A Bioassessment of Rocky Branch Creek

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Term Paper for Geography 549, Water and Watersheds
Spring, 2013

Streams act as conduits in carrying water from a drainage area into a river or larger water body. These streams are an important resource to plants, animals, and humans in many ways. Unfortunately, as a watershed becomes more urbanized streams that drain the watershed are put under added pressures due to the increasing levels of imperviousness, higher loads of non-point source pollution in the form of runoff, and a general decline in habitability. Due to these pressures, urbanizing streams begin to take on negative qualities like increasing channel and bank instability, declining water quality, and unhealthy aquatic habitat. (Wooten, 2008) In an attempt to better quantify the latter, our group completed a bio-assessment on the urbanized Rocky Branch Creek in hopes of providing the Rocky Branch Watershed Alliance with data on the condition of the aquatic habitat in the creek and the nature of organisms living within it.

Rocky Branch Creek (RBC) is a very small yet highly urbanized stream located in the center of Columbia, SC that drains an area known as the Rocky Branch Watershed (RBW). This creek itself is part of the larger Congaree River Watershed. The watershed is somewhat small but located in an area of biological interest. The watershed includes areas of extensive human development including residential areas, The University of South Carolina campus, and the popular retail, tourist and nightlife destination called Five Points. Where Five Points currently exists, was once a large wetland area that Rocky Branch Creek flowed through (Wooten, 2008). To create the Five Points district, in 1915 the City of Columbia diverted the stream's flow underground. This successfully drained the area but also laid the path for flooding problems over the next 90 years. (Holleman, 2006) In the century since it was drained, the Five Points area has flourished, which has in turn led to urbanization of the Rocky Branch Watershed in this area. Urbanization has also increased in other RBC adjacent areas, including the ever-growing USC campus and the revitalized Olympia area.

Over the last forty years or so, the understanding of effects that urbanization has on rivers and streams has improved (Wooten, 2008). Most studies of this type have shown that aquatic communities exhibit degraded conditions in urban environments, due to the fact that urbanization increases the surface areas of impervious cover (sidewalks streets, rooftops, parking lots etc.) (Herricks 2002). As impervious surface areas increase, water transport within the watershed drastically changes and the stream channels undergo multiple physical, chemical, and biological changes (Henshaw, 2000).

Physical changes to the stream come in the form of a new hydrologic regime as well as changes to the channel itself. As urbanization and imperviousness increases within a watershed, natural infiltration decreases. This causes an increase in storm runoff and a "flashier" hydrograph characterized by increased peak discharge and decreased low flows (Leopold, 1968). This increased peak discharge often causes flooding problems, like those associated with RBC and the Five Points area. As discussed earlier, Five Points is a natural floodplain surrounded on all sides by hill slopes. Increased imperviousness over the last 90 years drastically increased the volume of storm water Rocky Branch Creek transports. This, along with anthropogenic manipulation of the stream's natural features, has led to multiple flooding incidents in the areas surrounding the creek and subsequent property damage. These floods can be quite detrimental to the area financially, with single-event effects often causing hundreds of thousands dollars in damage to cars, businesses, homes, etc.

In an ideal setting, aquatic organisms require a fairly consistent source of water, sediment, and nutrient flow, which urban areas like that of Five Points artificially restrict. During construction and development along a creek, sediment yields can reach up to 200 times that of a "natural" stream. This increased sediment load may blanket the bottom of the stream and alter the habitat for bottom dwelling organisms (Wolman and Schick, 1967). Storm water runoff transports pollutants, chemicals, as well as other trash as it flows across different impervious surfaces. It also collects nutrients such as nitrogen, phosphorus, and pet waste as it travels across lawns and other artificially fertilized areas. These pollutants, nutrients, yard waste, and street debris enter through storm drains as well as directly into urban streams. Overall, urbanization typically severely degrades the physical and chemical properties of a stream, which in turn, compromise its biotic integrity and habitat diversity (Walsh et al. 2005).

These effects are multiplied in a highly urbanized watershed like Rocky Branch. A variety of human activities within this watershed are contributing degrading factors to the waterway. Richland County zoning within this watershed consists of areas of RG (General Residential), GC (General Commercial) LI (Light Industrial) and HD (Heavy Industrial), all of which can negatively influence waterways in different ways. A study by Wooten concluded that in 2007 imperviousness covered 49.1% of the total area in Rocky Branch Watershed. These different land uses display the multiple pressures that are put on RBC. Due to this severe urbanization throughout the whole watershed and the variety of land uses present, it is likely difficult to identify particular sources of contamination. However, by using bioassement practices not yet employed in the RBC area specific factors might be identified that previous non-biological assessments could not show.

This research is intended to further the efforts of a local community initiative. The Rocky Branch Watershed Alliance was formed in December, 2011 as a grassroots movement whose mission is to "unite residents, businesses, governments, and organizations to restore water quality, properly manage flooding, and care for the related natural resources in the Rocky Branch Watershed." (RBWA) Since historical data on the creek (especially biological) is limited, the Alliance will need to establish the current status of the stream and begin long-term monitoring programs. Although the literature would predict that RBC contains very few organisms due to urbanization stresses, a biological assessment (using methods from EPA's Wadeable Streams Assessment) is needed to accurately show what biotic species still inhabit RBC and empirically demonstrate this likely outcome.

Macroinvertebrate Importance & Advantages

Benthic macroinvertebrates serve as exceptional indicators of the overall aquatic ecosystem. Performing macroinvertebrate sampling has several advantages over other forms of data collection. For example, chemical tests may be too expensive or impractical. Additionally, macroinvertebrates serve as an early indicator of stress (i.e. pollution) within the aquatic ecosystem as expressed via physical responses or decreased abundance (Li et al. 2012). Another advantage to collecting macroinvertebrates instead of other organisms is their lack of mobility (Bode and Novak 1995). This is enormously important for a flashy stream like RBC. Most macroinvertebrates are highly immobile and prefer to live on the bottom of rocks or in the sediment itself, they are not swept away in every flood event. This lack of mobility also makes them easier to collect compared to other aquatic species such as a fish.

Macroinvertebrate studies can determine the impact of urbanization on a stream environment. Though the associated variables may vary, Cuffney et al. (2010) were able to determine that urbanization significantly impacts macroinvertebrate populations. Samples for their study came from all over the United States ranging from Atlanta, GA to Portland, OR, which demonstrates another advantage. Macroinvertebrate collection can be performed almost anywhere as they are found globally in virtually all freshwater streams. These results can then be compared to those from essentially anywhere else with only minor corrections for region. Furthermore, identification charts for macroinvertebrates are widespread and easily accessible and macroinvertebrates are easily identifiable down to the family level. To further improve outcomes, identification charts for specific regions also exist. For example, the Stream Monitoring Information Exchange has created a chart specific for the southern Appalachians that is applicable for use in RBC or any other local waterway (Raymond and Robinson 1999).

