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Monitoring Turbidity and Sediment Flux for Enka Lake

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Abstract

Enka lake has occurrences with high turbidity following abrupt and short, heavy thunderstorms. Turbidity was recorded hourly during a heavy rainfall at two stream location (each with data loggers: Wisebranch and Balsam High Bridge) that combine and collect into a cove that later empties into Enka lake. The highest turbidity measurements were more than 700 NTU (nephelometric turbidity units) and such samples suspended large amounts of sediment. A hydrograph plotting time versus streamflow showed parabolic trends with peaks at heavy storm flow. The goal was to then determine whether comparing total suspended solids (TSS) and flow versus time and TSS versus turbidity would exhibit any clear relationships depending on a storm than took place on 2/6/2020. Estimating the total sediment mass resealed for similar storm events would help approximate how much sediment is entering the lake through these streams and would help community members decide how often the lake would need to be drained to remove settled sediment.

1. Introduction

Enka Lake, located near Candler, North Carolina, is a man-made freshwater reservoir held via a small dam that once helped aid in the industrial manufacturing of parachute lines during World War II.[1] Today the lake is privately owned and surrounded by a residential community known as Biltmore Lake. Portions of the lake were recently dredged to remove settled sediment from upstream. Sediment continues to flow into the lake following heavy rainstorms, causing a visual eye sore for community members who drive by or use the lake for swimming or paddling.

Turbidity is caused by suspended sediments and is a distinct contribution of urban pollution in freshwater systems. Turbidity measures the clarity of a liquid by quantitatively determining the amount of light scattered as it goes through water; high intensity in this scattered light results in a higher turbidity readings. Turbidity can be caused by suspended clay or silt, organic/inorganic matter, microscopic organisms, and plants and is highly influenced by precipitation, runoff, and high stream flow.[2] Turbidity from suspended sediment (sedimentation/siltation) affects light penetration, habitat quality, ecological productivity, and visual appeal in lakes and streams.[2]

The goal of this study was to investigate how rainstorms and high streamflow events affect the turbidity and total suspended solids (TSS) of streams that flow into Enka Lake and whether there is any linear variation between the two. Some studies argue that turbidity readings are overly sensitive to particle size and type of sediment (Kirk, 1988; Lewis, 1996; Riley, 1998); certain studies are confident that homogenously-sized sediment concentrations respond linearly to turbidity (Green and Boon, 1993; Black and Rosenberg, 1994; Lewis, 1996).[3] Sediment load is improperly measured and calculated when studies forget to consider high sediment concentrations such as intense rainfall and elevated storm conditions (Beschta, 1978; Rieger et al., 1988; Thomas, 1988; Ollesch et al., 2005).[3]

A Sediment rating curve (SRC) usually plotted using logarithmic functions is used to estimate suspended sediment concentrations that are transported annually for a water system; time and method determines the error in flux calculations.[4] The mathematical relationship for a study with limited data uses the SRC known as $M = aQ^b$ where M is the concentration for total suspended solids (TSS), Q is the mean water discharge (flow) for the channel, and a and b are parameters based on the regression analysis of the data.[3]

A study done by Horowitz (2003) that estimates annual and quarterly SRCs for the Mississippi River at Thebes found that short time-frames monitoring suspended sediment led to over- or underpredictions for flux (higher range of error).[4] Although a 20-year study led to the least percent error, better flux estimates were made when individual annual SRCs were sampled monthly or every two months based on hydrological parameters.[4] The annual (20-year study) SRCs for the Mississippi River (Thebes) between 1981 and 2000 that plotted discharge (Q) vs concentration (C) had data resemble linear and second-order polynomial regressions.[4]

This study focused on the two main feeder streams into Enka Lake (Figure 1). Stop 1 was located where Wise Branch crosses under Case Cove Road and stop 2 was located where Bill Moore Creek crosses under Balsam High Road by a much larger bridge. Both streams flow into Case Cove and make up 81 percent of the sub-watersheds found upstream of Cove 3 (south of Case Cove Road) before the stream water and suspended solids flow into Enka lake. Each stop had a data logger collecting the water level and temperature.

