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Grain size and vegetation as controlling variables of stream channel morphology

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Grain Size and Vegetation as Controlling Variables of Stream Channel Morphology

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by Grant Delden Colip

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Accepted by the faculty of the Department of Geology & Environmental Science, James Madison University, in partial fulfillment of the requirements for the Honors College.

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PUBLIC PRESENTATION

This work is accepted for presentation, in part or in full, at the JMU Honors Symposium on April 5, 2019, and at the JMU Geology & Environmental Science Student Research Symposium on April 19, 2019.

This project is dedicated to the outstanding faculty of the JMU Department of Geology & Environmental Science, all of whom I have enjoyed working with immensely over the last four years. What a wonderful journey it has been.

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Abstract

Streams are one of the major driving forces that shape the landscapes in the Shenandoah Valley of Virginia and the eastern United States as a whole, and they serve an important role in transporting both water and sediment to the Atlantic Ocean. However, streams are often modified for human use, thus altering their natural equilibrium. These alterations have frequently led to the degradation of channel stability as well as damage to property and infrastructure. With this in mind, a better understanding of how both grain size (D_{50}) and vegetation impact sinuosity (S), which is related to stream channel stability, is needed to analyze the prevalence of channel degradation.

In this study, conducted from August 2018 – February 2019, five relatively undisturbed stream channels were analyzed in the George Washington National Forest in western Virginia. Stream width, depth, and bedload (D_{50}), as well as vegetation type and density, were analyzed using field measurements. Google Earth was used to analyze stream channel sinuosity, gradient, and catchment area size.

Positive relationships were found between sinuosity and basin area as well as gradient, findings which align with prior research. A positive relationship was also found between D_{50} and sinuosity, trends that run contrary to prior work. *T. canadensis*, *L. tulipifera*, *B. lenta*, and *Quercus spp*. were the most common adult tree species found among the stream sites, and it was found that there was a strong positive correlation between streamside vegetation density and stream sinuosity, suggesting that streamside vegetation serves as a stabilizing agent allowing streams to develop equilibrated meanders. Thus, streamside vegetation was found to be a critical part of stream stability, and its presence should be a consideration taken whenever analyzing channel degradation in this context.

Introduction

Streams are one of the major driving forces that modify the landscapes in humid temperate climates such as that of the mid-Atlantic region of the United States. They are largely responsible for the transportation of both water and sediment from the continents to the Atlantic Ocean. Stream channels develop naturally to provide dissipation for the kinetic energy of channeled water, and for the transportation of sediment (Rosgen & Silvey, 1996). However, this natural balance is often altered by humans via direct or indirect manipulation of channels and watersheds (Walter & Merritts, 2008; Ritter et al., 2011). Throughout its existence, most of human civilization has centered around sources of running water; and over the course of millennia these sources, including large numbers of streams, have been modified by humans in an effort to optimize their usefulness to society. These alterations have frequently led to the degradation of channel stability and water quality, and have further led to property and infrastructure damage (Walter & Merritts, 2008).

In the Shenandoah Valley of Virginia, both widespread farming and urbanization have affected stream morphology significantly and increased the volume of sediment transportation taking place (Hack, 1965). These changes can be observed in a number of geomorphologic features associated with streams such as their width, gradient, and degree of meandering. Such alterations have resulted in the disturbance of stream banks and channel beds, manifested in the form of large quantities of additional eroded sediment being carried away each year. The loss of equilibrium of these streams has led to stream instability on a large scale; previous work by Schumm (1960) has shown that unstable channels may be recognized by a deviation in their width-to-depth ratio from the expected (calculated) value based on their grain size.

A stream channel's measured bankfull width and depth can be used to calculate the channel's width-to-depth (W:D) ratio (Williams, 1986). This ratio and its implications have been the subject of many studies in the past, as the W:D ratio can infer how much energy a given stream channel dissipates and how stable it may be given the present bedload grain size (Schumm, 1960). Streams with high W:D ratios are relatively wide and shallow in most areas, allowing them to transport larger grain sizes and dissipate more energy. On the other hand, a low W:D ratio signifies a relatively narrow, deep stream channel that is only able to move particles of a smaller size. If a stream channel's W:D ratio deviates from the expected values given its bedload size, geometry, etc., then it may be considered unstable (Leopold & Wolman, 1957).

Furthermore, previous studies have shown that stream geometry, including channel sinuosity, is related to channel size, including width-to-depth ratio, and stability. Williams (1986) found that as a stream meander's radius of curvature (R_c) increases, the width, depth, and therefore the cross-sectional area of the stream increase. Moreover, meander length has been found to be strongly dependent on the dominant discharge, with some noted dependence on bedload grain size and sediment transport as well (Ackers, 1982). However, more studies in this area are needed to determine whether stream sinuosity and stability are more closely related to grain size, stream gradient, or drainage basin size.

With this in mind, a more rigorous and in-depth understanding of the controlling variables of stream dynamics is required to mitigate the increasingly large and serious problems associated with erosion and channel instability. This research project focused on this problem by addressing two main research questions:

A) Is stream sinuosity being controlled by the size of the basin being drained and the stream channel gradient, or is it controlled by the current bedload grain size in the stream?

B) Is there a relationship between stream sinuosity and streamside vegetation density and type?

It is with both of these research questions in mind that this project aimed to analyze the prevalence of channel degradation in the Shenandoah Valley.

Materials and Methods

Site Location & Description

The field work for this study was conducted from August 2018 – February 2019. Five stream channels located in western Rockingham County in the Shenandoah Valley were selected for data collection (**Figure 1**). All of the data used in this study were collected in locations that were:

- In forested/preserved areas with minimal human disturbance
- Upstream of any artificial reservoirs (e.g., Hone Quarry reservoir)
- On government-owned land (George Washington National Forest)
- On bedrock of the same lithology: the Brallier and Pocono formations, consisting of quartzic sandstones with some interbedded shales (USGS, 2017).

