Spring 2016

Effects of agricultural restoration practices on stream health in the Shenandoah Valley, Virginia

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Effects of Agricultural Restoration Practices on Stream Health in the Shenandoah Valley, Virginia

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An Honors Program Project Presented to

the Faculty of the Undergraduate

College of Science and Mathematics

James Madison University

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by Erin Louise Thady

May 2016

Accepted by the faculty of the Department of Biology, James Madison University, in partial fulfillment of the requirements for the Honors Program.

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PUBLIC PRESENTATION

This work is accepted for presentation, in part or in full, at the Honors Symposium on April 14, 2016 and at the Biosymposium on April 14, 2016.

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Acknowledgements

I would first like to thank Dr. Wiggins immensely for the enormous amount of time and effort that he has invested into helping me with my research and thesis; it would not have been possible without his continuous guidance and encouragement. I would also like to thank my readers, Dr. May and Dr. Cooper, for taking the time to provide me with helpful direction and suggestions. I also truly appreciate the cooperation from the landowners whose farms we visited. Finally, I owe a huge thank you to my colleagues, Kristianna Bowles, Amanda Crandall, Jessie Doyle, Rhiannon English, Mycah McNett, Megan Moore, Joseph Noel, Cole Roberts, Nathan Robinson, Becca Sanders, Katherine Stanley, and Ty Steve, for assisting me with the fieldwork, laboratory identifications, and GIS and statistical analyses that were vital to this project.

Abstract

The Shenandoah Valley encompasses some of the highest agricultural producing regions in Virginia, many of which are large contributors of nutrients and sediment. The Conservation Reserve Enhancement Program (CREP) assists landowners in the installation of riparian restoration projects in which cattle are fenced out or a riparian buffer is planted. We examined the temporal effects of riparian restoration and the impact of upstream landuse on water quality for eleven farms participating in the CREP program for various times (from 1 to 14 years). We hypothesized that the length of time that the CREP program has been established would have a positive effect on the water quality of a stream. Water quality was quantified by measuring benthic macroinvertebrate assemblages using the Hilsenhoff Biotic Index (HBI), Virginia Stream Condition Index (VA-SCI), Shannon Diversity Index, and total abundance. GIS analysis was also employed to calculate upstream land use and stream channel characteristics: land use, canopy cover, slope, impervious surface, relief, road density, and watershed area were assessed for the watersheds and 100-meter stream buffers at each sampling site. Single variable and multiple linear regressions were performed separately within the watershed and buffer zones. While no single variable showed a significant relationship, the time since restoration and the percentage of upstream forested land use predicted HBI values, both in the watershed ($p = 0.003$, $R^2 = 0.712$) and in the buffer zone ($p < 0.002$, $R^2 = 0.748$). VA-SCI was predicted by time since restoration and upstream impervious surface in the buffer zone only ($p = 0.001$, $R^2 = 0.777$). These data show that CREP efforts are having a positive effect on water quality, although upstream land use is also an important factor.

Introduction

Background of Study

The Shenandoah Valley encompasses some of the highest agricultural producing regions in Virginia, and agricultural activities comprise a major source of revenue for the people of the valley. High levels of land conversion, grazing activity, and other farming practices draw attention to issues associated with protection of waterways in the Shenandoah Valley. Agricultural activity comprises one of the greatest causes of nonpoint source pollution and runoff into streams downslope of farmland. Nonpoint source pollution can have many origins, and it involves the leaching of manmade pollutants, including pesticides, fertilizers, and other chemicals through the soil into waterways. Rate of runoff of nonpoint source pollution into streams is affected by land use and surrounding vegetation that can buffer the leaching of particulate substances.

The Conservation Reserve Enhancement Program (CREP) is a land conservation program that aims to protect and preserve privately owned lands that are impacted by human use. Areas of focus include reducing the impact of pollution, enhancing plant and wildlife diversity, and restoring the overall health of the environment (Farm Service Agency, n.d.). In the CREP program, high risk properties are identified and landowners are offered an annual rental rate in exchange for protecting their land or removing the harmful influences. Because many streams in agricultural areas of the Shenandoah Valley are negatively impacted by cattle activity and waste production in the streams, several landowners contacted the CREP program to undergo restoration projects in which cattle are fenced out of the stream and/or a riparian buffer zone vegetation is planted adjacent to the stream.

