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Anthropogenic litter in urban waterways: An analysis of litter, urbanization, and the emerging role of citizen science in Beargrass Creek, Louisville, KY.

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ANTHROPOGENIC LITTER IN URBAN WATERWAYS: AN ANALYSIS OF LITTER, URBANIZATION, AND THE EMERGING ROLE OF CITIZEN SCIENCE IN BEARGRASS CREEK, LOUISVILLE, KY

By

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B.S., Florida State University, 2022

A Thesis
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in Interdisciplinary Studies, concentration in Sustainability

Interdisciplinary Studies
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A Thesis Approved on

April 11, 2024

by the following Thesis Committee:

Dr. Tamara Sluss

Dr. David Wicks

Dr. Tyler Mahoney

DEDICATION

This paper is dedicated to Beargrass Creek, in gratitude of the hope I found in her beautiful resilience. Researching Beargrass Creek brought restoration after a painful season in my life. May the three forks of Beargrass Creek soon experience the restoration and care that has been much deserved, but long overlooked. A haiku to share…

Decades of abuse,
Still she runs resiliently.
Beargrass flows with *hope*.

ACKNOWLEDGEMENTS

I would like to thank my research partners and amazing friends from the 2023 Aqlan Lab Summer Internship: Alli Kling and Sam Howlet. Without our work together over the summer, there would have been no foundation for this thesis. I also thank Dr. Aqlan and Ms. Jaggers for the opportunity to be a part of that internship, an NSF grant funded research program (RET grant #2204601, RET Site in Manufacturing Simulation and Automation). So many community members and water-related professionals went above and beyond in their support of my research and were always happy to share their valuable insights to all my questions. In particular, I'm grateful for Mr. Winlock and Ms. Meyers from MSD showing up countless morning for our summer research team. We learned so much from them, and they were incredibly generous with their time and expertise.

I have oceans of gratitude for my advisory committee. I learned immensely from Dr. Sluss, as both my advisor and professor. She does so much for UofL Sustainability. Dr. Mahoney always goes the extra mile for his students, and with his support anything feels possible! I'm extremely thankful for his introduction into the world of engineering and look forward to where those lessons will lead in the future. Finally, it has been an

honor to have Dr. Wicks as a mentor of this project from the very beginning. The change his environmental work and advocacy has inspired in Beargrass Creek is incomparable. Dr. Wicks never stops imagining a better world, and his dedication to that vision is an extraordinary example that inspires me to keep fighting for the future too.

To all the professors that I have had the opportunity to work with, I'm so grateful for their examples of excellence and their commitment to teaching. It is such a gift to learn from professors that are so passionate about their work and the success of their students. I especially want to thank my first mentors at the Coastal Plains Institute, followed by those with Salt River Watershed Watch, for sharing their excitement for citizen science with me. I have been forever shaped by those early experiences of fieldwork, joy, and community!

I would like to thank my incredible parents for offering me endless encouragement and support throughout my entire academic career, and especially through the process of this paper. I look up to my uncle and his work in water management so dearly. This project would not have been possible without Dr. Kate Price either. She showed me a new path forward when I couldn't find a way, and I'm thankful to continually learn from her compassion and authenticity. My friends and family truly helped me believe in myself and this project. Thank you!

ABSTRACT

ANTHROPOGENIC LITTER IN URBAN WATERWAYS: AN ANALYSIS OF LITTER, URBANIZATION, AND THE EMERGING ROLE OF CITIZEN SCIENCE IN BEARGRASS CREEK, LOUISVILLE, KY

Ella Swigler

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This thesis addressed the ever growing presence and persistence of anthropogenic litter (AL) in urban waterways. AL has been studied in marine environments, but research gaps exist in riverine ecosystems. Most of the AL that reaches the Earth's oceans is carried by urban rivers, so understanding the relationship between these waterways and AL is critical in effectively fighting AL accumulation, especially for legacy plastic pollutants. The study explored fifteen sites throughout Beargrass Creek and recorded the quantity and type of AL present throughout the summer and fall of 2023. The National Geographic Marine Debris Tracker App was employed to successfully accomplish this analysis. Trends between AL quantity, flow rates, and watershed variables were investigated. The results of this project revealed the interconnected relationship between urbanization and AL accumulation in waterways, and they provided supporting evidence for the crucial change possible through participatory science.

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INTRODUCTION

This study explored anthropogenic litter (AL) and the factors contributing to its prevalence in urban waterways. The EPA (n.d.) describes AL, which can also be referred to as aquatic trash, the garbage polluting the nation's lakes, rivers, and streams. As defined by NOAA (2009), land use is the understanding of how people use the landscape. Land cover outlines the physical characteristics of earth's surface, such as the natural ecosystems and urban expanse. The watersheds of urban waterways are subject to extensive anthropogenic land use and land cover (LULC). As cities continue to grow and develop, it is important to fully understand the implications for local streams. While these waterways may be smaller and less recognized, they are no less connected to the issue of litter pollution in marine environments globally. If communities hope to reduce the amount of plastic accumulating in the earth's oceans and the consequential microplastics entering the global food chain, action needs to begin in the local streams where collection is much more feasible. Studying what makes a watershed more susceptible to the pollution of aquatic trash will provide important insight moving forward, so that mitigation efforts can be driven by data and effective action. The research of this study was inspired by the work done in the NSF grant funded Aqlan Lab Community-Engaged Educational Ecosystem Project at the UofL Speed School of Engineering, where student researchers conducted a litter analysis of Beargrass Creek in Louisville, KY, using the National Geographic Marine Debris Tracker App. The goal of this project was to expand the work that has been started in Beargrass Creek through tracking AL observations longer and incorporating discharge trends recorded by the USGS monitoring locations in Beargrass Creek. The results should be used to expand the knowledge of urban waterways and explore protection strategies best suited for local streams impacted by urbanization.

BACKGROUND

The accumulation of anthropogenic litter in waterways and aquatic ecosystems has severe negative effects on environment, as well as human health and livelihood. Lebreton et al. (2017) found that about two million tons of plastic are delivered to the oceans through rivers and streams every year. The focus of this study is critical in overcoming the issues of plastic pollution and advocating for clean waters because analyzing LULC in relationship to anthropogenic litter strengthens the knowledge guiding restoration work, and therefore can aid the development of mitigation strategies. In order to create effective solutions, the scientific community needs to understand all the mechanisms driving anthropogenic litter so that they can be fully resolved. There is much more that needs to be uncovered in this area, with the gaps primarily found in local hydrologic systems such as streams and rivers. As explained by Cowger et al. (2019), the majority of anthropogenic litter studies are predominately focused on beaches and the marine environment. Less work has been devoted to riverine litter in comparison, thus making this research question essential to expansion of the scientific knowledge surrounding local hydrologic systems, and ultimately to data-driven solutions protecting the global waters.

This project is an intersection of fields that furthers research through its multifaceted approach to sustainability, ecology, hydrology, and citizen science. This study recognized the need to develop the understanding of urban waterways in order to successfully manage anthropogenic litter, and achieved this by building on the work that has been done in Beargrass Creek and incorporating new technology into the methods of research.

Related Research

Given the effect of LULC on nonpoint sources of litter, this study also offers a perspective on urbanization. Brooks (2014) conducted a study to explore the potential effects of urbanization on the water quality in Beargrass Creek's Middle Fork. While the research focused primarily on the chemical indicators of water quality, Brooks analyzed each one in order to explore the potential effects of urban land cover in the Beargrass Creek watershed.

Beyond Louisville however, this study is connected to all the current research focused anthropogenic litter and water pollution. These studies are pioneering a new area of research, in response to the unprecedented era of plastic pollution and aquatic trash the planet presently faces. Moore et al. (2020) tested the effectiveness of four different field methods of trash quantification in waterways with a comparative analysis. The field survey of trash intensity and source types conducted by Clamann et al. (2022) evaluated the potential relationships between the concentration of anthropogenic litter and factors such as overflowing dumpsters, illegal dumping, historic dumping, encampments, as well as land attributes- such as population, transportation, and land use. McCormick and Hoellein (2016) quantified the density, mass, assemblage, and environmental drivers of anthropogenic litter in riparian and benthic zones in five rivers, with sites representing a gradient of urban land use in the Chicago metropolitan region of northeastern Illinois alongside northwestern Indiana. They additionally compared riparian and benthic litter assemblages and abundance in rivers to the well-studied marine habitats, while also measuring rates of riparian anthropogenic litter accumulation and export at biweekly, seasonal, and annual scales. The results indicated that future efforts should focus on the role of land use at the riparian and watershed scales (such as commercial, residential, and public property) and its influence upon litter distribution.

National Geographic Marine Debris Tracker App

The study connected Beargrass Creek to the National Geographic Marine Debris Tracker. This mobile app was developed by the NOAA Marine Debris Program and the College of Engineering at the University of Georgia in 2010, with the goal to provide a platform for individuals to take part in a worldwide citizen science initiative to document anthropogenic litter through a global standardized process of data collection. The app serves not only as an effective research tool for scientists in the field, but also to equip citizens and reconnect residents with the streams in their own backyards. According to Jambeck et al. (2015), over 400,000 items of trash have been tracked through the program. Exploring the potential of the app to engage Louisville residents with Beargrass Creek was an important component of this study that could foster the development of future citizen science programs focused on the restoration of the creek. In fact, there has already been work done in the Ohio River Valley with the National Geographic Marine Debris Tracker app. University of Georgia researchers launched a citizen science opportunity for individuals to collect litter observations along the river at four key sites (Youngblood, 2022). Data were analyzed to learn more about microplastic pollution in the Ohio River and its surrounding communities. Results of the project provided insight into this study, as Beargrass Creek is a tributary that flows into the Ohio River. Since this UGA study expands the knowledge of litter inputs from the Ohio River watershed, a research partnership through the Marine Debris Tracker app would strengthen data collection for assessing riverine litter.

Flow Rates of Urban Waterways

Urbanized streamflow is another important component connected the persistence of AL pollution in waterways. Analyzing the streamflow data at more than 3,000 stream-gaging sites across the nation from 1980 to 2014 revealed that low flows lasting for a shorter duration have increased over time (Carlisle et al., 2019). Furthermore, the analysis showed high flows are additionally more frequent, but they are also shorter than their natural duration and lower in magnitude. It is important to note that the high and low flows reflect a flashy hydrologic system, it is possible for baseflows to experience an overall decrease in magnitude and duration as a consequence of urbanization (Burns et al. 2005, Riley et al. 2005). The effect on baseflow is more variable because it can be possibly offset by imported water supplies, increased leakage from sewers, irrigation, discharge of wastewater effluents, increased infiltration due to recharge areas, or decreased evapotranspiration due to decreased vegetation (EPA, n.d.). These are manmade exceptions to the natural outcome of decreased watershed infiltration (due to impervious surfaces) causing decreased groundwater recharge, and therefore creating reduced stream baseflow conditions. Storm drain systems also lower groundwater recharge and magnify the conditions needed for low baseflow. This study examined the relationship between streamflow data and AL accumulation, and explored how a flashy hydrologic system with lower baseflows could relate to the quantity of AL recorded in urban waterways.

METHODS

The methods were designed to quantify litter using the National Geographic Marine Debris Tracker app in the three forks of Beargrass Creek in Louisville, KY and assess correlations with discharge, land use, and watershed attributes.

Site Description

The study encompassed the three forks of Beargrass Creek in Louisville, Kentucky: Muddy Fork, Middle Fork, and South Fork (Figure 1).