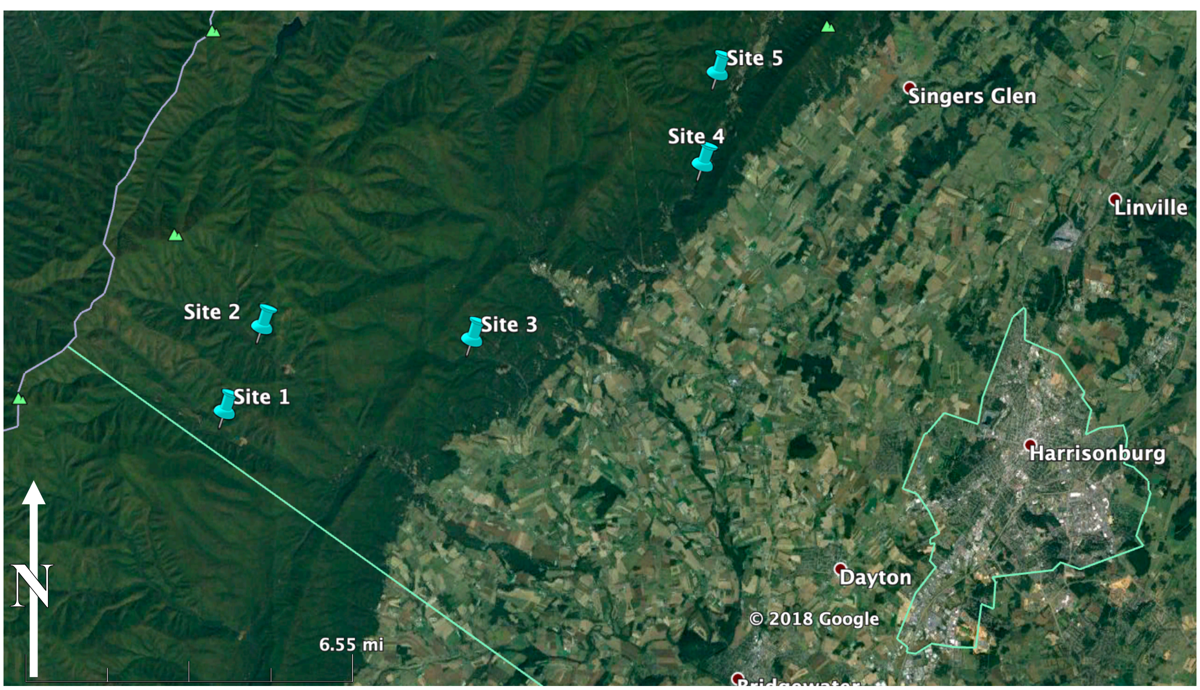
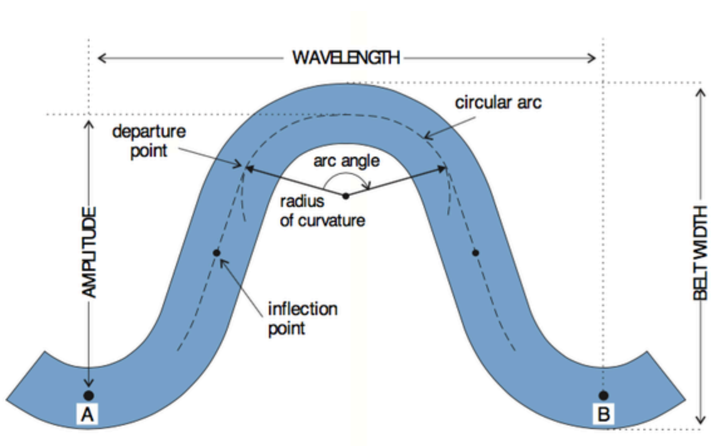


Figure 1 – Site map showing field area in proximity to Harrisonburg, Virginia. Map, *Google Earth*. Accessed 20 Mar. 2019.

Methods: Research Question 1

The **first** research question was addressed via analysis of sediments collected in the field in conjunction with measurements taken of the streams being surveyed. The grain size of a channel's sediment has been observed to exert control on channel width and depth at the bankfull stage; and so if grain size is the main control on stream sinuosity, then there should be a mathematical relationship between grain size and sinuosity at any point throughout the length of the stream channel (**Figure 2**) (Schumm, 1960). Given the governing equations for river dynamics based on prior knowledge of grain size information and bankfull channel width (w), the expected meander value may be predicted, and this value may be compared to the actual values using a combination of Google Earth analysis and on-site field work to determine if a stream is in equilibrium (**Figure 3**).



$$wavelength\ (\lambda) = 10.9w^{1.01}$$

$$amplitude\ (a) = 2.7w^{1.1}$$

$$sinuosity\ (s) = \frac{stream\ length}{valley\ length}$$

Figure 2 – Schematic of meander geometry (Rosgen & Silvey, 1996); parameters for defining meander geometry based on bankfull width (Leopold and Wolman, 1957)

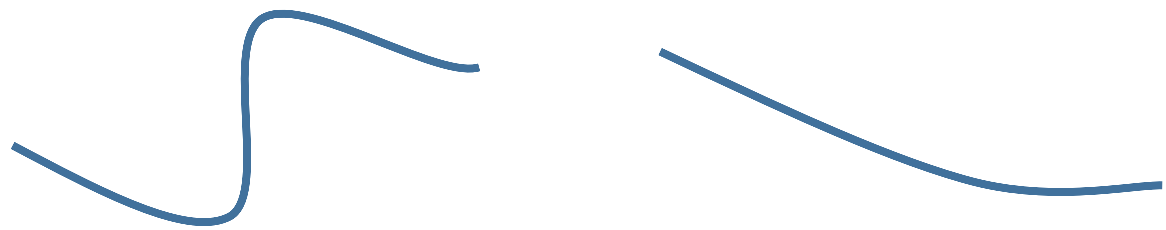


Figure 3 – Schematic plan view of a stream with equilibrium-tuned meander (left) and stream that has been straightened for human use (right)

A pebble count was conducted for each stream using a gravelometer, following a protocol set forth by Rosgen (1993) based on methodology by Wolman (1954). This method employs a systematic sampling technique based on the frequency of pools and riffles in the stream over a distance of 20 bankfull channel widths along the length of the stream. Therefore, hypothetically, if 60% of a stream's channel length (across two meander wavelengths) was composed of riffles and 40% was composed of pools, then 60 samples were taken from the riffle areas and 40 from the pools, totaling a sample size of 100 (Rosgen & Silvey, 1996). The 'first blind touch' approach was used to take samples to avoid sampling bias and skewed data. This approach ensured representative pebble size counts along the length of the channel, as the finer grain sizes usually found in channel pool zones must be factored in accordingly with the coarser grain sizes found along the riffles (Rosgen & Silvey, 1996). With this protocol, particles were categorized into standardized size classes; 100 particles were sampled at each site and their size class was recorded. From this dataset, D_{50} was calculated as the median size (in cm) of these samples.

Additionally, stream channel width and depth measurements were taken at each of the five sites. A 100m measuring tape was used to measure the channel width from one side of the channel to the other at bankfull stage height. A stadia rod was used to measure channel depth in meters. These measurements were taken at five different locations along the stream spaced approximately 50m apart. The 50m spacing was maintained across all stream channels. In locations where there was less accessibility due to steep rock cliffs, debris accumulations, or downed trees, all possible methods were adopted to approximate 50m spacing. Pebble counts were conducted at the location where the first width measurement was taken for each stream.

Google Earth aerial imagery was used to locate the stream channels, and GPS coordinates were used to identify the exact locations where stream measurements were taken at each of the five sites. The outline tool was used to delineate the drainage basin area for each site. Google Earth was also used to calculate stream gradient, which was measured from the site location to the furthest-upland location where a stream channel was evident in the imagery. These values were cross-referenced with a topographic map to ensure relative accuracy, and were recorded in a spreadsheet for data analysis.

Methods: Research Question 2

To address the **second** research question, the vegetation present along each of the five streams (the greenline) was quantitatively recorded and analyzed. This study used the protocol established by Archer & Leary (2008), which utilizes the establishment of vegetation transsects to analyze vegetation parameters (**Figure 4**). Adult trees were classified as having a DBH (diameter at breast height) of at least 5cm, saplings were classified as having a DBH of less than 5cm and being greater than 1m tall, and seedlings were classified as any woody tree species less than 1m tall. Field greenline analysis protocol was conducted as follows:

1. A 20m x 10m transsect was outlined with flags perpendicular to the stream bank at the location where the first (furthest upstream) stream width measurement was taken.
2. Names were recorded and DBH measurements were taken for all adult tree species within this area.
3. Within the 20m x 10m area, a 20m x 5m area was designated and all tree saplings within this smaller zone were recorded and tallied.
4. Within this 20m x 5m area, a 20m x 1m area was designated and all tree seedings within this smallest zone were recorded and tallied.