Maps of Field Data Results

Samples were collected on transects along each of five stream subsections. The five stream subsections used in the mapping analysis are MLK Park, Maxcy Gregg Park, Sumter Street to Assembly Street, the area adjacent to Capital City Stadium, and Olympia Park to the stream mouth (Figure 1). Hereafter, these sections will be referred as MLK, Maxcy Gregg, Sumter, Capital City Stadium, and Olympia respectively, the upstream locations where each section begins. The sections were established after data collection was completed based on notable landmarks or areas that serve as useful section dividers, limitations in using aerial imagery to define points, and ground-level observations for each data collection session. These factors are all interrelated, but the combinations at each reach were unique enough to determine the sections as having distinctive characteristics. Each section approximately represents a day's worth of sampling, moving downstream at a steady pace and sampling at sites of interest. Beginning and end points of sampling were often determined by human-defined areas such as parks or street intersections. The limitation of aerial imagery really comes into consideration when analyzing stream characteristics such as habitat. Field mapping the changing and varying stream habitats along RBC would have been desirable, but aerial imagery is sufficiently detailed. Field notes on stream conditions taken during sampling may have been used to map changes in habitat, but ran the risk of creating an inaccurate or overly generalized map with largely qualitative data.

The remaining maps describe findings from the sampling efforts. Figures 2 and 3 focus on the EPT results. EPT taxa are *ephemeropterans*, *plecopterans*, and *trichopterans* (stoneflies, mayflies, and caddisflies respectively). These organisms are generally accepted as the best bellweathers for overall ecosystem health when taken together. They are used in all major stream bioassessments and EPT is a highly conventional method of bioassessments. A more complete description of EPT organisms and their role is included later.

There was a complete absence of any EPT specimens in the upstream sections of MLK and Maxcy Gregg. The tributary that flows past Capital City Stadium and into the lower main branch of RBC from the south was also devoid of all EPT life. This tributary branch is separated from the main branch section for analysis because the results obtained from it are remarkably different from the main branch it feeds into (both upstream and downstream of the junction point). These two areas are called Stadium Branch and Stadium Main, respectively, on the maps. EPT specimens were found in the Sumter, Stadium Main, and Olympia at low quantities compared to an ideal stream, where they should be found in the hundreds or thousands per square meter (depending on regional corrections). These are also the three most downstream sections. EPT findings were not balanced within the three taxa. Each section with any EPT presence exhibited a strong presence of caddisfly larvae (*Trichoptera*) compared to all other EPT and non-EPT organisms. The Sumter and Olympia sections had nearly the same total with approximately fifty-three and fifty-two caddisfly larvae collected, respectively. Roughly twenty-five were collected in the Stadium Main sub-section within the Capital City Stadium section. Only one site exhibited any non-caddisfly EPT species. A total of three mayflies were captured and all occurred near the beginning of the Olympia section. These results are displayed in Figure 2.

While the EPT values given above represent the number of EPT organisms sampled, the number of distinct species identified; i.e., the *species richness,* refers to an important indicator of stream quality. Ideally, a healthy stream has both high abundance of EPT organisms as well as high EPT richness (number of species). Less ideal and moderately healthy streams have high levels of one or the other.

RBC exhibited extremely low values for both metrics. Only a single specimen of each EPT category needs to be documented for the entire category to be included, so both values should be taken into account in overall assessments. The possible values range only from zero to three.

Figure 3 shows EPT species richness instead of an overall count of organisms present. Both caddisfly and mayfly larvae were caught in the Olympia section, which had the highest richness total with a value of two. (The caddisflies included one net-spinning and one case building species). Note, however, that species identifications were not corroborated via DNA testing or other more conclusive means. Though the most extensive populations of caddisfly larvae were found in the Sumter and Stadium Main sections, both reaches had an EPT species richness value of only one; i.e., a large number of only one species was present. All other sites had a species richness of zero as no organisms were found. The limitation of the other EPT map, though helpful, is that it only measures a sample population. It would be impossible to determine the exact populations of the EPT species by the methods used in this study. Our sampling method, while consistent, was more broadly defined than those of formal bioassessments. However, the data appear to show that EPT values are highest at mid-to downstream points.

	Caddisfly	Mayfly	Damselfly	Midge	Worm	Skimmer	Leech	Crayfish	Riffle Beetle	Snail	Fish	Turtle
MLK					X	X						X
Maxcy Gregg			X	X	X	X	X		X			
Sumter	X						X	X		X		
Stadium Main	X						X					
Stadium Branch											X	
Olympia	X	X		X			X			X		

The importance and effectiveness of using the EPT index as a gauge in interpreting overall stream quality is illustrated by the confusion introduced when all species are considered. Measures of total organisms or total richness, while informative, can be misleading without fully understanding the dynamics of non-EPT organisms found in the respective reaches. Figure 4 is the species richness for all species found within each section. A more detailed breakdown of the species found in each section is provided in Table 1. When viewing Figure 4, one should not make the assumption in this case that species richness corresponds with stream quality of each section. For example, the Olympia and Maxcy Gregg sections tied for the highest species richness. Six species were found within both sections. However, in Maxcy Gregg, the majority of what was found were pollutant tolerant worms. None of the remaining five species were EPT. Meanwhile within Olympia, two of its six species were EPT, and it was the only section harboring fish. Putting much analysis into these fish sightings is outside the scope of macroinvertebrate collection, but it is noteworthy that they were only found in the Olympia section. Additionally, the species and health of these fish are unknown. Sample numbers are very small compared to those in an ideal setting and looking too deeply into patterns in this limited data may lead to erroneous conclusions.

	Caddisfly	Mayfly	Damselfly	Midge	Worm	Skimmer	Leech	Crayfish	Riffle Beetle	Snail	Fish	Turtle
MLK					X	X						X
Maxcy Gregg			X	X	X	X	X		X			
Sumter	X						X	X		X		
Stadium Main	X						X					
Stadium Branch											X	
Olympia	X	X		X			X			X		

The numbers of total specimens (Figure 5) tells a similar story. The Sumter and Olympia sections had the most total specimens collected with several of them being EPT species. The third highest count, MLK, is where potential trouble ensues. Though it is not possible to determine any conclusions from the data displayed on this map, if the current trends were to continue, it would appear as if the MLK section has, in comparison to all sections, a respectable species richness (relatively speaking). However, the underlying truth is that the majority of these species are, like Maxcy Gregg, pollutant tolerant worms associated with severe impairment. This once again constitutes the importance of utilizing the EPT index and not simply conducting an overall species count. Total species data is a useful addendum and point of comparison with EPT data, but alone is not very valuable for bioassment.

Figure 6 focuses on the pollutant tolerant worms and includes where and how many were caught. Most of the worms were found in locations dominated by sediment, a finding consistent with bioassessment principles. The results are quite the contrary compared to the EPT specimen totals in Figure 2. This time all the specimens were found upstream and nothing further downstream. The MLK section dominates the worm total with sixty-seven followed by Maxcy Gregg with fifteen. The remaining stream sections, all of which occur downstream from MLK and Maxcy Gregg, come up empty. Not a single worm was documented but several less tolerant species were observed in the area.