2. Methods

In early 2019, residents from the Biltmore Lake community formed a sampling team to collect turbid water samples during and after rainfall events. When a storm was approaching the Candler area heading towards Enka lake, the Biltmore team would prepare to sample as close to hourly as each person's schedule allowed. Sampling after dark was not encouraged for safety reasons. Unfortunately, the random pattern of sampling according to individual schedules and unpredictable weather prevented any estimation of total sediment load from an entire storm. For this study, we focused on an individual storm on 2/6/2020, when sampling began once it started raining and continued throughout the storm as heavy rainfall stirred up the sediment and caused higher turbidity readings. Sampling continued until the streams cleared of turbid waters and the heavy rainfall had passed.

Samples were collected hourly in HDPE plastic bottles and labeled with date, time, and stop location. Samples were recovered from the club house within a day and taken back on campus and stored in the fridge until later. In the lab samples were removed from the fridge and allowed to reach room temperature so condensation would not form on the glass cuvettes and affect the turbidity tests. A Hach turbidimeter was used to measure turbidity. Sample vials were cleaned and rinsed with Deionized (DI) water before shaking up each stream sample and transferring to the vials. Turbidity readings were performed three times following shaking/swirling and an average of the three recorded.

The same samples were filtered using 1.5 µm-filter paper while recording the sample volume filtered. Filters were carefully dried and weighed, and the weight of the filter paper (without any sediment) was subtracted to determine the sediment mass. Total suspended solids (TSS) was determined by dividing the filtered sediment mass by the filtered volume and was reported in mg/L.

3. Results

A hydrograph considers the relationship between flow (cfs) over time; for a rainfall event in the month of February (2020), water discharge begins to increase parabolically towards the end of February 5^{th} and into February 6^{th}, then discharge mostly resolves to baseflow by February 8^{th} (Figure 1). Based on the discharge readings from the data loggers, Wisebranch, Balsam High Bridge, and EL (Enka lake) Dam outlet exhibit a similar flow pattern at different intensities.

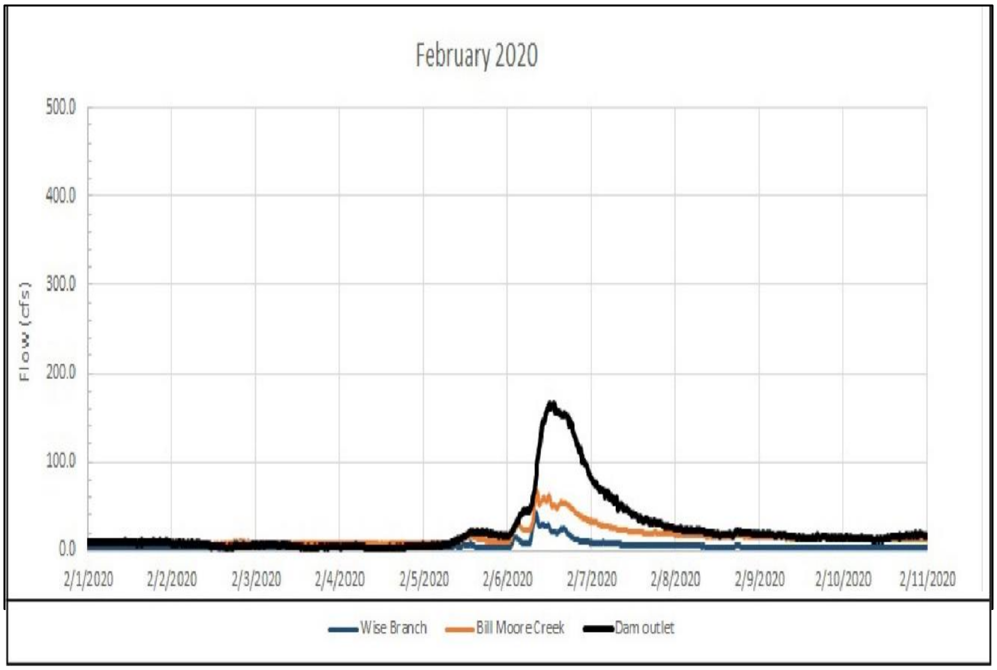

Figure 1. Map of Enka lake showing upstream sampling locations at Wise Branch (Case Cover Road), Bill Moore Creek (under Balsam High Bridge), and Pinkbeds (along Ponderosa Drive; location added later in the study).

