

Evaluation of Suspended Sediment Concentration in Woodcock Creek and Tributaries



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Abstract

Sediment buildup in streams can harmfully impair the quality of water by carrying pollutants such as nutrients, metals, and organic compounds, which can negatively impact water quality and the health of aquatic ecosystems. Sediment evaluations serve as an effective practice to assess stream health, and implications of upstream land use. The Watershed Conservation Research Center (WCRC) at Allegheny College has recently started to plan a potential restoration project on one of the sampled tributaries at Woodcock Creek. As a result, five different tributaries within the Woodcock Creek watershed were evaluated, recording suspended sediment concentrations and turbidity, in effort to show need of repair at one site. The purpose of this study was to 1) gather sediment concentration data for the five tributaries under different flow rates, and compare different concentrations among sites, and 2) gather land cover information and relation to sediment/turbidity levels. More specifically the study hypothesized that German Run, one of the sampled tributaries, had the largest sediment input and biggest impact to downstream areas of Woodcock Creek. This hypothesis was tested by measuring sediment concentrations and turbidity ratings. Samples were taken under both base flow and storm flow conditions, determined by United States Geological Survey (USGS) gauges placed at Price Rd, one of the main stem sample sites. Results showed that although there was too much variance in the samples to show differences in average concentrations. By testing under different flow conditions, results did show that under high flow conditions, German Run was exceptionally high. Data suggest that German Run has a large negative impact of sediment loading under storm flow conditions, increasing sediment loads downstream. The negative impact of German Run is also highlighted by its poor land cover. This suggest that restoration efforts at German Run should be considered by the WCRC.

Introduction

Streams and rivers across the world serve as a vital resource for the human population along with providing some of earth's most exotic, and diverse environments. Conservation of earth's aquatic ecosystems is crucial to protect the biodiversity of earth's natural world. As population increases and humans depend more on water, more threats than ever are being placed on water quality (Irfan and Alatawi, 2019). Sediment loading in streams has become one of the main pollutants affecting streams and rivers globally (Larsen et al, 2011). Sedimentation occurs naturally, but human activities such as agriculture, construction and deforestation heavily increase the amount of sediments and pollutants reaching streams and rivers. Concentration of sediments can not only disrupt habitat for benthic organisms, living along the beds of streams and rivers, but also block natural light, limiting nutrients for plant growth (Lemly, 1982). Excessive amounts of sediment can cause serious damage to streams and rivers but it is important to note that insufficient sediment loads can also have negative impacts leading to loss of habitat, structure, and protection from storm surges (Allan and Castillo, 2007). Aside from effects on biotic life, sediment loading and deposition can alter the physical structure of streams and rivers. Heavy sediment loads can change the natural shape and structure of the stream channel by filling in riffles and pools, which are important habitats for fish and other aquatic organisms. This can also lead to channel instability, such as increased erosion and sediment deposition, which can further impact the health of the stream ecosystem (Brierley and Fryirs, 2013).

This study examined the transport load of fine particles, specifically those under 0.0625 mm, as opposed to deposited sediments, which refer to larger sediment particles that settle at the bottom of the water and become bed material. The sediment load is defined as the amount of fine sediment passing through the water column, which may contain clay and silt particles carried even under low discharge velocities (Allan and Castillo, 2007). Hicks and Gomez (2003) have elaborated on the concept of sediment load, emphasizing that it comprises of finer particles that may originate from different sources, such as erosion and weathering of rock, soil, and vegetation cover. In addition to erosion and weathering, sediments in streams and rivers can also originate from human activities such as construction, mining, logging, and agriculture. In urban areas, sediment runoff from roads and rooftops can also contribute to sediment loading (USEPA, 1994).

High discharge caused by rain storms, harmfully increases channel flow which can erode the banks of streams and rivers, leading to the transport of sediment downstream (Prosser et al., 2010).