The EPT species observed in RBC are relatively pollution-tolerant on the EPT spectrum. A potential explanation for this disparity is that RBC differs in habitat between sections and that localized habitat (possibly heavily influenced by or synonymous with urbanization) is responsible for species abundance. However, these are unreplicated findings of low numbers and the only conclusive statement possible regarding RBC based on this pilot study is that it is heavily impaired according to standard bioassment doctrine. As noted later, there is a high probability that the overall RBC area is too urbanized and too small to be able to effectively break it into subsections with detectable impairment factors. Regional scale might be the most effective spatial level for detecting individual factors out of the general variability associated with urbanization for reasons to be described later.

Some inter-site or intra-site variations were minor while others were immediately noticeable. Some locations, including much of MLK, consist primarily of deep sediment and pools. As mentioned, this is where the majority of worms were found. Other locations consisted largely of rocks of varying size and shallow riffles. This description can be applied to many portions of the Sumter section and the sections thereafter. It was within this habitat type that most of the EPT species were caught and is exactly where we would expect to find them.

EPT Methodology and a Discussion on Spatial Scales

Certain macroinvertebrate classifications are substantially more important in the evaluation of the quality of waterbodies. These are commonly referred to as the 'EPT taxa', which refers to the Ephemeroptera taxa, Plecoptera taxa, and Trichoptera taxa respectively (Bailey 2012). Each ecosystem has its own unique taxa balance that requires careful calibration and of course the more organisms that can be sampled at one time, the more useful the survey is. However, the EPT taxa, which are common and proven indicators of ecosystem health, allow effective interpretations in non-ideal conditions (Aquatic Bioassessment Laboratory 2006). Ephemeropterans, commonly known as mayflies, exist as many species in and around streams, rivers, and lakes. There are almost 700 mayfly species in North America, and as with other EPT organisms the overall abundance of mayflies is more important than specific species are (since species can vary from region to region) (McCafferty 1996). Trichopterans, commonly called caddisflies, like other EPT species spend their juvenile stages in sediment and on rocks. They are the most diverse insect order where juveniles are exclusively aquatic and thousands of species exist worldwide. Additionally, caddisflies are unique in their ability to use natural silk to produce nets or fashion protective tubes out of small rocks, twigs, and other stream materials. Each species creates these cases in an identifiable pattern and this can be used for easy identification (Holzenthal 2010). Plecopterans are stoneflies and are among the most widespread and pollution intolerant insect species worldwide. This means that of the EPT taxa, the “P”are the least likely to be found in an impaired stream, as we saw in RBC (Fochetti 2008). Because of the near-universality of the EPT taxa and the proven relationship between EPT species richness and ecosystem health, the EPT analysis has become a standard of waterway bioassessment (US EPA 2011).

Other macroinvertebrate groups are also used in common bioassessments to establish a total measure of biodiversity. These organisms are less important in and of themselves, but instead are examined in relationship to the abundance of EPT taxa. These groups include many varieties of beetles (both mature and larvae) water striders and water bugs, mosquitos, worms, many varieties of snails, other fly species, leeches, crayfish, and a few other less common species (US EPA 2011, Raymond et al., 1999). The relative balance of the EPT and other taxa are very important for assessing ecosystem health but ideal balances differ between regions and calibrations are necessary to account for this. For example, the ideal balance in the Hudson Bay region calls for around 40% of total macroinvertebrates to be from a mayfly species with the non-EPT midges the next largest group at 20% (Hudson Bay River Watch). Other locales focus on having multiple EPT species in the same area (i.e., no one stonefly species dominating), with anywhere between 2-5 species from each taxa in a sample (California Watershed Assessment Manual 2007). Most models agree that combined EPT species should make up a significant portion of total macroinvertebrates in a healthy system. The EPT/Dipteran (true fly) ratios are also a key, as high relative populations of Dipterans are an indicator of poor stream health in some localities. (US EPA 2011, Hudson Bay River Watch, California Watershed Assessment Manual 2007)

There are many ways to examine EPT indices and a multitude of proposed formulas for quantifying stream health. They vary in terms of the spatial scale examined, period of time necessary for effective assessment, taxonomic level of identification necessary for a solid result, factors tested, whether combinations or clusters of factors are included, etc. For a simple example, a long-term USGS survey of Pennsylvania watersheds in the Delaware River basin based stream classifications entirely on the raw quantities of macroinvertebrate taxa, a practice that is used commonly as a general indicator of ecosystem health if not an approach that can conclusively determine causes of impairment. They classified streams into ‘nonimpacted’ (>30 taxa and >10 EPT), ‘slightly impacted’ (21-30 and 6-10), ‘moderately impacted’ (11-20 and 2-5), and ‘severely impacted’(0-10 and 0-1) (USGS 2002).

Macroinvertebrate assays have been proven effective in a variety of conditions and locations. Globally, correlations between high EPT and healthy streams hold true. The real variation in stream response and the major contested points in EPT research arise when watersheds of different spatial scales are compared. That is to say, EPT levels as well as overall species abundance levels can be used consistently to classify a stream broadly (as in the Pennsylvania example above) regardless of the size of the watershed, but for more specific claims of stream health the scale becomes much more important. For example, in four watersheds in the Chesapeake Bay region as well as 29 smaller subwatershed areas, Moore and Palmer (2005) documented patterns in macroinvertebrate number across all watershed types (both urbanized and nonurbanized), with differential changes based on watershed land use. However, to conclusively state what problems associated with urbanization caused macroinvertebrate declines is much more difficult.

Spatial scales must be taken into consideration when trying to tease out patterns from macroinvertebrate assemblages. A survey of many different streams and many different variables showed that macroinvertebrate numbers and relative abundance is impacted by both local, site-based variables and regional ones (Sandin, 2003). This makes it difficult to tease out a conclusive result from limited data in a small watershed like RBW. Most of the individual data point watersheds used in the Sandin (2003) assessment are much larger than RBW and we did not incorporate any regional factors into our analysis. Therefore, this supports our finding that macroinvertebrate studies are excellent for assessing overall, generalized stream health but that the method used in RBW is not yet sufficient to identify specific causes of impairment.

These patterns are not limited to macroinvertebrates; mussels are also impacted by factors ranging from immediate surroundings to regional scale ones (Vaughn). Heino et al. (year) also found that regional factors may be much more indicative of species richness and abundance patterns than localized ones. While this certainly would not fully explain our findings. (The extreme absence of macroinvertebrates in RBC is symptomatic of urbanization and no regional variables are significant enough to explain this.) Macroinvertebrates are not the only classifications that change with spatial scale and other common indicator species (fish, periphyton, and mosses) also exhibit concordance with macroinvertebrate abundance patterns at large spatial scales. Even birds and other large organisms show some concordance at larger spatial scales (Paavola et al., 2006).

Land cover assessments also show that multiple spatial scales are necessary to fully understand ecosystem dynamics (King et al., 2005). However, it has been shown in South Carolina that by combining six major factors and their respective components (habitat fragmentation, land use, land use change, populations density/change, road systems, and pollution sources both point and NPS) representative models can assess overall ecological integrity (Kupfer and Gao, 2011).