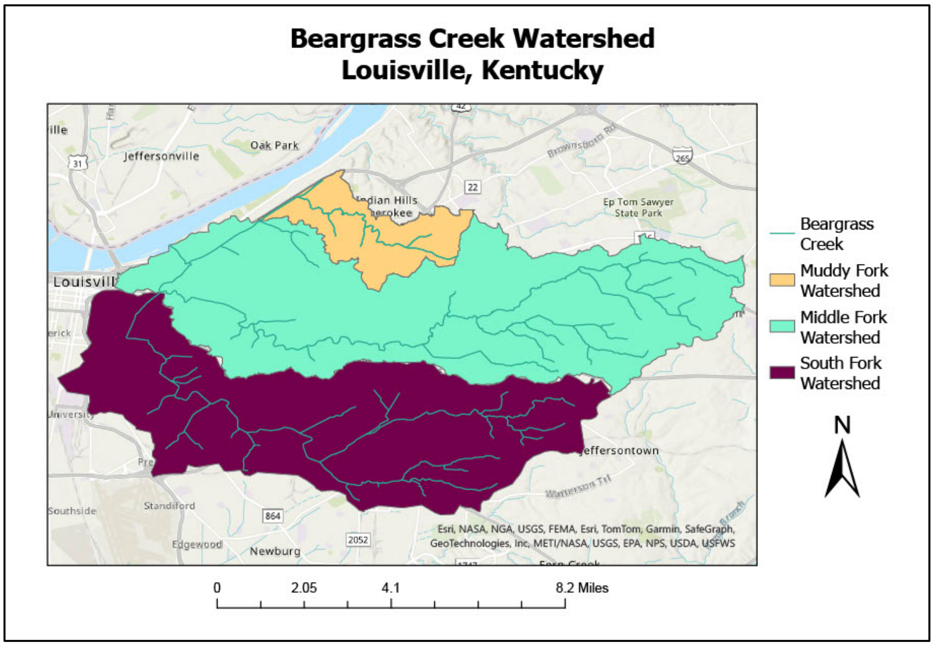


Figure 1. Map of Beargrass Creek and its three forks.

Beargrass Creek was an appropriate site for the goals of this analysis because it is an urban waterway significantly impacted by development (Louisville Jefferson County Metro, n.d.) and the three forks flow throughout the city, connecting many diverse areas. South Fork, Muddy Fork, and Middle Fork all have different percentages of land use types, which made a comparison of watershed characteristics possible. The three forks of Beargrass Creek create a watershed of about 60 square miles with South Fork stretching 27 square miles, Middle Fork covering 25 square miles, and Muddy Fork making up 7 square miles (US Army Corps of Engineers, 2021). The US Army Corps of Engineers (2021) also described in their ecological restoration feasibility study how these forks run through all the major neighborhoods of Louisville and are diverse as the city itself. South Fork begins near Bardstown Road and the Buechel area, before reaching Audubon Park and Germantown, and finally converging with Middle Fork in the Butchertown and Irish Hills region. As for Middle Fork, this branch starts in Middletown and flows to St. Matthews, passing through the parks of Seneca and Cherokee on its way to its convergence to the South Fork. Muddy Fork's beginning is found in the Windy Hills region and its path follows I-71 until it meets the converged South and Middle Fork, at which then all three forks shortly discharge into the Ohio River.

Procedure

The watershed was evaluated geographically, and fifteen sites were selected to create realistic representative of each fork, in terms of the predominant LULC (Figure 2). Sites were also chosen if they had been a part of previous AL research with the Aqlan Lab. Six sites were located in Middle Fork, five sites were located in South Fork, and four sites were located in Muddy Fork. The range in the number of sites per fork was a result of the span in sub-watershed sizes, as well as accessibility. There were some areas that could not be represented in the study as the researcher could not safety access those parts of the creek for the required observational radius of 200 feet. Sites S1, S2, S3, S4, S5 are located in the South Fork. Sites MI1, MI2, MI3, MI4, MI5, and MI6 are found across the Middle Fork. Sites MU1, MU2, MU3, and MU4 are located within the Muddy Fork.

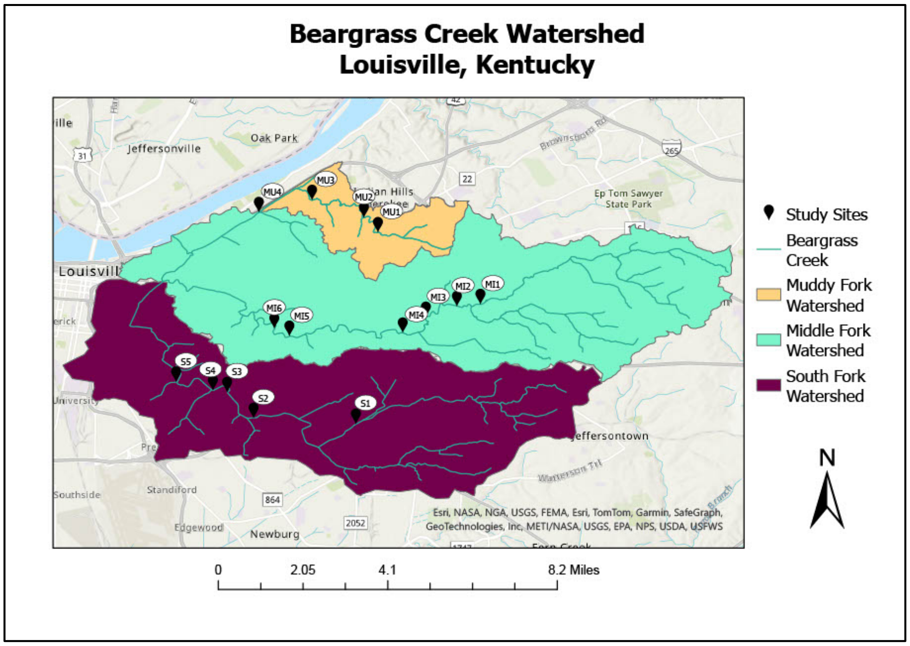


Figure 2. Map of sampling sites in the three forks of Beargrass Creek.

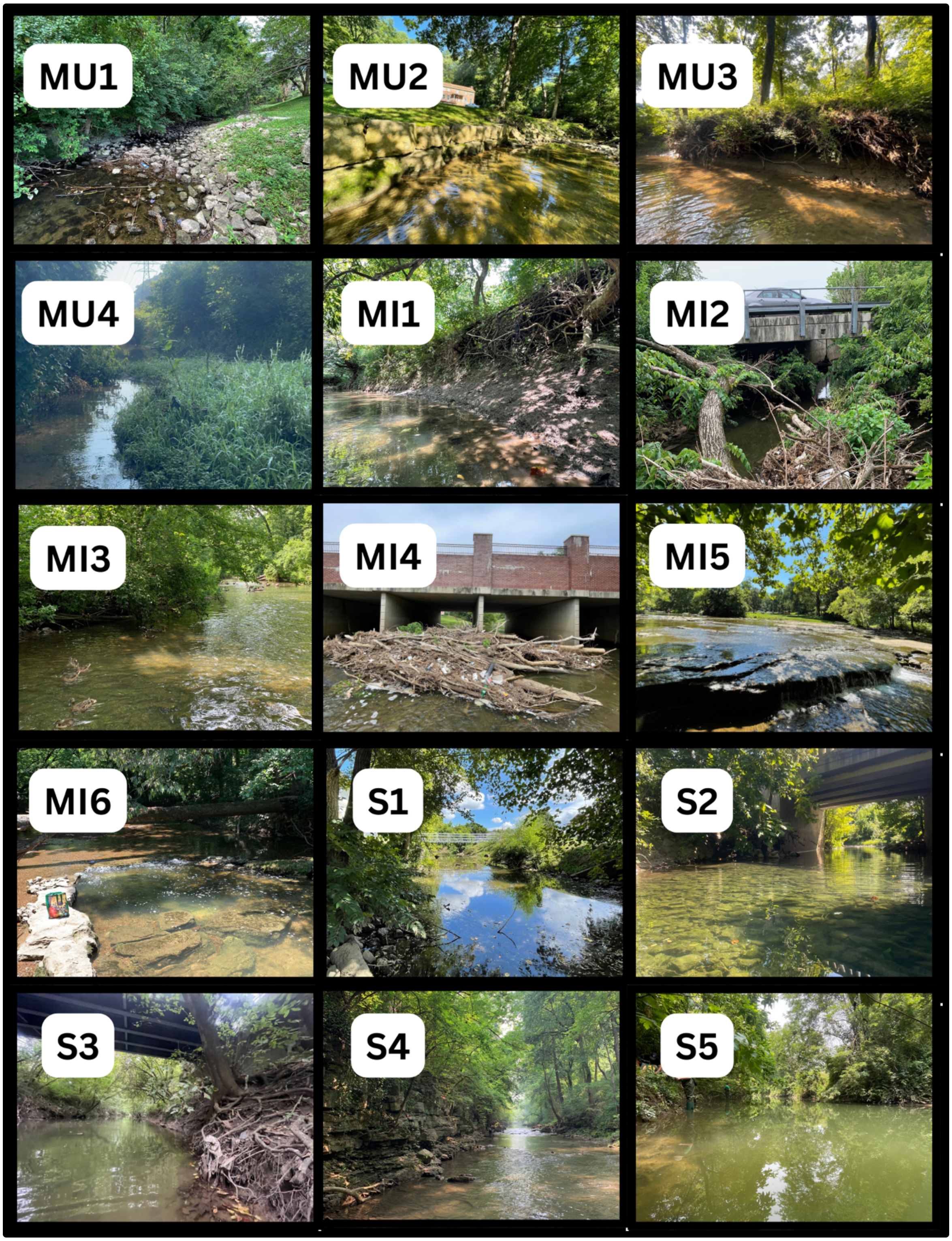


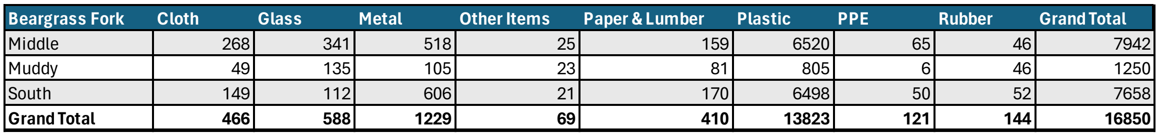
Figure 3. Pictures displaying the fifteen sites and their labels.

Each site was visited ten times total- with half of the visits in the summer season (June 28, 2023- July 31, 2023) and the other half of the visits providing insight into the fall season (September 6, 2023- October 12, 2023). Data were collected 100 ft upstream and 100 ft downstream from the entry point, documenting the individual litter items, the type observed, and the geographic location on the National Geographic Marine Debris Tracker app. Additionally, the health of the habitat was assessed at the first visit of each site through the use of the Kentucky Watershed Watch's standard rubric of stream ecology components (Appendix A). These categories were also continually monitored throughout the study in case the site experienced any major changes during the time of testing. Microsoft Excel and ArcGIS were used to transfer data for quantitative and spatial analysis. Daily discharge data (cfs) for the three forks were obtained from the USGS discharge monitoring stations, in order to record the past 24-hour mean flow rate for each visit. The station identification numbers were USGS 03293530, USGS 3292500, and USGS 03293000 for Muddy Fork, South Fork, and Middle Fork respectively. Trends between discharge and litter quantity were analyzed using Microsoft Excel.

RESULTS

Comparison of AL Between the Forks of Beargrass

The total quantity of litter observed in Middle Fork for all sampling dates was 7942 (Table 1). The total quantity of litter recorded in Muddy Fork for all sampling dates was 1250 (Table 1). Finally, the total quantity (number of pieces observed and recorded) of AL in South Fork for all sampling dates was found to be 7658 (Table 1).



Beargrass Fork	Cloth	Glass	Metal	Other Items	Paper & Lumber	Plastic	PPE	Rubber	Grand Total
Middle	268	341	518	25	159	6520	65	46	7942
Muddy	49	135	105	23	81	805	6	46	1250
South	149	112	606	21	170	6498	50	52	7658
Grand Total	**466**	**588**	**1229**	**69**	**410**	**13823**	**121**	**144**	**16850**

Table 1. Total quantity of AL observed from all sampling dates. Also classified by litter type (cloth, glass, metal, other items, paper & lumber, plastic, PPE, and rubber).

Plastic was the predominant type of AL observed in all three forks, both in grand total and on average for each visit (Figure 4).