Historically, humans' conversion of natural forest into mostly agricultural land have resulted in declining health of wetlands across the United States. In Western Pennsylvania, the area of interest for this study, 70-90% of forest had been cleared as early as 1900 (Whitney and DeCant 2003). These areas were deforested for timber and cleared for agriculture, directly resulting in massive amounts of sediment runoff and harm to nearby watersheds. While in the past 50+ years the decrease in farmland has helped restore forest cover back to 53% (Whitney and DeCant 2003), construction of developed areas, agriculture and poor water land management are still impacting stream health. Poor land management in many cases leads to increased and hazardous levels of runoff, damaging aquatic ecosystems. Runoff includes a variety of eroded material (sediment), chemicals, and fertilizers. Agricultural land use is one of the most impactful types of land usage, due to fertilizer runoff inputting nitrogen (N) and phosphorus (P) into sediment loads. N and P can cause nutrient deficiencies in streams and rivers. (Renwick et al. 2008). Therefore, consideration of high agricultural use in the surrounding area of a given stream that is biologically abundant, makes it essential to acknowledge the threat to biodiversity (Straffin 2003). Understanding the River Continuum Concept (RCC) (Statzner and Higler 1985), can highlight the impacts of upstream land use and the effects it can have on downstream areas. The RCC is a model that describes how the physical, chemical, and biological characteristics of a river change along its length from its headwaters to its mouth. In regards to sediment loading, the RCC suggests that sediment inputs to a river ecosystem increase downstream as the size and discharge of the river increase (Richey and Swanson, 1989).

Restoration of streams and rivers can help manage sediment loading and have positive impacts on overall stream health. Restoration practices can serve as protection from stream bank erosion causing sediment overload, limit agricultural impacts, or other human induced harm to rivers and streams. Although little is known about the long term effectiveness and implementation of restoration efforts (Armstrong et al. 2020), there has been research to prove that riparian techniques play an important role in limiting human impacts (Pusey and Arthington 2003). Riparian zones are plots or strips of land created at the interface between terrestrial and freshwater

habitats adjacent to flowing waters (González et al. 2017). Riparian zones can benefit structure of streams and rivers and overall health, but are typically large projects that take careful consideration of the location, and can be rather time consuming and costly. There are a variety of other stream restoration techniques that can be similarly effective, while being less time consuming and less expensive. The physical, financial, and intellectual complexity of restoration projects may seem difficult to overlook but could be extremely beneficial in the future of protecting our aquatic ecosystems.

This study was done with attention to Woodcock Creek, located about 50km south of Lake Erie, in northwestern Pennsylvania. Woodcock Creek is known for its recreation, encompassing campsites, hiking trails, and a dam which many people visit daily. The creek itself is over 20 km long, with a watershed that expands over 115 sq km, and serves as a tributary for the larger French Creek, which has a watershed that spans over 3000 sq km (U.S. Army Corps of Engineers 2019). The abundance of fish populations and other species present within the Woodcock Creek watershed were also taken into account using a large fish database published from former research (Kirk and Wissinger 2020). Woodcock Creek inhabits nine different darter species, popular game fish including smallmouth bass and walleye, and other species such as lamprey, stonecat and redhorse (Kirk and Wissinger 2020).

Much of the land cover of the Woodcock Creek watershed is forested, but a large portion of the downstream area of the creek, right before entering French Creek, is heavily pastured. Land cover data was acquired from GIS analyses of past studies (Kirk et al 2017). The large agricultural use and lack of forest downstream, make this an ideal area to assess and possibly restore.

Due to poorly eroding banks, the German Run site was selected as an area of interest for restoration by the Watershed Conservation Research Center (WCRC). Along with potential restoration of the German Run tributary, a Large Woody Debris (LWD) restoration was done last year on the Craig Run main stem site, in efforts to mitigate bank erosion and sediment transportation. Sediment evaluations such as these could be useful in determining effectiveness for such restorations.