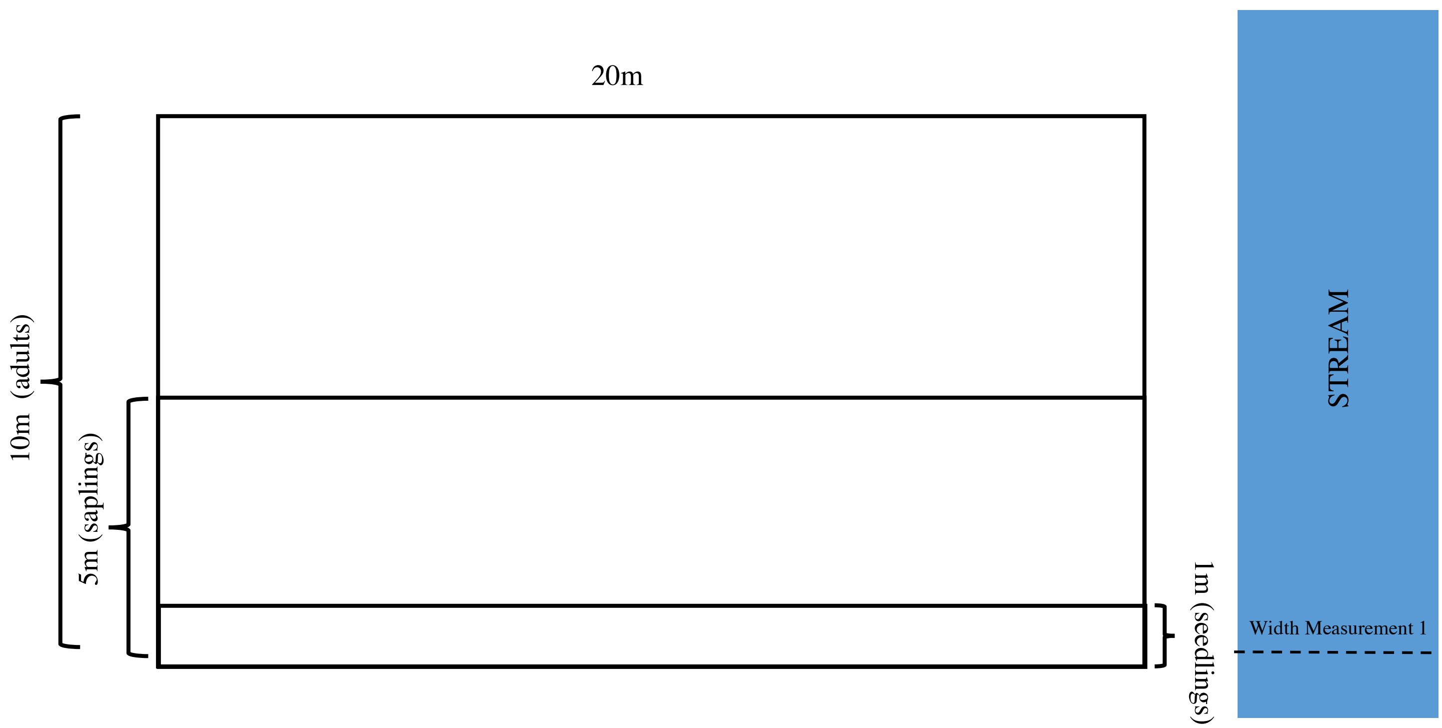


Figure 4 – Experimental plot design for vegetation (greenline) transsect surveying. Adult tree species were tallied and measured for DBH within entire 20x10m area, saplings tallied within the smaller 20x5m area, and seedlings tallied within the smallest 20x1m area.

To further measure the presence of vegetation quantitatively, a normalized vegetation density ratio (D_n) for each site was calculated using the following formula:

$$\mathbf{D_n} = \frac{\frac{\boldsymbol{total\ adult\ DBH\ (in\ cm)}}{\mathbf{100}}}{\mathbf{200}\ \boldsymbol{m^2\ total\ plot\ area}}$$

As with grain size control, this value for each site was compared to stream channel measurements such as sinuosity using both Google Earth and field measurements to determine its relationship to stream meandering and stability, which can in turn have implications for overall stream stability and degradation in the Shenandoah Valley.

Due to the labor- and time-intensive nature of the field work conducted in this study, only five sites were analyzed in establishing a dataset. With such a small dataset, any form of statistical analysis was deemed inappropriate as there may be a relatively wide degree of variation among sites sampled that would do injustice to any statistical tests performed.

Results and Discussion

Research Question 1

Raw data for meander geometry measurements, including channel width and depth, can be found in **Figure 5** in the appendix, and raw bedload data can be found in **Figure 6**.

A positive relationship was found showing that both channel width ($r^2 = 0.632$) and sinuosity ($r^2 = 0.494$) increase as the basin area increases (**Figures 7** & **8**). This finding aligns with previous work: as the size of the catchment area that a stream drains increases, the stream becomes wider and more sinuous to accommodate increased fluvial transport and energy dissipation (Leopold & Wolman 1957; Schumm 1960).

More interestingly, D_{50} was also found to increase with the catchment basin area. Even though the dataset analyzed in this study consisted of only five data points this relationship was fairly evident (**Figure 9**). This trend runs contrary to prior research: traditionally, most studies have shown that as catchment area increases, D_{50} should decrease, as particles would be broken up as they migrated downstream (Schumm, 1960). However, it is noted that the present study analyzed streams at locations relatively close to their headwaters, allowing minimal opportunity for the grain size reduction associated with bedload transport, which may have had an impact on the results of this study. Additionally, while the pebble count at each stream was conducted as uniformly as possible across the five sites following the protocol set by Rosgen (1993), differing field interpretations of what constituted a pool vs. a riffle may have led to samples being taken in a slightly inequivalent manner, as these geomorphological features were at times difficult to distinguish in the field.

Furthermore, it was found that sinuosity increased as D_{50} increased (**Figure 10**). This runs contrary to the expected outcome: previous work has shown that more sinuous streams

(streams with higher sinuosity values) have smaller bedload particle sizes and therefore meander more to dissipate excess energy via friction (Schumm, 1960). These findings may be due at least in part to the fact that, as mentioned previously, the streams sampled in this study were analyzed relatively close to the headwaters, and as such the observed differences in particle size relative to sinuosity may be insignificant to the patterns with greater distance downstream where the traditional relationship may be more evident. While the sample size in the present study consisted of only five streams, the r^2 value of 0.31 also suggests the lack of a strong relationship between these variables.

However, D_{50} was found to increase with stream gradient (**Figure 11**) , which aligns with prior findings, although the r^2 value was once again relatively small (0.49) (Schumm, 1960). A stream's gradient is largely correlated with D_{50}, as a steeper gradient is required to transport coarser bedload material.

Finally, it was found that the W:D ratio of stream channels did increase with D_{50}, aligning well with previous work done on this topic (**Figure 12**) ($r^2 = 0.86$). As W:D increases, or in other words the stream becomes wider and shallower, its ability to carry large particles increases and these particles are moved more effectively (Leopold & Maddock, 1957). Given shallow flow and greater opportunity for maximizing shear stress near the base of the channel, the coarse bedload would be more easily mobilized than in a narrower, deeper stream channel (Schumm, 1960).

Research Question 2

Raw data for adult tree, sapling, and seedling surveying can be seen in **Figures 13**, **14**, and **15**, respectively, in the Appendix.

