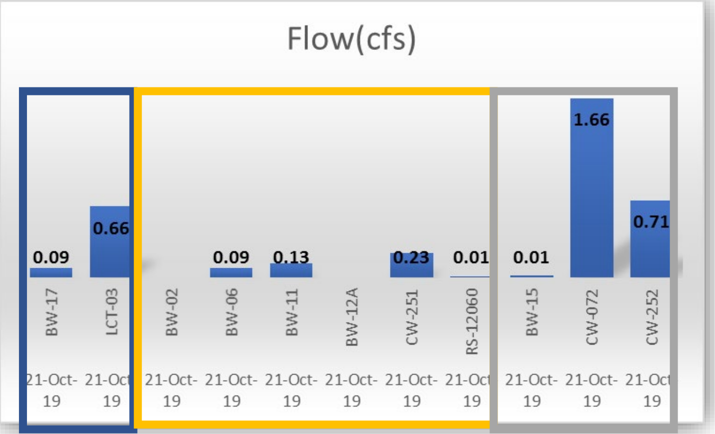
The sampling data from October 22, 2019

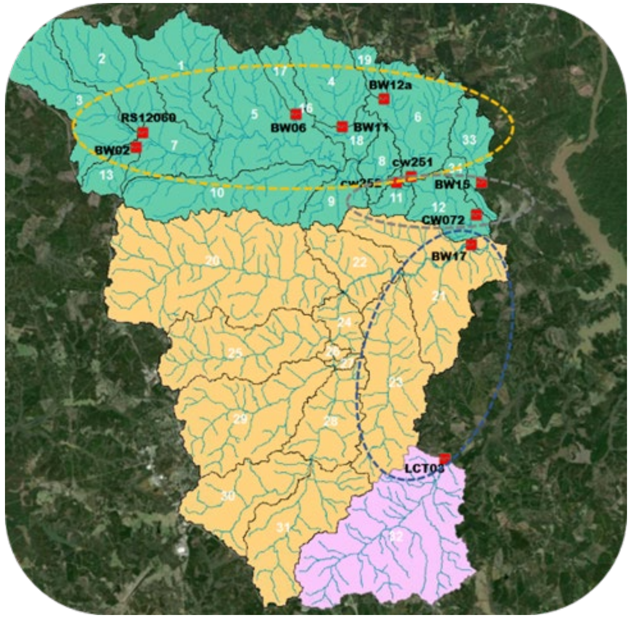


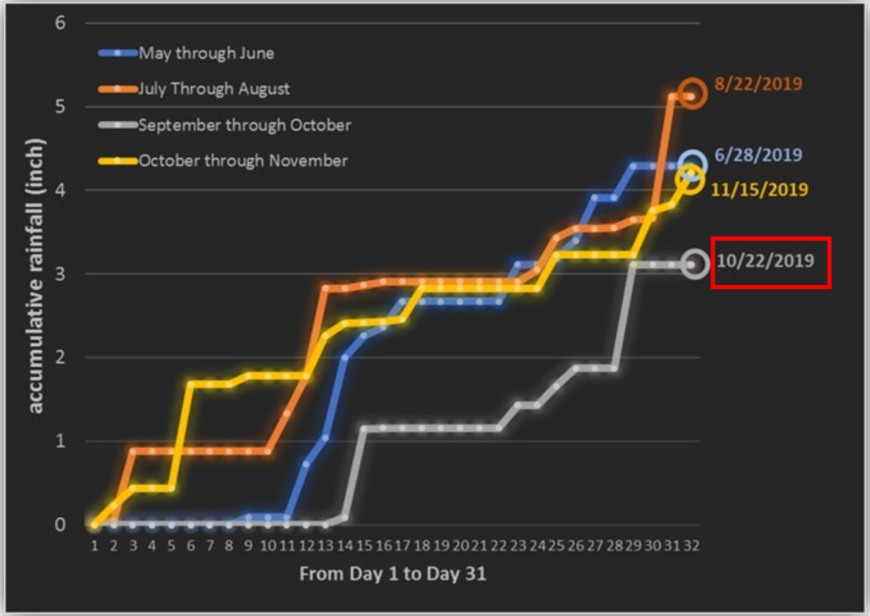
Concentration & NTU



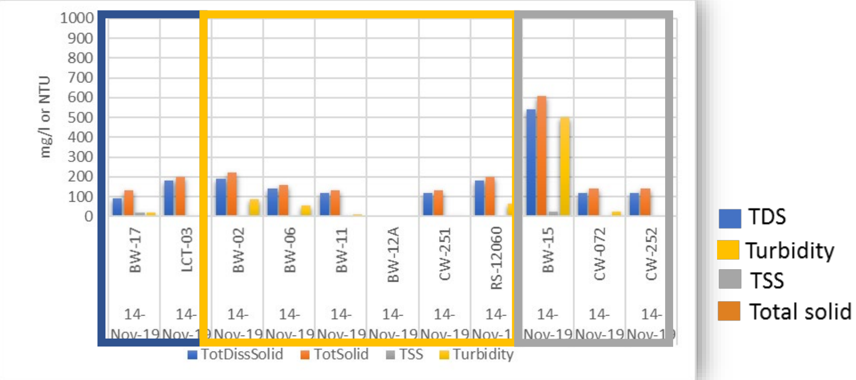
Loadings



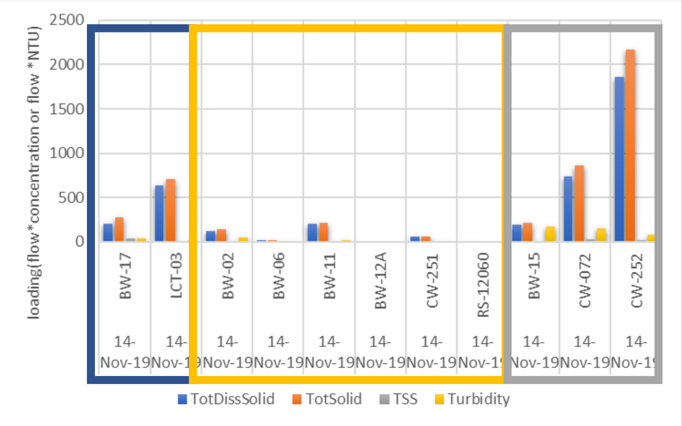




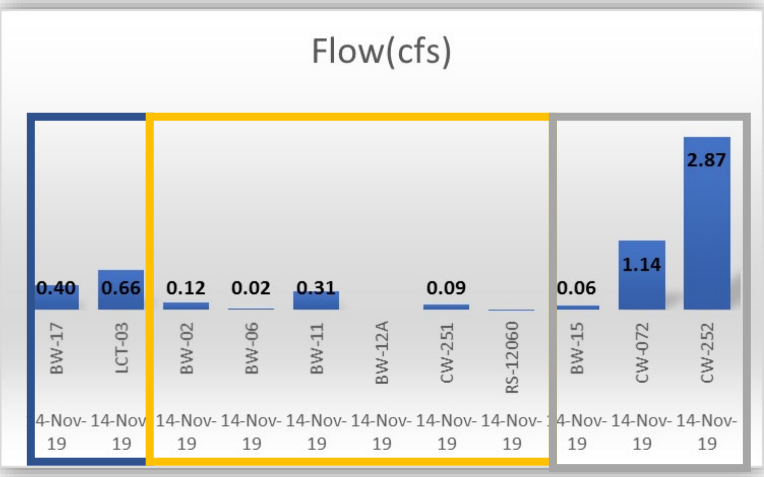
- A few days prior to the sampling, over an inch of rain occurred but the cumulative rainfall data shows that the total rainfall of October was the lowest (see the right bottom plot).
- The October data shows high values of all sampled parameters at BW-15.
- The loadings at BW-15 are lower due to the lower measured flow rate at that watershed. Although the dissolved solids loadings from CW-072 are high among the data here, it is still much lower than the data collected during the August sampling event.



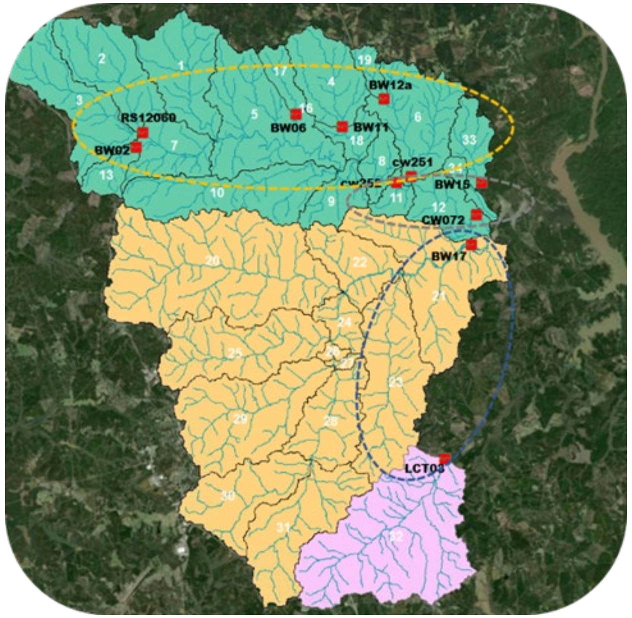
Concentration & NTU

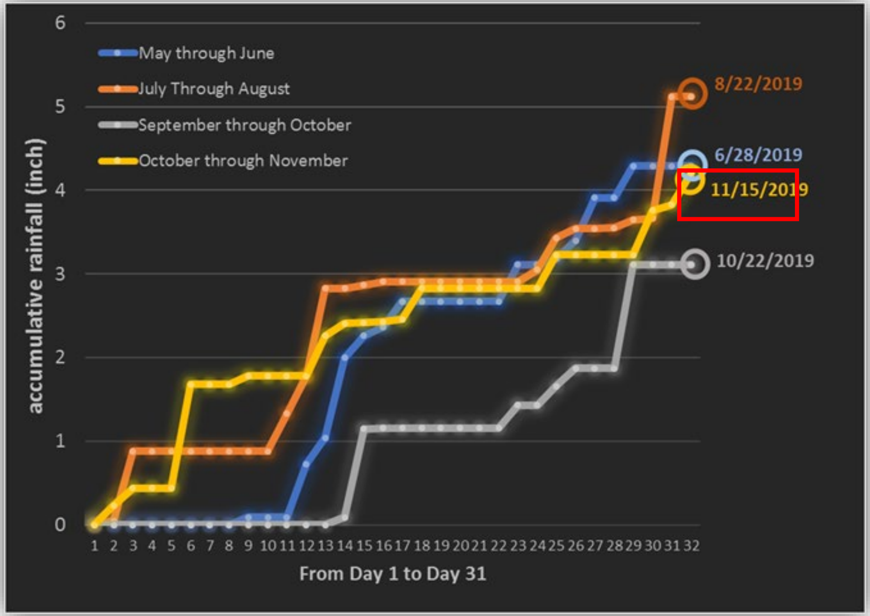


Loadings



The sampling data from November 15, 2019





- November rain data shows relatively steady rainfall events during the last 30 days up to the sampling event (the bottom right plot).
- The November data shows higher observed parameter values at BW-15, which is similar to the October pattern.
- Most of the observed constituents are mainly dissolved solids, with no significant particulate form.
- The loading at BW-15 is lower due to the lower flow rate at the watershed. The dissolved loading from CW-252 is high. The observed pattern is very similar to the October data but the magnitude of the loading between CW-072 and CW-252 is reversed. Although the loadings from CW-072 and CW-252 are high compared with any other location in this November sampling, the loadings are much lower compared with the August data.

What we found so far & next steps

- BW-15 constantly shows higher TDS values than any other stations except for June when no sample was taken from the site.
- High TSS concentrations were observed at the station BW-15 during August and October.
- High TSS concentrations were observed at the station CW-072 and CW-252 during August rainfall event.
- Main problematic parameters and locations were summarized the table below.

	TSS	TDS
BW-15	X	X
CW-072	X	
CW-252	X	

The next few slides further explore the two questions:

1. The first question is why there are consistently high TDS values at BW-15.
2. Is the observed TDS at BW-15 influenced by anthropogenic activity or within natural range?

Analysis to conduct for the TDS questions:

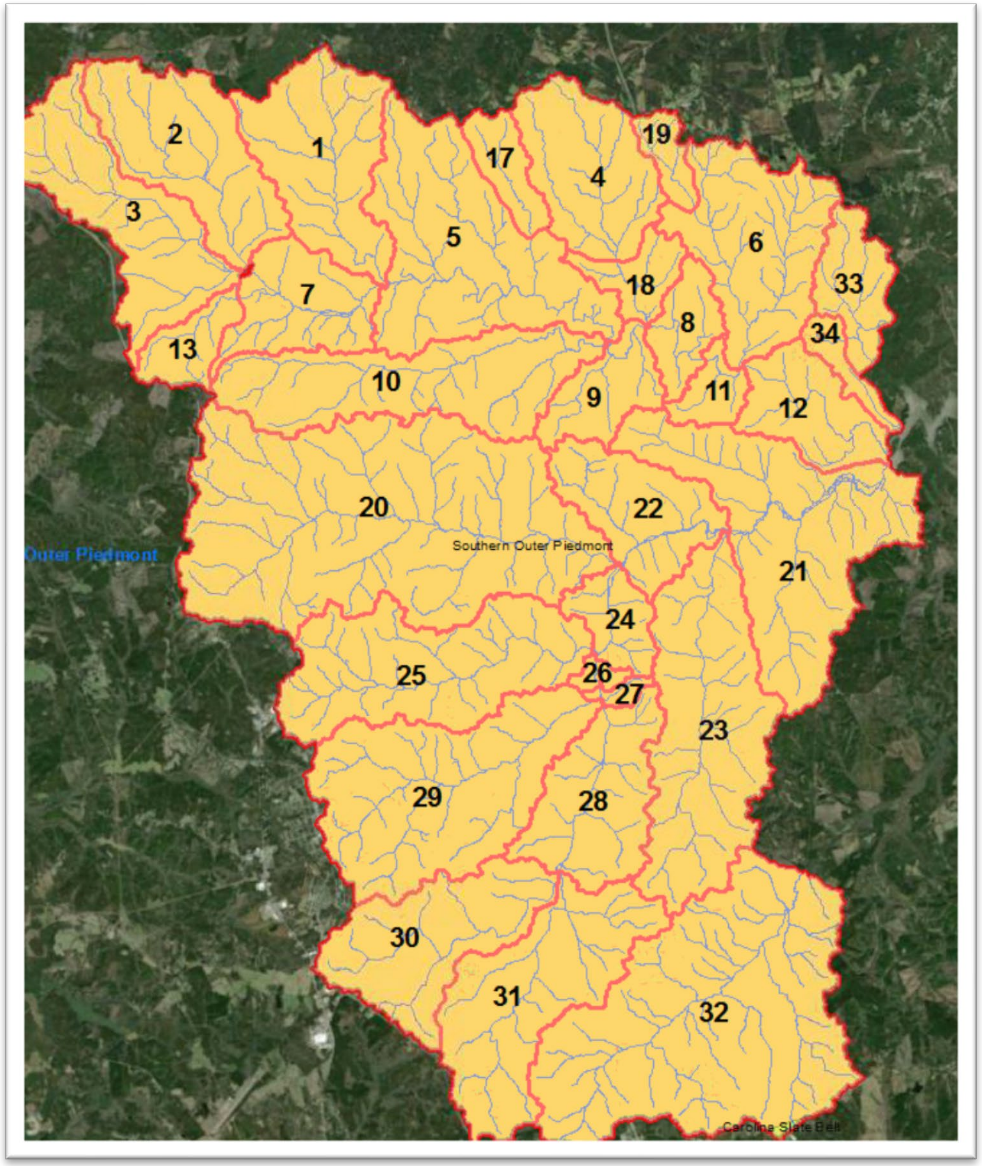
1. Ecoregion-The natural differences in climate, geology, soil, landform, and vegetation may not conform strictly to hydrologic regions or subwatershed levels. In order to identify some potential differences in the ecological character of surface water and near-surface groundwater conditions, this parameter was selected.
2. Geology
3. Data interpretation