The purpose of this study was to determine input of sediment transportation into Woodcock Creek. Specifically, this study hypothesized that one of the evaluated tributaries, German Run, had the largest input of sediment, and the biggest impact to the downstream area of the creek. To test this hypothesis, samples were taken from eight different sites along Woodcock Creek. Sample site locations were selected on a large spatial scale to help better convey where the true problem or highest sediment input is located.

Methods

Site Description

Sediment evaluations were done at eight different sites (Figure 1), five being tributaries flowing into Woodcock Creek, three of the sites were main stems of Woodcock Creek. To account for the presence of the dam located in Woodcock Creek, two of the main stem sites were downstream of the dam. Due to the dam's ability to decrease sediment transportation, the Stainbrook site being the closest to the exit of the dam, was used as a baseline for sediment levels downstream of the dam. The furthest downstream main stem site was the Craig Rd site. The amount of accumulated sediment from the Stainbrook to the Craig Rd site would be used to determine the impact of German Runs input of sediment.

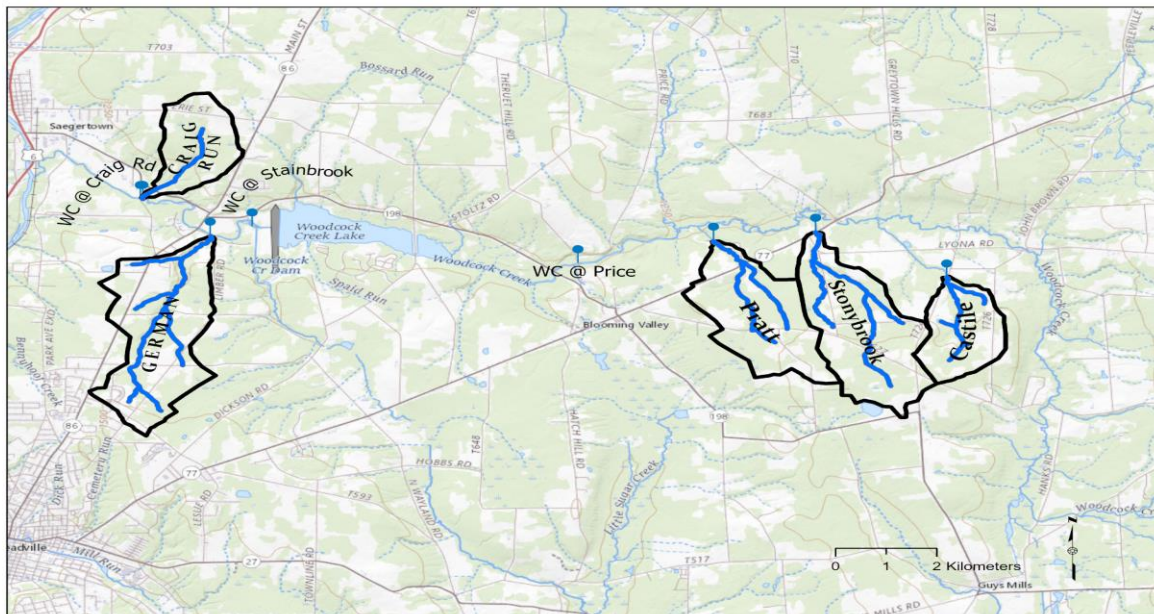


Figure 1: Each of the five tributaries and the delineated watershed boundaries along with the three main stem sites (ArcGIS pro version 3.0 by ERSI).

Craig Run is the only first order stream of the five tributaries, meaning the headwaters have no other upstream tributaries. All the others are second order streams, meaning there are two first order streams forming the tributary where samples were taken. The watersheds of the five tributaries ranged from 1.89 square kilometers to 4.44 square kilometers. Craig Run being the smallest and German Run the largest. The five tributaries were perennial streams, having continuous flow throughout the year.

Sampling Process

To account for expected differences among sediment concentration under high or low flow rates, samples were taken under both base flow and storm flow conditions. Flow conditions were recorded using the Blooming Valley USGS Monitoring Data, which is located at the Price Rd site. Recording the storm and base flow conditions also allowed the study to show differences of increased sediment transportation throughout the different sites under the two different conditions.