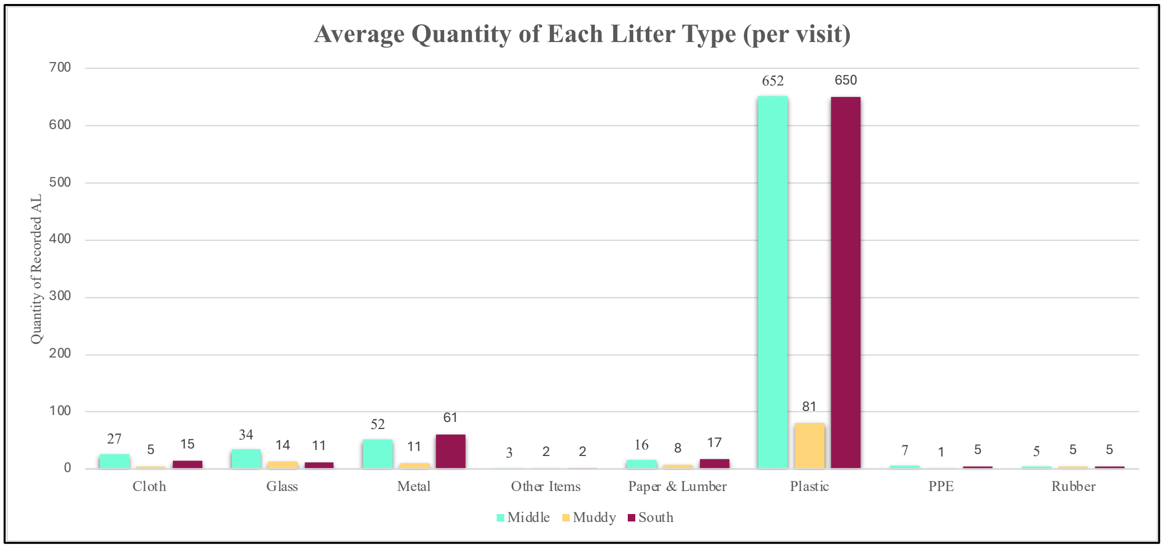


Figure 4. The average quantity of each AL type observed per visit.

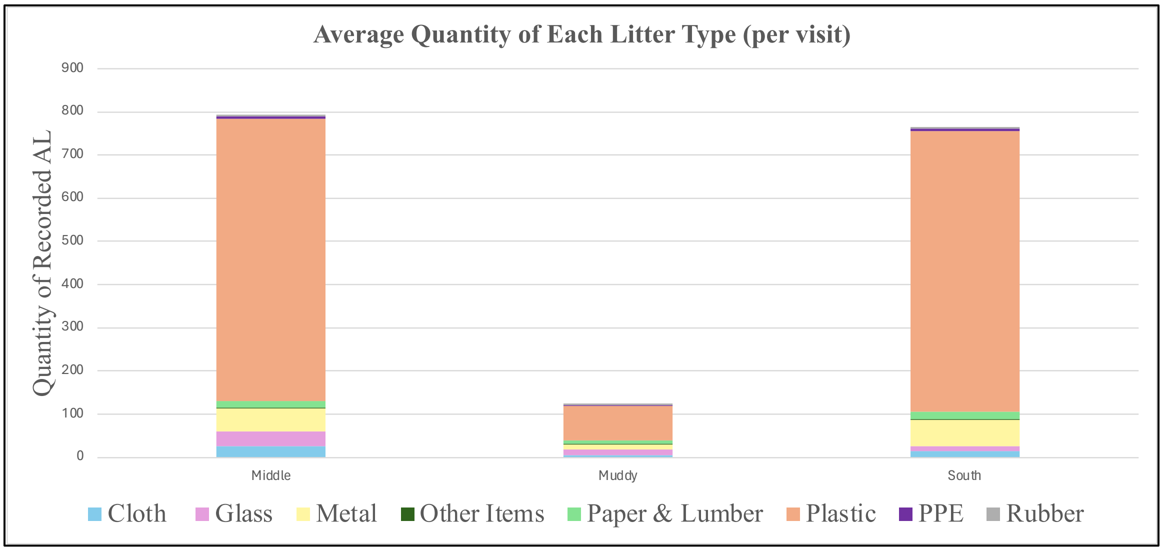


Figure 5. Stacked bar graph displaying the average quantity and type of AL per visit, according to Beargrass Creek Fork.

While the Middle Fork had the highest total of AL recorded throughout the course of the study, when the forks were divided by distance studied (to account for the number of sites in each fork), South Fork had the highest average of AL per studied foot. It is followed by Middle Fork, and then Muddy Fork reflected the least (Figure 6).

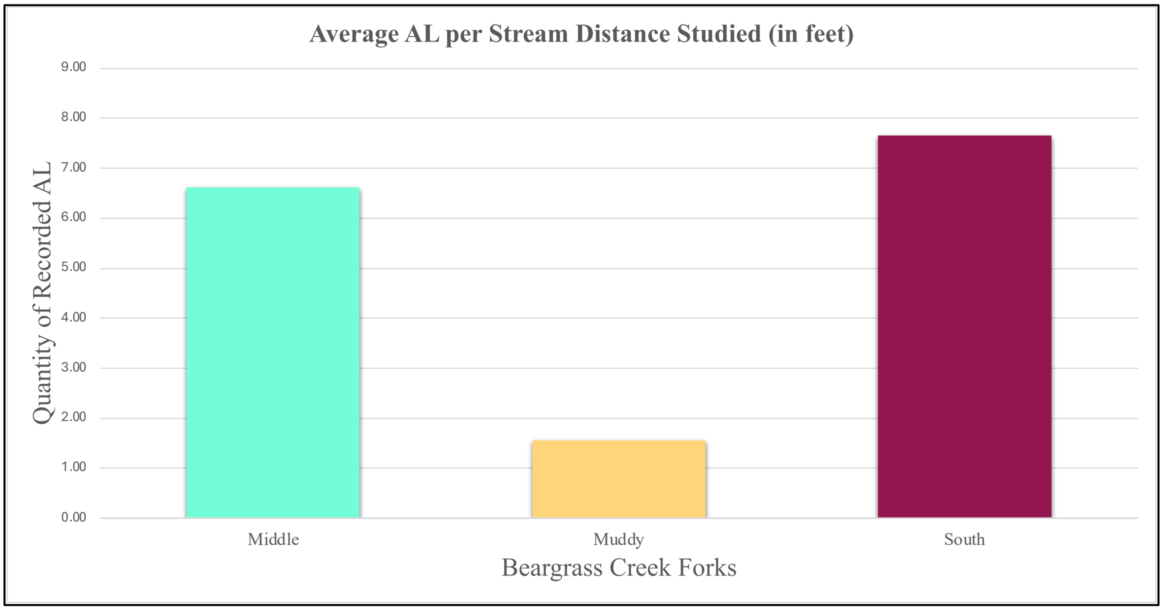


Figure 6. Average AL per fork when the number of test sites are accounted for.

Amount of AL and Type at Sites in Middle Fork

Composition of litter at sampled sites in Middle Fork during the sampling period; plastic debris was the predominant type of litter sampled Middle Fork. (Figure 7).

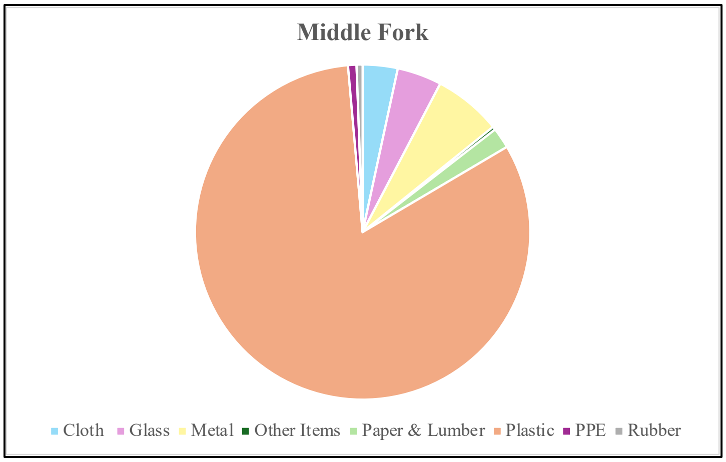


Figure 7. Composition of AL type observed through the sampling dates of Middle Fork.

MI2 was recorded with the highest abundance of AL in Middle Fork, and MI5 had the least (Figure 8).

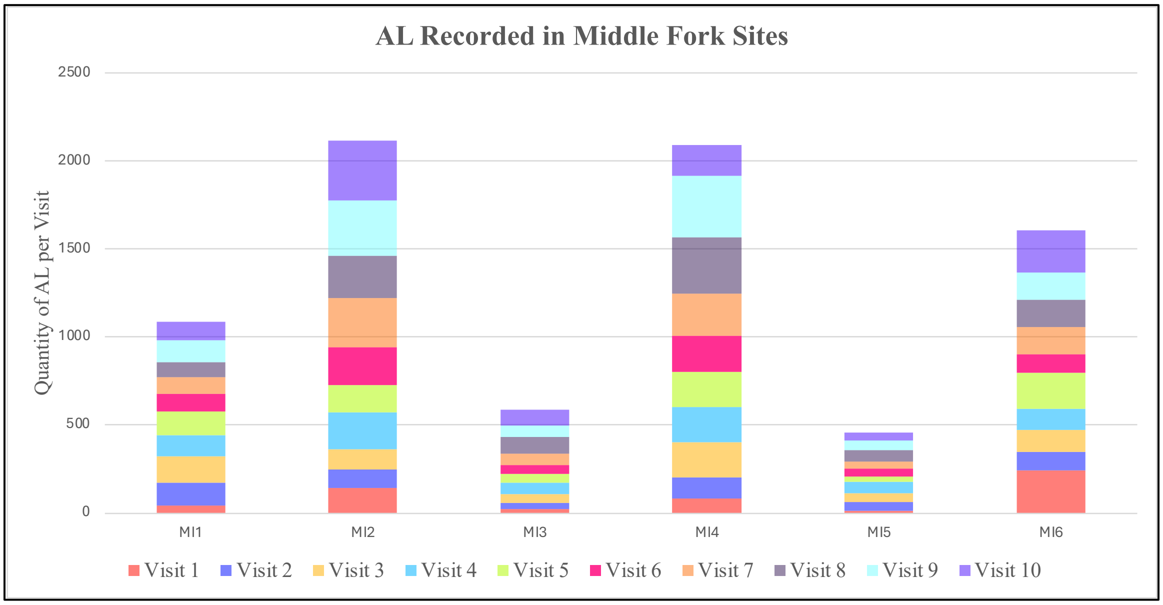


Figure 8. AL recorded for all five sites of Middle Fork.

The standard deviation was calculated between each visit to study the characteristic flow of litter defining the site. The litter at MI5 was the most consistent, while the quantity of litter at MI2 was showed the most variability (Table 2).

Standard Deviation					
MI1	**MI2**	**MI3**	**MI4**	**MI5**	**MI6**
31	83	23	80	15	52
S1	**S2**	**S3**	**S4**	**S5**	
36	83	75	82	42	
MU1	**MU2**	**MU3**	**MU4**		
4	1	37	1		

Table 2. The standard deviation of AL quantity between visits, for all three Beargrass Creek Forks.

Amount of AL and Type at Sites in Muddy Fork

Composition of litter at sampled sites in Muddy Fork during the sampling period; plastic debris was the predominant type of litter sampled Muddy Fork. (Figure 9).

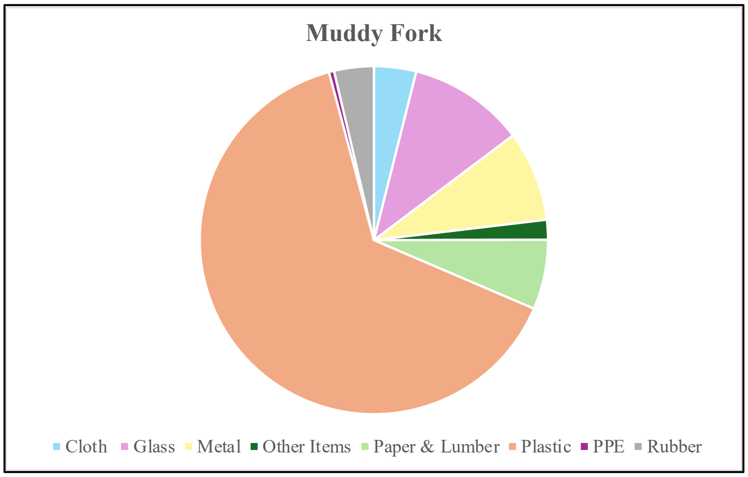


Figure 9. Composition of AL type observed through the sampling dates of Muddy Fork.

MU1 was recorded with the highest abundance of AL in Muddy Fork, and MU4 had the least (Figure 10).