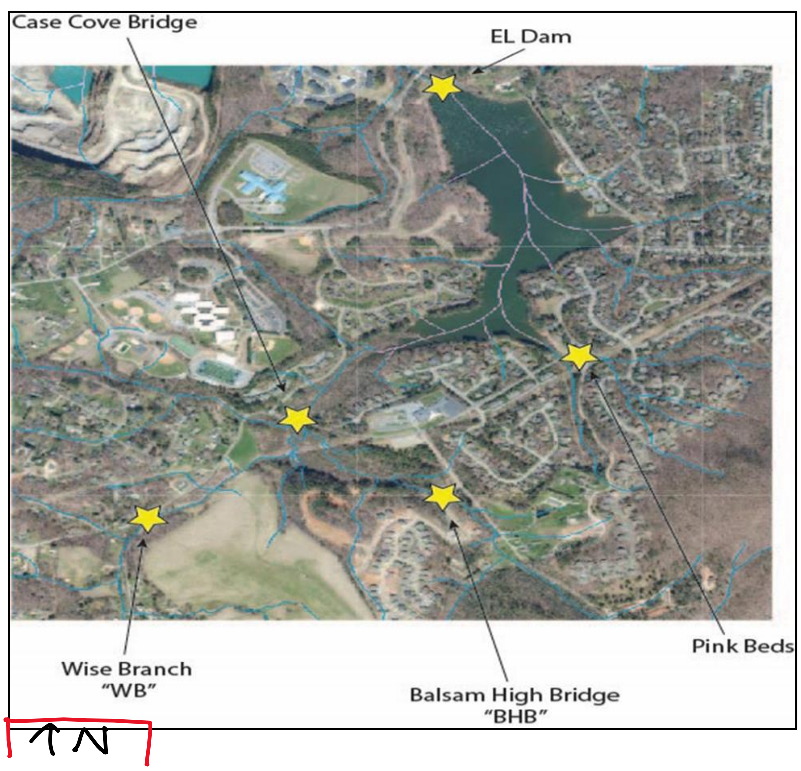

Figure 2. Hydrograph (time vs flow in cubic feet per seconds) of Wisebranch (blue), Bill Moore Creek (Balsam High Bridge; orange), and the Enka Lake Dam outlet (black) for February 2020.

Both flow (cfs) and TSS (g/ft^3) for WB and BHB respond similarly with time throughout the heavy rainfall on February 6th (Figures 3 and 4). This finding provided more confidence to look at the SRC for WB and BHB for this storm event by plotting discharge (flow) and concentrations in suspended solids also known as TSS. As the flow increased, TSS would also increase where both trendlines best fit a second-order polynomial regression by providing better R^2-values than for a linear regression (Figures 5 and 6). Logarithmic scales for both discharge and TSS led to higher R^2-values for both WB and BHB when graphed using a second-order polynomial regression.