The relative densities of each of the three most common adult woody tree species found at each site is shown in **Figure 16**. *T. canadensis* (Eastern hemlock) was the most commonly found species, appearing in the list of the top three most common species at all of the five sites and also holding the highest relative density for any species at any site with a value of 0.41 at Site 2. All noted *T. canadensis* adults were live and had not yet succumbed to the wooly adelgid pest; if dead they were categorized as snags and counted separately. Interestingly, *Quercus spp*. (oak) did not appear in this dataset whatsoever. Although it was observed as a largely dominant tree in the canopy at nearly all of the sites, there were typically only one or two *Quercus* adults in each transsect. One possible explanation of this is that the wetter conditions such as those found adjacent to stream channels are generally not preferred by *Quercus* (US Forest Service, 2016). This may also be related to the ongoing mesophication of North American temperate forests; increased competition from other species such as *Acer spp*. (maple) and *N. sylvatica* (black gum) have been previously noted to outcompete *Quercus* thus lessening its dominance in the understories of many forests (Himes & Rentch, 2013).

As many of the greenline analyses conducted for this study were completed in the late fall and winter season, many tree species had already lost their leaves by the time surveying was completed. Unfortunately, even for a trained eye this made tallying saplings and seedlings extremely difficult, and in some cases nearly impossible, especially with seedlings. For this reason, sapling inventories were only able to be taken at sites 1, 2, 3, and 4, and seedling counts were only conducted at Sites 1, 2, and 3. Sites 4 and 5 were analyzed the latest in the season, making counts at these locations especially problematic. As such, this data was not analyzed or factored into the results or conclusions in this study.

More interestingly, as shown in **Figure 17** a strong correlation between the normalized vegetation density (D_n) and stream channel sinuosity ($r^2 = 0.96$) was found. Streams with a more densely vegetated greenline were found to be more sinuous, whereas streams with less adult trees rooted by their banks were generally much straighter. This finding accords well with prior work in this subject area, as when streams are buffered by stronger and more dense root systems, this offers the system more stability and leads to the development of meanders (Ielpi, 2017).

Conclusions and Future Studies

Based on the findings of this study, stream channel sinuosity appears to be impacted by both drainage basin size and bedload (D_{50}). Across the five stream sites surveyed in this study, an increase in catchment size was observed to contribute to more sinuous streams, which aligns with previous research (Schumm, 1960; Leopold & Wolman, 1957). An increase in D_{50} was also linked to an increase in stream channel gradient, as well as in the W:D ratio; steeper, wider streams are able to more easily transport larger particles. While these results are promising, more work is needed to fully understand which of these variables has a larger impact on stream sinuosity, and a larger data set would allow for statistical analysis.

Additionally, it was also found that there was a rather strong relationship between greenline vegetation density and stream channel sinuosity. Vegetation is known to exert significant control on fluvial sinuosity in both braided and meandering streams, "providing bank stability and buffering surface runoff" (Ielpi, 2017; Coulthard, 2005). If the vegetation along the stream channel is a controlling variable of its morphology, then this information should show a relationship to the ideal degree of meandering along the stream. While there was less of a clear image regarding which types of vegetation contributed to the results of this study, the results of this study show that more densely populated vegetation (adult trees) leads to an increase in sinuosity. This aligns with previous research on this topic as well, and further enforces the notion that streamside vegetation in the form of a riparian buffer is essential to the stability of a stream channel.

With this information in mind, there are many ways in which this study could be expanded upon in the future. Future studies would ideally analyze a larger sample size of stream channels so that, as mentioned previously, statistical analysis could be performed on resultant data. While this was beyond the scope of this project, doing so would enable the controlling variables of stream channel gradient, D_{50}, and catchment area to be further parsed out so that their individual effects on stream channel sinuosity may be better understood.

Furthermore, as this study focused on gravel-bed streams, the inclusion of finer-grained stream channels would also benefit the scope of a future project. In this effort, fine sediment samples could be taken from streams' bedload and bank walls for use in laser-diffraction particle analysis to further understand the impact of the fine grain size fraction in addition to that of the coarser, pebble-sized material that was analyzed in this study. Protocol established by Montero-Serrano et al. (2009) suggests sieving these sediments and separating them into three size classes: >250µm (sand), 63-250µm (silt), and <63µm (clay). These cohorts could then be analyzed using a laser diffractometer, such as the LS 13 320 LD Particle Size Analyzer housed at the JMU Department of Geology & Environmental Science. This information would benefit the scope of this project and give a highly precise and accurate picture of the grain sizes present in the finer fraction of stream channels.

Additionally, as all of the channels analyzed in this study were located in relatively undisturbed forested areas, investigation in more disturbed, human-impacted areas would be beneficial in this case so as to understand how these greenline buffers contribute to stream stability. Further investigation notwithstanding, it can be said that vegetation is a critical part of stream stability and is an important aspect that should be taken into consideration during stream restoration. Many streams outside the field area of study were not observed to possess riparian buffers, especially when located on farmland, and so this is a consideration that should be taken whenever analyzing channel degradation in this context.

Appendix

	Site 1			
#	**Stream Width (m)**			
(upstream) 5	5.9		Median width	7.30
4	6.6		Predicted λ	83.13
3	7.3		Predicted a	26.56
2	7.1		Stream length (m)	240.17
(downstream) 1	7.9		Valley length (m)	188.65
			Sinuosity	1.27
			Depth	0.30
	Site 2		W/D	24.33
#	**Stream Width (m)**			
(upstream) 1	13.0		Median width	13.00
2	13.6		Predicted λ	148.90
3	18.0		Predicted a	50.10
4	9.7		Stream length (m)	257.10
(downstream) 5	5.5		Valley length (m)	207.49
			Sinuosity	1.24
			Depth	0.40
	Site 3		W/D	32.50
#	**Stream Width (m)**			
(upstream) 1	8.5		Median width	8.50
2	7.0		Predicted λ	96.94
3	8.6		Predicted a	31.40
4	6.5		Stream length (m)	255.00
(downstream) 5	8.5		Valley length (m)	200.45
			Sinuosity	1.27
			Depth	0.30
	Site 4		W/D	28.75
#	**Stream Width (m)**			
(upstream) 5	10.2		Median width	7.80
4	10.6		Predicted λ	88.88
3	7.8		Predicted a	28.56
2	5.3		Stream length (m)	215.28
(downstream) 1	7.5		Valley length (m)	196.69
			Sinuosity	1.09
			Depth	0.35

	Site 5		W/D	22.29
#	**Stream Width (m)**			
(upstream) 1	8.4		Median width	6.90
2	6.2		Predicted **λ**	78.53
3	7.3		Predicted a	24.96
4	6.9		Stream length (m)	353.72
(downstream) 5	6.2		Valley length (m)	302.78
			Sinuosity	1.17
			Depth	0.29
			W/D	24.16

Figure 5 – Raw data for stream meander geometry measurements.

Particle Size (mm)	**Site 1**	**Site 2**	**Site 3**	**Site 4**	**Site 5**
<2	0	0	0	0	0
2	0	0	0	0	0
2.8	0	0	0	0	0
4	0	0	0	0	0
5.6	0	0	0	1	0
8	1	0	0	1	1
11	3	0	1	4	2
16	2	1	0	2	0
22.6	8	3	4	4	1
32	16	7	5	9	8
45	19	14	14	16	19
64	21	23	23	22	24
90	21	26	27	24	22
128	4	15	15	10	16
180	1	8	7	5	5
>180	4	3	4	2	2
TOTAL	100	100	100	100	100

Figure 6 – Raw data for stream bedload measurements.