TDS analysis

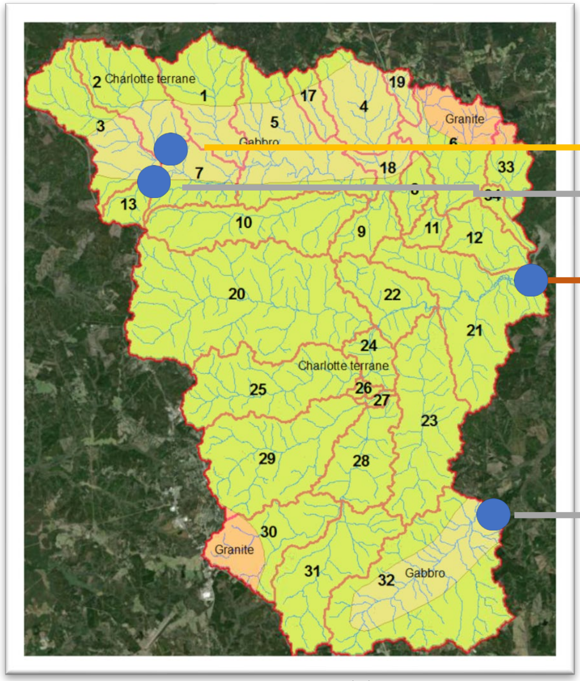
Ecoregion analysis

Ecoregion: Southern Outer Piedmont

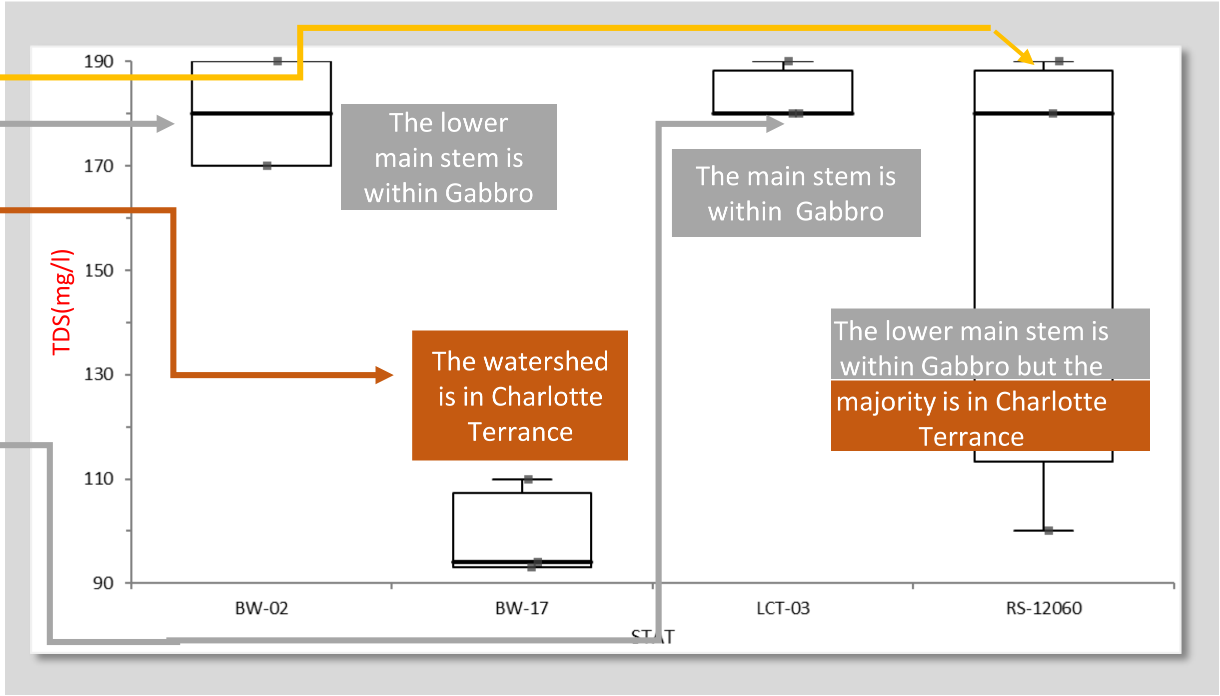
The Southern Outer Piedmont ecoregion has low elevations, less relief Gneiss, schist, and granite are typical rock types. As the watershed is within one ecoregion, there will not be any differentiation in the basin in terms of ecoregion.



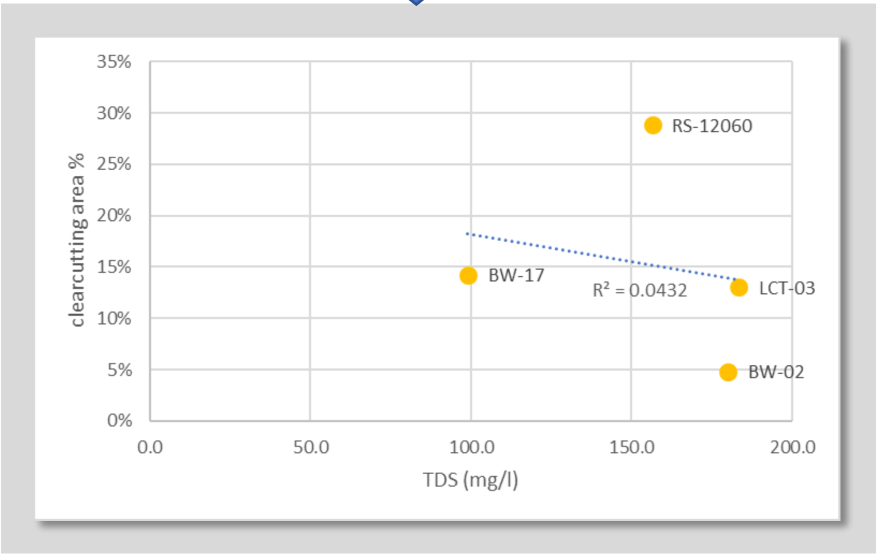
Geology & sampled data & clearcutting area analysis



Geology of the basin: Gabbro: Coarse-grained, mafic igneous rock intruding the rocks of the Charlotte terrane. Charlotte Terrance: Infrastructural, mainly metaigneous taconites. However, the majority of the basin is charlotte terrance.



The data indicate that Gabbro based geology generate slightly higher TDS than the one observed from Charlotte Terrance. The data from RS-12060 contain both Gabbro and Charlotte terrance, and the TDS data range shows both ends.

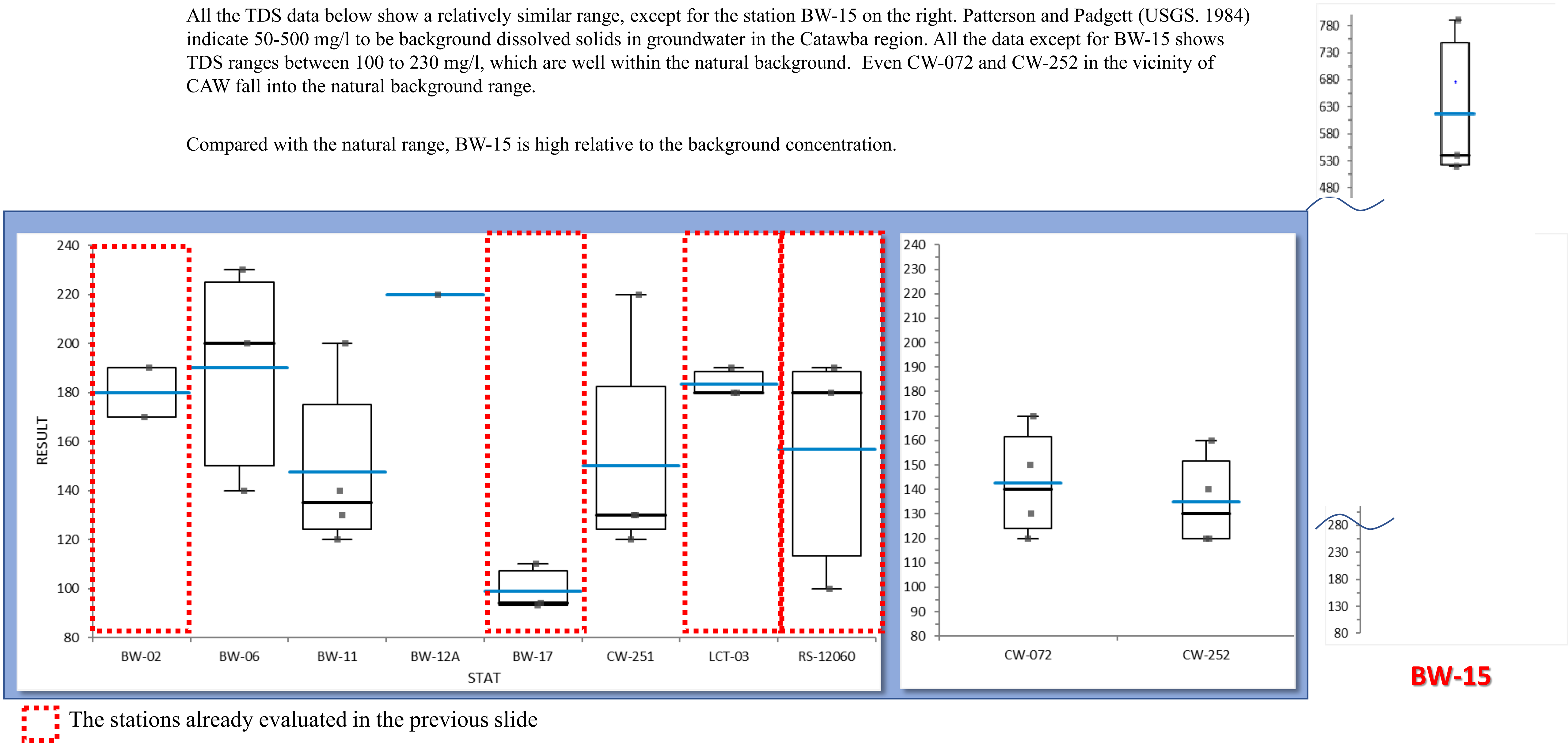


At each sampling station above, the percentage of forest clearcuttings area within each watershed was regressed with TDS. As the R-square between the clear-cuts and TDS shows, the relationship is non-detect. Then, are these observed TDS ranges natural?

In terms of TDS concentrations, what is the natural background concentration in these basins?

All the TDS data below show a relatively similar range, except for the station BW-15 on the right. Patterson and Padgett (USGS. 1984) indicate 50-500 mg/l to be background dissolved solids in groundwater in the Catawba region. All the data except for BW-15 shows TDS ranges between 100 to 230 mg/l, which are well within the natural background. Even CW-072 and CW-252 in the vicinity of CAW fall into the natural background range.

Compared with the natural range, BW-15 is high relative to the background concentration.



The stations already evaluated in the previous slide

So why TDS and turbidity is high at BW-15?

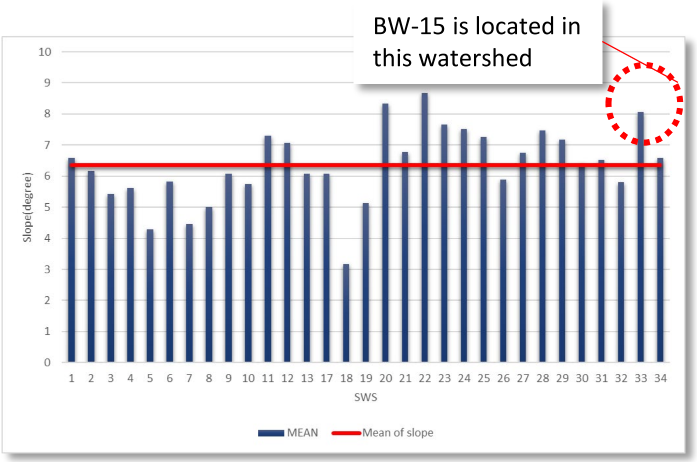
At first, please look back at Slide 10 .

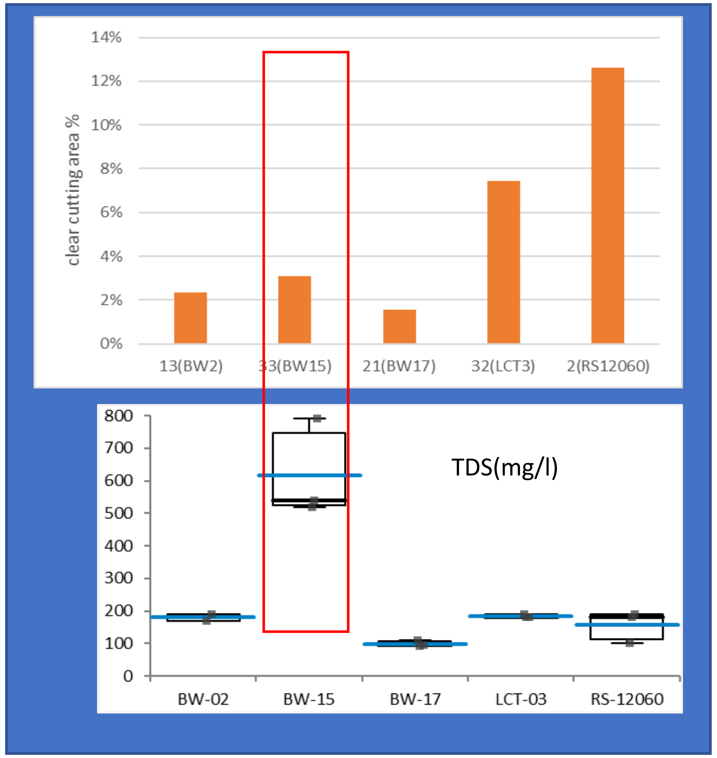
TDS considerations at BW-15

There is a detention pond at the headwater section. The picture indicates the water in the reservoir is very turbid. If this water is being discharged so often during storm events, it could add potentially high silt/clay content to the water. Silt/clay particles are small particles; thus, they tend to stay in the water column, not being deposited quickly/easily and potentially end up in the arm of the Lake Wateree. A plot of an averaged watershed slope for each subwatershed (on the top right plot) indicates the watershed's slope of sws 33 is one of the steepest ones. The average gradient in degree indicates sws 33 is ranked as a third steepest watershed among the delineated watersheds. In terms of erosion, this steeper slope could work in the following ways:

- Flow velocity would be higher, and the travel time would be shorter and give less opportunity for particles to deposit.
- Turbulence due to a higher flow rate also keeps the particles suspended in the water column.

The plot in the middle shows the percentage of clearcutting area within each subwatershed. Compared with the other sampling locations with forest clearcuttings, BW-15 shows much more elevated TDS. Clearcuttings in SWS 15 is relatively small compared with the other sites. Therefore, constant high TDS values observed at BW-15 is not clearly linked to forest clearcuttings, probably more related to other sources such as the potential reservoir discharge during the storm event flow.





The number before the sampling station id is subwatershed number.

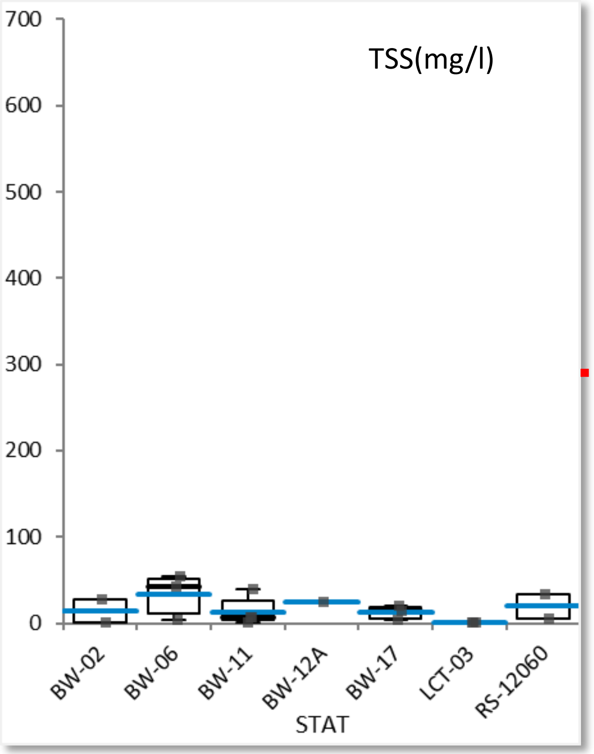
Next Questions:

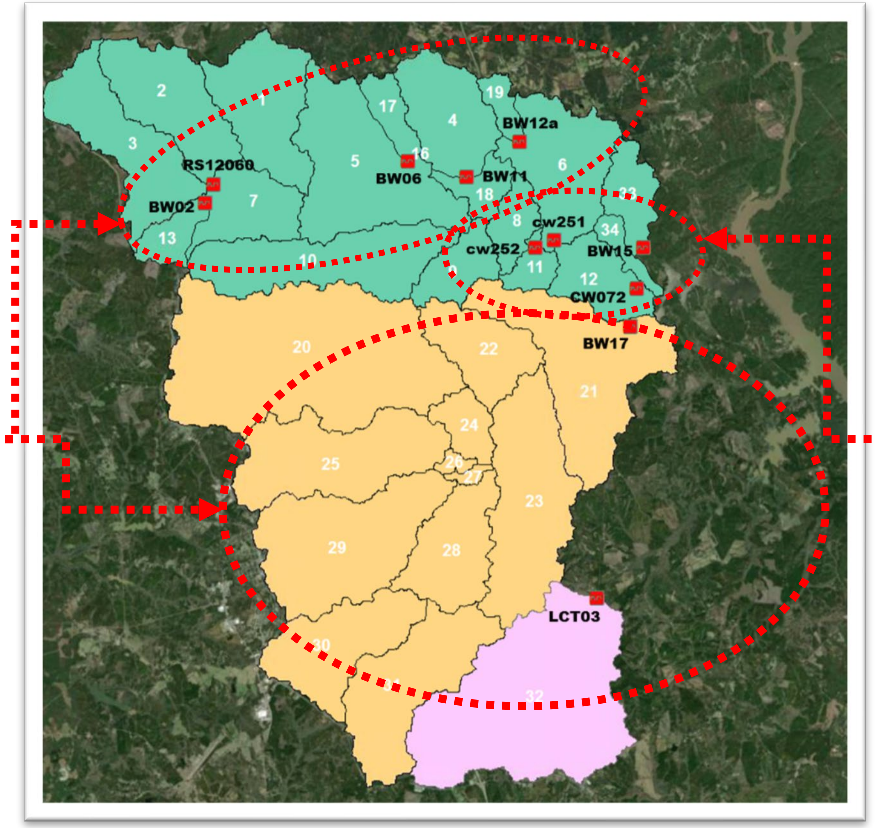
What are TSS sources in lower Big Wateree Creek?