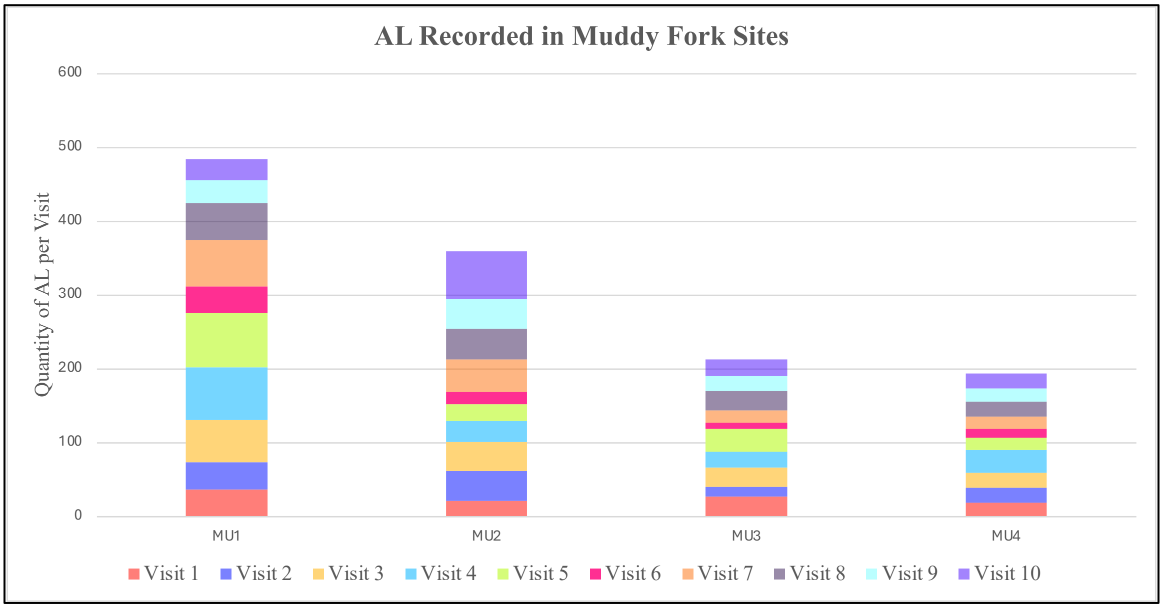


Figure 10. AL recorded for all four sites of Muddy Fork.

Once again, the standard deviation was taken between each visit to study the characteristic flow of litter defining the site. The litter at MU4 and MU2 were the most consistent, while the quantity of litter at MU3 was showed the most fluctuation (Table 2).

Amount of AL and Type at Sites in South Fork

Composition of litter at sampled sites in South Fork during the sampling period; plastic debris was the predominant type of litter sampled South Fork (Figure 11).

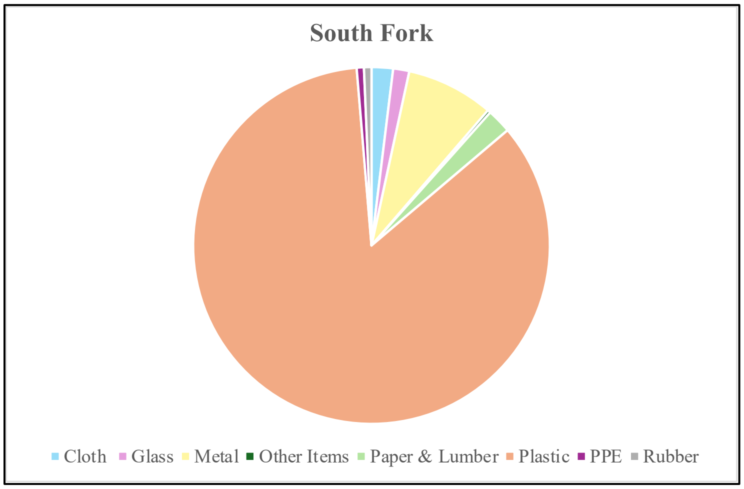


Figure 11. Composition of AL type observed through the sampling dates of South Fork.

S3 was recorded with the highest abundance of AL in South Fork, and S5 had the least (Figure 12).

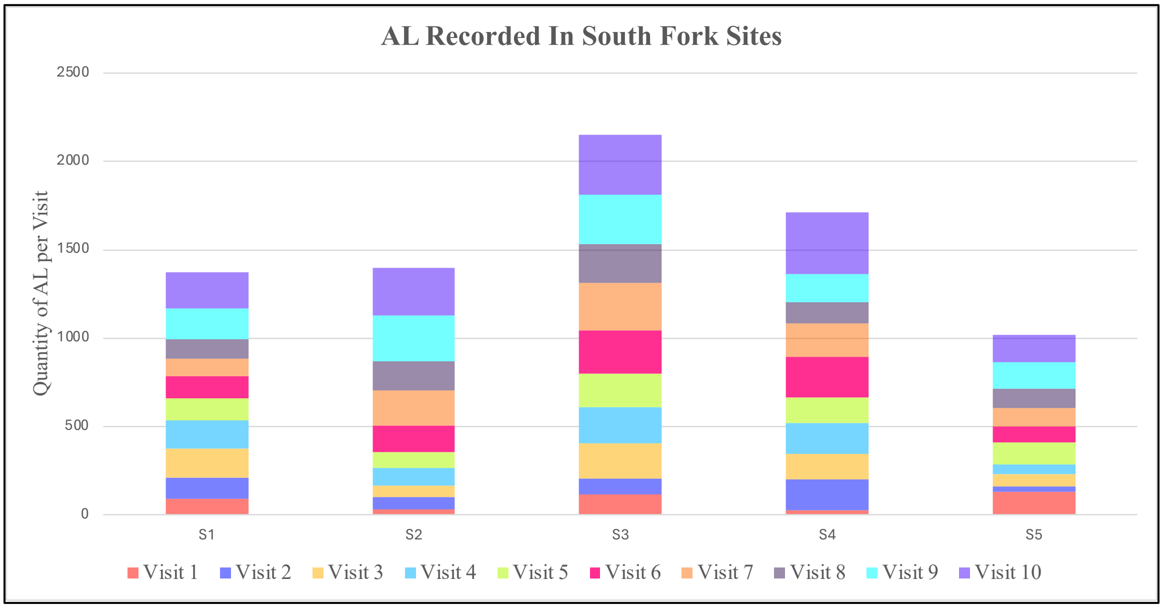
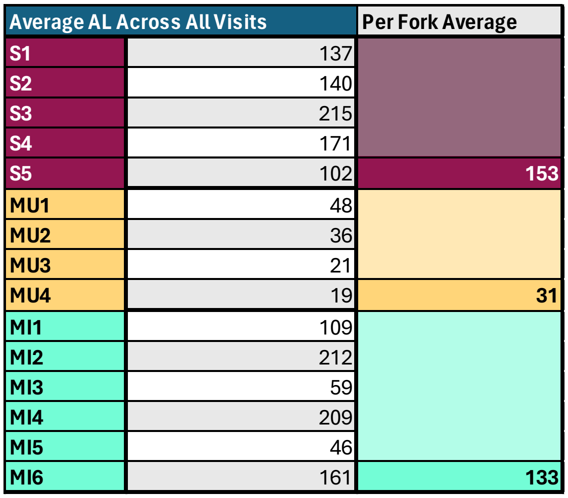


Figure 12. AL recorded for all five sites of South Fork.

The standard deviation was also taken between each visit within South Fork. The litter at S1 was the most consistent, while the quantity of litter at S2 was showed the highest variability within the fork (Table 2).

Variation between Forks

When the mean was found for the average quantity of AL per site across the 10 visits (rather than per fork), the South Fork represented the highest value (Table 3). Muddy Fork had the lowest average quantity of AL per site after calculating all 10 visits (Table 3).



Average AL Across All Visits		Per Fork Average
S1	137	
S2	140	
S3	215	
S4	171	
S5	102	153
MU1	48	
MU2	36	
MU3	21	
MU4	19	31
MI1	109	
MI2	212	
MI3	59	
MI4	209	
MI5	46	
MI6	161	133

Table 3. The mean values of AL for each site, across all 10 visits- categorized by South Fork, Muddy Fork, and Middle Fork.

AL Quantity and Discharge in the Forks of Beargrass Creek

The relationship between discharge and AL for Middle Fork was best explained by a power trendline (R^2= 0.6868) (Figure 13). The relationship between discharge and AL for Muddy Fork was best explained by a polynomial trendline (R^2= 0.3361) (Figure

14). The relationship between discharge and AL for South Fork was best explained by a power trendline ($R^2 = 0.6018$) (Figure 15).

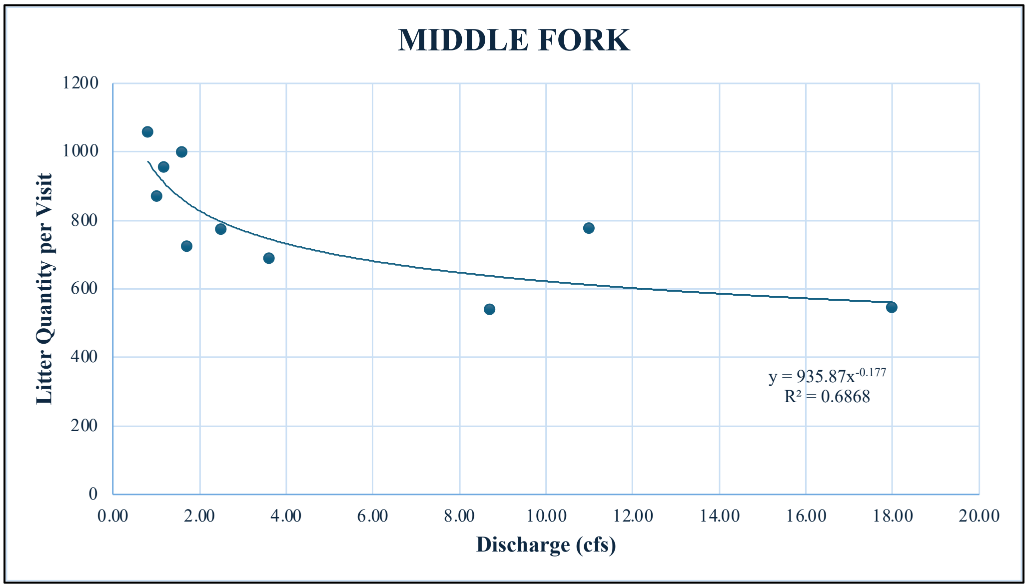


Figure 13. Correlation of AL Quantity and Discharge in Middle Fork.

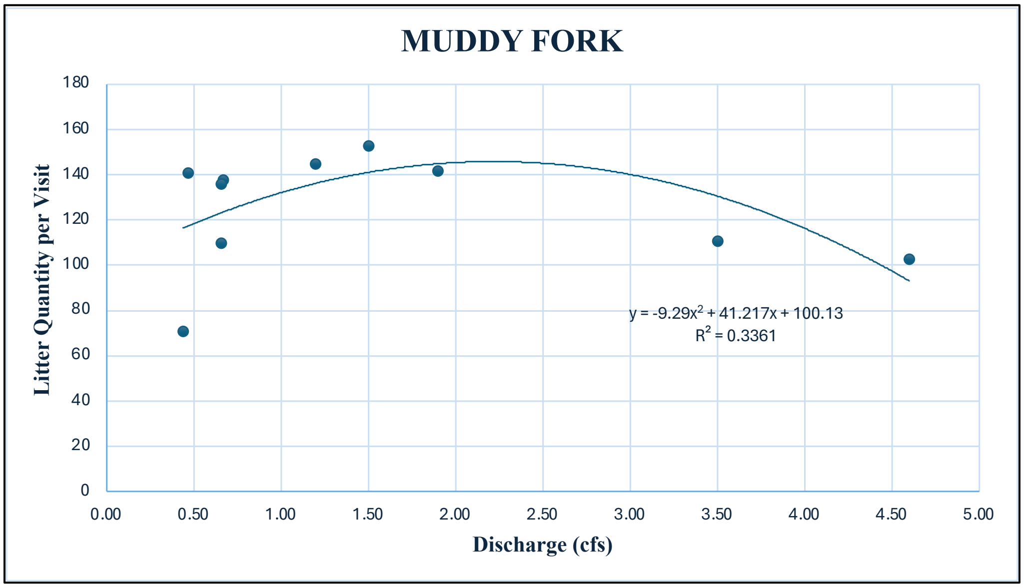


Figure 14. Correlation of AL Quantity and Discharge in Muddy Fork.