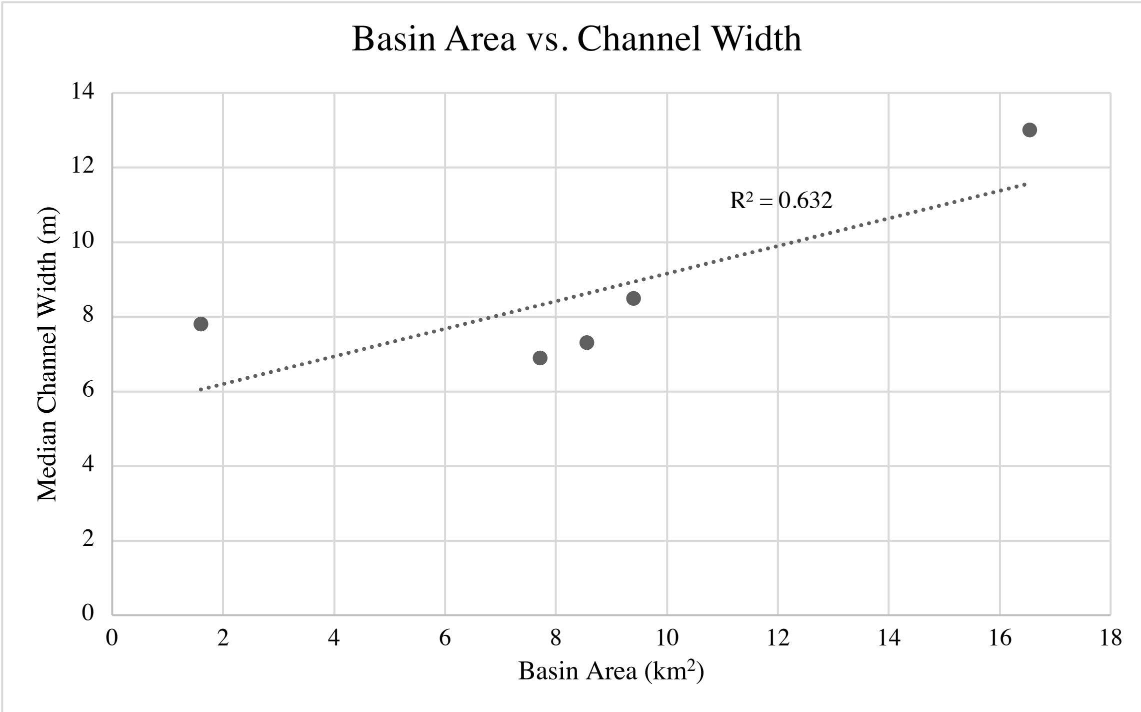


Figure 7 – Drainage basin area vs. stream channel width. These data suggest these two variables exhibit a direct positive relationship.

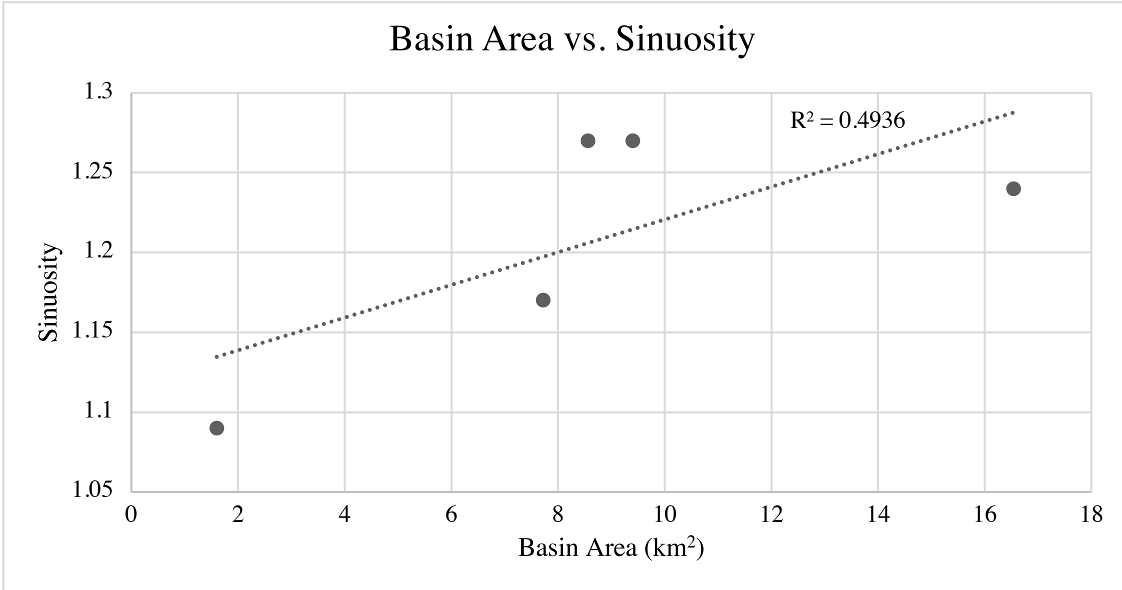


Figure 8 – Drainage basin area vs. stream channel sinuosity. These two variables also exhibit a positive relationship in this study.

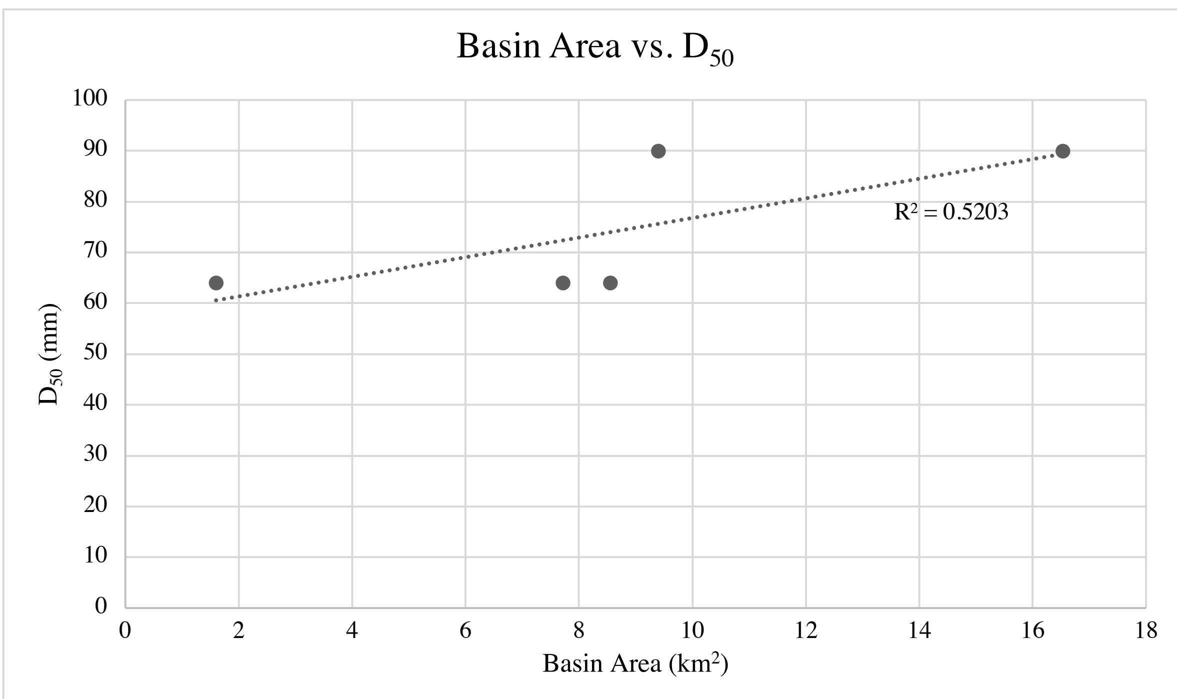


Figure 9 – Drainage basin area vs. D_{50}. These variables were found to have a positive relationship in this study, which is the inverse of the predicted findings.