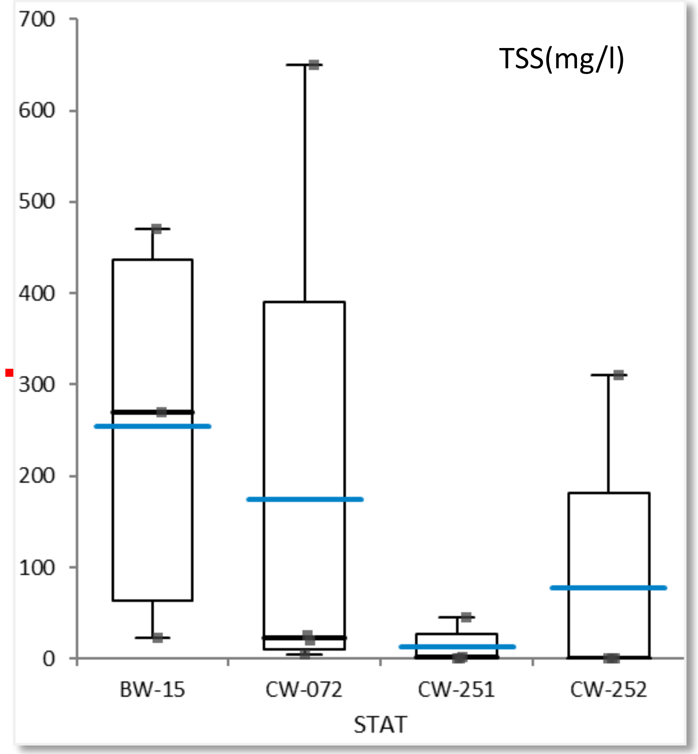
We will revisit the instream sampled data and additional data to evaluate TSS conditions. Furthermore, in order to better quantify the erosion conditions from a potential source, the Revised Universal Soil Loss Equation (RUSLE) model will be applied to the basin.

TSS analysis

Is TSS only a problem around lower portion of Big Wateree Creek?







1. At first, a range of the TSS sampled data was re-examined throughout watersheds. The box plots on the left show the data sets collected outside of the lower Big Wateree Creek. The box plots on the right show samples collected around the vicinity of CAW. The data around CAW indicate higher TSS concentrations, except for CW-251.

2. As a next step, we will examine potential erosion sources. For that purpose, the Revised Universal Soil Loss Equation (RUSLE) model will be applied to quantify the erosion loads better. The model (RUSLE) is widely used to evaluate site erosion. The next slide will explain the model in a little more detail.

land cover	Cfactor
Developed, Open Space	0.04
Developed, Low Intensity	0.02
Developed, Medium Intensity	0.01
Developed, High Intensity	0
Barren Land	0.35
Deciduous Forest	0.0005
Evergreen Forest	0.0005
Mixed Forest	0.0005
Shrub/Scrub	0.001
clearcutting	0.014
Sedge/Herbaceous	0.01
Pasture/Hay	0.01
Cultivated Crops	0.24
Woody Wetlands	0
Emergent Herbaceuous Wetlands	0
CAW	0.35

C factor was from NLCD modified based on the information from

https://msu.edu/~xuhui3/index_c.html and Jung, H., Jeon C.S. W., and D.K. Lee. Development of soil water erosion development of soil water erosion module using GIS and RUSLE, 2004

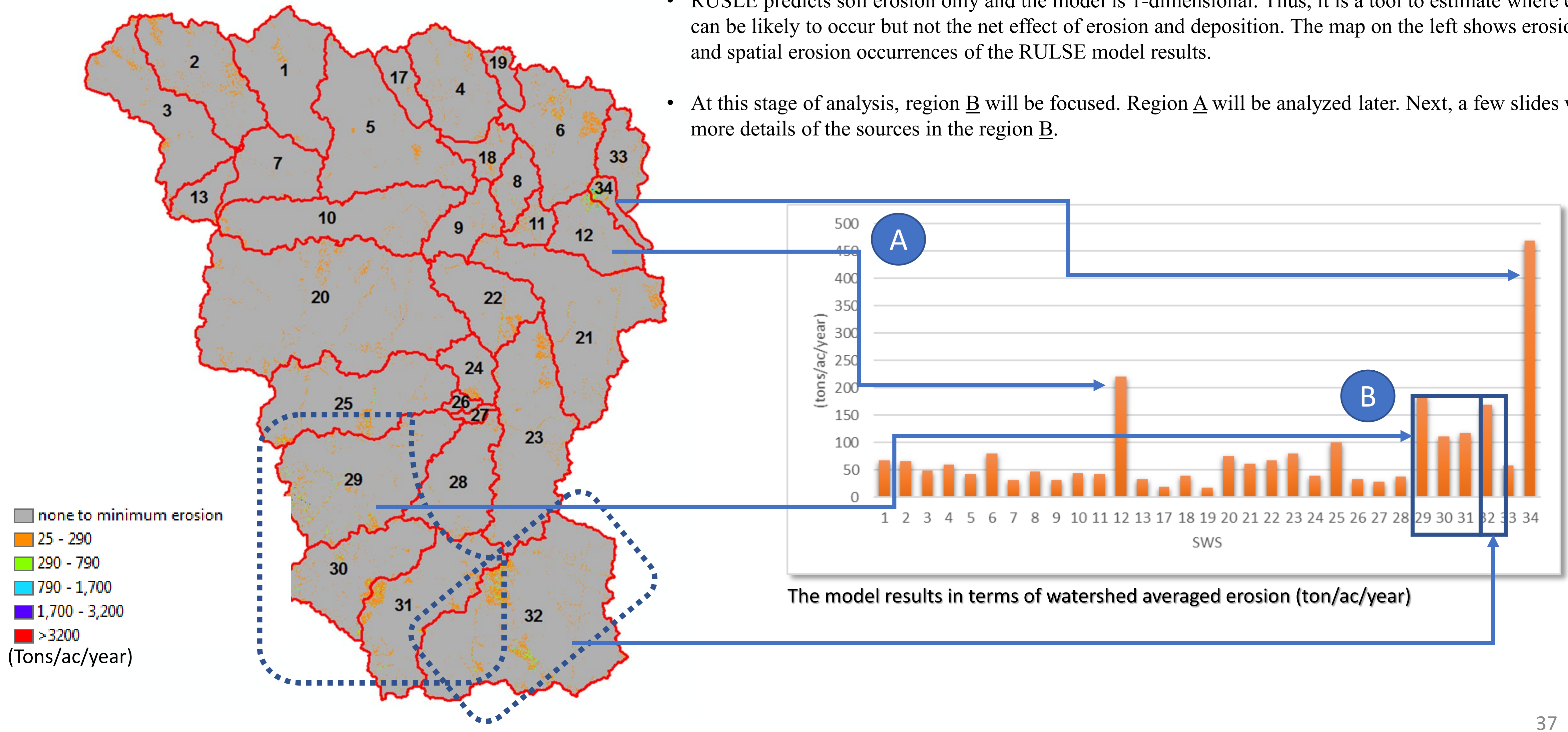
**Herbaceous land-use in NLCD was identified to be mainly clearcuttings. This was confirmed based on the visual analysis using 2016 NLCD and aerial photo (see also slide 6). C-factor for clearcuttings is from USDA's "predicating erosion losses" .*

Revised USLE - RUSLE

Revised USLE - RUSLE uses the same empirical principles as USLE; however, it includes numerous improvements, such as the incorporation of convexity/concavity using segmentation of irregular slopes, and improved empirical equations for the computation of LS factor. To incorporate the impact of flow convergence, the hillslope length factor was replaced by the upslope contributing area. C-factor (reflecting the effect of cropping and management practices on erosion rates) was selected based on literature values (see the table on the left). K-factor (susceptibility of soil to erosion) was derived from USDA's SURRGO database. 10m*10m DEM grid was used for this analysis. Rainfall erosivity index was selected to be 290 from South Carolina Columbia region.

RUSLE Model Results

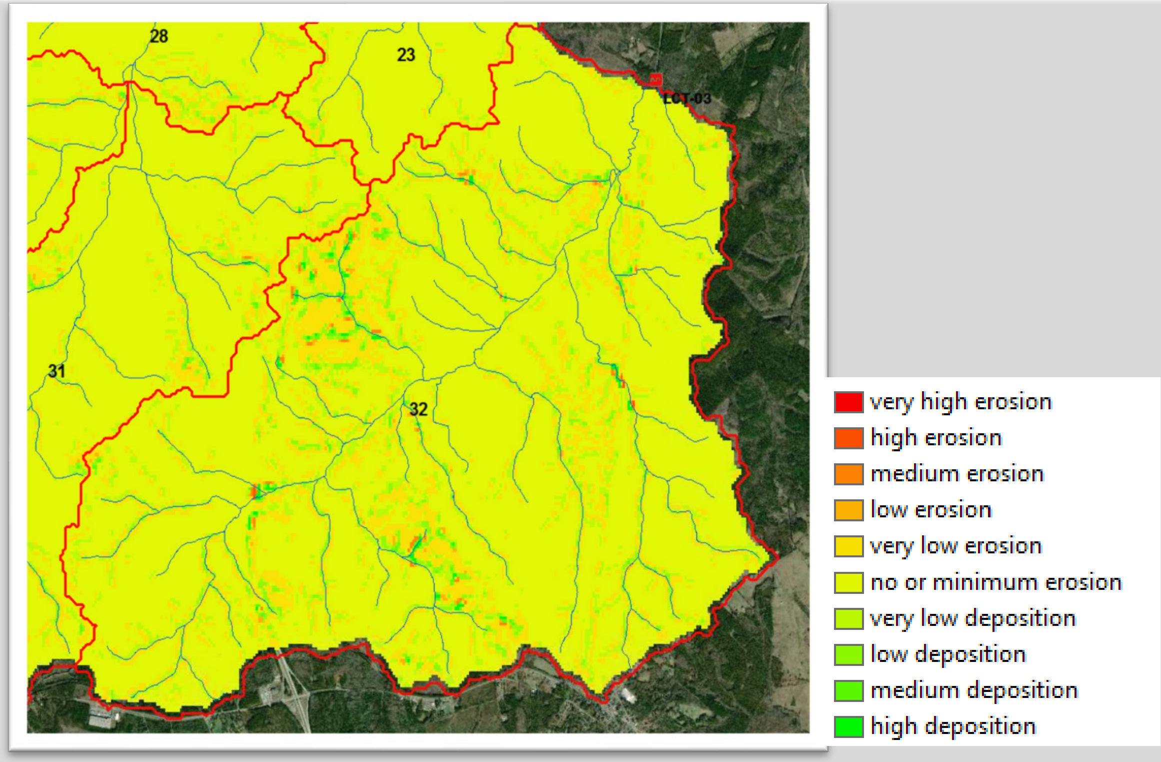
- RUSLE model's results showed that sws 12 and 34 (near CAW), and sws 29 through 32(located in Little Wateree Creek and Dutchmans Creek) have higher erosion loadings (see the plot below). Sws 12 & 34 will be identified as a region A hereafter while sws 29-32 will be named as a region B.
- RUSLE predicts soil erosion only and the model is 1-dimensional. Thus, it is a tool to estimate where erosion can be likely to occur but not the net effect of erosion and deposition. The map on the left shows erosion load and spatial erosion occurrences of the RULSE model results.
- At this stage of analysis, region B will be focused. Region A will be analyzed later. Next, a few slides will look more details of the sources in the region B.



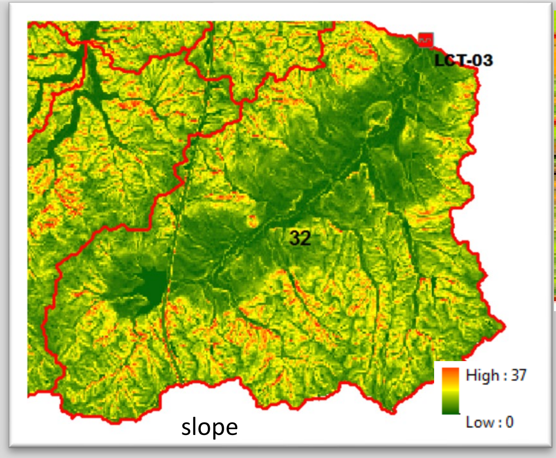
The model results in terms of watershed averaged erosion (ton/ac/year)

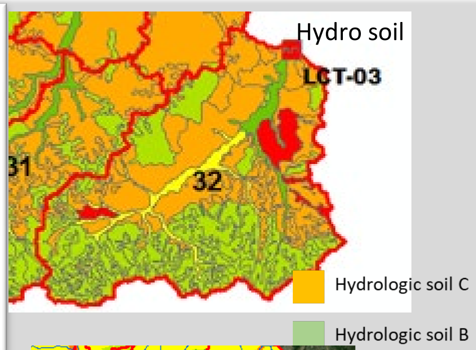
Sws 32

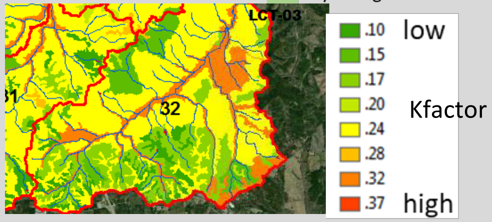
A comparison of the high erosion area and the aerial photo reveals that the higher erosion area mainly corresponds with forest clearcuttings. However, the instream observed data collected at downstream from the clearcuttings in 2019 don't support any elevated TSS concentrations in the region B. Since RUSLE only predicts erosion, additional model, USPED (Unit Stream Power – based Erosion Deposition) was applied to visually verify not only erosion but also where deposition might occur. USPED is a 2-dimensional soil erosion model. Unlike the 1-dimensional revised universal soil loss equation (RUSLE) model, USPED assumes that soil erosion and deposition based on the 2-dimensional water and sediment fluxes under the influence of local terrain features.



USPED model indicates that potential erosion (orange color) occurring around the forest clearcuttings and barren land. However, the model also suggests that depositions (green color) occur around the eroded area due to concave/flat land surface to reduce the runoff sediment carrying capacity. And also, the upland land use type, such as forest, can reduce potential accumulated water runoff and reduce the erosive power at the downstream end. In the end, the USPED model result indicates that erosion occurs around the disturbed land area, but the eroded mass tends to deposit in the vicinity of the eroded area as well.