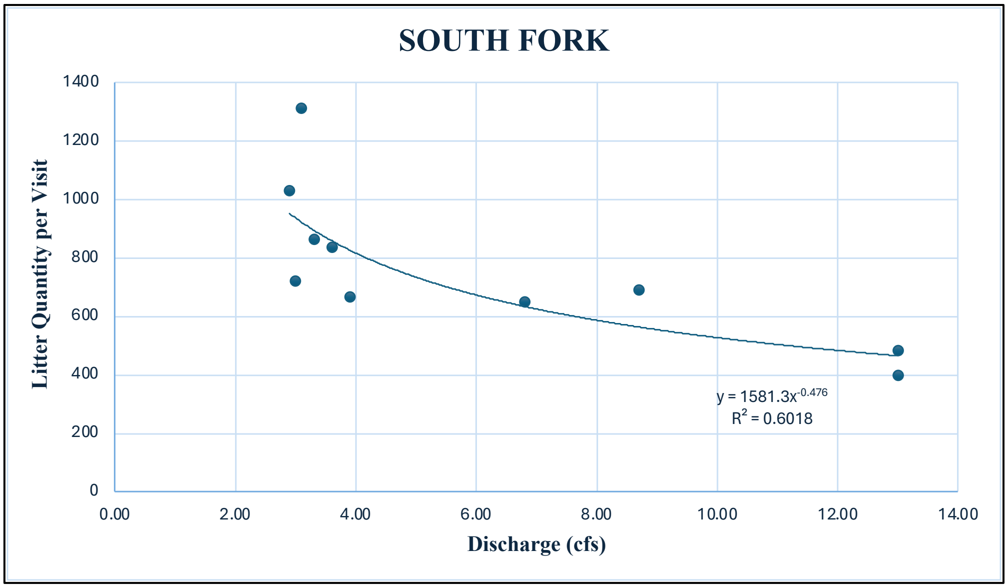


Figure 15. Correlation of AL Quantity and Discharge in South Fork.

Geospatial Analysis of AL and Land Use Throughout the Beargrass Creek Study Sites

The Marine Debris Tracker data was integrated into ArcGIS and organized according to study site and visit. The following figures illustrate the accumulation of AL at each site and display the predominant land use defining each location. A 500’ buffer of land use was created along the main stems of the three forks, in order provide upstream and downstream context for the factors at work.

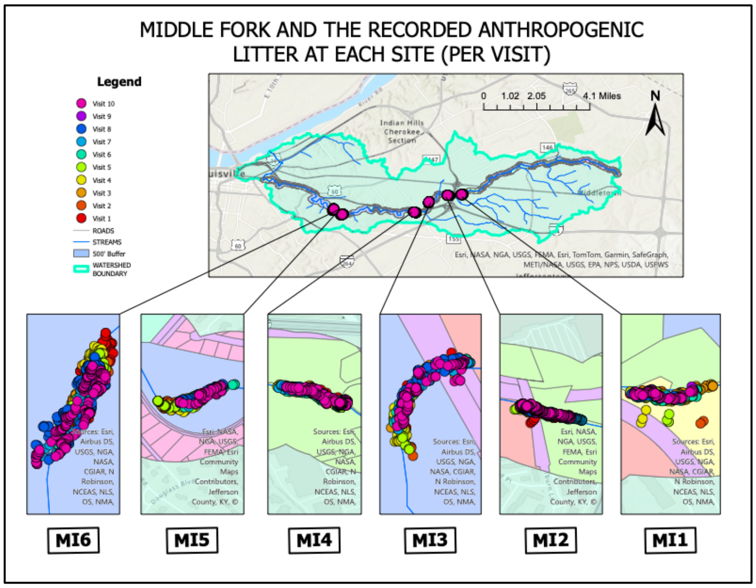


Figure 16. Map of Middle Fork and the recorded AL at each visit (per site).

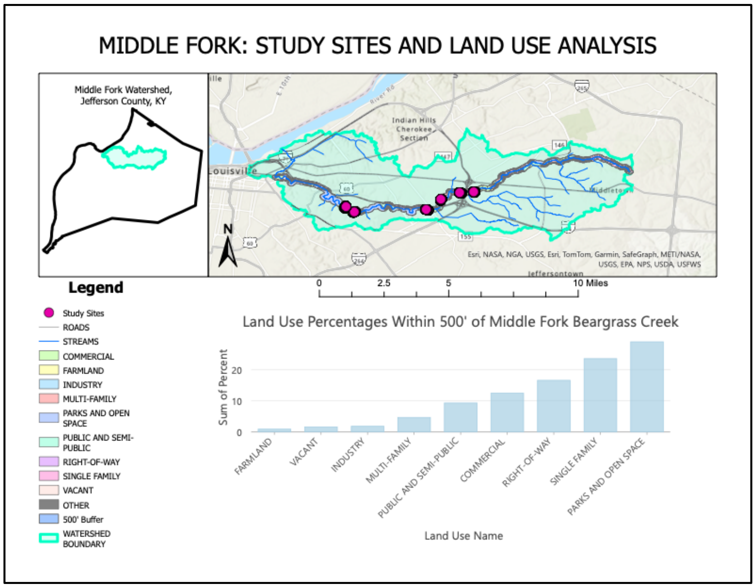


Figure 17. Map of the Middle Fork study sites and land use percentages.

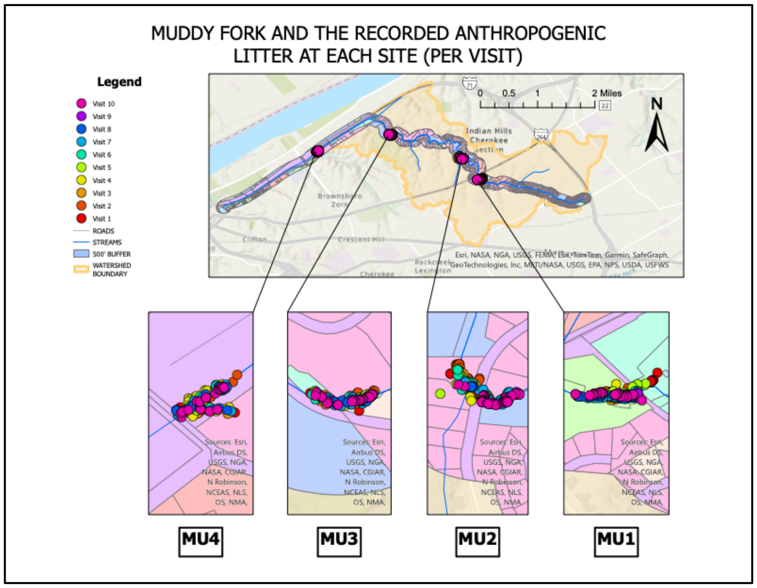


Figure 18. Map of Muddy Fork and the recorded AL at each visit (per site).

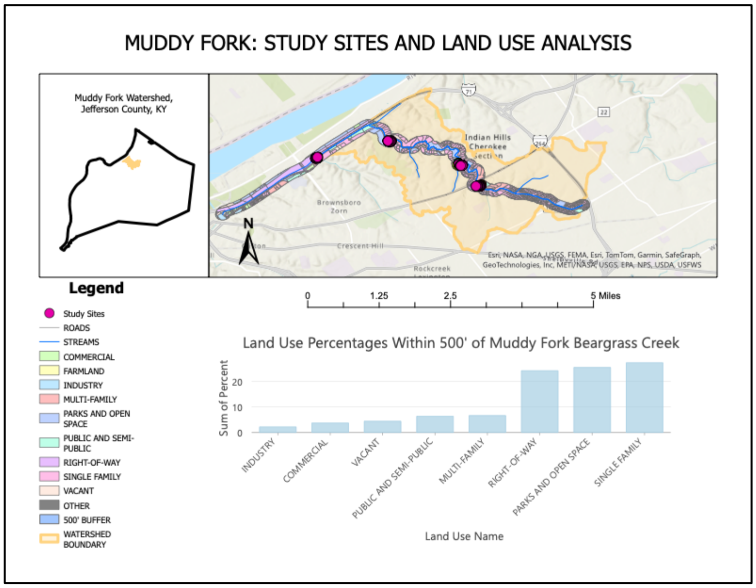


Figure 19. Map of Muddy Fork study sites and land use percentages.

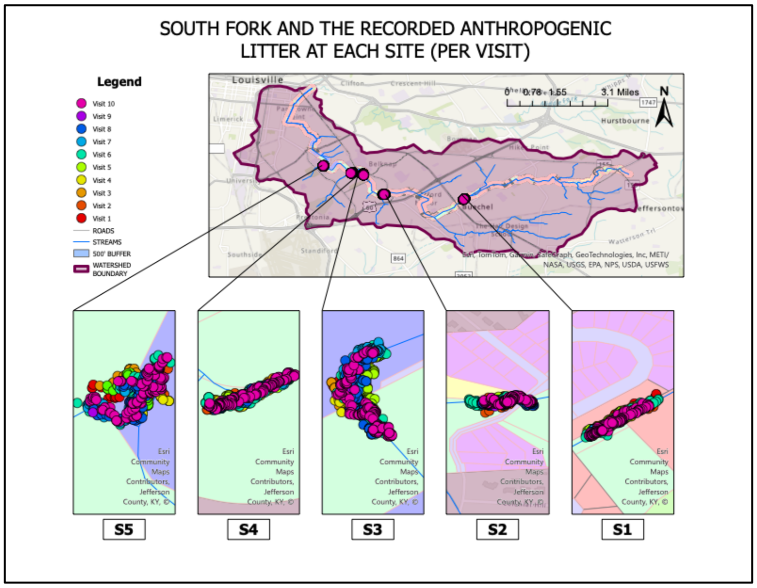


Figure 20. Map of South Fork and the recorded AL at each visit (per site).

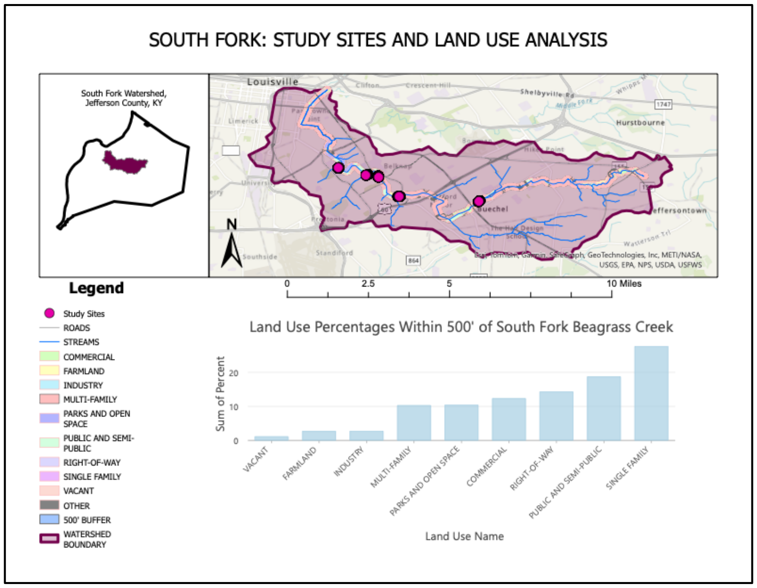


Figure 21. Map of South Fork study sites and land use percentages.

AL Quantity and Watershed Variables

Each study site was delineated through the USGS Stream Stats program, in order to obtain their specific watershed variables. For all 15 sites, the average quantity of AL per site was compared alongside the site drainage area (square miles), the average percentage of impervious area for each site, and the percentage of urban land for each site. The R^2 was calculated for all three delineated attributes, therefore evaluating the proportion of variance in the average AL quantity per site that could be explained by each watershed variable.

Watershed Variables	S1	S2	S3	S4	S5	MI1	MI2	MI3	MI4	MI5	MI6	MU1	MU2	MU3	MU4
DRNAREA (sq miles)	7.10	16.10	17.50	18.50	20.90	6.63	10.90	15.20	17.30	20.00	20.40	2.00	2.44	3.77	1.25
ELEV (ft)	574.00	544.00	540.00	539.00	535.00	664.00	651.00	623.00	616.00	604.00	602.00	560.00	559.00	549.00	535.00
KYVARIND10	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
KYVARIND93	0.70	0.69	0.68	0.67	0.67	0.69	0.69	0.67	0.66	0.65	0.65	0.60	0.60	0.60	0.60
LAT_OUT (degrees)	38.20	38.20	38.21	38.21	38.22	38.24	38.24	38.24	38.23	38.23	38.24	38.27	38.27	38.28	38.28
LC11DEV (%)	88.20	88.20	87.80	87.40	86.00	70.10	74.00	77.70	79.60	79.10	78.70	69.90	66.70	55.20	46.20
LC11IMP (%)	33.80	34.10	34.90	34.50	33.40	20.70	23.00	25.80	26.30	24.80	24.50	16.40	15.30	11.70	8.13
AVERAGE AL (per site)	137.30	140.10	215.20	171.10	102.10	108.80	211.50	58.90	209.00	45.50	160.50	48.40	35.90	21.30	19.40

Table 4. Watershed variables delineated per site through USGS Stream Stats.