Samples were collected using a ~500mL bottle by holding the bottle directly under the surface to collect the surface water flow. Bottles were then placed in refrigerators for up to 48 hours before being filtered, dried and weighed.

Lab Process

Once samples were brought to the lab, they were first measured for turbidity using a LaMotte turbidity meter, which provides Nephelometric Turbidity Units (NTU). This measures the amount of suspended particles within the liquid, by measuring the amount of light that is scattered throughout the liquid. Turbidity ratings were used to depict correlations in turbidity and suspended sediment weights.

Water samples were then filtered using a vacuum filtration apparatus, separating the suspended sediments from the water. Filters were dried and weighed before use. After filtration, filters were dried in an oven at approximately 50°C for at least 48 hours.

GIS/Land Cover Analysis

Using Geographic Information Systems (ArcGIS Pro version 3.0 ERSI) (GIS), watershed delineations were drawn for each site's upstream watershed/catchment area. Using GIS analysis tools, land cover percentages of agricultural, developed, forested and water were able to be analyzed for both the entire watershed, and within the riparian buffer zone (30m buffer around stream). Land cover data was imported to ArcGIS, using the Multi-resolution Land Characteristics Consortium (MRLC) viewer (2019) (Appendix A).

Results

A total of 65 samples were collected and analyzed. Of those samples, 27 were under base flow conditions, the other 38 were under storm flow conditions. The highest 20 sediment weights all were samples during storm flow conditions. Storm and base flow conditions were determined using discharge rates published by the USGS gauge at the Price Rd site. Storm flow conditions include any discharge rates over 55.6 cubic ft. /second, the highest recorded storm flow was 748 cubic ft. /second. The highest base flow condition was 42.4 cubic ft. /second, and the lowest recorded discharge was 4.1 cubic ft. /second. Using a 2-way ANOVA test, results showed that there was too much variance in data to depict one specific site as higher concentrations. The same test showed no significant difference in concentrations under the two flow conditions.

While there was significant differences in concentrations, when looking specifically at the German Run site, it was clear that under storm flow conditions sediment concentrations were exceptionally high (Figure 2).

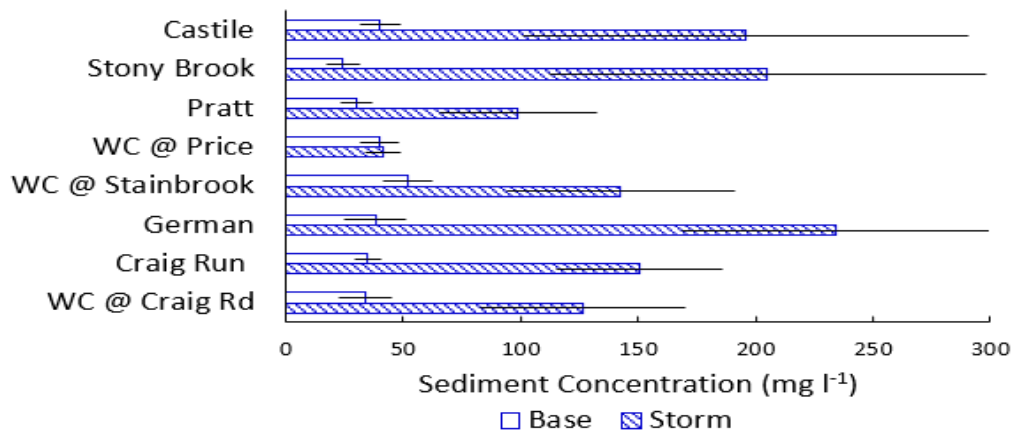


Figure 2: Average sediment concentrations (+SE) among the eight different sites under base and storm flow conditions.

Sediment concentrations are strongly correlated with turbidity (NTU) ratings (Figure 3). Mean turbidity ratings under base and storm flow conditions showed similar results to the sediment concentrations. Figure 4 and 5 show the drastic difference of German Run under base vs storm flow.