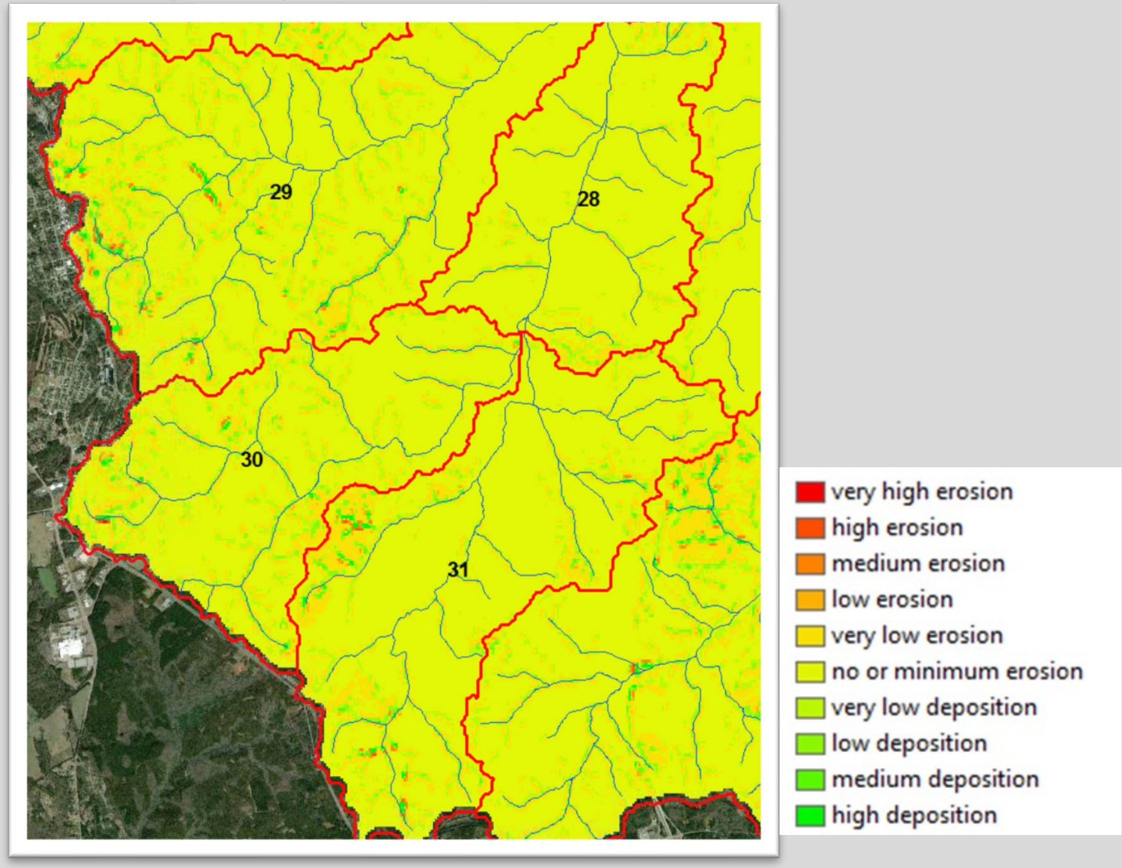


The basin slope data at Dutchmans creek indicate the very flat area around the main stem (see the top left figure) and to LCT-03. This low relief of the surface elevation would tend to slow down water movement and could trap sediments. Additionally, the hydrologic soil evaluation (plot on the top right) reveals that there are two types of soils in the watershed: B & C. B is characterized as a higher infiltration. Thus, lesser runoff compared with C. The steeper slope region appears to have higher infiltration, which would provide less runoff from the area, thus less erosion. K-factor (susceptibility of soil to erosion) also indicates low erosion potential in the same steeper region (the figure on the lower right). Higher K-factor around the stream is covered by riparian vegetation, so lower erosion potential. The clearcuttings appear to be located higher slope where less erosion could occur. All this evidence, in addition to the localized deposition, those predicated eroded soils were deposited within the basin, which supports low TSS values at LCT-03.

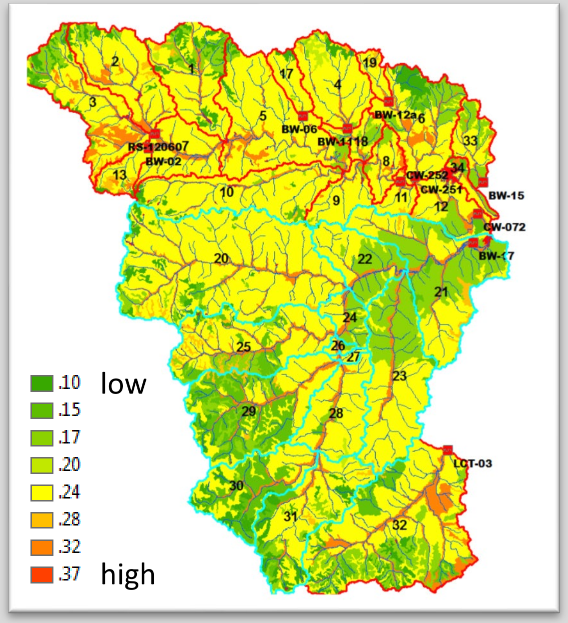
Sws 29, 30, and 31

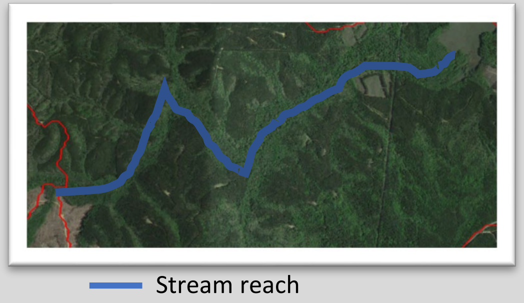
There is no direct downstream sampling location for the outlets of these watersheds. However, BW-17 is located at the outlet of Little Wateree Creek (sws 29, 30 and 31 located at headwaters of Little Wateree Creek).

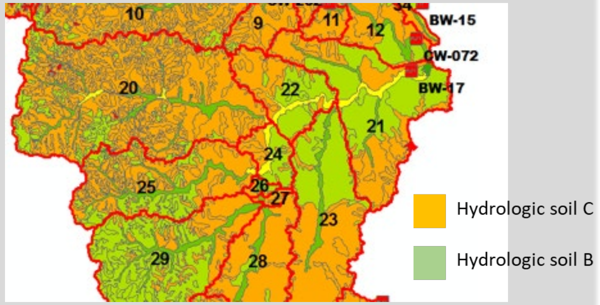
A comparison of the high erosion area and the aerial photo reveals that the higher erosion area mainly corresponds with forest clearcuttings and some loads from the residential setting area. The USPDE analysis was expanded to sws 29 to 31 where RUSLE identified sediment erosion (orange color). A similar story here that erosion coincident with clearcuttings and co-occurring with deposition (green color) area within short proximity to where the erosion occurs.



The left figure shows the K-factor (susceptibility of soil to erosion) of the Little Wateree Creek (the blue highlighted area). K-factor data reveals that the large portion of lower Little Wateree Creek's soil is categorized as minimum erosion potential soil. Additionally, K-factor shows erodible soil existing around the stream reach area (dark orange color). However, the aerial photo indicates that the area is covered by riparian vegetation, thus less likely that erosion occurs there, but more deposition. Hydrologic soil type at the outlet is also B, which is higher infiltration, thus less runoff and erosion. Therefore, no significant erosion mass is predicted to be added from the near outlet of the creek. All these data support BW-17 showing no significant TSS observed at the sampling location.







What do we know so far?

Forest clearcutting potentially erodes ground surface but also deposits the eroded material within the vicinity of the disturbed area due to both the localized concave/flat land surface and the reduced runoff by piled organic litter on the ground.

↓

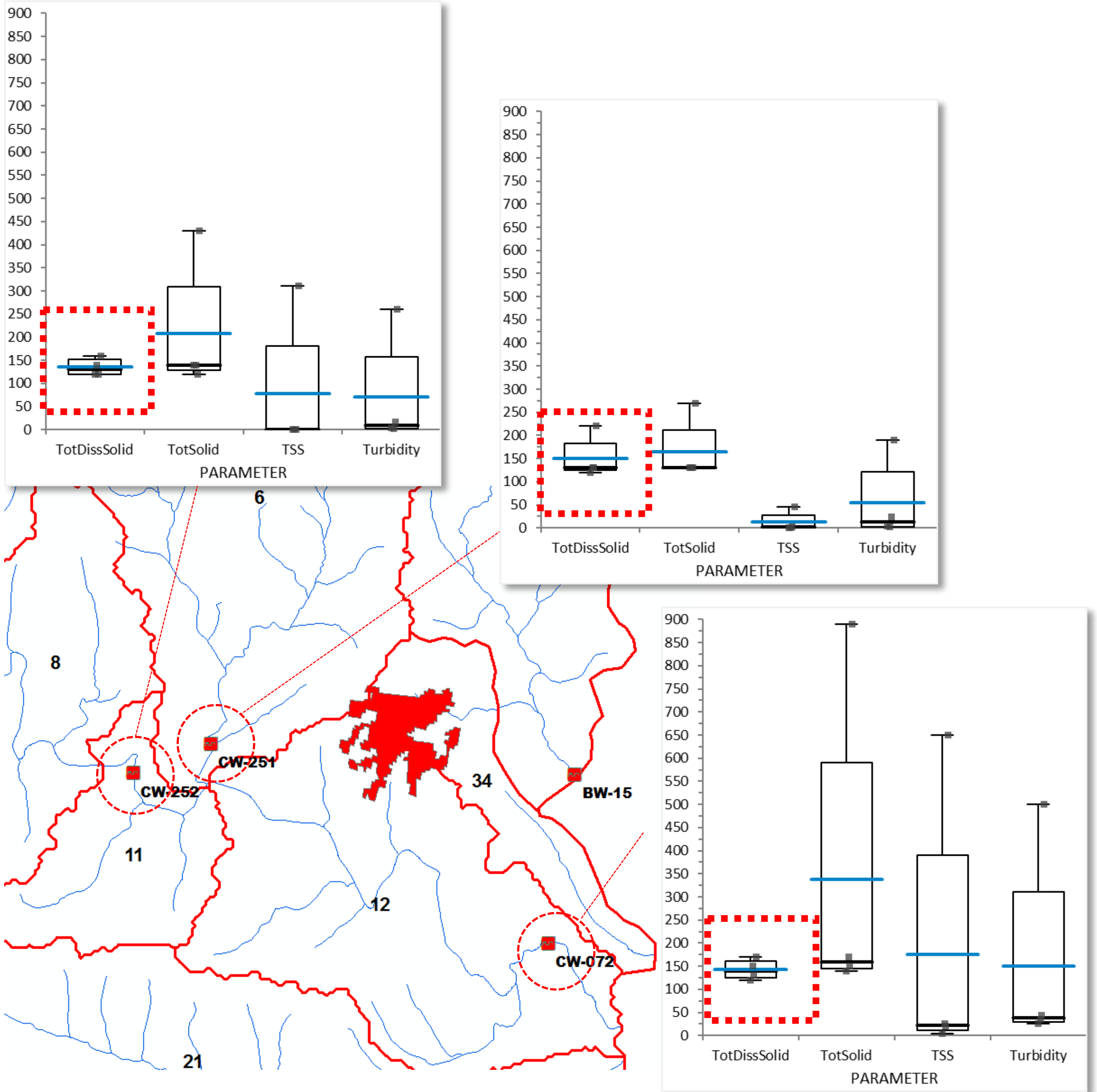
Dutchmans Creek and Little Wateree Creek (Region B) have lower potential to generate TSS: A threat to Lake Wateree's turbidity and TSS conditions is minimum from these basins.

↓

At this point, our focus will be sifted to an evaluation of CAW and surrounding area (Region A)

CAW & the surrounding area (Region A)

All the units in the plots are mg/l but NTU is used for turbidity



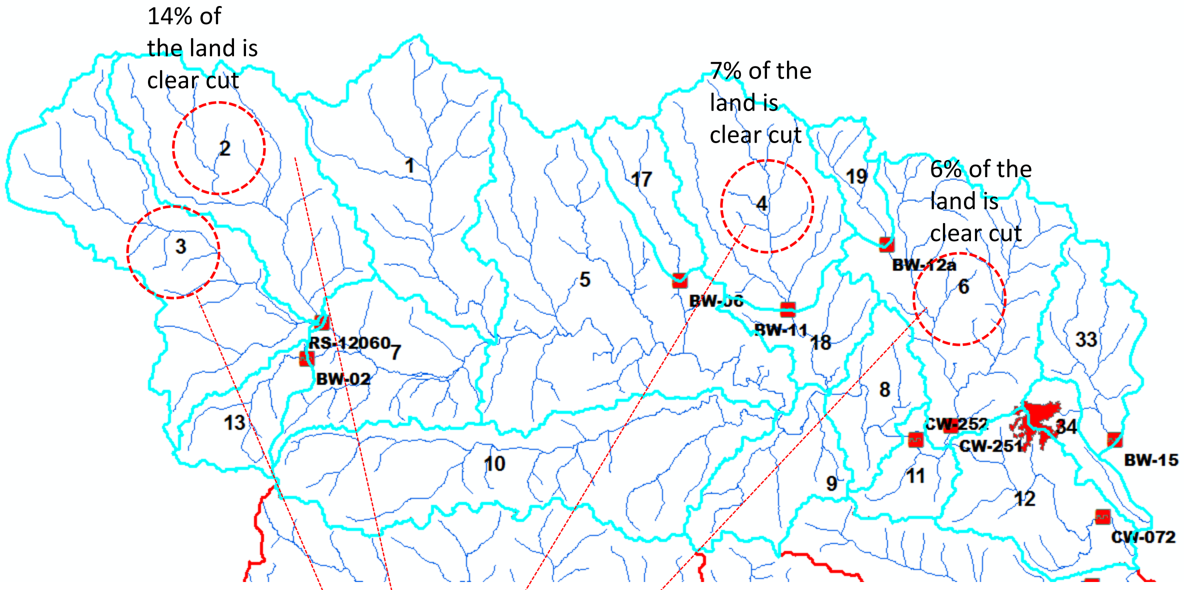
Three stations were selected (CW-251, CW-252, CW-072, see the location in the map on the left) to evaluate a spatial transition of the parameter values from the upstream of CAW to the downstream of CAW. At first, we will be assessing whether subsurface loadings from the surrounding area of CAW has influenced the jumps (TSS, Total solids, turbidity) at the outlet of Big Wateree Creek. Subsurface loading could be significant, especially for turbidity and total dissolved solids. After the subsurface loading's evaluation, surface loading will be examined next.

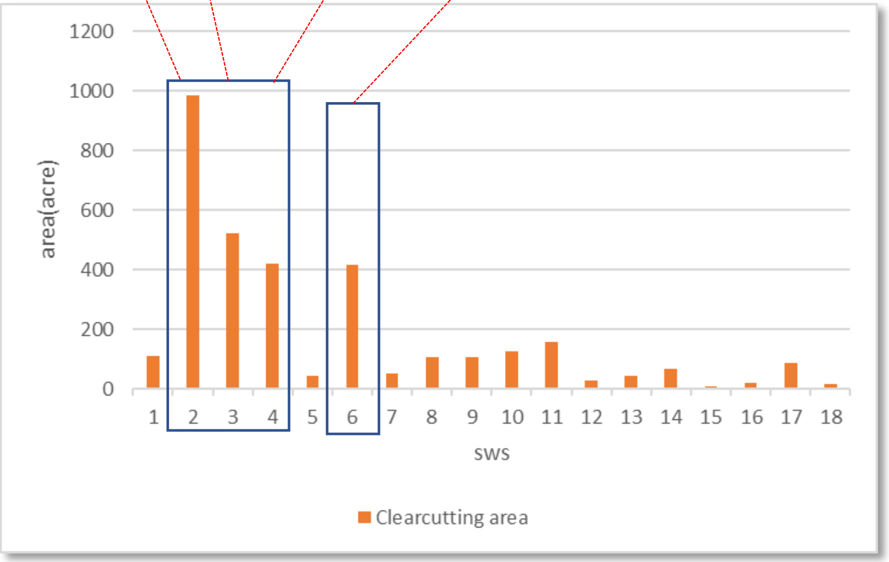
Subsurface loading evaluation

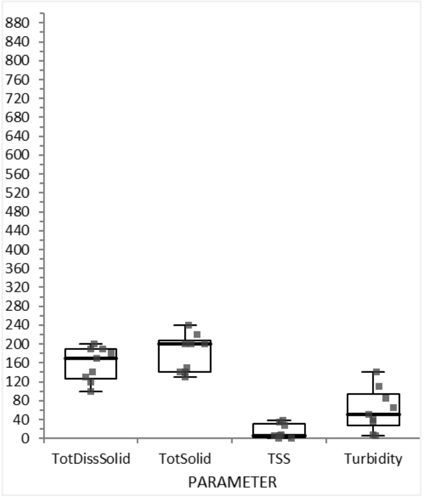
In order to evaluate subsurface loadings, total dissolved solids (TDS) was selected. TDS usually consists of calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulfates. These chemical components are rather conservative, so it is a good indicator of whether some large loading is being added to the system since the large loading would dominate the mixed solution. Here, it appears that TDS values show the background concentration of around 150 mg/l and not much fluctuation in spite of the observed flow being varied at each location. This relatively constant low TDS indicates that subsurface sources contributing to these sampling locations are more likely the same local and/or regional natural subsurface sources. Thus, the low TDS and the consistency of the TDS values indicate that no specific anthropogenic subsurface source influenced Turbidity or TSS conditions observed at CW-072.