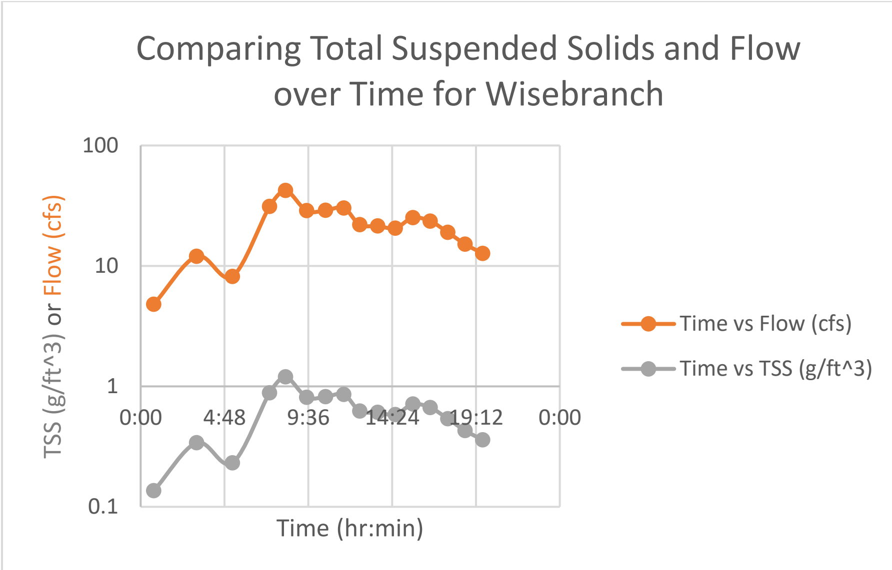

Figure 3. Total Suspended Solids and Flow plotted as a function of time for Wisebranch; sampled during a rainstorm on 6/2/2020.

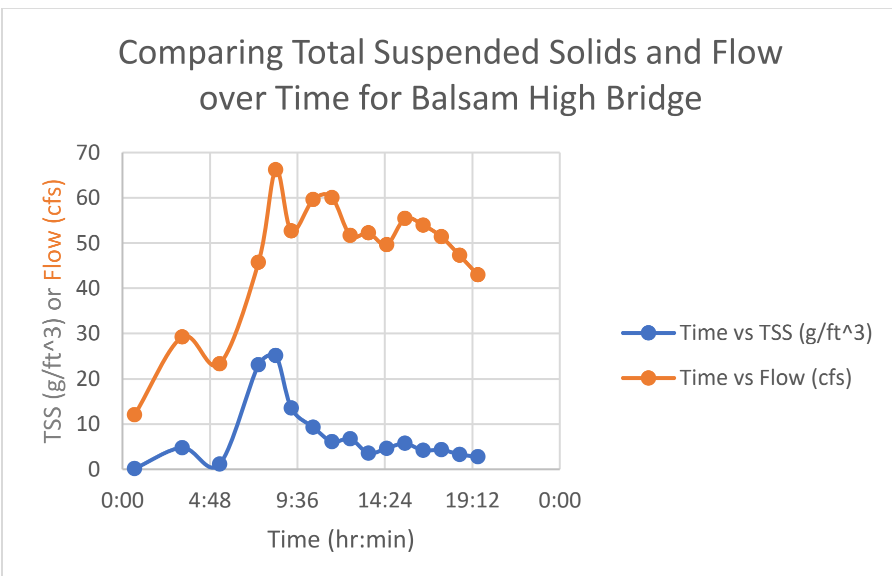

Figure 4. Total Suspended Solids and Flow results plotted as a function of time for Balsam High Bridge; sampled during a rainstorm on 6/2/2020.