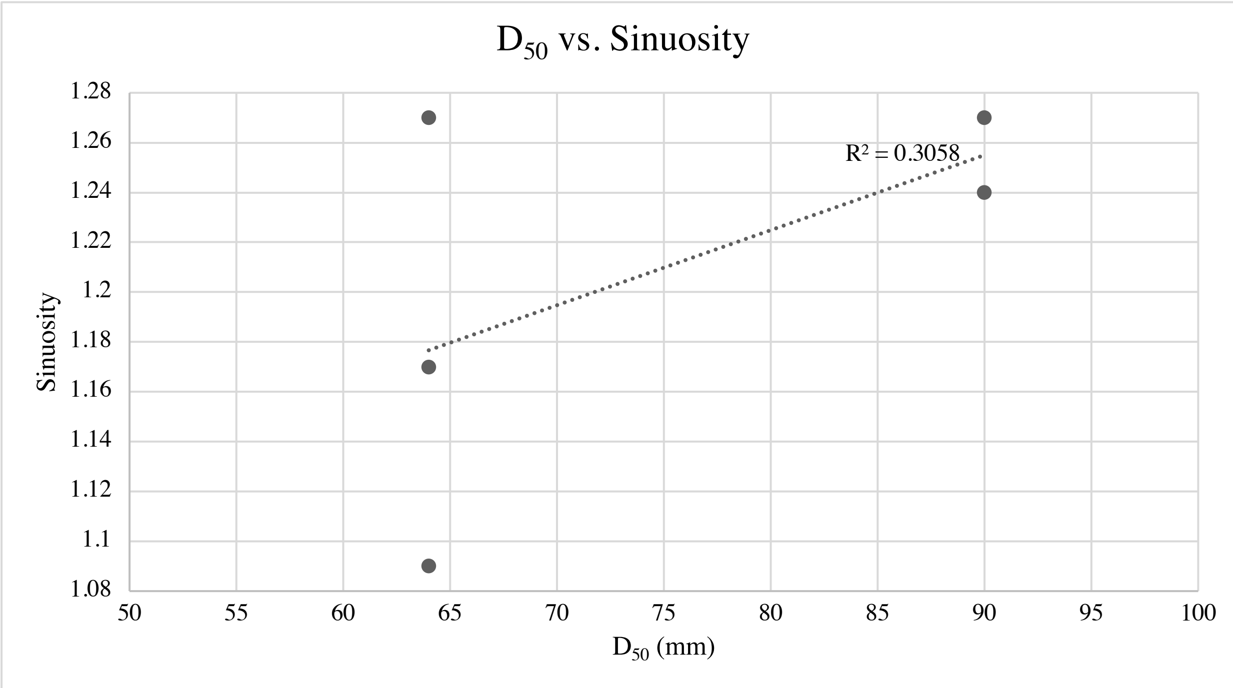


Figure 10 – D_{50} vs. stream channel sinuosity. This relationship exhibited a weak positive correlation, opposite of the expected findings.

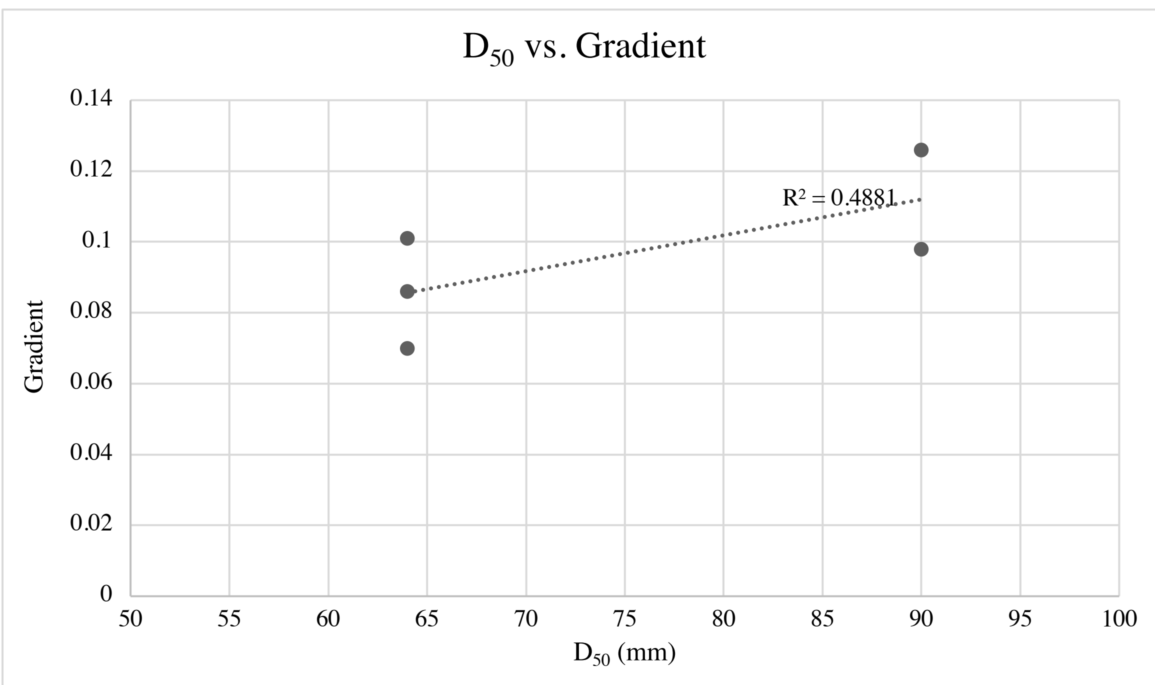


Figure 11 – D_{50} vs. stream channel gradient. The findings in this study exhibit a direct relationship between these two variables, aligning with prior research.