Now, with the evaluation of subsurface source, our focus will be sifted to surface loading, such as CAW and/or clearcuttings occurring within the Big Wateree Creek basin.

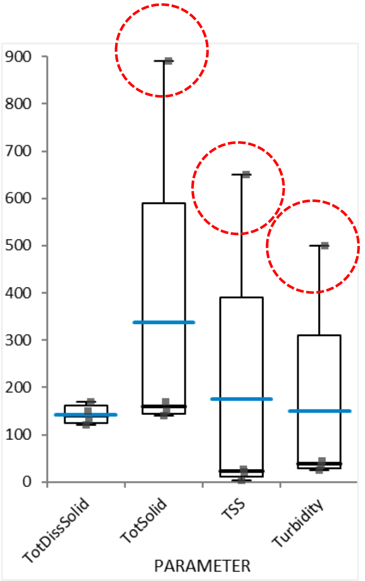
Is clear cutting affecting TSS and other parameters in Big Wateree Creek?



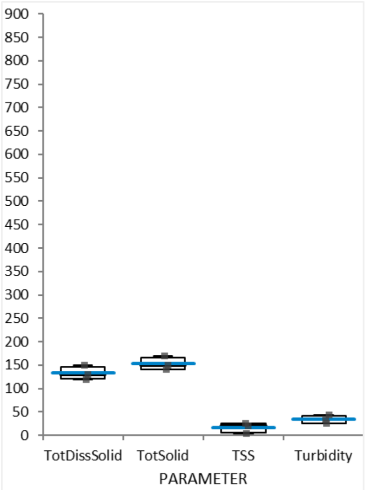




Sws 2 & 3, 4 and 6



CW-072



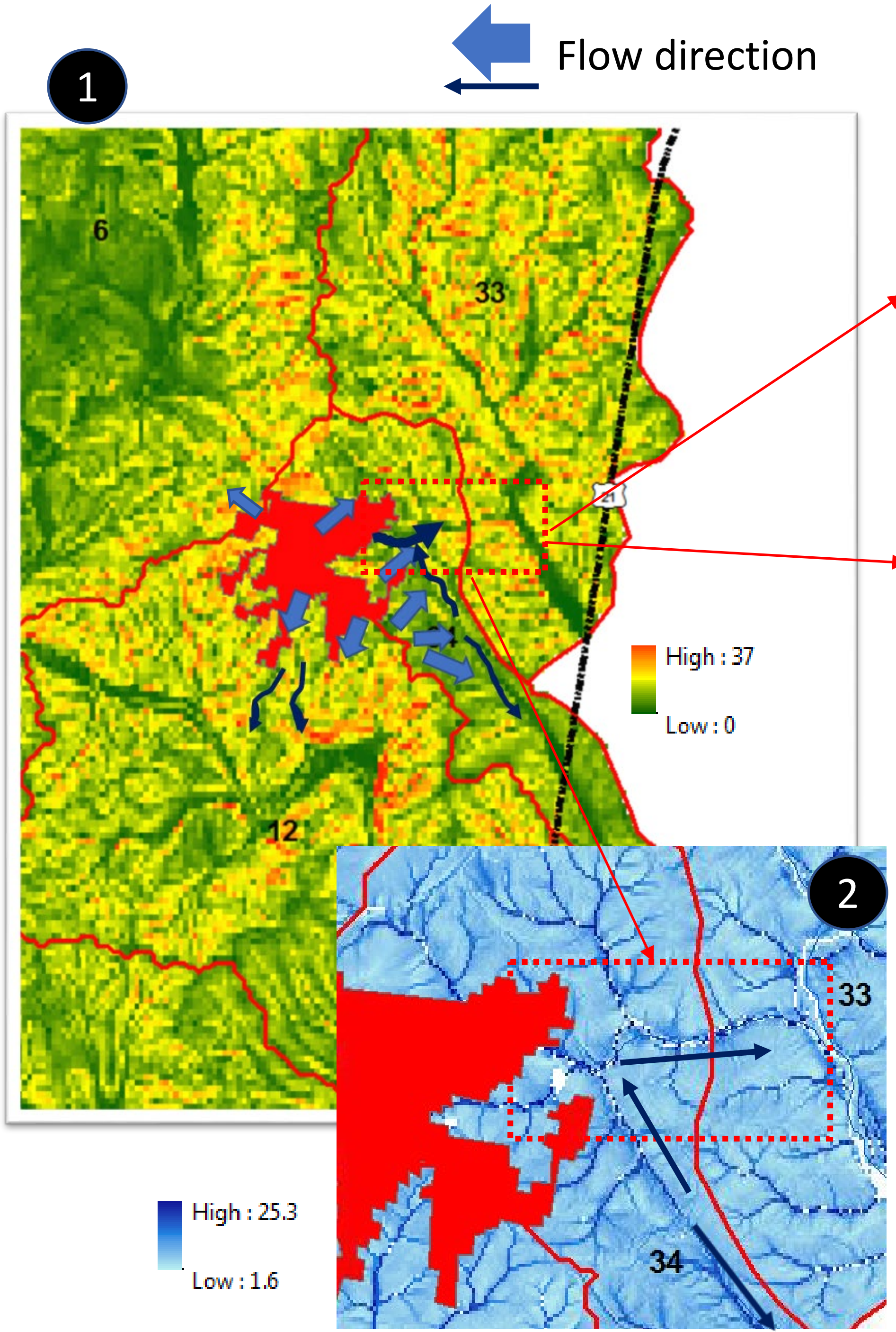
CW-072 without August data

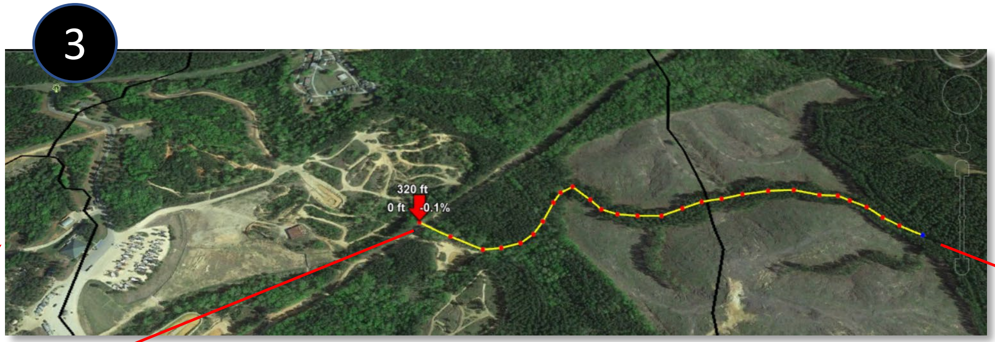
- A relatively large area of clearcuttings are located in sws 2, 3, 4 and 6 (the plot in the lower left). All these sites have the data collected during 2019. The box plot on the above left show the data trends. All the data at these locations are low as the plot shows.

- TSS value (15mg/l as averaged) and any other values at the locations (sws 2, 3, 4 and 6) are much lower than the data from CW-072. Thus, at this stage of the analysis, it is safe to say that the clearcuttings in sws 2, 3, 4 and 6 didn't affect TSS conditions at CW-072 or any other parameters of CW-072.

- The other thing noticeable here is that CW-072 (the middle plot) was skewed due to the sample collected from the August sampling event. If there was no August data, the CW-072 data appeared to be no different from TSS conditions at the headwater watersheds (sws 2, 3, 4, and 6)(the plot on the right). This indicates that without some extreme event, such as the high intensity of rain, TSS and turbidity conditions between the headwaters and the outlet location would be the same.

CAW's physical characteristic analysis





The figure on the left (figure 1) shows the slope condition of the CAW area and potential flow directions based on the slope.

Two things to notice from this plot:

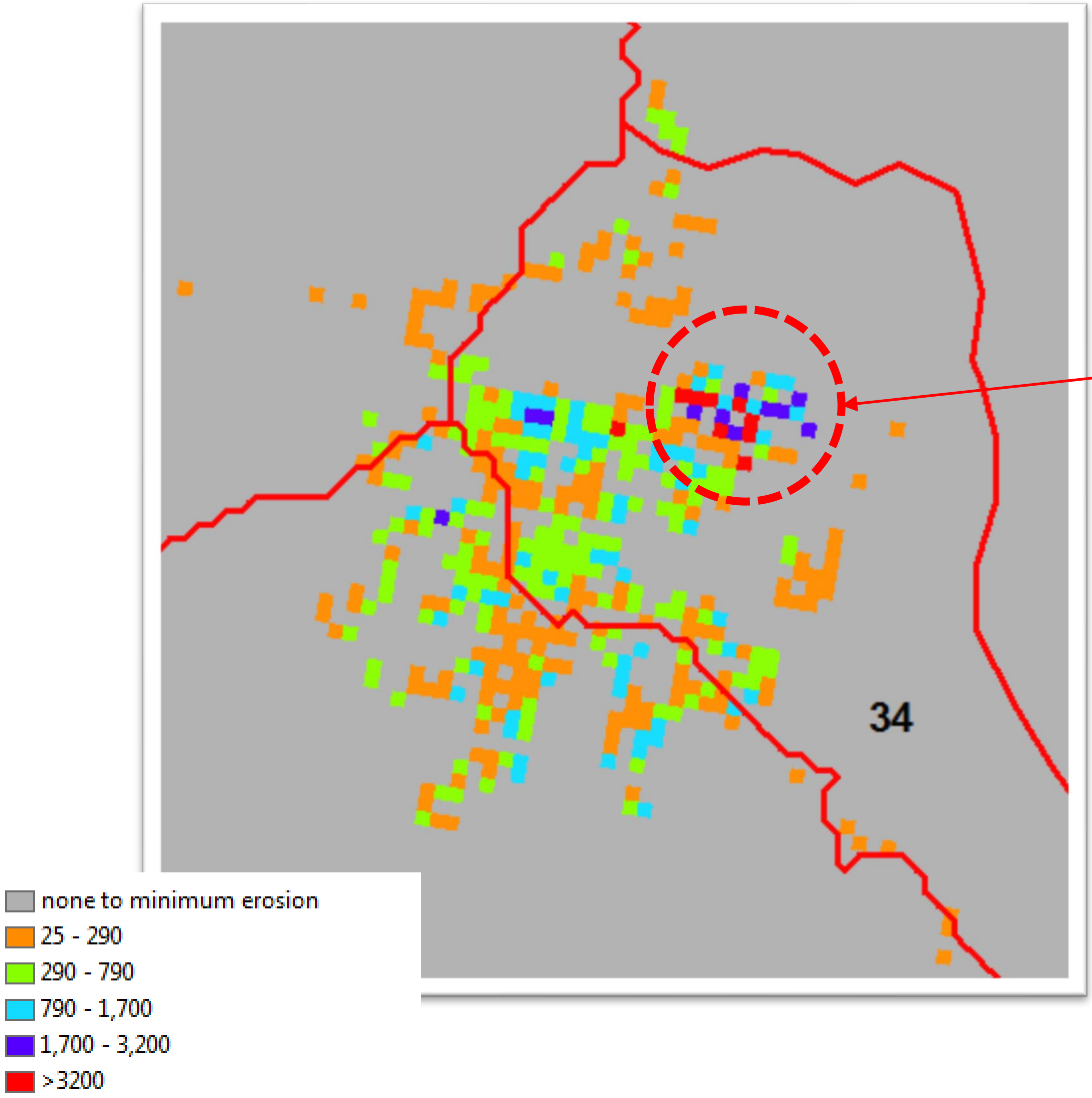
1. The slope map indicates three general slopping directions from CAW: toward sws 6, sws 12 and sws 34. However, according to CW-251 data, the sediment flow toward sws 6 is probably minor (refer to slide 22 though 25).

2. Flow directions of CAW east side is a direction toward to sws 33. The map and the slope condition plot above (figure 3) show the possible flow path into sws33 from sws34. TWI map (see the lower left , figure 2) also indicates the moisten soil/shallow subsurface water as runoff/flow paths into sws33 from CWA area (the blue arrows indicate the flow directions).

–TWI (the wetness topographic index) . The TWI represents a relative likelihood that a rainfall event saturates the soil and generate overland runoff based on the upslope contributing area per contour length and the local slope base on the grid data.

RUSLE results for CAW

This figure show RUSLE model result of CAW. It shows exceptionally high intense erosion at the right edge of the property.

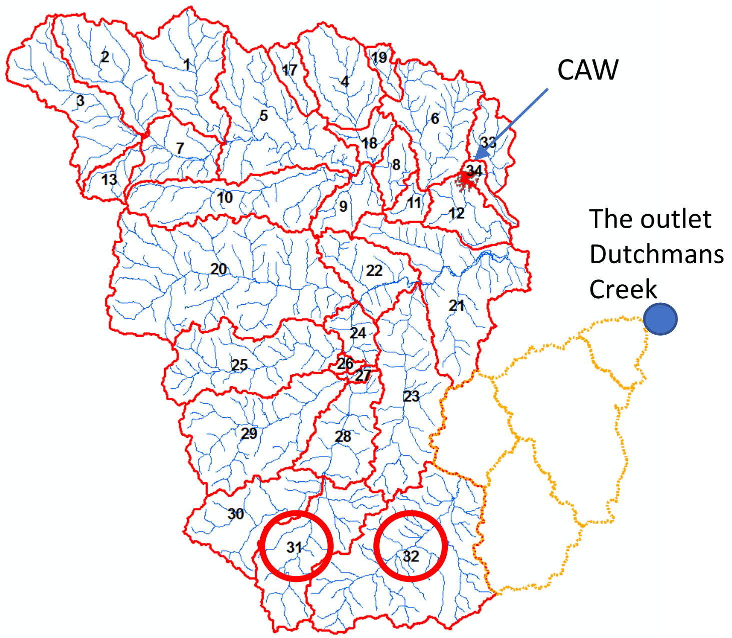


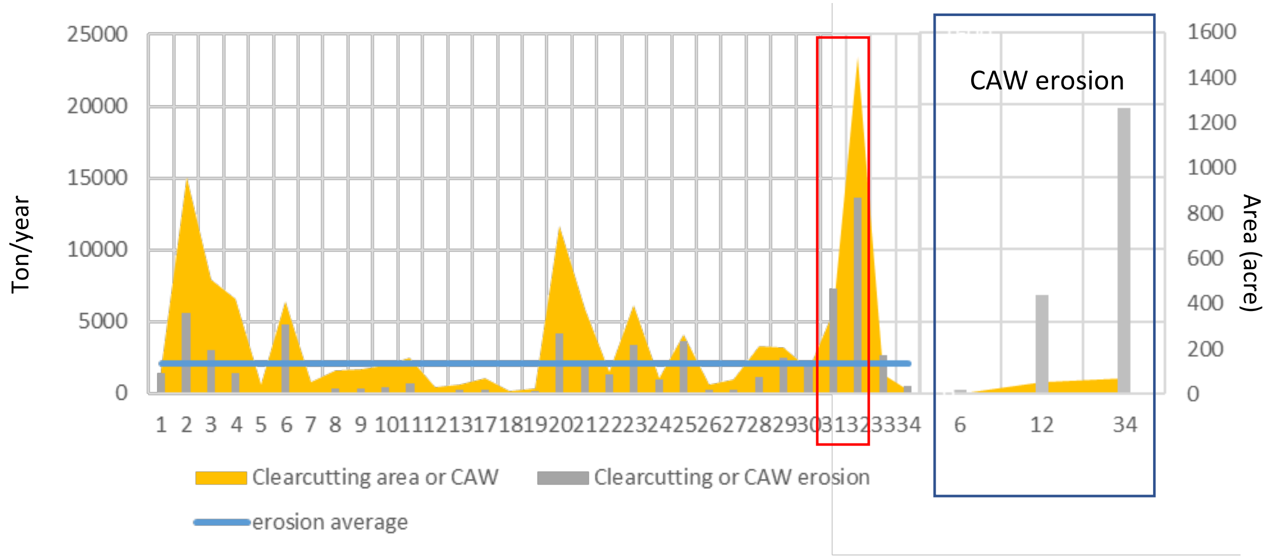
This figure shows the corresponding location of the intense eroding location

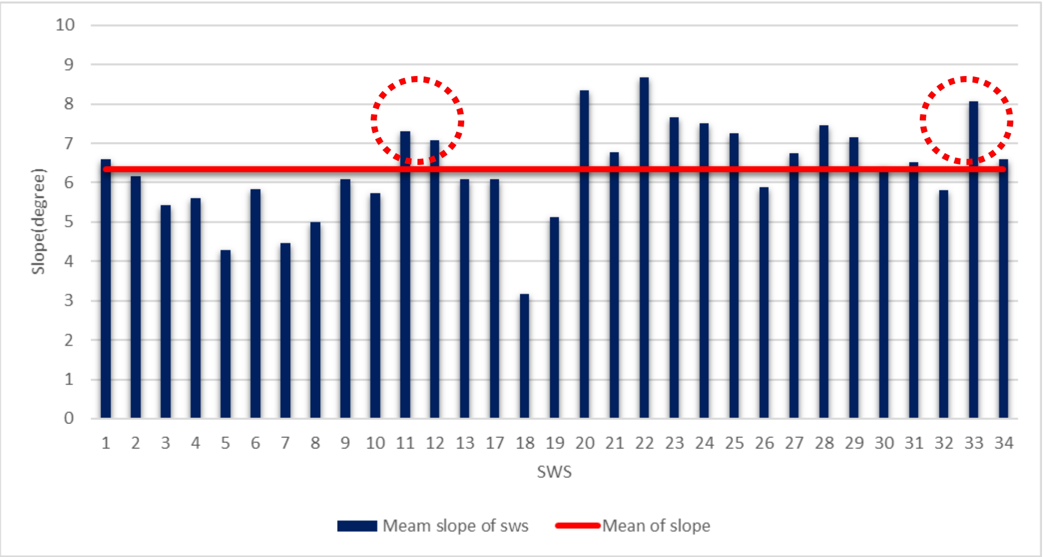
RUSLE model for CAW

CAW loadings from RUSLE (the blue rectangle) are shown here next to the clearcutting erosion loadings plot. In spite of the small CAW area, the sediment loading of CAW in sws12 and sws34 is similar or significantly more than the clearcutting loads of sws 31 and 32, which is one of the largest loads besides the CAW. It was concluded that the previously described factors (K-factor, slope, depositions, etc.) to be a reason why the clearcutting's sediment loadings from sws 31 and 32 didn't end up leaving significant effect (e.g., high TSS) at the outlets of the basin (LCT-03 and BW-17).