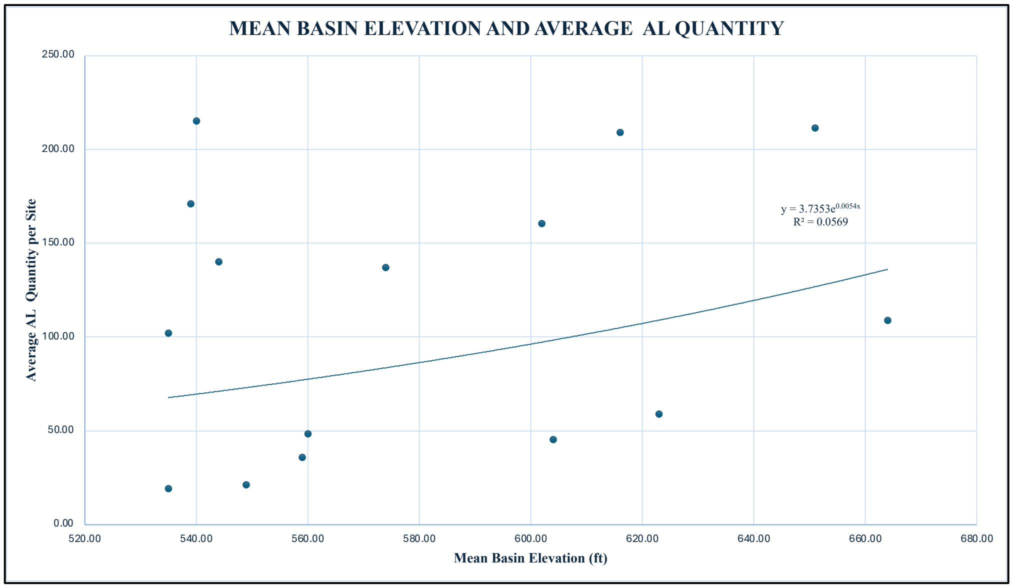


Figure 22. Mean basin elevation and average AL quantity (per site).

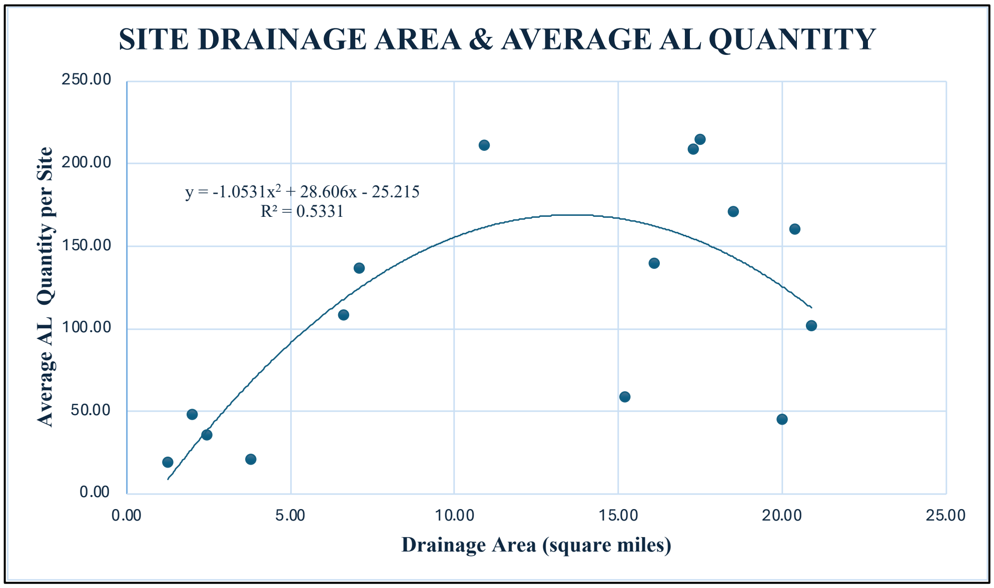


Figure 23. Study site drainage area and average AL quantity (per site).

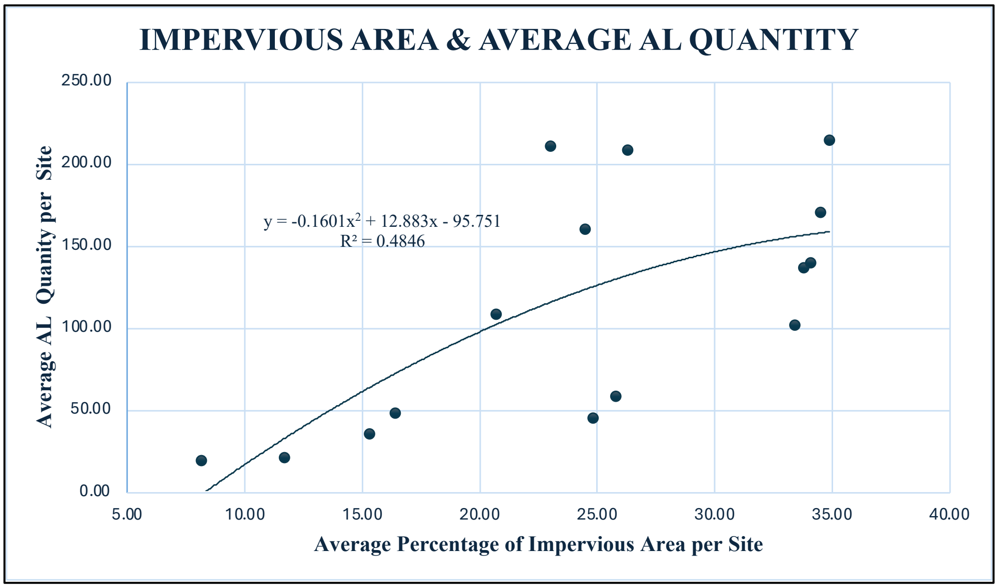


Figure 24. Impervious area and average AL quantity (per site).

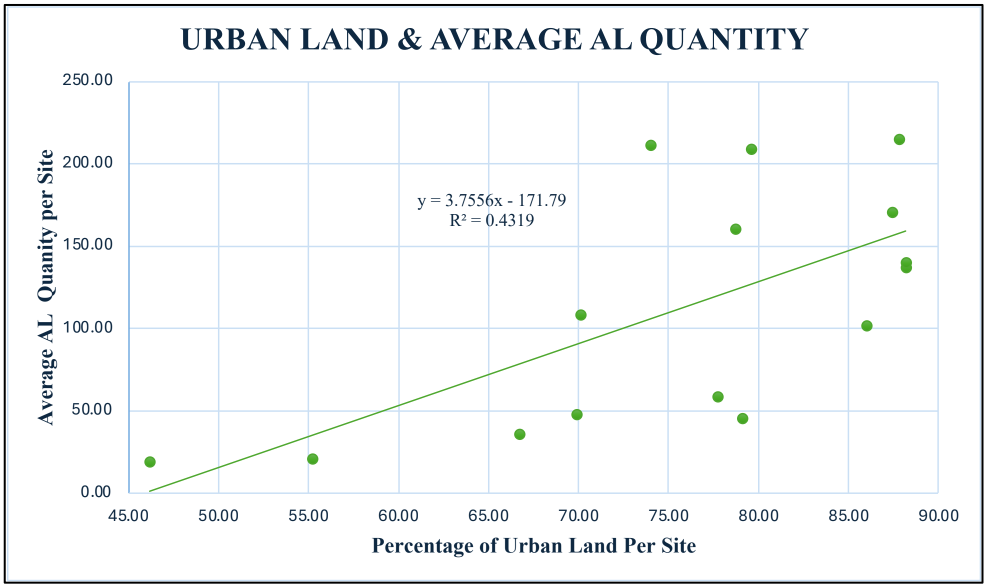


Figure 25. Urban land and average AL quantity (per site).

DISCUSSION

Flow Rates, Watershed Variables, and AL

From the results, the R^2 values presented a strong goodness-of-fit statistical measure for the trendlines between discharge and AL in both Middle Fork and South Fork. Less of the AL variation could be determined by discharge in Muddy Fork. The trend revealed that lower discharge rates were typically associated with higher AL accumulation. Furthermore, the R^2 values derived from the average percentage of impervious area, the percentage of urban land, and the site drainage area (all in relation to AL quantity per site) indicated that each of these watershed variables could statistically explain the variation in AL. In general, the higher the percentages of urban land and impervious area within a study site, greater were the quantities of AL observed.

The trash is an indicator of larger anthropogenic processes at work. Much of Beargrass Creek has been channelized or altered as the city of Louisville developed. Beginning in 1800s through mid-1900s, industries (slaughterhouses, distilleries, and meat packing businesses) operated along Beargrass Creek's banks so they could directly dump their waste waters into the creek until regulations were eventually established (Spellmon, 2022). In the 1920s, urbanization led to the development of Louisville's combined sewer system, in which the city constructed combined sewers and segments of Beargrass Creek were straightened and lined with concrete (Spellmon, 2022). The natural flow dynamics of Beargrass Creek were drastically altered so the waterway could be controlled and employed as an effective waste removal system. The flashy flow dynamics and variable discharge patterns seen today are common results of point source inputs (such as CSOs), land cover alteration (increased area of impervious surfaces), storm drain systems, and channel alteration. The evidence of channel erosion and dry stream segments observed during this study, as well as the recorded discharge rates, all indicate the impact of anthropogenic flow alteration (EPA, n.d.). In fact, the flashier hydrograph and altered channel morphology are symptoms of the urban stream syndrome (Walsh et al., 2005).

Given the historic management of Beargrass Creek and the increasingly urbanized environment encompassing the waterway, accumulation of AL is a part of a greater positive feedback loop at work. Urbanization increases the production and presence of single-use litter, which can be deposited into the waterways of developed areas through various vectors. Then, reduced baseflow (also caused by urbanization) yields lower discharge rates, and higher AL accumulation. Without preventative strategies in place, there will be no limit to the levels of trash entering urbanized streams.

Areas of Impervious Surface

This study also found South Fork experiencing the highest average of anthropogenic litter accumulation out of the three forks, based on the mean average per visit and grand total after accounting for stream distance studied. Middle Fork was not far from the values of South Fork, but Muddy Fork substantially showed the least amount of AL at each of its sites. After delineating each of the forks through USGS Stream Stats (USGS, n.d.), it was determined that 49.5% of the Muddy Fork watershed is classified as developed (urban) land from the National Land Cover Dataset 2011. The same process determined Middle Fork's land cover to be 80.2% developed. South Fork had the greatest percentage of developed land within its watershed, with 88% belonging to urban development. The results reveal a trend between land cover and AL, as South Fork had the greatest percentage of urban land, and the highest average of AL. Muddy Fork also had the lowest percentage of urban land and the lowest average of AL recorded as well. This is echoed by the work of McCormick and Hoellein (2016), in which they found their three most urbanized watersheds to have the highest AL densities, as well as their two less urbanized watersheds to have lower AL densities.

AL Quantity and Type

Another critical finding from the results was the distribution of AL material type in Beargrass Creek. Plastic was the predominant material type across all three forks. Plastic had an overwhelming presence at the sites. This trend was supported by other AL research studies. Hamilton (2023) found plastic to make up the majority (30%) of all the AL quantified in his study of the Salado Creek Watershed. Furthermore, McLaughlin et al. (2023) found that plastic pollution was present in 69% of Southern California's coastal stream kilometers, and it was the most abundant type of AL. Their study estimated the plastic waste quantity in the streams to be over 4.3 million pieces.

For a further look into the factors behind anthropogenic litter accumulation, it is important to examine the sites themselves. The top five sites for recorded AL were S3 (2,152 total pieces), MI2 (2,115 total pieces), MI4 (2,090 total pieces), S4 (1,711 total pieces), and MI6 (1,605 total pieces). The five sites with the lowest recorded AL quantities were MU4 (194 total pieces), MU3 (213 total pieces), MU2 (359 total pieces), MI5 (455 total pieces), and MU1 (484 total pieces).

Figure 26. Predominant types of plastic AL observed in Beargrass Creek: plastic bags, foam fragments, food wrappers, other plastic, and beverage bottles.

Figure 27. Examples of the various types of AL found in Beargrass Creek throughout this study period.