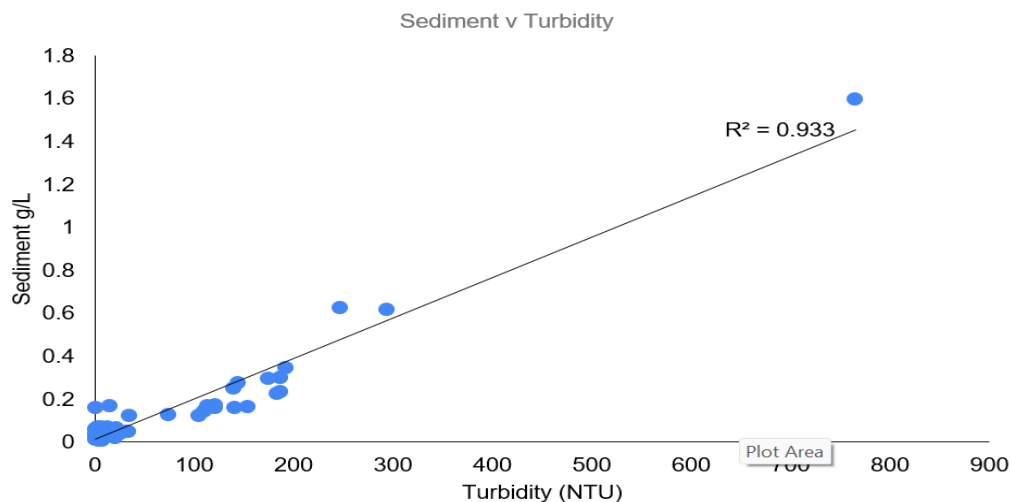


Figure 3: Suspended sediment weights (g/L) strongly correlated with turbidity ratings (NTU). $R=0.933$

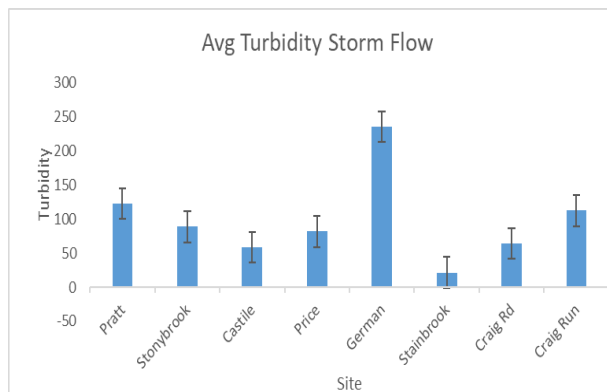


Figure 4: Average turbidity (+SE) under storm flow

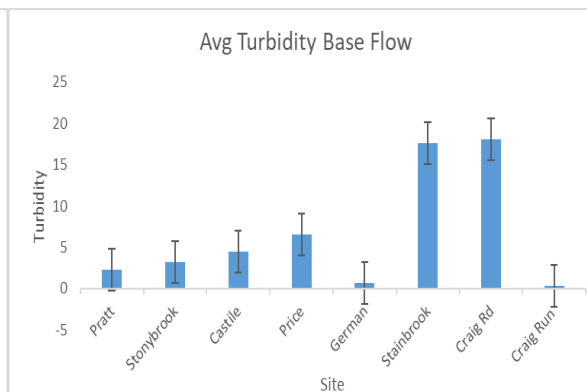


Figure 5: Average turbidity (+SE) under base flow

Analysis of sites downstream of the dam, showed that German Run had the highest sediment and turbidity rates under higher flow, between the Stainbrook Park and Craig Rd main stem sites. German Run showed the highest sediment and turbidity ratings downstream of the dam.

Craig Rd, the furthest downstream, main stem site, was heavily impacted by concentrations of German Run (Figure 6 and 7).