Water Quality Analysis

A benthic macroinvertebrate survey is one of several methods to characterize and quantify water quality. Other commonly employed methods might include measuring turbidity, pH, temperature, dissolved oxygen, ion concentrations, conductivity, suspended sediments, or the presence of bacteria (Barbour et al., 1999). While these surveys provide a direct measurement of changes in water quality, a benthic macroinvertebrate survey offers a quantification of how organisms respond to water quality. Brua and Culp (2010) found that kick-net sampling is an effective means of quantifying macroinvertebrate community composition in streambeds. This method of biomonitoring is particularly useful because macroinvertebrates may live in a particular stream for months to years; therefore, a long residence time allows them to be indicators of the long-term effects of pollution. Additionally, they occupy the same portion of a stream for extended periods and are subject to constant exposure of variables in the water, making them a reliable group of study organisms.

The effects of stream restoration have often been investigated through assessment of benthic macroinvertebrate assemblages. Voshell (2002) noted that these organisms possess varying degrees of tolerance to pollution in their aquatic environment and are thus good indicators of changing water quality over time. Some invertebrate groups may be highly sensitive to certain types of pollution, like sediment or chemicals, but are resistant to other forms of pollution. Therefore, a standard of resistance levels was established and each taxonomic group was evaluated and scored individually. The Hilsenhoff Biotic Index (HBI) and Virginia Stream Condition Index (VA-SCI) are two metrics utilized to assess macroinvertebrate responses to water quality. The HBI assigns a tolerance value of water quality to benthic macroinvertebrates (Hilsenhoff, 1988). The VA-SCI is a multimetric index that incorporates measures of diversity, community composition, and tolerance to pollution to assess benthic macroinvertebrate response to stream conditions (Burton & Gerritsen, 2003). While visually assessing the condition of a stream habitat can be useful in many regards (Barbour et al, 1999), it is often an inadequate means of determining the effect of the agricultural pollution on aquatic life. Willey (2008) researched streams in the Shenandoah Valley and found that comparing quantifiable metrics like taxa richness and diversity is the best way to categorize water quality. An additional metric often employed in community studies, the Shannon Diversity Index, is used to calculate species diversity and evenness (Spellerberg & Fedor, 2003).

Effects of Landscape Variables

GIS analysis is integral to this study because it can quantify environmental factors that impact stream community composition by accounting for the effects of elevation, slope, impervious surface, road density, land use, and canopy cover. Elevation changes, average slope, amount of impervious surfaces, and road density within a particular watershed each impact water flow pathways (Barbour et al, 1999). As water and runoff tend to flow downhill and over impermeable surfaces, they accumulate at lower elevations. These are useful mapping tools, especially if agricultural lands exist at higher elevations than stream pathways. Runoff will carry pollutants more easily to streams downslope of farmland, which in turn is carried to other downstream locations, spreading nonpoint source pollution.

Taking land use into consideration has proven to be an effective means of predicting future impacts on aquatic systems. In agricultural areas, cattle pose a large threat to aquatic environments because they often have unrestricted access to streams from which they drink and cool off. Braccia and Voshell (2006) found that macroinvertebrate assemblage metrics are directly associated with cattle density near streams. Waste produced by cattle may directly or indirectly enter a stream and introduce harmful pollutants, such as nitrate, phosphorus, or ammonia. These compounds may foster or inhibit macroinvertebrate growth and diversity of community structure. Kyriakeas and Watzin (2006) determined that pollution from cattle was more detrimental to the stream system than runoff from corn fields. Thus, it is often important to make the distinction between cattle induced runoff or pesticide runoff from agricultural fields.

Another environmental metric associated with land use, canopy cover, can be analyzed with GIS technology. Braccia and Voshell (2007) found that the presence and cover of trees and shrubs within the buffer zone impact available sunlight, which then determines water temperature and contribution of coarse particulate organic matter. The addition of descending matter from trees and shrubs provides a variable food base for the macroinvertebrates. Voshell (2002) determined that light is the most important factor that dictates the proportion of food derived from decaying matter on land compared to plants growing within the stream; thus, invertebrate community composition, distribution, and abundance are established. Calculating percent canopy cover within a buffer zone provides an estimate of the degree to which the stream ecosystem is influenced by sunlight and falling organic matter.