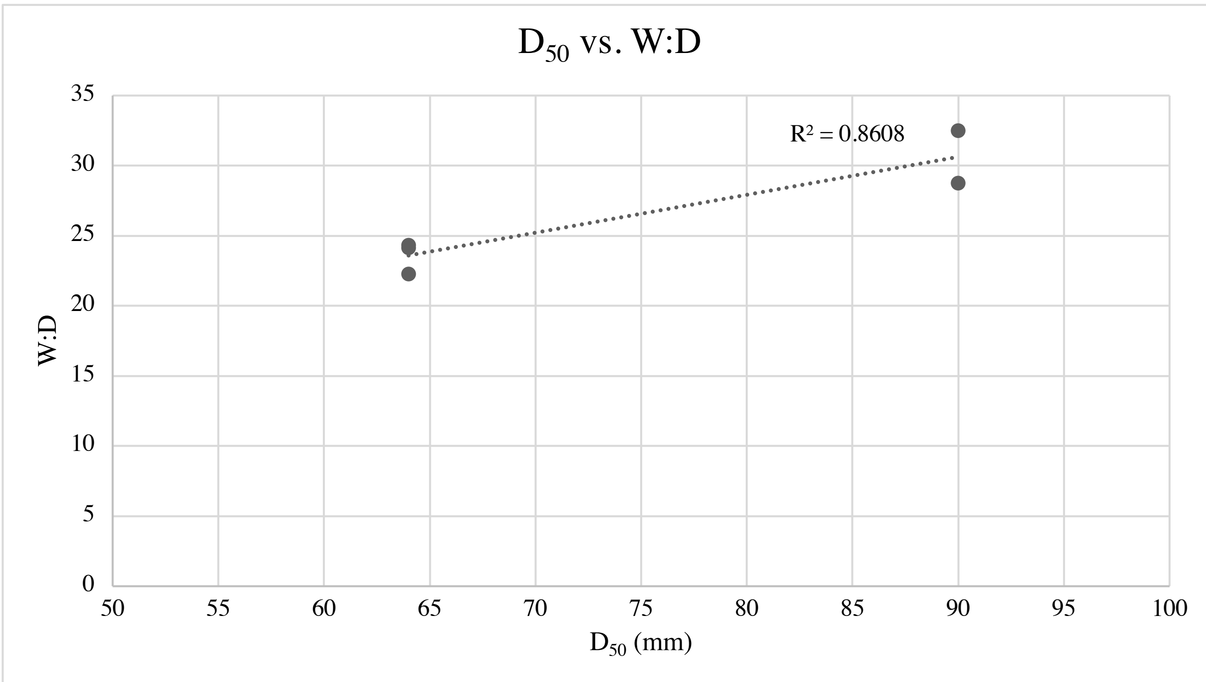


Figure 12 – D_{50} vs. stream channel W:D ratio. It was found that these two variables exhibited a direct relationship, aligning with previous research done in this field. As W:D increases (the stream becomes wider and shallower), its ability to carry large particles increases as well.

Site 1 (@ Width 1)		
Adults		
Species	dbh	notes
A. rubrum	31.3	
A. saccharum	17.3	
A. saccharum	39.9	
A. saccharum	27.0	
A. saccharum	19.0	
A. saccharum	10.6	
N. sylvatica	33.0	
N. sylvatica	20.7	
N. sylvatica	8.1	
Q. alba	73.8	
Q. rubra	84.3	charred @ base but seems OK
S. albidium	39.4	
snag	9.7	burned
snag	10.4	burned
snag	25.0	burned
T. canadensis	30.0	
T. canadensis	44.1	
T. canadensis	5.5	
Site 2 (@ Width 1)		
Adults		
Species	dbh	notes
?3	6.5	
A. saccharum	46.8	
B. lenta	24.7	alternate, serrated
B. lenta	12.8	
B. lenta	20.2	
P. occidentalis	53.2	
P. strobus	76.6	
P. strobus	100.7	splits into 3 trunks above bh
snag	23.5	
T. americana	10.0	
T. canadensis	6.1	

T. canadensis	8.0	
T. canadensis	8.5	
T. canadensis	12.9	
T. canadensis	11.7	
T. canadensis	25.5	
T. canadensis	20.1	
Site 3 (@ Width 1)		
Adults		
Species	dbh	notes
A. rubrum	7.7	
A. rubrum	17.8	
A. rubrum	14.8	
A. saccharum	12.0	
A. saccharum	7.5	
A. saccharum	12.1	
A. saccharum	8.8	
B. lenta	12.3	
P. strobus	46.8	
P. strobus	33.5	
Q. alba	52.9	conjoined trunks
Q. alba	51.2	
Q. rubra	72.7	
snag	24.3	
snag	16.1	
T. canadensis	19.5	
T. canadensis	7.0	
T. canadensis	9.6	
T. canadensis	21.7	
T. canadensis	5.8	
T. canadensis	30.8	
Site 4 (@ Width 1)		
Adults		
Species	dbh	notes
C. canadensis	5.2	
C. glabra	10.3	

F. grandifolia	9.0	
F. grandifolia	20.0	
J. nigra	43.9	
L. tulipifera	12.8	
L. tulipifera	30.2	
L. tulipifera	14.3	
L. tulipifera	24.9	
L. tulipifera	22.3	
L. tulipifera	12.1	
L. tulipifera	38.7	
P. serotina	16.0	
P. serotina	9.2	
P. strobus	18.5	
Q. rubra	13.1	
Q. velutina	8.0	
snag	9.9	
T. canadensis	11.5	
Site 5 (@ Width 1)		
Adults		
Species	dbh	notes
A. saccharum	25.6	
B. lenta	24.7	
B. lenta	32.0	
B. lenta	17.1	
B. lenta	21.7	
B. lenta	14.8	
F. grandifolia	6.5	
L. tulipifera	54.7	
N. sylvatica	30.0	
N. sylvatica	35.1	
snag	14.0	
snag	30.0	
T. canadensis	49.7	
T. canadensis	20.6	
T. canadensis	17.4	

Figure 13 – Raw data for adult tree surveying.

Site 1	
Species	tally
N. sylvatica	3
A. negundo	1
C. canadensis	2
U. rubra	1
A. pensylvanicum	1
snag	1
A. rubrum	1
Site 2	
Species	tally
B. lenta	2
A. pensylvanicum	1
A. saccharum	3
T. canadensis	3
Q. rubra	1
Site 3	
Species	tally
P. serotina	2
A. pennsylvanicum	1
Site 4	
Species	tally
C. canadensis	26
P. strobus	1
Q. rubrum	1
C. florida	1
T. canadensis	1
Site 5	
Species	tally
no data (winter)	

Figure 14 – Raw data for sapling surveying.

Site 1	
Species	tally
S. albidium	21
N. sylvatica	2
T. americana	1
P. strobus	1
Site 2	
Species	tally
A. saccharum	8
Q. velutina	3
C. canadensis	2
Q. alba	2
Q. rubrum	1
Site 3	
Species	tally
L. tulipifera	3
Q. rubra	7
A. rubrum	2
Q. alba	13
Q. montana	2
T. canadensis	1
No data for sites 4 & 5 (winter)	

Figure 15 – Raw data for seedling surveying.

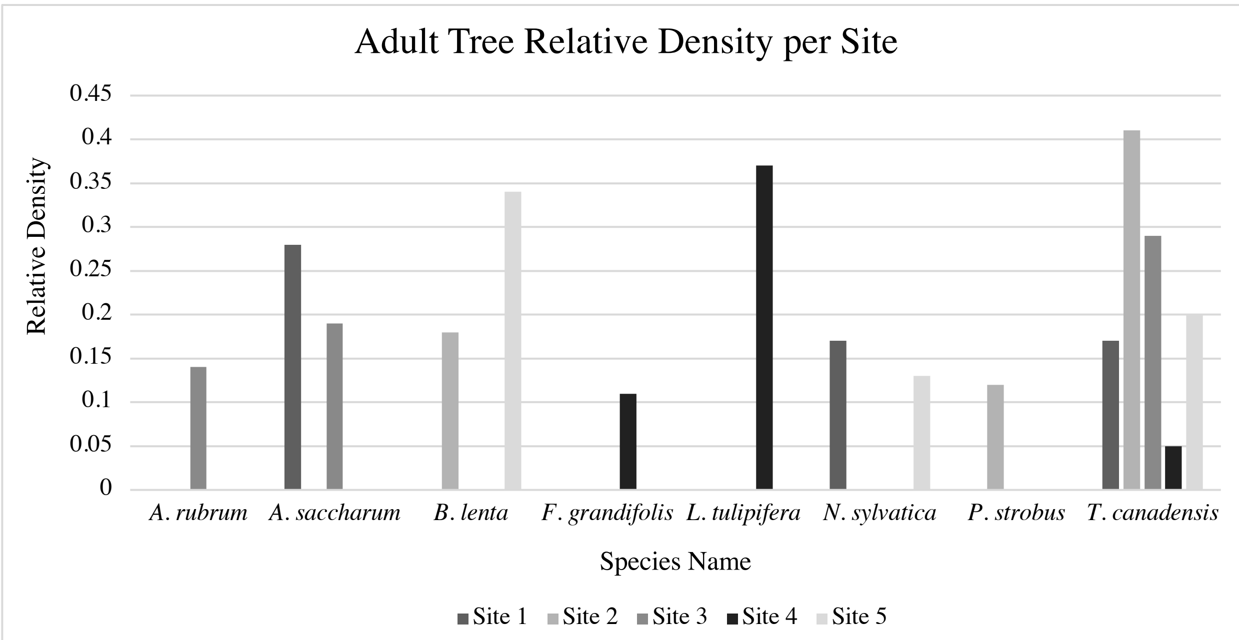


Figure 16 – Relative densities of the three most common woody tree species at each site. Data only includes adult tree species. *T. canadensis* was the most common adult tree found in this study across all the sites.