These landscape-scale models can be applied to large scale assessments where intense data collection and comprehensive assessment are limited by practicality. These studies only scratch the surface of what can be gleaned from a complete understanding of aquatic macroinvertebrates and their value as indicator species, but one common thread runs through all of them. Without more effort in this field and more refined models that are as site-specific as possible, we run the risk of applying inaccurate or detrimental practices to some of the most fragile ecosystems that exist.

Other processes that can impact macroinvertebrates include drilling and mining operations (e.g. natural gas), which can cause sedimentation problems (Jensen, 2012). While no substantive evidence suggests that the quarrying operations in RBW are causing problems, some deeply sedimented areas were noticed during the walkthrough of the quarry zone of the creek. Future investigations could look into this possibility, as few organisms were observed in this stretch in spite of some ideal habitats present.

Recommendations for the future

The unclear nature of our findings is not surprising. A multitude of factors impact macroinvertebrate species so they function as overall indicators of ecosystem health. Specificity in how they respond to changes in the many possible inputs is lacking, however. This makes both pinpointing causes of impairment and tracking stream recovery with respect to a specific factor quite difficult. Rather, a suite of measurements and tracking of long-term changes are required to accurately assess both impairment causes and stream recovery, but that was not possible for this pilot study. Additionally, recovery can be assessed at many different species assemblage levels and the small scale of the RBW limits the capabilities of this approach (Adams et al.).

One paradigm of stream restoration holds that we should establish habitat heterogeneity by reshaping degraded streams to include meanders, artificial riffles, and other physical structures to restore macroinvertebrate balance by providing fragile and diverse taxa with plenty of microhabitats. Palmer et al. (2010) found that this practice, while commendable in intent and aesthetic value, only was correlated with improvements in 1/3rd of the observed treatments and that none of them could claim the physical changes as the primary reason for improvement. They suggest that conservation and restoration work in stream beds should move away from a focus on physical characteristics and instead look at factors including mineral balance, temperature, invasive species, water extractions, and others (Palmer et al., 2010).

Why the frequency of benthic macroinvertebrates (both in raw numbers and in terms of indices like EPT abundance) are so low in the RBW remains unknown, except that the area is highly urbanized. However, many potential avenues for future work could help tease out some patterns. As noted previously, the small size of the watershed acts as a major limitation on potential future outcomes but does not rule out conclusive findings entirely. By tracking macroinvertebrate levels over longer time periods we may begin to tease out relationships. Additionally, water quality data, such as pH, DO, EC, and turbidity, collected at the same sampling sites over a long term could also provide important information. More data from larger, neighboring watersheds (like Gills Creek) would help establish local and regional baselines and characteristics. More local data from unimpaired streams would also provide an overall baseline, especially from a small unimpaired watershed of a comparable size to RBW.

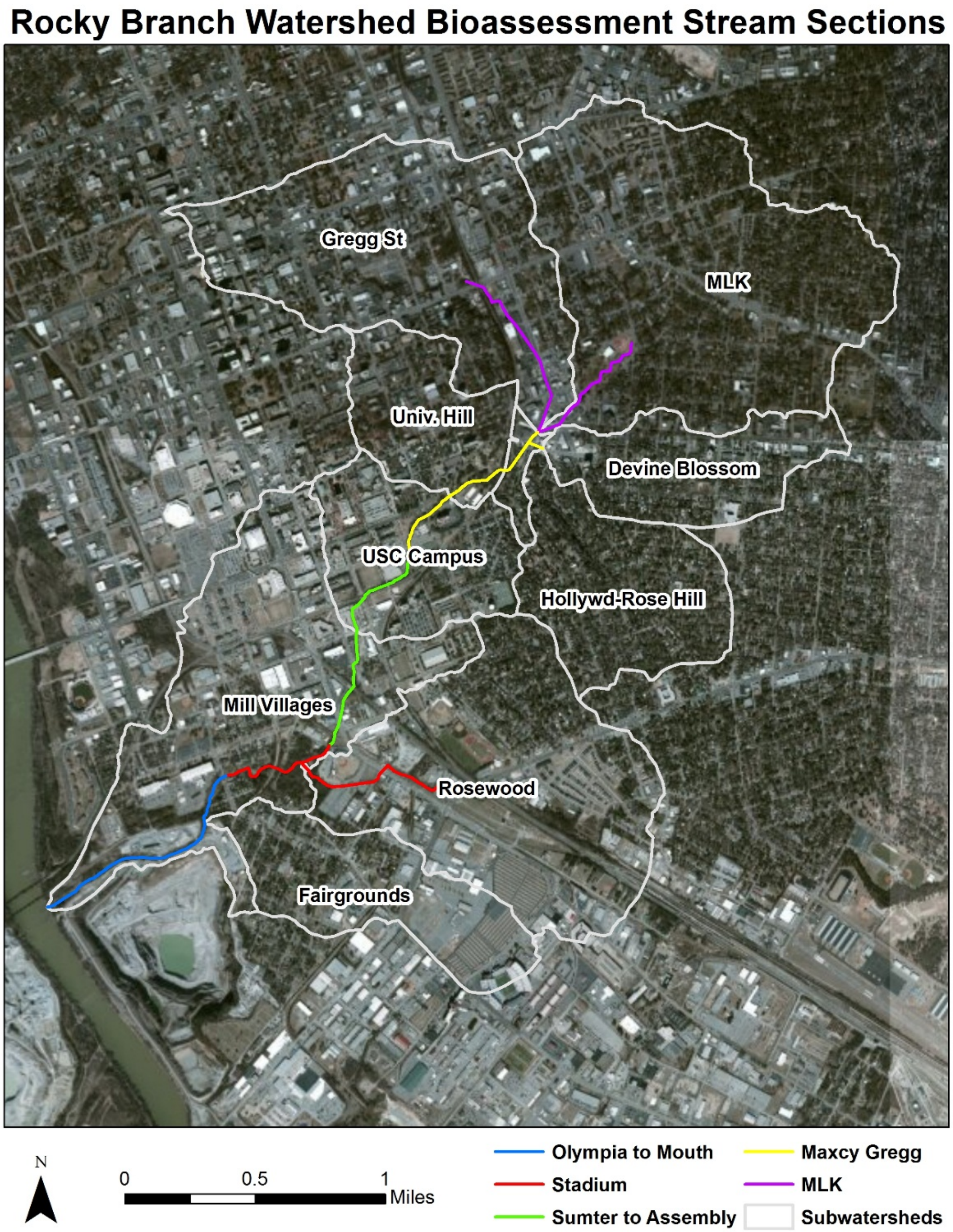
Summary

In review, this preliminary assessment of RBC from MLK Park to the Congaree River shows that it is heavily impaired according to standard bioassessment protocols and metrics and that urbanization is likely the overall defining reason. Beyond that, details about spatial and temporal patterns of impairment and the specific contributing factors remain unknown. Future efforts and more data are needed in order to establish more specific causal relationships. The field research shows that RBC and the surrounding watershed is of very poor biological quality and that immediate and significant remediation practices are necessary if organism levels are to recover.