Woody streamside riparian buffers are considered best management practices for the preservation of streams and biotic communities. By evaluating the primary functions of streams, Sweeney & Newbold (2014) found that a thirty meter minimum buffer width is necessary to inhibit and degrade the flow of pollutants. Therefore, while changes to grazing patterns may reduce the immediate effects of pollution, buffers are valuable tools to counteract several sources of nonpoint source pollution. Piechnik et al. (2012) used GIS aerial photo digitizing and calculation of drainage basin area to evaluate the effect of riparian buffers on pollutant interception. They found that the existing buffers only received runoff from a small percentage of areas heavily used by livestock. Thus, studies that use GIS to evaluate environmental characteristics of the surrounding land are necessary when planning future establishment of riparian buffer zones.

Importance of this Study

This study quantifies the effects of stream restoration through water quality assessment, and it examines the influences of surrounding environmental factors on water quality. As restoration projects mature, it is important to evaluate the water quality to measure improvements over time. Comparisons can then be made to assess if the quality of the stream improves over time. Such evaluations are important because over one billion dollars was spent nationally on stream restoration projects since 1990 (McDermond-Spies et al., 2014). Thus, researchers may determine if it is economically viable to support restoration projects over other forms of stream management.

Hypothesis and Predictions

The landowners participating in the CREP program have had their particular restoration strategies in place for various numbers of years; thus, the streams on their properties are likely to be at different stages of restoration. In particular, this study examines the temporal effects of restoration and the effects of the surrounding environment on water quality. We hypothesize that the length of time that the CREP program has been established has a positive effect on the water quality of a stream. Additionally, the characteristics of the landscape within the watershed will impact the water quality despite the current restoration status. Thus, GIS analysis is integral to the assessment of current and future land planning strategies. By evaluating characteristics of streams surrounded by agricultural lands, the effects of elevation, slope, impervious surface, land use, canopy cover, and riparian buffer size can be predicted and used to determine sustainable ways to maintain agriculture in the Shenandoah Valley.

We predict that the farms in which the CREP program have been in place for the greatest lengths of time will have better water quality than streams in which the CREP program was newly established. This will be quantified by analyzing taxa abundance, tolerance, richness, and diversity values with the Hilsenhoff Biotic Index (HBI), Virginia Stream Condition Index (VA-SCI), and the Shannon Diversity Index. We predict that, if water quality is improving, HBI levels will decrease and VA-SCI and Shannon Diversity Index values will increase. Additionally, agricultural land use upstream of the restoration zone will be correlated with poorer water quality, despite the presence of a riparian buffer. Likewise, greater amounts of forested land and canopy cover within a watershed should positively impact the water quality. We predict that various type of impervious surfaces, such as roads and urbanized areas will be correlated with poorer water quality. Lastly, slope, relief, and area of a watershed would also be expected to have a relationship with water quality, as they work together to influence water flow pathways.

Methods

Site Selection

All sites are located within the Shenandoah Valley, part of the Valley and Ridge physiographic province of Virginia. The Valley and Ridge province is primarily composed of sedimentary rocks, including sandstones, shales, and limestones. The long parallel ridges of the region create a trellis drainage pattern (Fichter and Baedke, 2000). In the Valley and Ridge, temperature decreases by an average of 6.4°C every 1,000 m increase in elevation. This region is in a rain shadow, and average yearly precipitation ranges from 850 mm to 1,300+ mm (Virginia Department of Conservation and Recreation, 2013).

In 2014, the Shenandoah Soil and Water Conservation District compiled a list that contained information of site locations, year in which restoration took place, and what type of restoration practice was used (fencing and/or vegetation buffer). From this list, land owners were contacted to assess stream accessibility and current condition (Appendix 1). Twelve farms were selected based on stream conditions and owner participation (Table 1), and a $1m^2$ sample was taken from a single riffle on each farm during the months of September and October in 2014 and 2015.