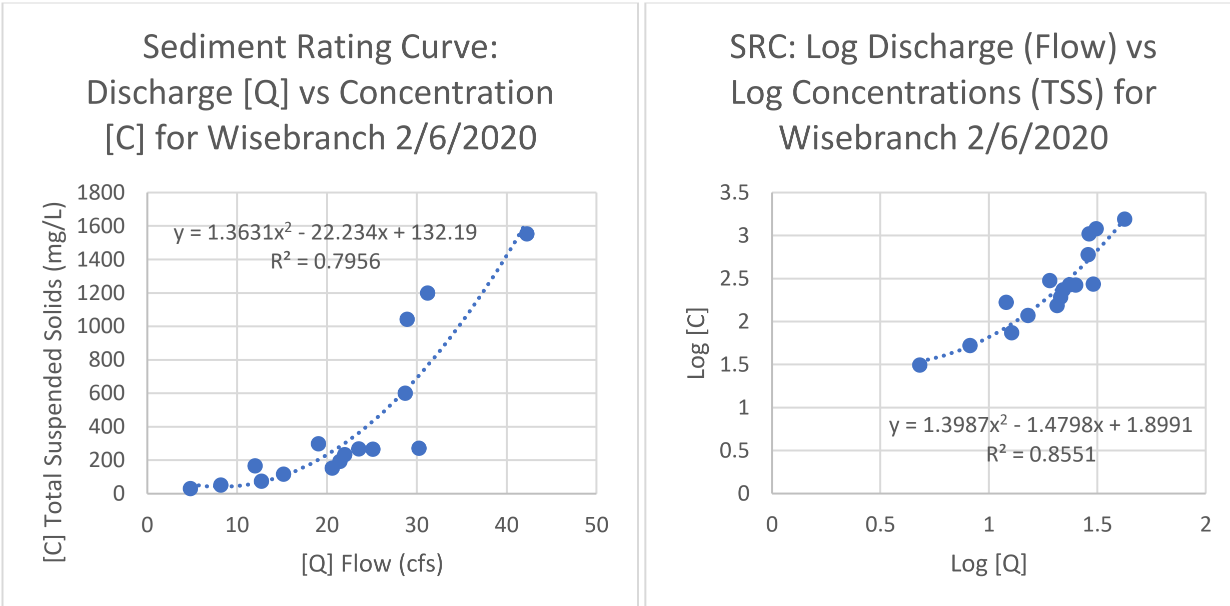

Figure 5. The sediment rating curve for Wisebranch done by plotting discharge verses suspended sediment concentrations (log[Q] vs log[C] relationship on the right); a relationship is indicated by the trendline for a second-order polynomial regression.

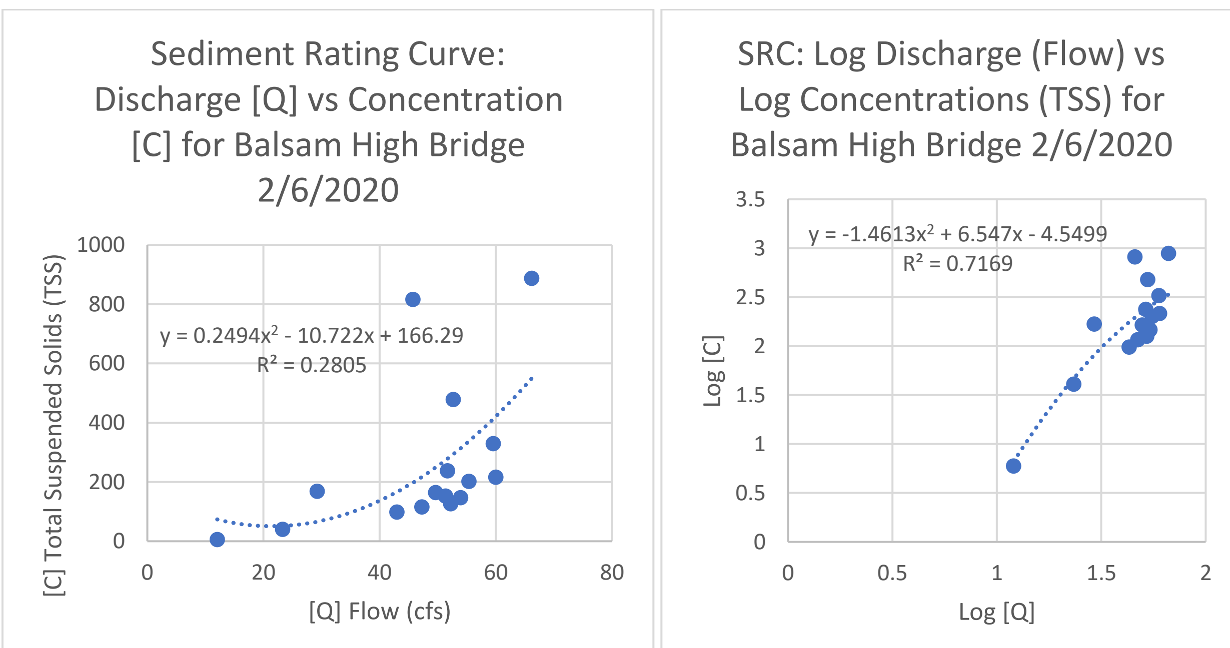

Figure 6. The sediment rating curve for Balsam High Bridge done by plotting discharge verses suspended sediment concentrations (log[Q] vs log[C] relationship on the right); a poor relationship is shown with a trendline for a second-order polynomial regression.