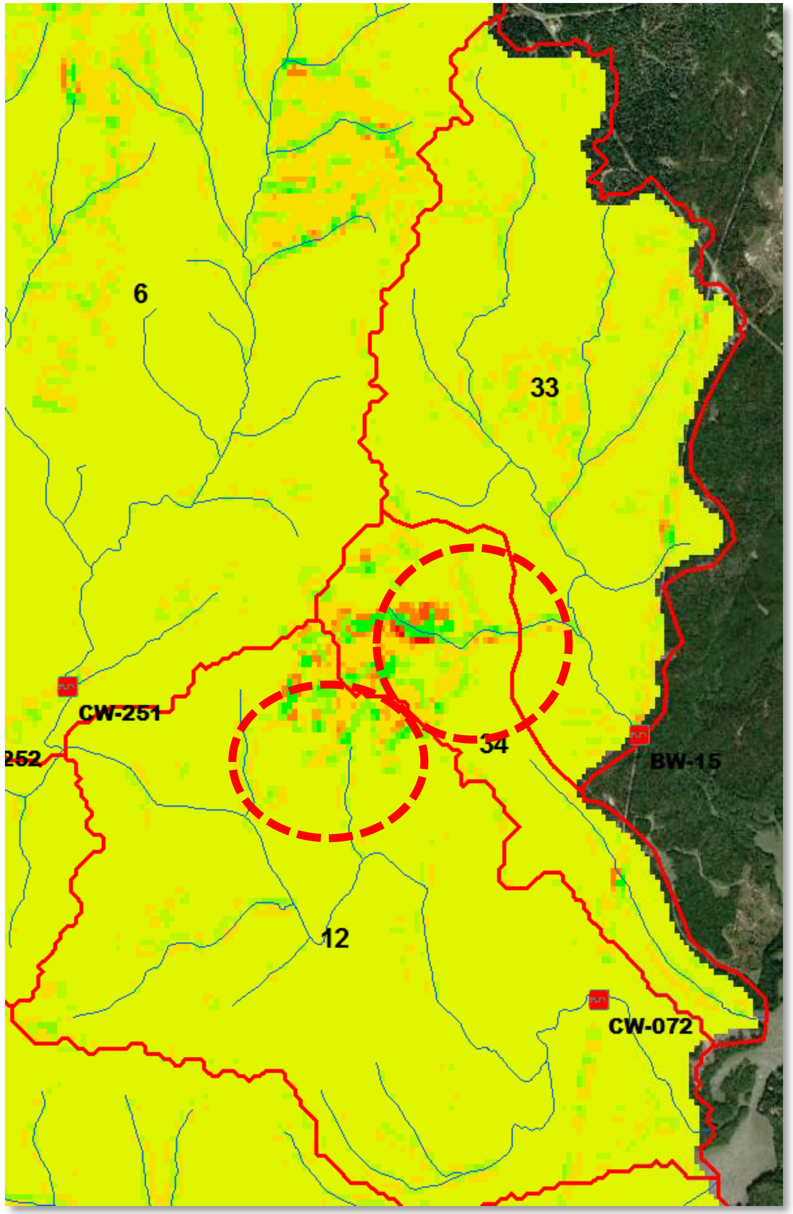
For the case of CAW, the exposed/uncovered land surface of CAW is located very close to the flow pathways that lead to the lake Wateree within much shorter distance, thus, provide more chances that eroded mass can reach the cove. Additionally, slopes of sws11, sws 12 and sws 33 are one of the steepest ones, which also could accelerate the mass delivery to the inlet of the lake during the high rainfall event.







USPED model results around CAW

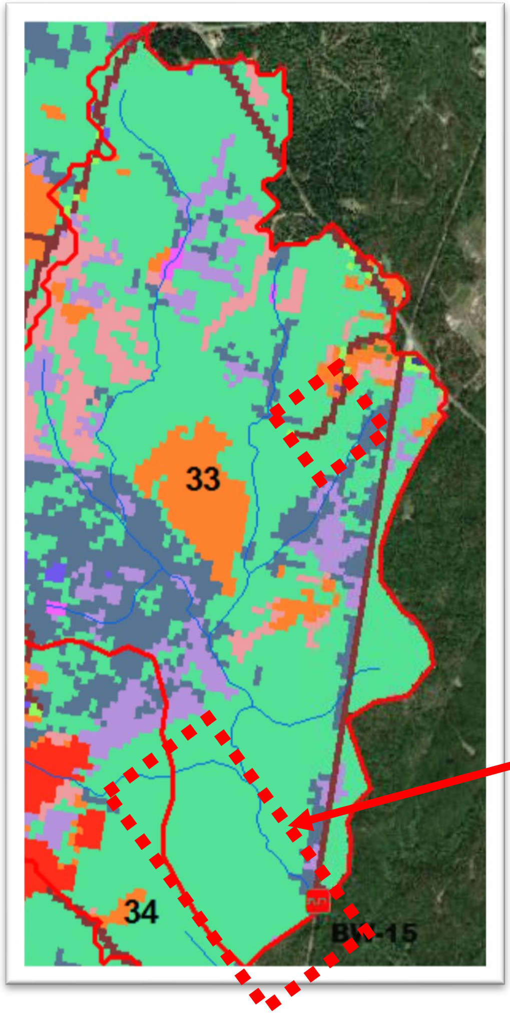


USPED results also indicate high erosion results similar to the RUSLE model. However, depositions (green color) around or near the potential stream reach is also visible(the red circle). During the high storm event, these accumulated sediments could scour away from the deposited location.

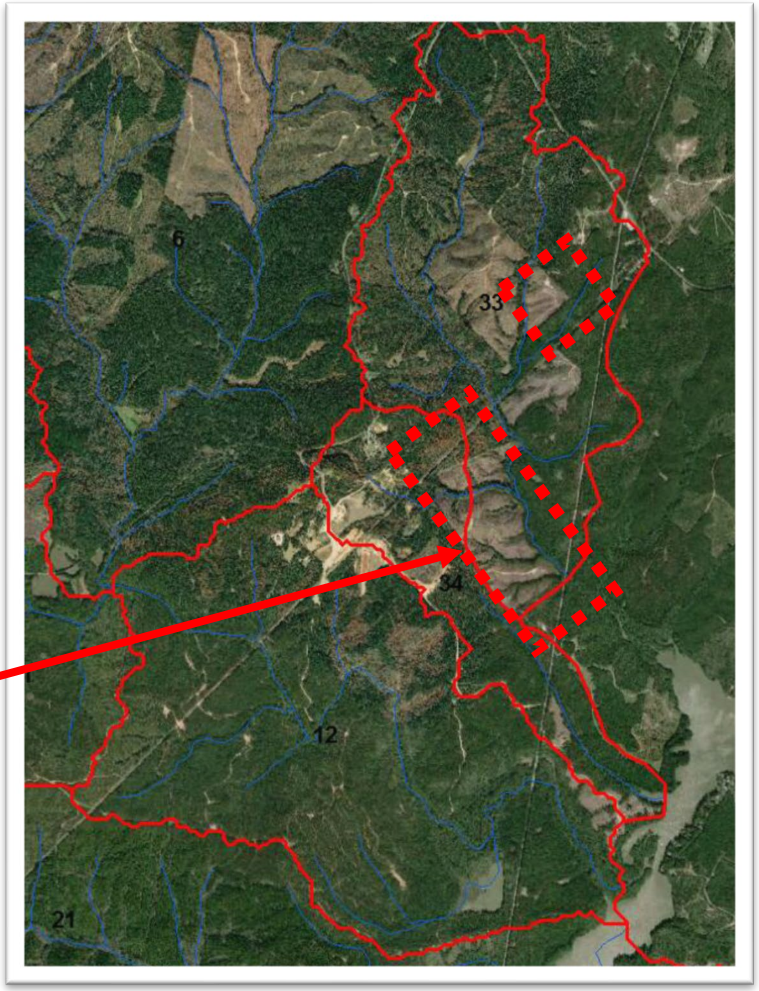
The missing clearcutting area near CAW

It appears that additional clearcutting activity happens after 2016 (the time during the most recent land use data was created). The clearcutting area missing from 2016 NLSD data is shown with the red box. The previous clearcutting analysis indicates that the tree harvesting activities usually do not end up generating a high load of any observed parameters. However, the location is very close to the Lake Wateree cove; thus, a further analysis was conducted.

2016 NLCD land use model

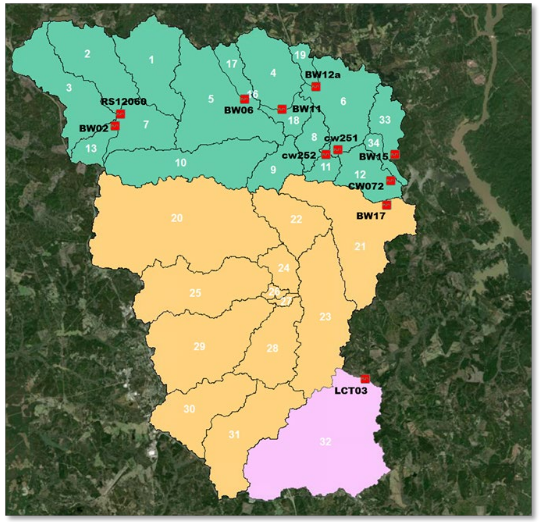


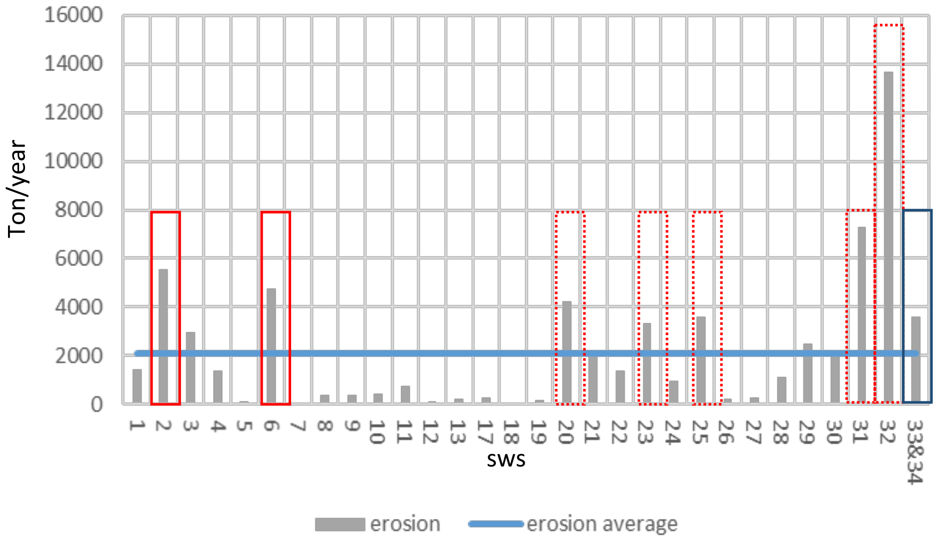
2019 March Ariel photo



Additional RUSLE model was run and erosion loading results of the clearcuttings in sws 33 and sws 34

After the missing clearcutting area was incorporated, an additional RUSLE model run was conducted. The plot on the right below shows the total erosion from the clearcuttings throughout the basin. USDA's sediment delivery ratio (SDR) method was assigned to account for deposition along the path from the erosion source to the watershed outlet. The watershed map is also shown here as a spatial reference purpose.





- Compared with the averaged clearcutting erosion of the whole basin (the blue line), sws 2, 6, 20 23, 25, 31 and 32 exhibit higher total erosion from the clearcutting area. The erosion conditions in Dutchmans Creek (sws2) and Little Wateree Creek (sws 20, 23, 25 and 31) were already discussed in the previous slides 37 through 39. Although it shows higher erosion from the clearcuttings, they tend to deposit and incorporate into soils over the extent of the watershed.

- According to the results, the clearcutting sediment loadings from sws 33 and 34 is lower than the erosion rates from sws 2 and 6 in Big Wateree Creek basin (see the plot on the right). As previously investigated, the TSS data at sws2 and 6 showed much lower concentrations than the ones observed at sws 33. Therefore, even if the clearcuttings in sws 33 and 34 generate sediment loads, an impact from the loadings can't be expected to be larger than sws 2 and 6 and likely to be not the dominant source of high TSS concentrations observed at BW-15. There is a potential of beaver dams located at these upstream watershed and detained eroded particles. If that is the case, it requires more investigation at these watersheds.

- The high TSS periods at BW-15 correspond with the high TSS occurrences at CW-072. CW-072 is located downstream from CAW area. As it was described in slide 41, TSS loading from CAW could be transported into the unnamed tributary in sws 33 through the moisten pathway during high flow events (see slide 43) .

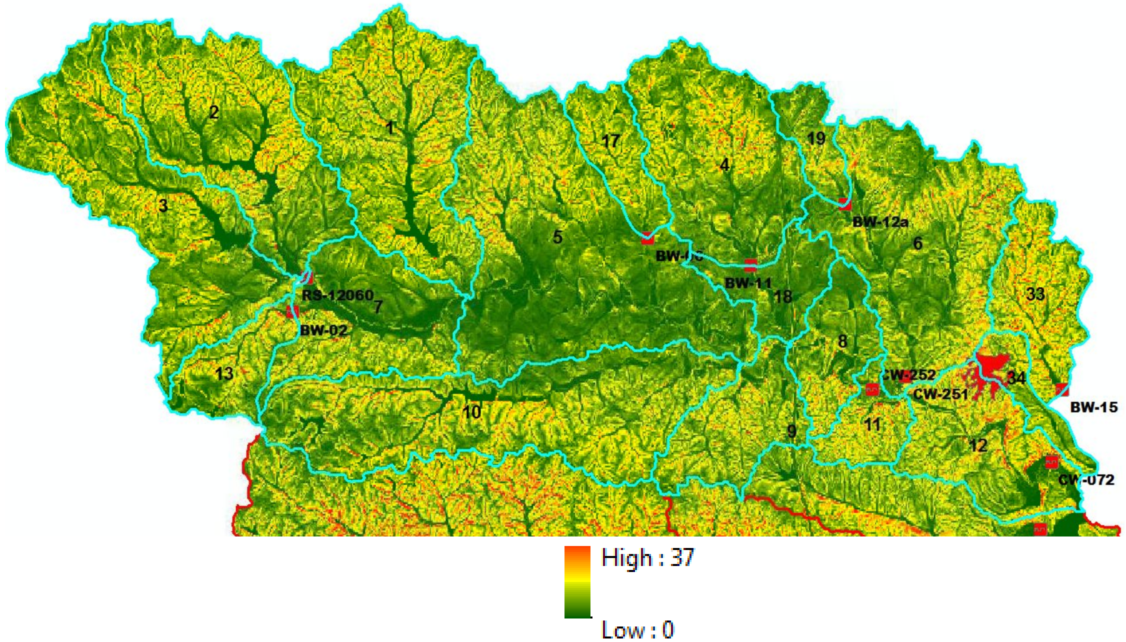
- The previously investigated reservoir water discharge within sws 33 could contain higher silt and clay particles that might have contributed to the August and October's observed high TSS at BW-15.