Sampling Methodology

Coordinates of sampling locations were recorded with a Trimble GeoXT GPS (Datum: *WGS 1984*). Riparian growth around stream was assessed visually by comparing height and density of growth relative to other streams (Table 1). Riffle abundance was assessed by the number of accessible riffles adequate for sampling. Kick nets were used to sample macroinvertebrates from riffles in an area of $1m^2$ (Figure 1). Rock scraping and feet shuffling methods were employed for one minute each to get the macroinvertebrates into the net. The kick net was laid on a field table for better visualization, and the macroinvertebrates were removed and preserved in 70% ethanol for transportation to the laboratory.

Table 1. Description of stream sampling sites. Riparian growth around stream was assessed visually by comparing height and density of growth relative to other streams. Riffle availability was assessed by the ease of accessing riffles adequate for sampling. Stream features are any additional characteristics that were observed during sampling.

Farm Number	Internal Sample Number	Year of Restoration	Sampling Date	Restoration Method	Stream Name	Riparian Growth Around Stream	Riffle Abundance	Stream Features
1	51	2002	9/20/2014	Riparian Buffer	Smith Creek	High	High	Pebbly and fast-flowing; Moderate disturbance from trucks crossing stream
2	52	2011	10/12/2014	Riparian Buffer and Fencing	Long Glade Creek	High	Moderate	Cattle fenced out; Stream runs underneath major roadway
3	53	2012	9/28/2014	Riparian Buffer	Brocks Creek	Moderate	High	Very wooded landscape
4	54	2007	10/18/2014	Riparian Buffer	Long Meadow	Moderate	Low	Downhill from a poultry farm; Very grassy stream bed
5	55	2013	10/19/2014	Riparian Buffer and Fencing	Smith Creek	Low	High	Water low at time of sampling
6	56	2006	9/6/2015	Riparian Buffer and Fencing	Smith Creek	High	High	Cattle fenced out of stream
7	57	2002	9/5/2015	Riparian Buffer and Fencing	Smith Creek	High	High	Cattle fenced out; many adult trees surrounding stream
8	58	2011	9/13/2015	Riparian Buffer and Fencing	Joes Creek	Moderate	High	Cattle fenced out
9	60	2009	9/20/2015	Riparian Buffer	Shoemaker River	High	High	Pebbly and fast-flowing
10	61	2001	9/26/2015	Riparian Buffer and Fencing	Big Spring	High	High	Cattle fenced out
11	62	2007	10/10/2015	Riparian Buffer and Fencing	Cub Run	High	High	Very wooded landscape
12	64	2014	10/15/2015	Riparian Buffer and Fencing	Bennett Run	Low	High	Cattle fenced out nearby

Classification of macroinvertebrates took place in the laboratory. Each sample was spread onto a tray divided into twelve equally sized quadrants (Figure 2). A twelve sided die was used as a random number generator to select a subsample from a tray with twelve divisions. Each side of the die corresponded to a section on the tray, and all organisms within that section were subsampled. For adequate statistical power, at least 200 organisms were subsampled for identification, and the number of remaining macroinvertebrates were counted. A dissecting microscope was used to identify all macroinvertebrates to the family level (Voshell, 2002 and Benthic macroinvertebrate key, 1995). Family level identifications were employed because of a greater level of precision between the samples, expertise of undergraduate researchers, and time available for identifications. The counts of each family level classification were imported into an Excel spreadsheet that calculated the macroinvertebrate metrics: HBI, VA-SCI, and Shannon Diversity Index.

Figure 1. Example of kicknet sampling in a riffle at one of the sampling locations.

Figure 2. Randomized subsampling of macroinvertebrates collected at each sampling location.

GIS Analysis

ESRI software (ArcGIS Version 10.3) was used to look at the influence of slope, impervious surface, road density, land use, canopy cover, relief, and area on the stream sampling locations. Coordinates of the sampling locations taken with the GPS unit were imported into ArcMap. Each sampling site was used as the pour point to calculate the area of the associated watershed. Flow direction and flow accumulation layers (*"Fdr_proj"* and *"Fac_proj"*) were used to construct a flow path using the Watershed tool that delineates the watershed draining into the sampling site (Table 2). From the creation of watershed boundaries and conversion to a shapefile using the Raster to Polygon tool, the total area of the watershed was determined. The watershed shapefile was used as a mask in the Clip tool to extract values within the watersheds for the variables.