Calculated total suspended sediment was plotted with turbidity readings to determine whether any relationship or trendline takes place during the February 2020 storm event. Estimated linear regressions with equations (R^2-values at 0.8203 and 0.8695) indicates that there is a relationship between total suspended solids and turbidity for WB and BHB during storm flow (Figures 7 and 8). One sampled data point from WB during this rainstorm event had a lower turbidity reading (about 200 NTU) corresponding to a higher result in TSS that was calculated near 1000 mg/L.

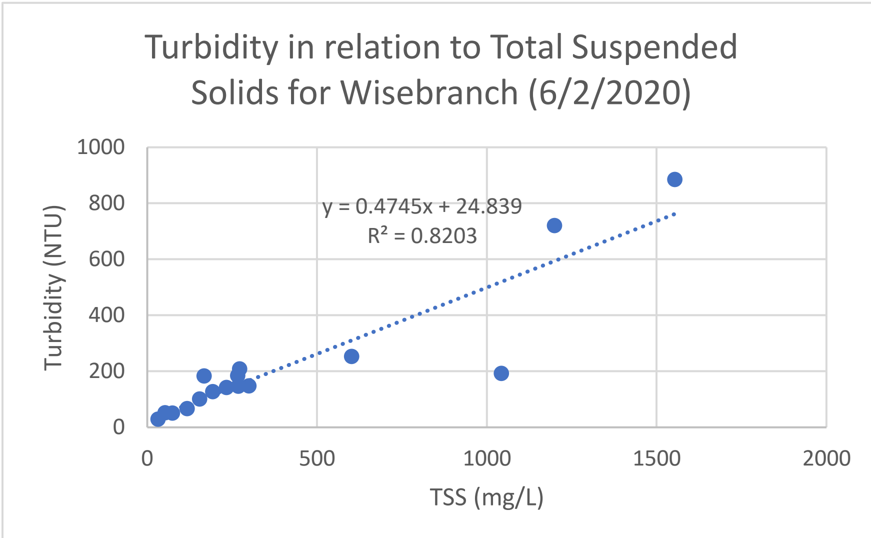

Figure 7. Plotting the relationship between Total Suspended Solids and Turbidity for Wisebranch within a linear trendline.

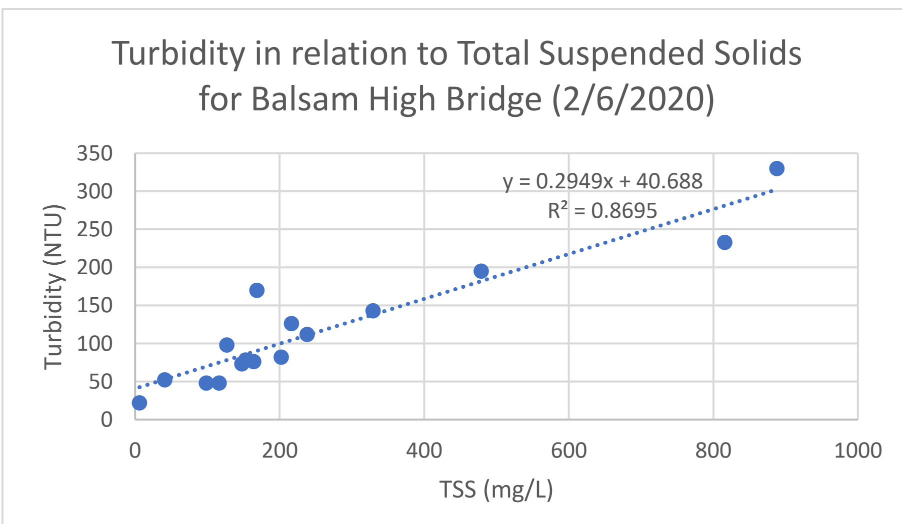

Figure 8. Plotting the relationship between Total Suspended Solids and Turbidity for Balsam High Bridge within a linear trendline.

By rearranging data/calculations from TSS and flow, total grams per interval were estimated for each sampling time for WB and BHB and then added for the 2/6/2020 storm event. Nearly 10,000,000,000 milligrams were calculated to wash downstream into the cove or lake from Wisebranch alone. An estimated 31,000,000,000 milligrams of suspended sedimented were estimated to transport downstream to the cove/lake (Table 1).