According to lower flow rates observed at BW-15 locations throughout the sampling events, the loadings can be expected to be low despite the higher TSS . Thus, although elevated TSS is possible in sws 33 and 34 from the clearcuttings, the impact of the loading from the sources in sws 34 and 33 to Lake Wateree shouldn't be the dominant TSS source to the Lake Wateree.

Physical & Soil & CW-252 analysis in Big Wateree Creek

Topographical relief consideration

The slope data below indicates that the relatively flat area occupies at the middle of big Wateree creek, then steeper slope starts from sws 11 and continue to sws 12(see the plot at the right bottom corner) .

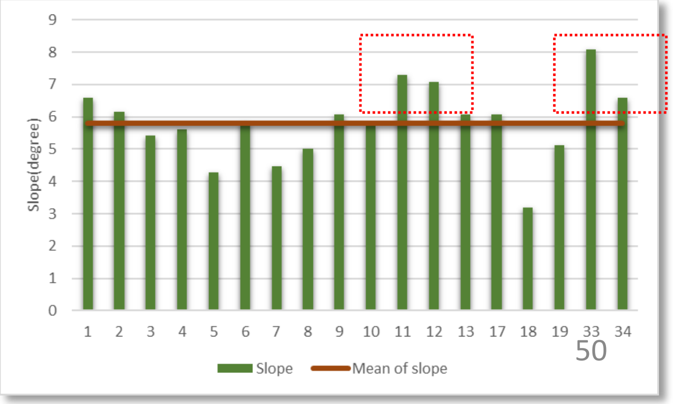


What can be explained from this topographical information-

1. The flat area could function as temporary water storage. So during the relatively small rainfall event or dryer period, it works as water storage. However, once this storage is filled up and there is no capacity to absorb more of the rainwater, it sends the excess water with a higher velocity with higher eroding capability due to the steeper slope from the end of the flat area. It potentially scours the already deposited erosion material around CAW and within the stream reach.

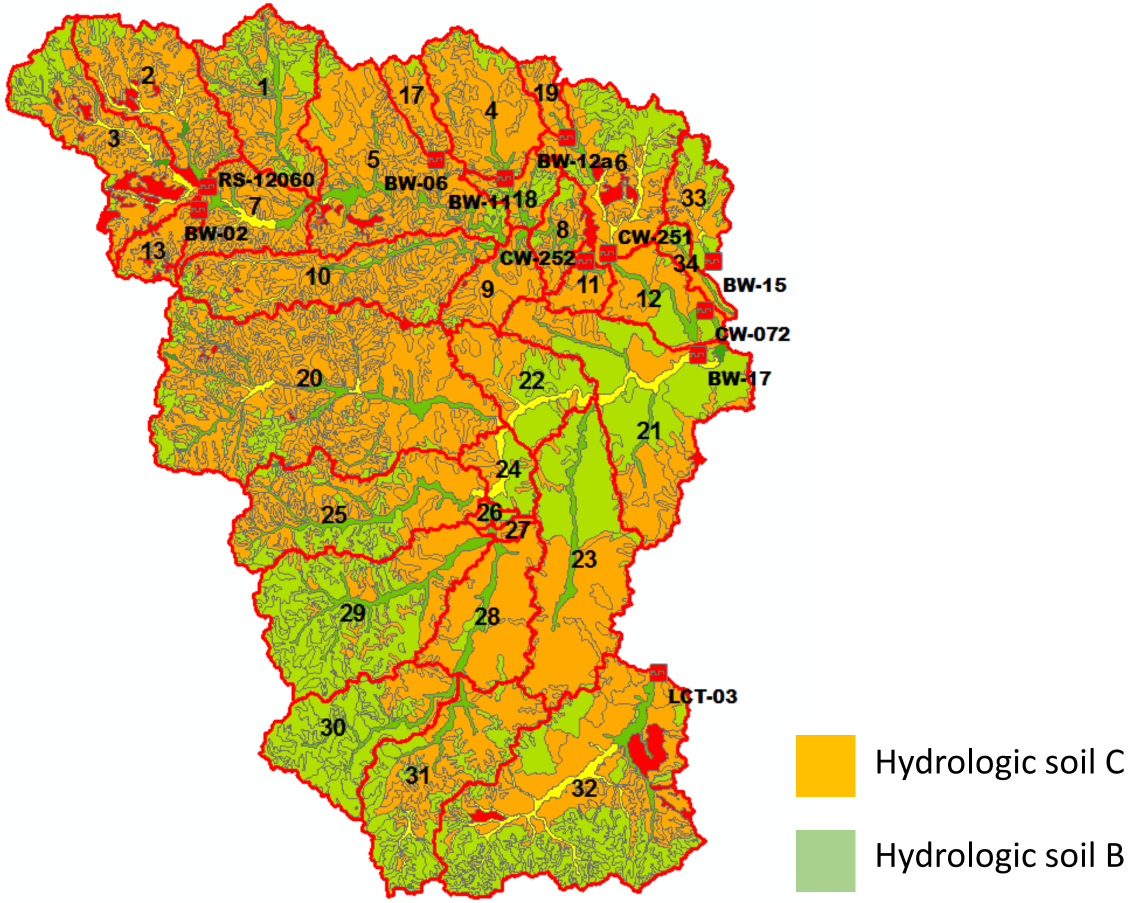
2. The eroded sediments can be quickly carried away to the Lake Wateree cove due to the short distance from the CAW and the steeper slopes. The slope of sws11, 12, 33 and 34 is above the averaged slope of Big Wateree Creek basin (the brown line, see the plot on the right).

The combination of these two conditions might have contributed to the observed high TSS in August 2019.



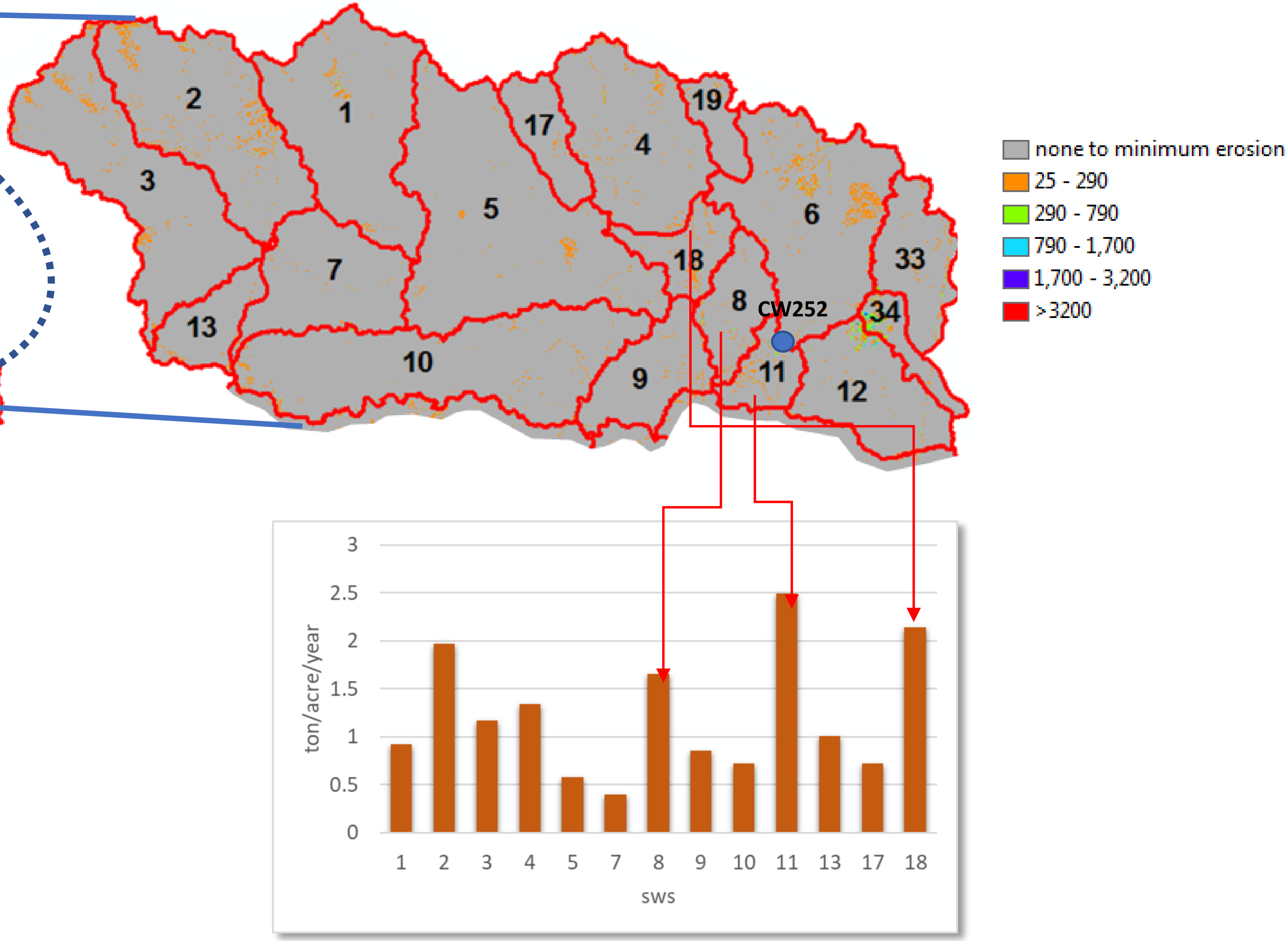
Hydrologic soil type consideration

The hydrologic soil group of the basin is mainly a combination of B and C, which indicate runoff potential to be moderate (see the map below). At a closer look, Little Wateree Creek and Dutchmans Creek has more soil B, less runoff potential than C. In contrast, Big Wateree Creek is dominated with type C, more runoff potential, thus higher erosion power.



A consideration on TSS at CW-252

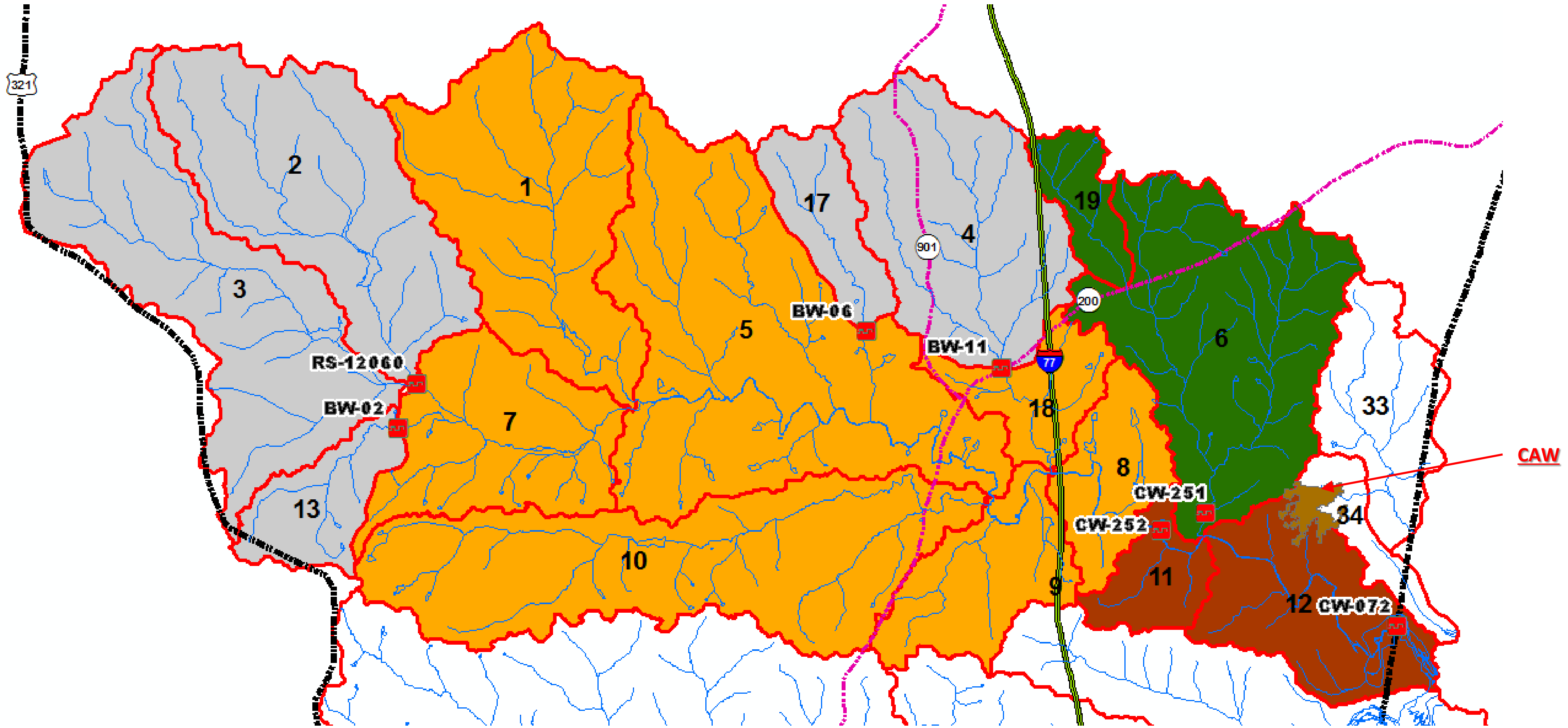
In the August sampling, TSS at CW-252 has recorded relatively high concentration as 310 mg/l, while CW-072 recorded TSS to be 650 mg/l. The right top map shows the results of RULSE in Big Wateree Creek. The plot at the bottom shows the loading rate of each watershed located upstream of CW-252. Three subwatersheds close to CW-252 (sws 18, 8, and 11) show the high unit area sediment erosion loading (see the bottom plot). The erosion site mainly corresponds with clearcuttings. Due to the proximity to the mainstem, these subwatersheds can be potential sources. Therefore, the subwatersheds proximity to the main stem, with the previously described flat area, the steeper slope, and the soil type in the slide 50 & 51, could cause high TSS conditions at CW-252 due to scouring of the deposited sediment in the watershed (sws 18, 8 and 11) during high rainfall event such as the August 2019.

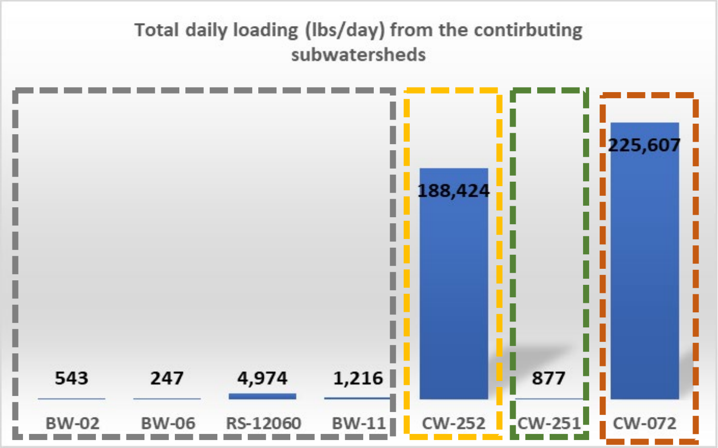


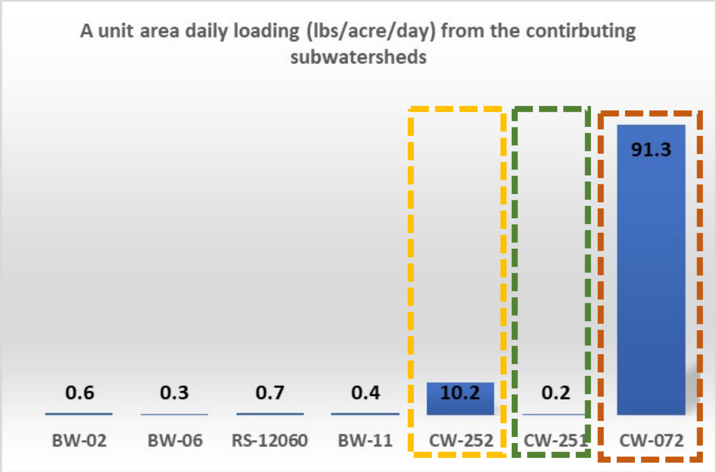
Additional analysis of TSS between CW-252 and CW-072

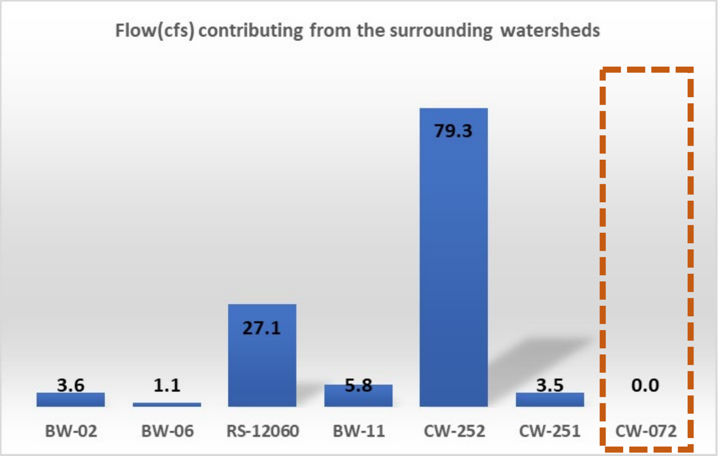
At first, the previously delineated sub-watersheds were grouped into four groups;

- The grey color watersheds (the grey): mainly associated with the headwater watersheds with the observed data at the outlets.
- The orange color watersheds (the orange): the section of the sub-watersheds to evaluate the mid-section of the basin with the observed data (CW-252) at the outlet.
- The green color watersheds (the green): the watersheds contribute to flow and load to the section between CW-252 and CW-072.
- The brown color watersheds (the brown): the lower portion of the basin that evaluate the loading between CW-252 and CW-072.