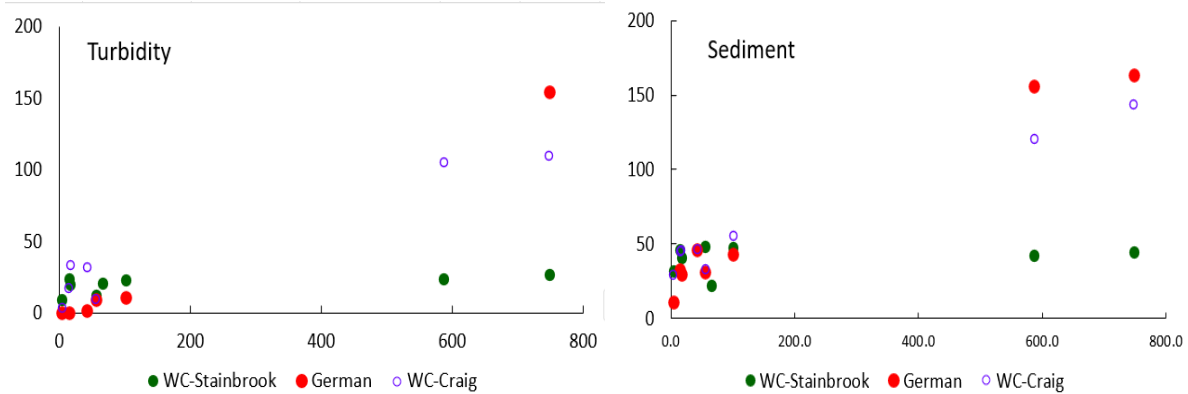


Figure 6 & 7: Shows turbidity and sediment concentrations from low flow to high, showing German Runs huge spike in extreme conditions.

ArcGIS land cover data analysis was able to show the exact percentage of agricultural, developed, forested and water land cover within each of the five sampled watersheds (Table 1). German Run had the highest percentage of developed land (18.93%) and the lowest percentage of forested land (54.69%). Additionally, GIS analysis of the riparian zone for each of the five tributaries provided data showing land cover within a 30m buffer zone of each of the five tributaries (Table 2). Riparian zone land cover percentages were rather similar to the watershed, including German Run again having the highest percentage of developed land (11.62%) and the lowest amount of forested land cover (63.07%).

Table 1: Percentage of land cover type within the entire watershed of each sampled tributary.

Site	% Agriculture	% Developed	% Forested	% Water
Pratt	22.92	7.28	67.35	2.45
Stonybrook	20.60	8.00	68.08	3.32
Castile	33.12	5.40	61.39	0.09
German	22.26	18.93	54.69	4.12
Craig	29.26	3.62	63.70	3.43

Table 2: Percentage of land cover within the 30m riparian buffer zone of each of the five sampled tributaries.

Site	% Agriculture	% Developed	% Forested	% Water
Pratt	1.39	5.92	90.94	1.74
Stonybrook	5.71	5.00	84.29	5.00
Castile	2.11	3.16	94.21	0.53
German	3.53	11.62	63.07	21.78
Craig	5.56	11.11	83.33	0.00

Discussion

The point of the study was to show that German Run was the largest contributor of sediment concentration compared to the other tested sites. The small sample size is why the study could not show significant differences of sediment concentrations among the individual sites. More samples spread out under different flow conditions would have helped to show if there was a significant difference throughout the eight sites along with between different flow conditions. A past study used 14 separate sample sites within eight different basins and analyzed a greater number of samples (Melton and Wohl, 2012). Another similar study used data that was recorded over a span of 6 years, also using multiple different gauging stations to record discharge (Lin and Chen, 2011). Both articles (Melton and Wohl, 2012; Lin and Chen, 2011) showed that sediment transport and sediment concentrations, consistently increased with higher flow rates. Mean values still we're able to show that under high flow conditions, the input of sediment loading caused by German Run, is exceptionally high. Although it may not be a constant issue, the extreme situations have large, longer-term impacts on stream health. Research has been done showing there is a positive correlation between storm events and sediment loading (Gardner and Reichert, 2009). Although heavy particles can settle on the riverbed under low flow conditions, under high flow conditions sediment transport can increase (Kondolf and Wilcock, 1996).