Review of Team Roles

This project was largely a group effort both in the field and in our final report. The project topic largely originated from Sam's thesis project on local watersheds and bioassessments. Jake provided materials for sample collection and fieldwork. Sam and Jake began data collection and covered the first two sites (MLK park and Maxcy Gregg). Sam covered the Capital City Stadium, Olympia Park, and Assembly Train bridge collection sites independently. All three of us covered the remaining stretches of the sampled watershed. Sam recorded data findings and was in charge of species identification. Jake provided GIS analysis of the data, created the maps and tables included in the appendix, and provided the map assessment section. Greyson provided the introductory paragraphs for the paper. Sam provided the EPT/spatial scale background (much of which is excerpted from his course term paper and thesis draft) as well as final revisions for content and flow.

Figure1



Rocky Branch Watershed Bioassessment Stream Sections
Gregg St
MLK
Univ. Hill
Devine Blossom
USC Campus
Hollywd-Rose Hill
Mill Villages
Rosewood
Fairgrounds
N
0
0.5
1
Miles
Olympia to Mouth
Stadium
Sumter to Assembly
Maxcy Gregg
MLK
Subwatersheds

Figure 2:

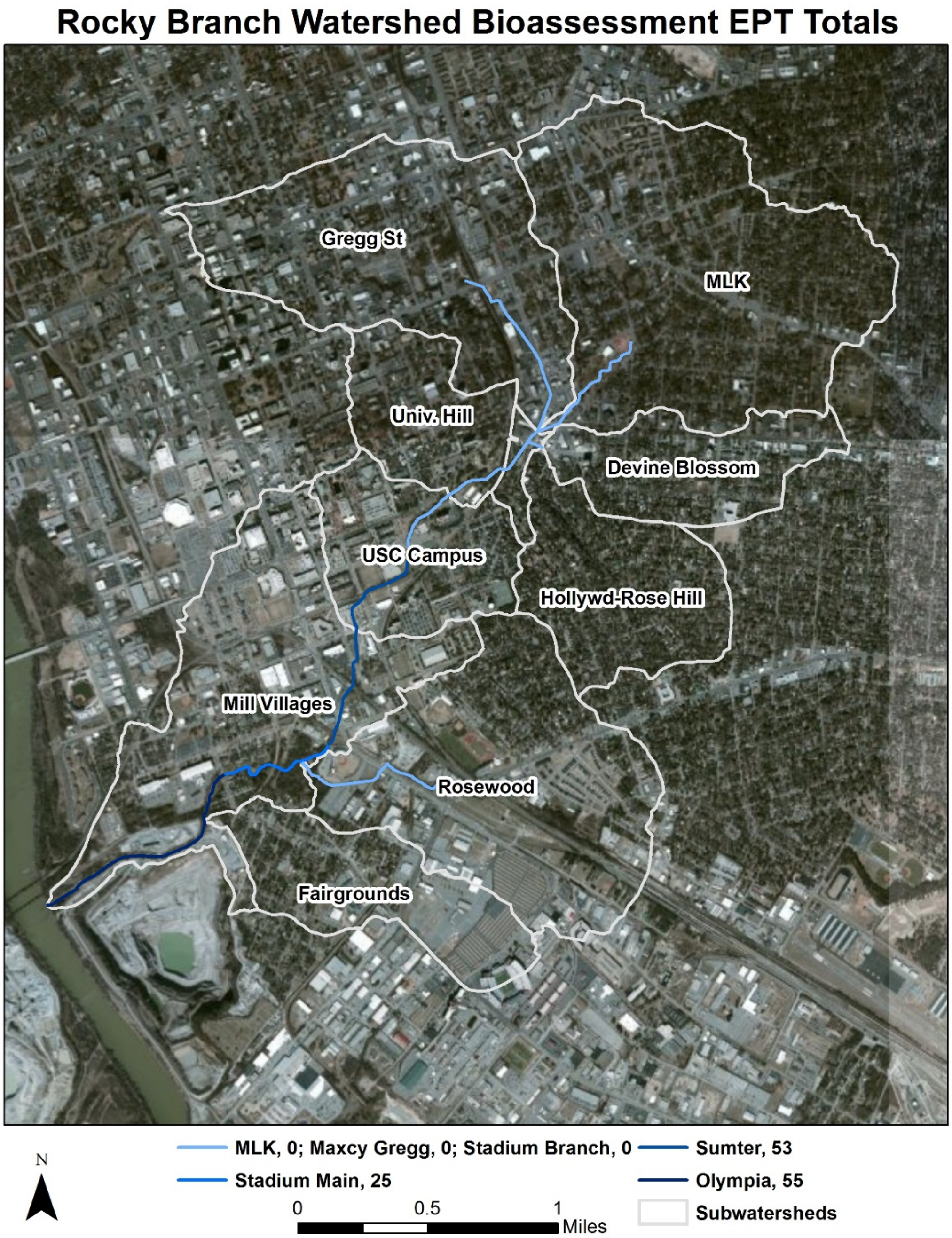

Rocky Branch Watershed Bioassessment EPT Totals
Gregg St
MLK
Univ. Hill
Devine Blossom
USC Campus
Hollywd-Rose Hill
Mill Villages
Rosewood
Fairgrounds
N
MLK, 0; Maxcy Gregg, 0; Stadium Branch, 0
Stadium Main, 25
Sumter, 53
Olympia, 55
Subwatersheds
0
0.5
1
Miles

Figure 3:

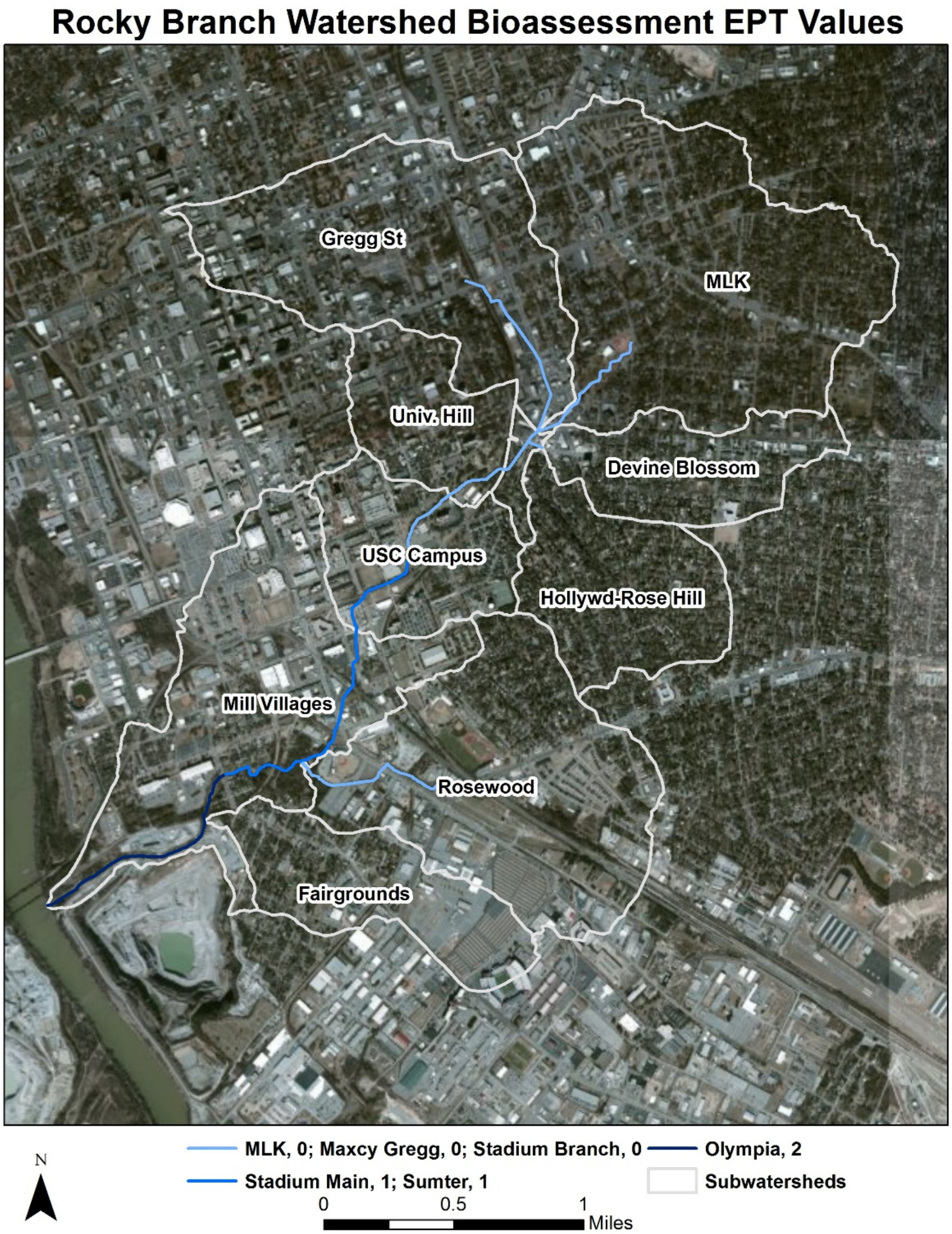
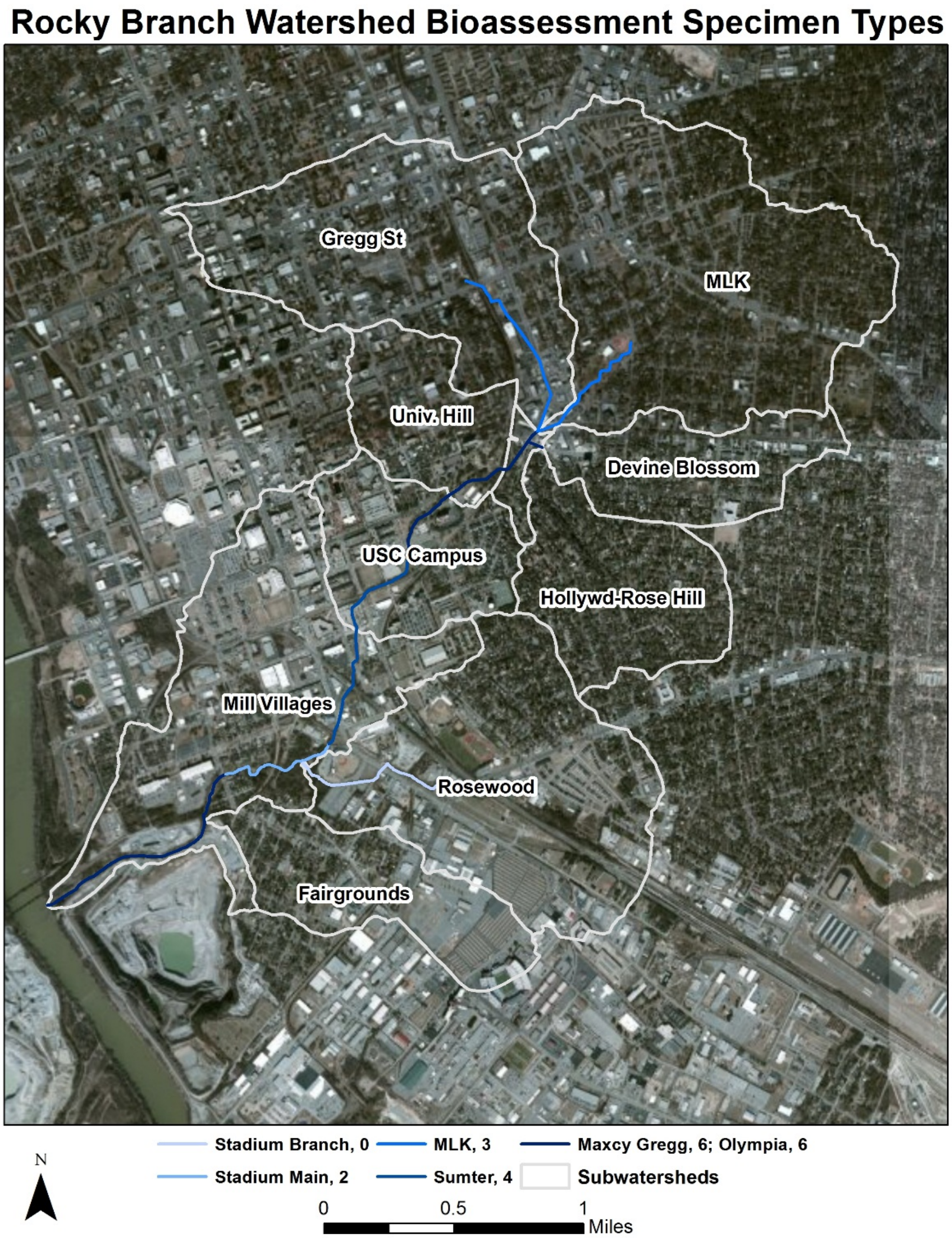

Rocky Branch Watershed Bioassessment EPT Values
Gregg St
MLK
Univ. Hill
Devine Blossom
USC Campus
Hollywd-Rose Hill
Mill Villages
Rosewood
Fairgrounds
MLK, 0; Maxcy Gregg, 0; Stadium Branch, 0
Olympia, 2
Stadium Main, 1; Sumter, 1
Subwatersheds
N
0
0.5
1
Miles

Figure 4:



Rocky Branch Watershed Bioassessment Specimen Types
Gregg St
MLK
Univ. Hill
Devine Blossom
USC Campus
Hollywd-Rose Hill
Mill Villages
Rosewood
Fairgrounds
Stadium Branch, 0
MLK, 3
Maxcy Gregg, 6; Olympia, 6
Stadium Main, 2
Sumter, 4
Subwatersheds
N
0
0.5
1
Miles

Figure 5:

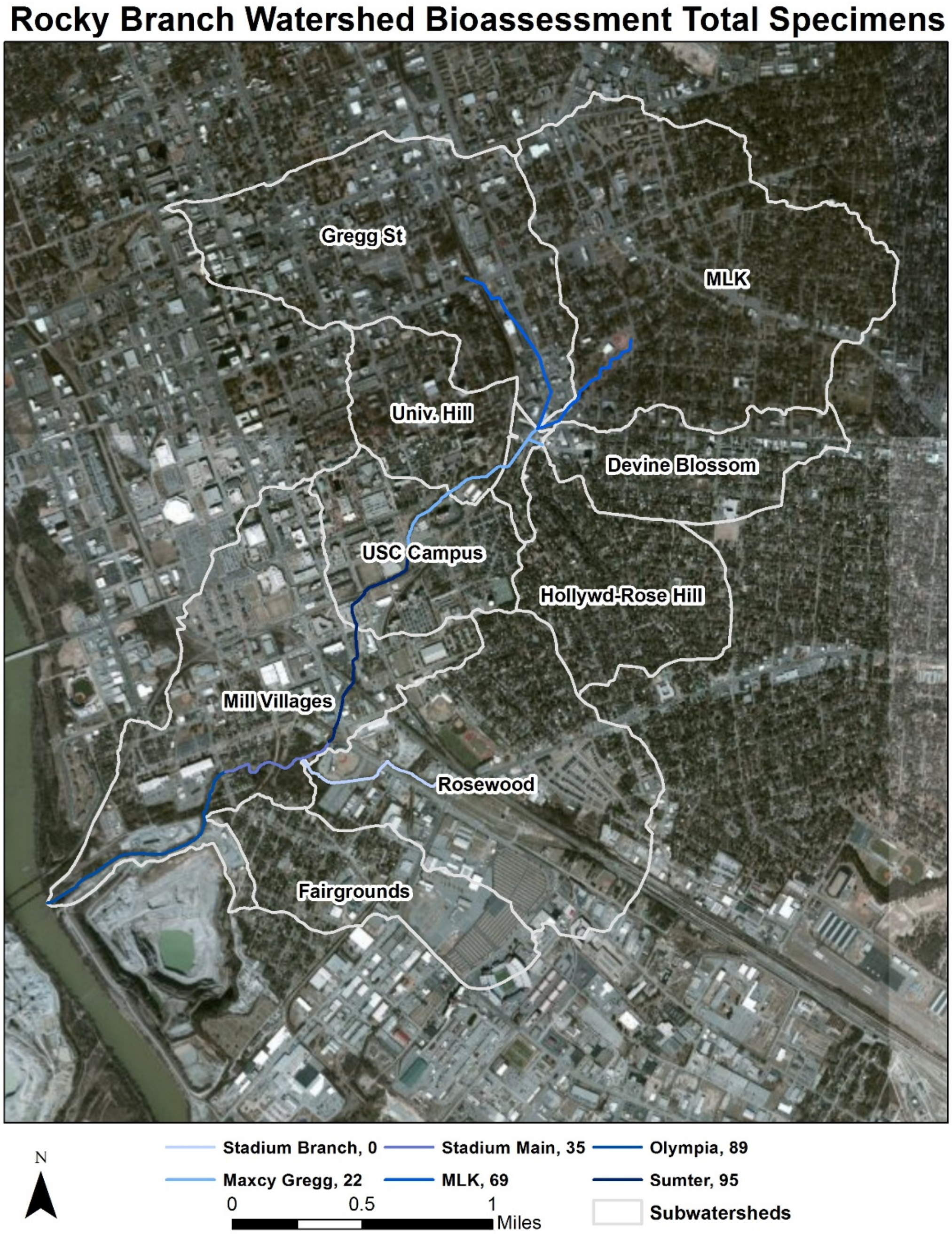
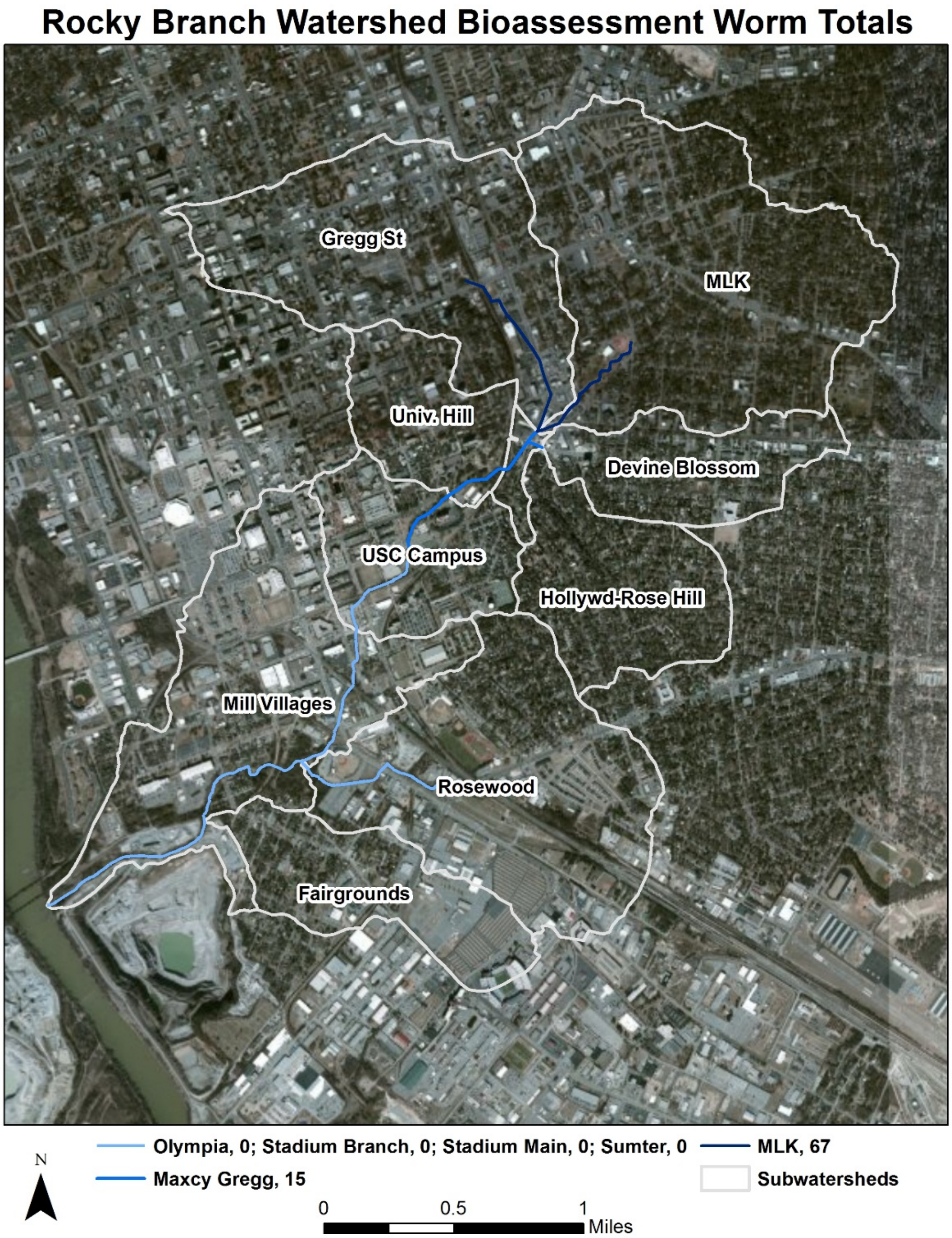