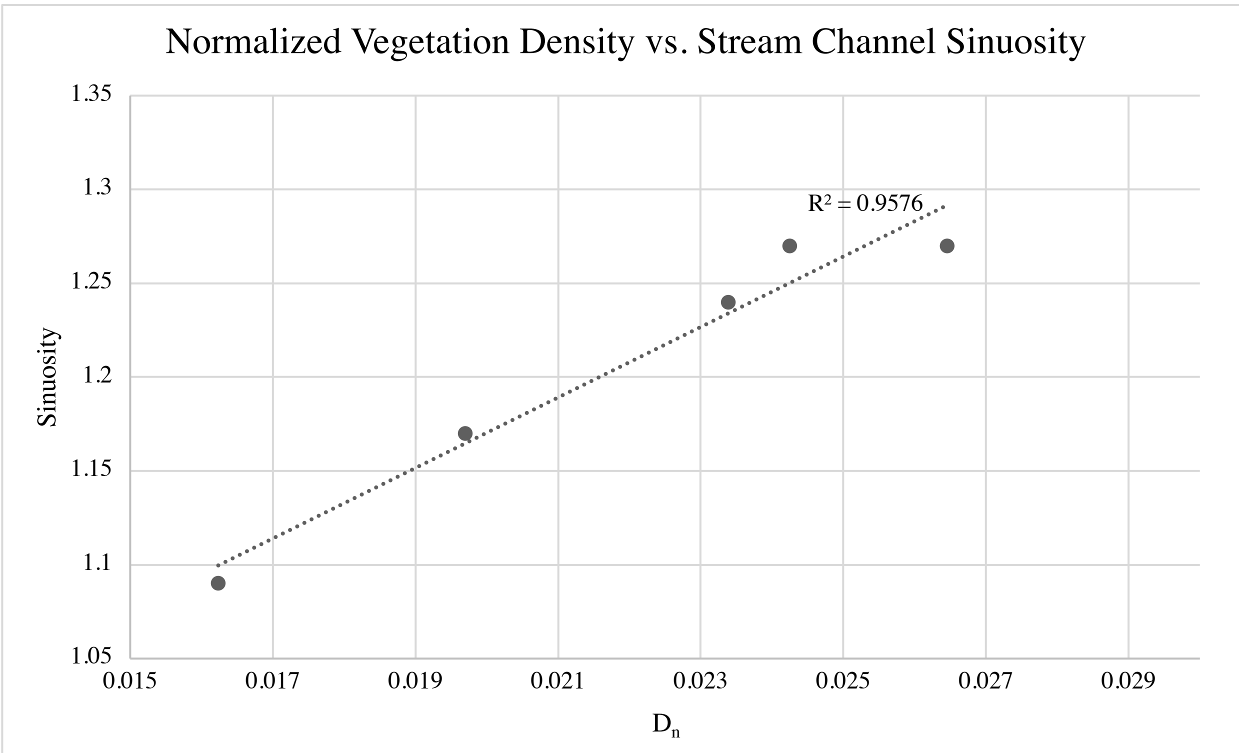


Figure 17 – Normalized vegetation density (D_n) vs. stream channel sinuosity at each of the five sites. This dataset shows a strong positive relationship between the two variables.

Bibliography

Ackers, P, 1982, Meandering Channels and the Influence of Bed Material. *Gravel-Bed Rivers*, p. 389–415, doi: 10.2937/1982.wr038131.

Archer, E., and Leary, R., 2008, Effectiveness Monitoring for Streams and Riparian Areas: Sampling Protocol for Vegetation Parameters: US Forest Service Publications, p. 5–27.

Coulthard, T.J., 2005, Effects of vegetation on braided stream pattern and dynamics: Water Resources Research, v. 41, doi: 10.1029/2004wr003201.

Gellis, A.A., and Sanisaca, L.G., 2017, Sediment Fingerprinting to Delineate Sources of Sediment in the Agricultural and Forested Smith Creek Watershed, Virginia, USA: JAWRA: Journal of the American Water Resources Association, v. 54, p. 1197–1221, doi: 10.1111/1752-1688.12680.

Hack, J. T., 1965, Geomorphology of the Shenandoah Valley, Virginia and West Virginia, and origin of the residual ore deposits: *Professional Paper*, doi:10.3133/pp484.

Himes, J.M., and Rentch, J.S., 2013, Canopy Gap Dynamics in a Second-Growth Appalachian Hardwood Forest in West Virginia: Castanea, v. 78, p. 171–184, doi: 10.2179/13-006.

Ielpi, A., 2017, Controls on sinuosity in the sparsely vegetated Fossálar River, southern Iceland: Geomorphology, v. 286, p. 93–109, doi: 10.1016/j.geomorph.2017.03.013.

Leopold, L.B., and Maddock, T., 1953, The hydraulic geometry of stream channels and some physiographic implications: US Government Printing Office.

Leopold, L.B., and Wolman, M.G., 1957, River channel patterns: Braided, meandering, and straight: US Government Printing Office, doi: 10.3133/pp282b.

Montero-Serrano, J.C., Bout-Roumazeilles, V., Tribovillard, N., Sionneau, T., Riboulleau, A., Bory, A., and Flower, B., 2009, Sedimentary evidence of deglacial megafloods in the northern Gulf of Mexico (Pigmy Basin): Quaternary Science Reviews, v. 28, p. 3333–3347, doi: 10.1016/j.quascirev.2009.09.011.

Ritter, D.F., Kochel, R.C., and Miller, J.R., 2011, Process geomorphology: Long Grove, IL, Waveland Press.

Rosgen, D., 1993, Report submitted to USDI National Park Service, Yellowstone National Park, Pagosa Springs, CO: Wildland Hydrology, p. 82.

Rosgen, D., and Silvey, H.L., 1996, *Applied River Morphology* (2nd ed.): Wildland Hydrology.

Schumm, S.A., 1960, The Shape of Alluvial Channels in Relation to Sediment Type: USGS Professional Paper, doi: 10.3133/pp352b.

US Forest Service, 2016, *Quercus macrocarpa*: Retrieved from https://www.fs.fed.us/database/feis/plants/tree/quemac/all.html

USGS, 2017, Updated lithologic unit descriptions for western Virginia and eastern West Virginia, doi: 10.3411/p.324792a.

Walter, R. C., & Merritts, D. J., 2008, Natural streams and the legacy of water-powered mills: Biomedical Journal, doi: 10.3410/f.1100199.560155.

Williams, G.P., 1986, River meanders and channel size: Journal of Hydrology, v. 88, p. 147–164, doi: 10.1016/0022-1694(86)90202-7.

Wolman, M.G., 1954, A method of sampling coarse river-bed material: Transactions, American Geophysical Union, v. 35, p. 951, doi: 10.1029/tr035i006p00951.