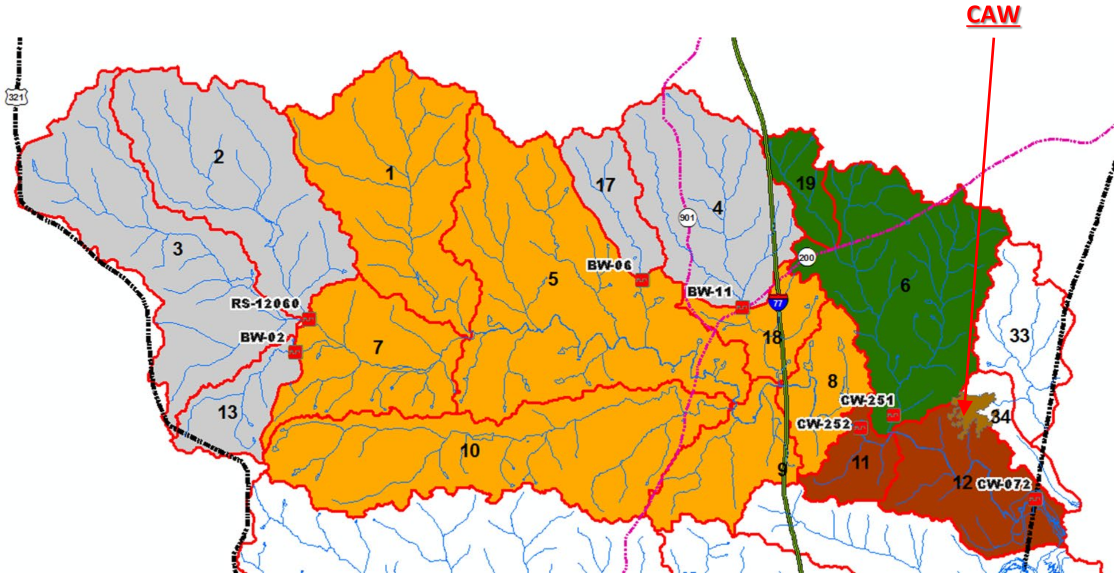




The total loading representing the mid-portion of the watershed (the orange) and the loading found from the localized drainage nearby CAW (the brown) are similar (see the left plot). The loading from the green watersheds (sws 6+sws 19) that contributes to the reach between CW-252 and CW-072 is minor. *Please note that the loadings showing in the left plot are the net loading from only the specified color basin. The station IDs are there for a reference purpose.*

Although the total loadings from these two drainages (the orange and the brown) are comparable, the unit area loadings (lbs/acre/day) indicate the loads from the watersheds between CW-252 and CW-072 (the brown) is much higher than the one from the orange color basin. A part of the CAW facility's perimeter is within sws 12 (see the map on the right). The unit area load from the green is very minor. Thus, the highest unit area loading is the sediment loading generated within sws11 and 12 (the brown).

As described above, the highest unit area loading occurred in the brown basin (sws 11 and 12). However, the flow mass balance calculation reveals that the net drainage inflow from surface/subsurface is negligible in this section of the creek (the segment between CW-252 and CW-072). In fact, the calculation resulted in zero net flow into the brown area from the surrounding watersheds. The flow observed at CW-072 is approximately only the sum of the flow from the orange + the grey and the green watersheds. So, why does the concentration and the load change between CW-252 and CW-072 in August 2019 TSS data ?

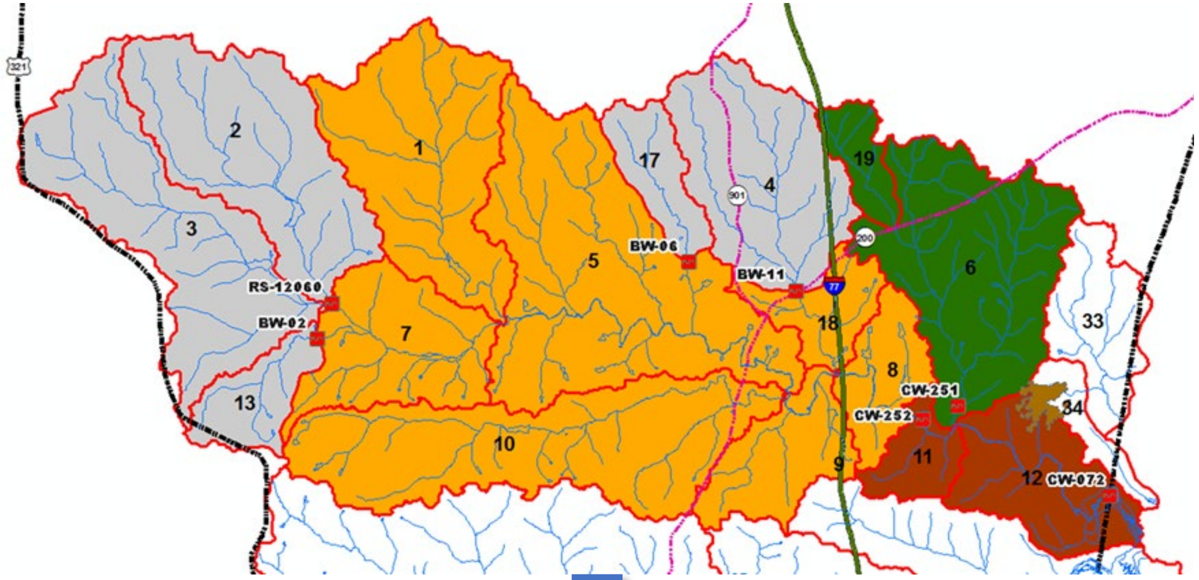


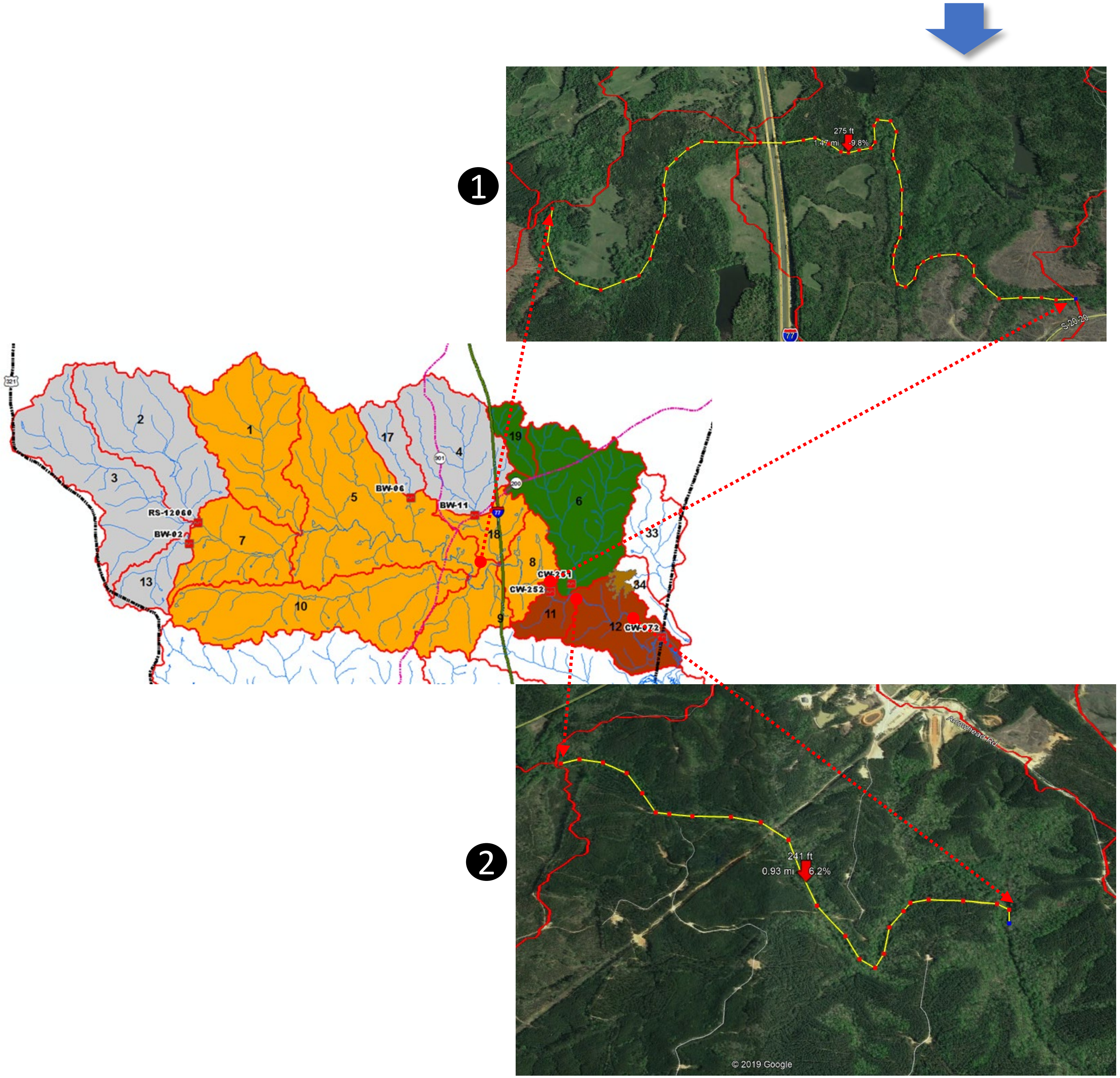
Without the external loading input, potential internal sediment loading was suspected. The next few slides will evaluate the internal loadings.

A streambank erosion function included in the GWLF-E model (Generalized Watershed Loading Function-enhanced) was applied to evaluate the bank erosion loading. The model can generate an annual stream bank erosion based on long term meteorological data (30 years). The bank erosion should be distinguished from erosion of the stream bed, which is referred to as scour. The bank erosion function in the model does not consider any effects from clearcutting activities or CAW so that it can be thought of as background bank erosion without any influences from the land disturbances. The bank erosion functionality of the model is based on the concepts of geomorphology, which requires various watershed information (e.g., monthly averaged flow rate, runoff coefficient, soil erodibility (k factor), mean watershed slope, soil bulk density). The streambank height is assumed to be 5 feet in the model.

The model results indicate that the bank erosion above CW-252 (the orange and the grey section) generates 1.8 times higher load compared to the one in the brown basin. Due to the sensitivity of the arithmetic averaging to extreme values (possible high bank erosion) and complexity of simulating the bank erosion, the model results (long term annual average) should be interpreted only as an approximate representation of the averaged bank erosion and the spatial stream bank erodibility within the Big Wateree Creek basin. As the model indicates, if the bank erosion is not the leading cause of the higher TSS in the lower basin (the brown), what would be an additional instream erosion mechanism that could explain the higher loading?

Next, the scouring of the streambed was examined.





Segment1

The shear stress: 0.11 (lb/ft2)

Erodibility of the mid-lower watershed (Figure 1) and the stream segment nearby CAW (Figure 2) was compared based on the shear stress. The shear stress is a measure of the stream's ability to entrain bed material. When the shear stress is higher than critical shear stress, channel degradation (erosion) will likely occur. The critical shear stress is known to be the magnitude of shear stress required to move a given particle. The critical shear stress can be influenced by a particle's size on the stream bed. In this analysis, the particle sizes distribution on the stream bed between the two locations (segment1 and segment2) was assumed to be similar, so mainly the difference of the shear stress was assumed to influence the sediment scouring.

The shear stress at these two locations was calculated based on stream slope and hydraulic radius of the sites. The sear stress at the nearby CAW (segment 2) is almost twice as high compared to the one at segment 1 of the mid watershed. The result indicates that the loading observed at the CW-072 is more likely caused by the scouring of the deposited sediment from previous erosion/deposition events. Again, having identified no significant runoff affecting the section between CW-252 and CW-072, land surface erosion and runoff transport of the sediment mass are not one of the expected mechanisms of the high sediment loadings observed in the August 2019.

Segment2

The shear stress: 0.19 (lb/ft2)

Five physical characteristics and loading sources in Big Wateree Creek which are different from the other basins (Little Wateree Creek, and Dutchmans Creek)

1. Topographic relief – a transition of the lower slope in the middle of the watershed to the higher slope of the lower portion of Big Wateree Creek (BWC). The topographic relief characteristics could affect flow rate/flow velocity: thus, sediment scouring potential and flow's sediment transport capacity.

2. The flat area in the middle section of BWC, which relates to water storage, which can influence surface runoff.

3. Low infiltration potential at BWC, which gives a higher potential to surface runoff; therefore, more potential erosion.

4. Potentially high sediment mass around CAW, including nearby stream bottom.

5. Location and exposed land surface of CAW with a proximity to the lake cove.

All these characteristics make Big Water Creek unique compared to the other basins and contribute to the TSS/turbidity issues experienced in the lake arm of Big Wateree Creek and possibly beyond into Lake Wateree.

Conclusion:

- Clearcuttings can generate erosion, but deposition generally occurs around the vicinity of the clearcutting sites. Due to the concave shape/flatness of topography and the existence of underlining organic litter, the eroded material tends to deposit within a short distance from where the erosion occurs. However, depending on the rainfall intensity, some of the eroded sediments could potentially end up a nearby waterway (e.g., streams, ditches) and further transported to downstream.

- Potential bank erosion can add additional TSS load to the existing instream load.

- The moderately elevated solids at CW-252 under the high flow of August data is probably caused by the combination of natural physical characteristics of the upland watershed and scouring of the deposited sediments.

- Streambed scouring from the flat middle area during high intensity rainfall appears to be a major contributing source.

- CAW having exposed land surface and being near lake Wateree could exacerbate the cove's solids and turbidity condition. All the storm sampling data, physical data, and the modeling analysis points to the facility as being one of the major sources for the higher observed parameter concentrations observed at CW-072.

A take home message:

All these analyses concluded that Big Wateree Creek has three possible sediment loading sources; sources above CW-252 (mainly clearcuttings related topography as described in this study), between CW-252 and CW-072 (CAW), and internal loading sources within the stream (mainly accumulated sediment mass on the streambed). On the land surface, some of the eroded sediments are detained and become unavailable to further transport due to the sediment trapping processes (e.g., the base of a slope, a concave section of the hill, and organic litter accumulated at the land surface). However, sediments from other sources eventually find a way to a nearby stream or ditch. Then, the transport process shifts from land surface to instream transport processes, which is controlled by deposition and scouring. The internal loading, such as bank erosion, also increase the instream sediment load.

The repeated erosion/deposition, while the sediments are being transported, at both the land surface and within the stream can create a lag response from the time that erosion occurs at the land surface to when the eroded mass eventually reach to the sample location. The loading observed at CW-072 is an excellent example of the time lag, which points out the scouring of accumulated sediments potentially eroded from the upper basin and CAW during previous rainfall events.

Erosion/deposition processes, including bank erosion, are a part of the natural process controlled by factors such as land topography, soil characteristics/stability, and the rainfall intensity/duration. However, the analysis conducted throughout this study indicates that the sources related to disturbed lands, such as the exposed surface (e.g., clearcuttings/access roads and CAW), could accelerate the erosion processes. The surface without any vegetation cover increases erosivity of the ground through direct rainfall and increases scouring by higher runoff leading to the higher flow in the stream. Therefore, the continued land disturbances above a critical threshold are probably the causes of the higher solids concentrations in the Big Wateree Creek and the Lake Wateree cove.