Correlations between sediment concentration and turbidity (NTU) ratings were consistent with many other studies. Ellison et al. (2010) performed a two-year long study comparing suspended sediment concentration (SSC) and turbidity ratings. Additionally, the study showed that

the increase in SSC and turbidity was significantly related to the increase of flow, much similar to this present study. While some previous studies suggest that using turbidity can be an alternative method for evaluating SSC (Williamson and Crawford, 2011), other research shows that doing so can have negative implications for environmental monitoring (Rymaszewicz et al, 2017).

Over the last decade, and even longer, there has been a variety of research done, pointing out the impacts of land cover on aquatic health. A key purpose of this study was to analyze if it would be beneficial to perform a restoration project at the German Run site, by assessing sediment contribution in relation to other adjacent tributaries. The reason for evaluation of German Run was the poor land cover and rapidly eroding stream banks (Figure 8).



Figure 8: Image of German Run's poorly structured stream bank, which under high flow is heavily eroded.

Research has consistently shown land cover relation to SSC and more specifically lack of forested land cover. Erol and Randhir (2013) used GIS spatial data to determine land cover effects on freshwater ecosystems. Results showed that forest loss and urbanization can directly affect aquatic health by increasing sediment loads. This type of research can be used to explain the dramatic increase of SSC of German Run under high discharge (Figure 2), given the land cover within the German Run watershed and riparian buffer zone (Table 1 and 2). Sutherland et al (2002), carried out a study that determined impacts of land cover on aquatic fish life. Their study revealed

that as non-forested land cover decreased, fish spawning also decreased due to sediment loading. Studies suggest that forested land cover manages runoff and helps to stabilize stream banks (Li et al, 2017). German Run not only has the lowest forested land cover but also the highest percentages of developed land cover also classified as urban land cover. Arnold and Gibbons (1996) are two of many researchers that point out urbanized land's influence on SSC because of increased runoff due to impervious surfaces of developed land.

To gain a deeper understanding of the impact of German Run, further analysis was focused on sites located downstream of the dam (Figure 6 and 7). This investigated the effects of extreme flow conditions on sediment and turbidity concentrations. Findings revealed that, during storm flow events characterized by high discharge, the main stem Stainbrook site exhibited relatively stable sediment and turbidity levels. However, at the Craig Rd site downstream of the German Run, sediment and turbidity concentrations increased significantly, indicating that German Run's inflow contributed to sedimentation downstream of the dam. This could likely be due to German Run being in between the two sites, resulting in a higher sediment input at the Craig Rd site. Past studies show that larger particles may become trapped on the bed of a river during low flow but can be dislodged during high flow, increase sediment transport, ultimately resulting in higher flood risk downstream (Kondolf and Wilcock, 1996). These observations suggest that managing the inflow of sediment from German Run could help to mitigate the impact of extreme flow conditions downstream of the dam.

A potential limitation of the study was not recording individual stream size, including width and depth, in addition to discharge rates for individual streams. This is an important consideration because stream size can vary significantly, and this can impact the amount of sediment that a stream can handle without being adversely affected. The complexity of different streams and rivers is largely determined by their fluvial or stream geomorphology. Understanding stream geomorphology can help to determine the severity of sediment loading and hypothesize hydrologic patterns (Fryris, 2017). Additionally, it can be useful to know a stream's capacity when determining the specific effects of discharge levels and amounts of suspended sediment that are deemed harmful to the stream. Stream capacity refers to the amount of bed material that a stream can carry, and this varies depending on the situational characteristics of each stream (Allan and

Castillo, 2007). By considering stream size and capacity in future studies, researchers can gain a more nuanced understanding of the impact of sediment loading on stream ecosystems.