Habitat Attributes of Top Polluted & Least Polluted

Sources of AL into the waterways include litter from vehicles (such as uncovered truck beds), litter from garbage and recycling bins (spills and uncovered cans), pedestrian litter (fast food wrappers, discarded items from events or other public places, discarded beverage bottles, etc.), and illegal dumping and encampments (Santa Clara Valley Urban Runoff Pollution Prevention Program, n.d.). The mechanisms of transport include the wind, in-stream dumping, and storm drains. Urban streams all face these sources and mechanisms for AL flux. This study evaluated the influence of discharge rates and impervious surfaces on AL accumulation, but it is also important to discuss habitat health. It is necessary for researchers to continue to learn the relationship between habitat health and AL, and if there are physical attributes that could indicate the vulnerability of a specific site to AL accumulation.

Therefore, the habitat scores of the five least AL polluted sites (MU4, MU3, MU2, MI5, MU1) were compared to the five most polluted sites (S3, MI2, MI4, S4, MI6). However, the difference between the average habitat scores of the two groups were insignificant ($p = 0.832067007$). All of the sites had manmade structures or signs of anthropogenic alteration along their banks. Additionally, all the sites had scores of good and fair for vegetation surrounding the bank- except for MI1. In these specific sites of worst and least AL pollution, the more polluted sites had slightly better scores for embeddedness and buffer width. They scored lower to the least polluted sites in the terms of erosion, bank stability, and velocity. These three categories could be further impaired under the influence of urbanization, which is reflected in how the sites from more urbanized forks exhibit these habitat traits to a greater extent than those less affected by AL and city development.

While these habitat assessments are beneficial locally, they fail to fully address the relationship between habitat health and AL accumulation because there are so many litter sources and mechanisms of transport at work. For instance, MI2 has more streambank vegetation which provides local protection- but no defense to the AL that has already entered the creek *upstream*, possibly due to MI4's lack of streambank vegetation. Therefore, while the habitat scores are not conclusive indicators for specific site vulnerability, they should be applied as standards for each fork as a whole. Preventative measures against AL will not be effective if they are not applied thoroughly along the fork and AL is still able to enter the stream at sites of vulnerability.

The variability seen among sites in the standard deviation values calculated for changes between visits could also be attributed to the geomorphology of the steam at the location, as well as the particle transport properties defining the AL type in the flow velocity. The absence of a strong correlation between the various watershed variables and average AL quantity per site (Figure 22, Figure 23) could be explained similarly. Habitat components and hydrologic principles should be isolated and investigated further in future AL studies.

MI5 and S4: Case Example

Beyond the physical conditions of land cover, habitat health, and flow rates, there is another component critical to this discussion: human perception. Above all the sources and transport mechanisms of AL, human perception plays a major role in the positive feedback cycle of urbanization and AL accumulation in waterways. A case example of the influence of human perception can be observed in the comparison of two sites in Beargrass Creek, MI5 and S4. S4 flows behind Bellarmine University; the site can be accessed from the university campus but is otherwise secluded from other trails and pathways. MI5 is also known as Big Rock, a major attraction in Cherokee Park. During the summer, Big Rock brings many people to the creek for swimming and community cookouts by the water. A very interesting point from this study revealed that while MI5 and S4 have the same habitat score, MI5 is the 4th cleanest and S4 is the 4th most polluted, in terms of AL accumulation. Both sites exhibit very healthy habitat conditions and mirror each other in physical characteristics. However, while Big Rock is seen as a community asset and valued by several different neighborhoods, the site behind Bellarmine is overlooked and isolated in comparison. The AL found at the Bellarmine site was irregular and suggested disrespectful loitering (examples including plastic bags filled with several cans of whipped cream and alcohol bottles, along with the usual fast food wrappers and Styrofoam drinks). The major difference between these two sites was how their value was interpreted by individuals and the way communities engaged with the waterways.

This trend has been reported in other studies as well. Wisbrock (2021) found that riparian characteristics that created isolated sites in urban watersheds often facilitated littering behavior that included loitering and illegal dumping. The research found that sites with the most obvious signs of loitering had the highest average AL abundance by count (Wisbrock, 2021). McCormick and Hoellein (2016) also found evidence of alcohol containers and graffiti to be consistent indicators of high AL density in urban riparian zones. The cumulative meaning of all these studies shows that mitigation strategies cannot be focused on the physical characteristics of urban watersheds alone.

Reasoning

Based on the data analysis, this study showed that **altered discharge rates** and **increased area of impervious surface** (both impacts of urbanization), alongside the **human perception** of an urban waterway, are the three major components (that several other factors can fall into) contributing to AL accumulation. If Beargrass Creek still retained its original steady flow dynamic, it is highly probable that AL would not be able to remain in the creek to the extent that it does today. As it is, the present flashy conditions of discharge rates observed in Beargrass Creek present more challenges to the health of the watershed, as a symptom of urban stream syndrome (Walsh et al., 2005). The increased area of impervious surface, especially in South Fork and Middle Fork, enhance the issues of stormwater pollution, which AL pollution strongly follows. Not only do the impervious surfaces feed the flashy discharge rates, but they also enable trash to travel further in storm events and enter waterways in the same manner as other stormwater pollutants. Finally, this study has revealed the importance of human perception. This last component completes the feedback loop because as the health and resilience of urban streams steadily decline, the community mindset shifts around these waterways as well. Once it is no longer seen as an asset, encouraging change becomes a challenge- as the waterway becomes enveloped in a negative stigma of pollution and waste. While the degradation might be chronic and slow to appear, conditions will worsen without public investment in the value of local streams. This misguided management is very much an example of shifting baselines (Pauly, 1995) and as people are removed farther and farther from urban streams, waterways suffering from urban stream syndrome are likely to become the accepted standard overtime and AL will have a permanent home in whatever remains of the city’s aquatic habitats.

Strategies

Therefore, the recommended strategies address physical conditions and community perceptions. In order to combat the effects of urbanization, there are several preventative measures that can be implemented. Low Impact Development (LID) is a stormwater management approach that would greatly reduce the amount of AL entering streams. These include projects such as rain gardens, rainwater cisterns, green roofs, stream buffers, tree planting, and pervious pavement (UC Berkeley, n.d.).

There have also been several advances in trash capturing technology. Investing in technology such as the “litter gitter” or the “Bandalong” litter trap could be a worthy investment for sites particularly vulnerable to AL accumulation, or those that are inaccessible for community cleanup events (Teague, 2021, Bandalong International, n.d.). Methods of green infrastructure, vegetative buffers, and erosion protection could all be critical in reducing the chance for AL to make it into the stream from the start.

From a legislative approach, there are many steps that could encourage positive decision making at a local level and enforce standards of stream protection. For example, under the Clean Water Act, local jurisdictions have the authority to write Municipal Separate Storm Sewer System (MS4) permits limiting the amount of AL that is allowed to be released from stormwater outfalls (EPA, 2020). While total maximum daily loads

(TMDLs) are not required for AL through the Clean Water Act, cities have the power to use the legislation to combat AL pollution in urban waterways. According to the EPA (2020), the Los Angeles region was the first to apply the Clean Water Act to aquatic trash, as early as 1996, when the area began to add its water bodies to the 303(d) list for trash impairments. There are only six jurisdictions in the United States aiming to reduce trash in local streams and waterways through AL TMDL implementation plans (Baltimore County Government, 2023). Another legislative method would be the passage of container deposit laws (also known as "bottle bills"). This bill gives individuals a monetary incentive to return purchased containers for recycling (KY Legislative Research Commission, 1999). The refund value per container is typically about five to ten cents, and it encourages the return of beverage bottles and other cans before they potentially enter the waterways and contribute to AL pollution. Many would argue that society is beyond the three environmental pillars, repeated as "reduce, reuse, recycle." Given the dangers of plastic pollution on human health and the global environment, many are advocating for a new mindset: "*refuse*, reuse, recycle". Banning single use plastic or taxing plastic bags would be a significant legislative action that could substantially reduce AL accumulation in urban waterways, as it addresses the original source of waste-rather than most mitigation strategies currently focused on the cleaning up of what has already been produced.

The most promising and powerful way to combat AL accumulation in urban waterways is already in every urban setting: community. From educational canoe trips to environmental education, any opportunity of outreach is critical in changing the currents trends of AL pollution. The more people have a reason to care and a platform to see urban streams in their full beauty and potential, the human perception has the ability to shift from a negative influence to a positive force of change. In particular, citizen science sampling and volunteer monitoring encourages individuals to interact with the stream running through their own neighborhoods. This gives local communities a voice in watershed management and agency to advocate for their local stream, therefore cultivating a space for equitable accessibility and environmental justice to take root.

Incorporating the National Geographic Marine Debris Tracker App into the public outreach efforts is a recommendation supported by the success of its application in this research. The app is user-friendly; and it provides individuals with helpful visual metrics and feedback to aid understanding within the data collection. Based on the Aqlan Lab Beargrass Creek research project, Miller (2023) created an ArcGIS Dashboard displaying a map of the watershed with interactive points showing where AL had been recorded through the Marine Debris Tracker app. Users could explore the distribution of AL type by hovering over a pie chart positioned adjacent to the map. This application is a powerful example of the work that could be continued in Beargrass Creek with citizen input and engagement. A proposal recommended by this research is a specific citizen science week planned in the year where the Aqlan Lab partners with watershed organization (such as the Kentucky Watershed Watch and the Kentucky Waterways Alliance) and as many volunteers as possible are encouraged to use the app to record AL (and remove it if possible) in the Beargrass Creek watershed. Logistics would be planned so that there is a uniform observation procedure, and areas of the forks would be claimed in the registration process, in order to prevent overlapping records. This event could be a new strategy to encourage people to explore the local streams and see the AL themselves.

Supplementing the week with informative articles and environmental curriculum in various forms could share a new perspective on AL and teach community members what steps can be taken to make a change in urban waterways and AL pollution. Keeping the Beargrass Creek Dashboard updated through ArcGIS during these efforts would be a wonderful teaching tool, in addition to revealing the week's results. Afterwards, the data collection could serve as a continual baseline for AL in Beargrass Creek that could be monitored yearly. It would also guide targeted cleanups and reveal where hotspots of AL tend to develop most frequently.

AL accumulation is an issue ever growing in presence and persistence in urban waterways that affects everybody, but it is an issue that everybody can make daily choices to improve. After decades of controlling natural streams and shaping them into corridors of urban wastewater, it is time to reclaim and restore the beautiful potential of waterways that truly shape the cities themselves.

Explanation of Limitations

There were some limitations of the study that must be addressed. Due to constraints of time and resources, the entirety of Beargrass Creek could not be analyzed within the research. There are parts of the creek that are inaccessible for litter tracking. However, to address this limitation, fifteen sites were chosen throughout the forks as the best representatives of the creek as a whole. These included a balanced mix of the land use and habitat health seen throughout Beargrass Creek. Also due to the project's time constraints, a potential limitation could arise from the fact that visits were not conducted from November to May.

The study also tested the application of the National Geographic Marine Debris Tracker app, to determine the effectiveness of its application in the study of urban waterways. While it was a strong tool, the use of the app presented some weaknesses in the study that need to be acknowledged as well. While other studies evaluated the presence of trash through density or volume of the litter in an area, the app strictly recorded the quantity. This method was suited for the study but should be considered before comparison between other studies focused on aquatic trash. In addition, the site visits could only provide insight into the stationary AL within the stream at that moment in time. To learn more about the transport mechanisms of AL, incorporating drone technology to monitor AL movement between sites would be an innovative approach.

There was also the limitation of human error. The app relied solely on human identification and documentation of litter. The researcher encountered waters in which the level of turbidity prevented her from seeing the bottom of the stream bed- therefore, there could have been trash gathered beneath what was visible to the human eye. In other areas, trash had accumulated in the environment for so long that it was challenging to count all the pieces submerged in the banks and woven into masses of natural debris. In these cases, the researcher simply had to record the amount of litter to the very best of their ability. The study overcame these limitations to the greatest extent possible, however.

The limitations experienced in this study should be considered in the planning of future studies and used to build upon the work established in this study. Within the Debris Tracker app, one can record the piece of litter, and include a picture with notes. Incorporating this function into a future procedure could aid in recording whether the AL was found most along the bank, on the streambed, or entangled in a woody debris dam.