Rocky Branch Watershed Bioassessment Total Specimens
Gregg St
MLK
Univ. Hill
Devine Blossom
USC Campus
Hollywd-Rose Hill
Mill Villages
Rosewood
Fairgrounds
N
Stadium Branch, 0
Stadium Main, 35
Olympia, 89
Maxcy Gregg, 22
MLK, 69
Sumter, 95
0
0.5
1
Miles
Subwatersheds

Figure 6:



References:

Aquatic Bioassessment Laboratory, 2006. "Standard Operating Procedures for Collecting Benthic Macroinvertebrate Samples and Associated Physical and Chemical Data for Ambient Bioassessments in California." California Department of Fish and Game Water Pollution Control Laboratory. Rancho Cordova, CA.

Bailey, R C; Scrimgeour, G; Cote, D; Kehler, D; Linke, S; et al. “Bioassessment of Stream Ecosystems Enduring a Decade of Simulated Degradation: Lessons for the Real World.” *Canadian journal of fisheries and aquatic sciences/Journal canadien des sciences halieutiques et aquatiques* 69. 4 (2012): 784-796.

“Bioassessments in California.” California Department of Fish and Game Water Pollution Control Laboratory. Rancho Cordova, CA. 2006

Bode, R. W., and M.A. Novak. 1995. “Development and Application of Biological Impairment Criteria for Rivers and Streams in New York State, pp. 97-107. In W.S. Davis and T. P. Simon (eds.) *Biological assessment and criteria; Tools for water resource planning and decision making*. Lewis Publishers.

California Watershed Assessment Manual, Volume II – Chapter 6 2007

Cuffney, Thomas H., Robin A Brightbill, Jason T. May, and Ian R. Waite *Ecological Applications*, 20(5), 2010, pp. 1384–1401 “Responses of Benthic Macroinvertebrates to Environmental Changes Associated with Urbanization in Nine Metropolitan Areas”

Fochetti, Romolo and José Manuel Tierno de Figueroa “Global diversity of stoneflies (Plecoptera; Insecta) in freshwater” Developments in Hydrobiology, 2008, Volume 198, 365-377, DOI: 10.1007/978-1-4020-8259-7_39

Henshaw, P.C., Booth, D.B., 2000. “Natural restabilization of stream channels in urban watersheds.” Journal of the American Water Resources Association. 36(6): 1219-1236.

Herricks, E. (2002) “Observed Stream Responses to Changes in Runoff Quality.” Linking Stormwater BMP Designs and Performance to Receiving Water Impact Mitigation: pp. 145-157.

Holleman, J., 2006. “Stream routinely causes calamity.” The State. 26 Aug. 2006, A1. Columbia, SC.

Holzenthal, Ralph W., Roger J. Blahnik, Aysha Prather, and Karl Kjer. 2010. “Trichoptera. Caddisflies.” Version 20 July 2010 .*http://tolweb.org/Trichoptera/8230/2010.07.20 in* The Tree of Life Web Project, *http://tolweb.org/*

Hudson Bay River Watch Guiding Document. “Benthic Macroinvertebrate Sorting (EPT & Total Taxa Richness) Worksheet”. Accessed at http://www.ucratx.org/Benthic%20worksheets.pdf

Jensen, Erica Nicole Leslie “Effects of Changing Land use on Macroinvertebrate Communities in North-central Arkansas” University of Central Arkansas, 2012.

King, Ryan S Matthew E. Baker, Dennis F. Whigham, Donald E. Weller, Thomas E.Jordan, Paul F. Kazyak and Martin K. Hurd “Spatial Considerations for Linking Watershed Land Cover to Ecological Indicators in Streams” Ecological Applications, Vol. 15, No. 1 (Feb., 2005), pp. 137-153

Kupfer, John and Peng Gao “Spatial Patterns of Ecological Integrity in South Carolina Watersheds” *Southeastern Geographer*, Volume 51, Number 3, Fall 2011, pp. 394-410 Published by The University of North Carolina Press

Leopold, L.B., 1968. “Hydrology for urban land planning – a guidebook on the hydrologic effects of urban land-use.” Geological Survey Circular 554.

Li, Fengqing; Chung, Namil; Bae, Mi-Jung; Kwon, Yong-Su; Park, Young-Seuk “Relationships Between Stream Macroinvertebrates and Environmental Variables at Multiple Spatial Scales” *Freshwater Biology* 57. 10 (Oct 2012): 2107-2124.

McCafferty, W. P. "The Ephemeroptera species of North America and index to their complete nomenclature". *Transactions of the American Entomological Society*. 122 (1): 1–54. (1996)

Moore, Aaron A. and Margaret A. Palmer “Invertebrate Biodiversity in Agricultural and Urban Headwater Streams: Implications for Conservation and Management” *Ecological Applications* , Vol. 15, No. 4 (Aug., 2005), pp. 1169-1177.

Paavola, Riku, Timo Muotka, Risto Virtanen, Jani Heino, Donald Jackson and AkiMäki-Petäys “Spatial Scale Affects Community Concordance among Fishes, Benthic Macroinvertebrates, and Bryophytes in Streams” *Ecological Applications*, Vol. 16, No. 1 (Feb., 2006), pp. 368-379

Palmer, Margaret A et al. “River Restoration, Habitat Heterogeneity and Biodiversity: a Failure of Theory or Practice?” *Freshwater Biology.* 2010 Supplement 1, Vol. 55, p205-222

Raymond, Kara, Jason Robinson, *BIO-ASSESS.* 1999 ECO Photo Guide to Aquatic Macroinvertebrates of the Southern Appalachian Mountains

Sandin, Leonard. “Benthic Macroinvertebrates in Swedish Streams: Community Structure, Taxon Richness, and Environmental Relations. *Ecography* 26: 269–282, 2003

Walsh, C.J., Roy, A.H., Feminella, J.W., Cottingham, P.D., Groffman, P.M., Morgan, II, R.P. 2005. The urban stream syndrome: current knowledge and the search for a cure. Journal of North American Benthological Society. 24(3): 706-723.

Wolman, M.G., Schick, A.P., 1967. Effects of construction on fluvial sediment, urban and suburban areas of Maryland. Water Resources Research. 3(2): 451-464.

Wooten, John. 2008. Assessing the Restoration Feasibility of Rocky Branch Creek: An Integrated Watershed Management Approach. Unpub. MS thesis; Masters in Earth and Environmental Management (MEERM), University of South Carolina.