Table 1. Estimated total sediment mass in milligrams and kilograms that was released downstream following the storm event for the date 6/2/2020 (final estimate only to 2 significant figures).

	Wisebranch	Balsam High Bridge
Total Sediment Mass (milligrams)	9979166359	30810891183
Total Sediment Mass (kilograms)	9979	30810

4. Discussion

High stream flow took place following heavy rainfall at WB and BHB on 2/6/2020 that similarly affected the water discharge at the Enka Lake Dam (output). Data loggers show that the discharge for each location would return to base flow after a few hours or one to two days after the storm. Turbidity levels would be significantly lower after a few hours and would depend on the TSS which data suggests is dependent on the flow/discharge of the stream during storm sampling. The parabolic trend of TSS with time for this individual storm is like other event-based temporal scales for time versus suspended sediment concentrations in rivers world-wide (Vercruysse et al. 2017). Results for TSS responds similarly to the discharge or flow during storm conditions for WB and BHB when both parameters are compared as a function of time. Two peaks signifies that there were two different times rainfall was most intense. Weather monitoring data has peak rain time for this day at around 7:15 AM which is reflected in the graphs with a slight time lag meaning TSS and stream flow measurements will delay and be recorded shortly after peak rainfall.

It is important to identify whether there is a relationship between discharge and suspended sediment concentrations during a heavy thunderstorm. Within a logarithmic axis for discharge/flow [log of Q] and sediment concentrations/TSS [log of C], a second-order polynomial regression indicated a clear SRC for WB and BHB with similar and/or higher R^2-values compared to annual SRCs for the Mississippi River study at Thebes (Horowitz 2003). High water levels in WB and BHB streams because of intense rainfall typically results in stirred up sediment which is later transported downstream into Case Cove and later EL Dam. A study that looked at the SRC for Celone River, Italy using logarithmic discharge versus logarithmic suspended sediment concentrations had a similar trendline to WB and BHB when using second-order polynomial regression (Vercruysse et al. 2017).

As more sediment (TSS) stirs into the stream water, the visual cloudiness of freshwater (turbidity) will increase indicating there is relationship between suspended solids/sediments and how turbid WB and BHB streams will become. Possible outliers to the trendline suggests certain sediment types will result in lower turbidity readings while suspended clays will most likely increase the turbidity levels. The linear relationship between TSS and turbidity occurring during storm flow conditions suggests that turbidity measurements, which can easily be measured in the field, can replace having to estimate TSS which requires filtering, weighing, and calculations. A review by Vercruysse et al. (2017) mentions studies that suggest turbidity can be used to represent suspended solid concentrations when only a few sediment samples are collected (Bilotta and Brazier, 2008; Gao, 2008).

For the thunderstorm event that took place on 2/6/2020, estimating total sediment load that each stream contributed during the span of the intense rainfall led the statistical calculations to conclude that Balsam High Branch contributed to greater suspended sediment concentrations (31,000,000,000 milligrams) than Wisebranch (10,000,000,000 milligrams). Both WB and BHB suspended sediment loads would eventually travel and settle into Case Cove/Enka Lake. Bill Moore Creek is a much larger stream with greater discharge than Wisebranch and flows past built subdivisions, farmed/housed properties and along a main road which result in greater sediment sources.

5. Conclusion

Wisebranch and Bill Moore Creek (BHB) sampling streams both contribute to sedimentation of Case Cove and later Enka lake and is elevated following thunderstorms with high intensity rainfall. Trends between turbidity, flow, and total suspended solids indicate that sediment transport is taking place at an accelerated rate resulting in increased sediment loads for the Enka watershed. By monitoring the number of thunderstorms that result in high discharge (storm flow conditions) throughout the year, annual representations for suspended sediment can be estimated for fluvial deposits. According to a WLOS news report, the dredging project for Enka lake in 2016 was estimated to cost $200,000 for the residents.[5] The community has since then considered alternative methods to mitigate the sediment problem with planned forebays, rock-lined ponds, and cascades/plunge pools that would be placed before streams entered the coves or Enka lake. An ecological debate is whether riparian restoration and increasing local beaver populations would naturally help control erosion and sedimentation for Enka lake.

6. Acknowledgements

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