Conclusion

Overall, the results of this study did not significantly support the hypothesis that German Run was the largest contributor of SSC compared to the four other tributaries sampled. The variance in samples did not allow statistics to show average differences in sediment concentration among sites. By testing under different flow conditions, German Run showed exceptionally high impact of SSC under storm flow conditions resulting in lasting impacts downstream. Therefore the data showing high SSC along with poor land cover in relation to other sampled watersheds, suggest that the WCRC should still carry out planning for restoring the poorly eroding banks of German Run.

Insufficient data that lead to insignificant statistics showing German Runs as a leading contributor to SSC could have been avoided by a better sampling method. A better method would include a much larger quantity of samples and a larger variety of storm flow vs base flow samples. Effects of sedimentation on fish life both historically and current, could be useful information to consider and analyze. This would have enabled the study to explore differences in abundance of fish life between the five tributaries and correlate it with sediment concentration data.

In the end, data showing German Runs huge change of sediment loading under storm flow along with GIS providing data to show the poor land cover, is sufficient to consider German Run as a tributary for restoration. Data collected by this study could, in the future, be used to determine the efficiency of any restoration project that is potentially done regarding German Run. Despite not finding the expected differences in sediment concentration among the tributaries tested, the results of this study still have important implications for environmental restoration efforts of German Run. Specifically, the findings suggest that restoration efforts should focus on addressing poor land cover and eroding banks at German Run, which appears to be contributing to high levels of sedimentation during high flow events.

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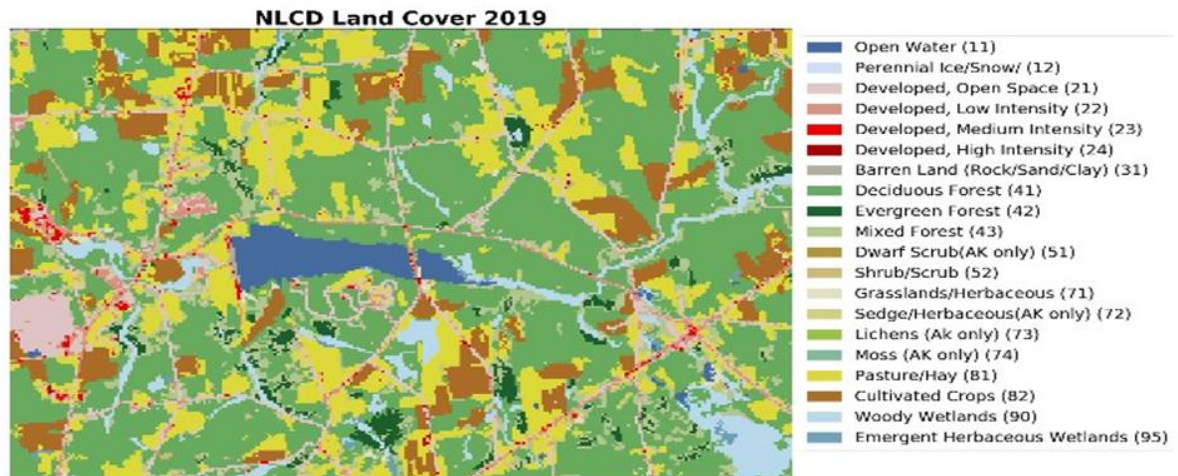
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Appendix A.

Image of land cover data using the Multi-resolution Land Characteristics Consortium MRLC viewer (2019).



Appendix B.

Base flow vs storm flow averages of turbidity for each site.

Site	Avg Base Flow Turbidity	Site	Avg Storm Flow Turbidity
Pratt	2.25	Pratt	122.73
Stonybrook	3.21	Stonybrook	88.61
Castile	4.49	Castile	58.71
Price	6.51	Price	81.64
German	0.7	German	234.88
Stainbrook	17.64	Stainbrook	21.5
Craig Rd	18.12	Craig Rd	64.01
Craig Run	0.35	Craig Run	112.13