Researching AL entrapment between these different locations within a stream and AL type should be pursued further. Allegorically, this study observed plastic bags frequently caught in branches and vegetation along the bank. Denser AL materials (such as soda cans and glass bottles) were observed on the streambed. How this affects transport time and AL accumulation could be valuable in mitigation work and cleanup approaches. If the study could be expanded, incorporating additional watersheds that could represent different watershed scale LULC would provide greater insight into AL accumulation and surrounding land cover. While the study primarily focused on the percentage of impervious surface, investigating the role of land use in several differentiated watersheds would expand the discussion in future studies.

This study also creates the space for future studies to explore the influence of human behavior further. Designing a study to examine how accessibility affects AL accumulation (such as the stream site's distance to paved roads or trails) or one that surveyed local neighborhoods about the watershed of focus could provide meaningful insight into community engagement and environmental education activities.

Another question formed from this study would be if AL type varies by land use. Again, incorporating different watersheds of land use and measuring the percentage of AL type could explore the relationship between the two components. Muddy Fork was the most residential fork from the three, and it had the least amount of plastic in comparison. It would be interesting to study if single use plastic is more prevalent in urban watersheds, and what the effects of that might be. Examining the biological impact of AL and potential ecological changes due to the presence of AL is another component to consider.

Incorporating more geographic analysis and modeling in future studies could potentially reveal trends between AL and stream geomorphology, the presence of CSOs, or the effect of manmade structures and/or woody debris dams on AL retention. Research in AL in urban waterways is an emerging field that incorporates a diverse range of factors. While this study encountered limitations, it has contributed to the increasingly urgent emphasis on the health of urban streams and the issue of AL pollution and recommends the next steps required of future studies, in order to close the current gaps in AL research.

CONCLUSION

The purpose of this study was to examine the factors behind anthropogenic litter in urban waterways and evaluate the relationship between streamflow and AL in Beargrass Creek. Another goal of the study was to explore the application potential of the National Geographic Marine Debris Tracker app as a citizen science initiative and within geospatial technology. The project used the app to record the quantities of trash at fifteen specific sites in Beargrass Creek through the summer and fall seasons. The analysis of the collected data provided insight into AL and how habitat conditions, LULC, watershed structural properties, and anthropogenic behavior influences its accumulation in urban waterways.

The results can be used to explore possible solutions in the restoration of Beargrass Creek. Riverine plastic transport has been significantly understudied in past research. For a long time, the scientific community thought that the ten largest emitting rivers contributed the majority of all the plastic waste from rivers. It was only a few years ago that Meijer et al. (2021) discovered the flaw in this modeling due to the scarcity of data on microplastic pollution in freshwater ecosystems. Therefore, they conducted a study with improved modeling which discovered that more than 1,000 rivers account for 80% of the global plastic emissions per year- with small urban rivers found among the top contributors. This pivotal perspective has called for a crucial shift in AL and marine debris research, because it revealed that effective prevention strategies must target rivers and urban waterways, in order to significantly reduce the amount of anthropogenic litter entering the global oceans.

A deeper understanding of the transport mechanisms of AL from this research provides the opportunity to design manageable yet highly effective action strategies that strive to prevent the litter entering urban streams from the watershed (before it is nearly impossible to retrieve from the vast oceans). This study presented the importance of further research in anthropogenic litter and local watersheds, sustainable management of water resources and urban development, and finally environmental education and community engagement, not only in the restoration of Beargrass Creek, but for all the urban waterways that continue to shape and sustain our cities.

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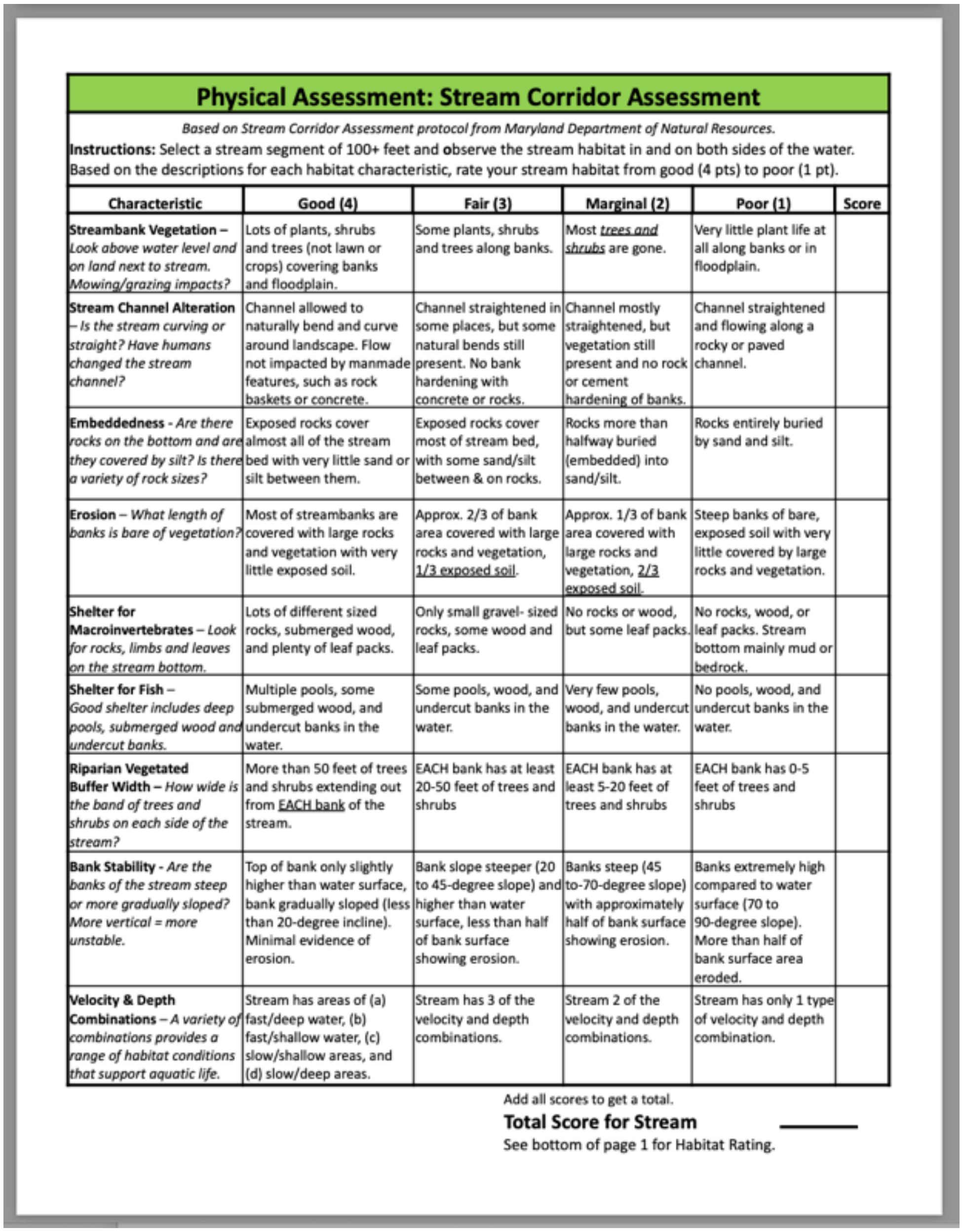
APPENDIX A



Physical Assessment: Stream Corridor Assessment

Based on Stream Corridor Assessment protocol from Maryland Department of Natural Resources.

Instructions: Select a stream segment of 100+ feet and observe the stream habitat in and on both sides of the water. Based on the descriptions for each habitat characteristic, rate your stream habitat from good (4 pts) to poor (1 pt).

Characteristic	Good (4)	Fair (3)	Marginal (2)	Poor (1)	Score
Streambank Vegetation – *Look above water level and on land next to stream. Mowing/grazing impacts?*	Lots of plants, shrubs and trees (not lawn or crops) covering banks and floodplain.	Some plants, shrubs and trees along banks.	Most trees and shrubs are gone.	Very little plant life at all along banks or in floodplain.	
Stream Channel Alteration *– Is the stream curving or straight? Have humans changed the stream channel?*	Channel allowed to naturally bend and curve around landscape. Flow not impacted by manmade features, such as rock baskets or concrete.	Channel straightened in some places, but some natural bends still present. No bank hardening with concrete or rocks.	Channel mostly straightened, but vegetation still present and no rock or cement hardening of banks.	Channel straightened and flowing along a rocky or paved channel.	
Embeddedness *- Are there rocks on the bottom and are they covered by silt? Is there a variety of rock sizes?*	Exposed rocks cover almost all of the stream bed with very little sand or silt between them.	Exposed rocks cover most of stream bed, with some sand/silt between & on rocks.	Rocks more than halfway buried (embedded) into sand/silt.	Rocks entirely buried by sand and silt.	
Erosion *– What length of banks is bare of vegetation?*	Most of streambanks are covered with large rocks and vegetation with very little exposed soil.	Approx. 2/3 of bank area covered with large rocks and vegetation, 1/3 exposed soil.	Approx. 1/3 of bank area covered with large rocks and vegetation, 2/3 exposed soil.	Steep banks of bare, exposed soil with very little covered by large rocks and vegetation.	
Shelter for Macroinvertebrates *– Look for rocks, limbs and leaves on the stream bottom.*	Lots of different sized rocks, submerged wood, and plenty of leaf packs.	Only small gravel- sized rocks, some wood and leaf packs.	No rocks or wood, but some leaf packs.	No rocks, wood, or leaf packs. Stream bottom mainly mud or bedrock.	
Shelter for Fish – *Good shelter includes deep pools, submerged wood and undercut banks.*	Multiple pools, some submerged wood, and undercut banks in the water.	Some pools, wood, and undercut banks in the water.	Very few pools, wood, and undercut banks in the water.	No pools, wood, and undercut banks in the water.	
Riparian Vegetated Buffer Width – *How wide is the band of trees and shrubs on each side of the stream?*	More than 50 feet of trees and shrubs extending out from EACH bank of the stream.	EACH bank has at least 20-50 feet of trees and shrubs	EACH bank has at least 5-20 feet of trees and shrubs	EACH bank has 0-5 feet of trees and shrubs	
Bank Stability *- Are the banks of the stream steep or more gradually sloped? More vertical = more unstable.*	Top of bank only slightly higher than water surface, bank gradually sloped (less than 20-degree incline). Minimal evidence of erosion.	Bank slope steeper (20 to 45-degree slope) and higher than water surface, less than half of bank surface showing erosion.	Banks steep (45 to-70-degree slope) with approximately half of bank surface showing erosion.	Banks extremely high compared to water surface (70 to 90-degree slope). More than half of bank surface area eroded.	
Velocity & Depth Combinations *– A variety of combinations provides a range of habitat conditions that support aquatic life.*	Stream has areas of (a) fast/deep water, (b) fast/shallow water, (c) slow/shallow areas, and (d) slow/deep areas.	Stream has 3 of the velocity and depth combinations.	Stream 2 of the velocity and depth combinations.	Stream has only 1 type of velocity and depth combination.	

Add all scores to get a total.

Total Score for Stream ______

See bottom of page 1 for Habitat Rating.

Appendix A. Kentucky Watershed Watch habitat assessment scoring rubric.

CURRICULUM VITA

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EDUCATION

University of Louisville	**Louisville, KY**
Master's Degree, Sustainability	Spring 2024
Academic Advisor: Dr. Tamara Sluss	
Florida State University	**Tallahassee, FL**
Bachelor's Degree, Environmental Science	Spring 2022
Academic Advisor: Dr. Timothy McGann	

AWARDS AND HONORS

2021 Spring	Dean's List, Florida State University
2020 Fall	Dean's List, Florida State University
2020 Fall	Florida State Femina Perfecta Award

INTERNSHIPS & EXPERIENCE

2022 Spring	FSU Capstone Student, training in water quality testing, differential leveling, pace and basic mapping
2022 Summer	Research intern for the Coastal Plains Institute- preparing a future field book for community outreach and education, water quality testing, and dip-netting & drift fence data collection
2022 Fall	Extensive coursework studying remote sensing and the application of ArcGIS technology to water resource data analysis
2023 Spring	Deep knowledge of ecosystem ecology and biodiversity grid sampling in the field
2023 Summer	Research intern for the Aqlan Lab- focused on the analysis of water quality, GIS application, and ecological preservation
2023 Fall- Present	Employed by the UofL Stream Institute as an assistant field tech for their ecological restoration work

2022 Fall- Present	Active steering committee member of the Salt River Watershed Watch, an organization that allows volunteers to participate in water quality monitoring and citizen science initiatives focused on local streams and urban waterways