An elevation raster (*"Elevation_cm"*) was used to determine relief (highest elevation minus lowest elevation) and average slope, using the Slope tool, within each watershed. An impervious surface raster (*"NLCD_2011_impervious_2011_ edition_2014"*) was used to calculate the percentage of cells in each watershed that are impervious and do not drain water. A roads layer (*"Roads_2015"*) was used to determine the total length of roads divided by the total area of each watershed. Each watershed layer was also used as a mask to extract values from the land use ("*NLCD_2011_landcover_2011_ edition_2014*") and canopy cover ("*NLCD_2011_USFS_tree_canopy_2011_edition*") rasters. From these layers, the percentage of cells categorized as agricultural land, forested land, or urbanized land was calculated. Additionally, the percentage of each cell that was considered under canopy cover were averaged together to determine the mean canopy cover percentage in each watershed (Table 2).

The streams layer (*"R02_NHDFlowline_proj")* at a scale of 1:24,000 was clipped to the area of each watershed, and a buffer zone was created around the streams in each of the watersheds using the Buffer tool (Table 2). A buffer width of 100 meters was chosen as a model to represent riparian vegetation surrounding the stream at each sampling site. Each of the above landscape calculations was repeated within the buffer surrounding the stream to determine if there was a difference between the watershed as a whole and the surrounding buffer. A complete list of the macroinvertebrate and landscape metrics is shown in Appendix 2.

Table 2. Input layers and sources used to make calculations in ArcGIS.

GIS Input Layer Names	Type of Data	Resolution	Description	Source
NED "Elevation_cm"	Raster	30 x 30 m	Elevation of each cell in cm	USGS: <http://nationalmap.gov/ elevation.html>
NHDPlusFdrFac02a "Fdr_proj"	Raster	30 x 30 m	Flow direction raster shows the direction that water flows between cells	EPA: <https://www.epa.gov/ waterdata/nhdplus-national-hydrography-dataset-plus>
NHDPlusFdrFac02a "Fac_proj"	Raster	30 x 30 m	Flow accumulation raster shows total number of cells draining into each cell	EPA: <https://www.epa.gov /waterdata/nhdplus-national-hydrography-dataset-plus>
R02_NHDFlowline_proj	Shapefile	n/a	Hydrography provides a layer with stream lines data	USGS: <http://nhd.usgs.gov/data. html>
NLCD_2011_USFS_tree_canopy_2011_edition	Raster	30 x 30 m	Tree canopy cover percentage in each cell	USGS: <http://www.mrlc.gov/nlcd 11_data.php>
NLCD_2011_landcover_2011_ edition_2014	Raster	30 x 30 m	Land cover classification for each cell	USGS: <http://www.mrlc.gov/nlcd 11_data.php>
NLCD_2011_impervious_2011_ edition_2014	Raster	30 x 30 m	Impervious surface percentage in each cell	USGS: <http://www.mrlc.gov/nlcd 11_data.php>
Roads_2015	Shapefile	n/a	Layer with roads line data	United States Census Bureau (MAF/Tiger): <https://www.census.gov/ geo/maps-data/data/tiger-line.html>

Statistical Analyses

SPSS (Version 23) was utilized to explore the data for normality and outliers and to determine potential correlations between the variables. A bivariate correlation analysis was performed to determine if both macroinvertebrate and landscape variables overlapped in their predictive power. The watershed data and the buffer data were analyzed separately using individual and multiple linear regressions. The independent variables included length of time in which the restoration project has been implemented, as well as the landscape variables analyzed with GIS: area, relief, normalized relief, average slope, impervious surface, road density, land use, and canopy cover. The following macroinvertebrate metrics were assessed as dependent variables: HBI, VA-SCI, Shannon Diversity Index, and total abundance. In the individual and multiple linear regressions, the “Enter” method was used to control the input of variables. From the individual and multiple linear regressions, significance values and adjusted R^2 values were obtained to determine if any of the landscape variables or sets of variables had statistically significant predictive power on water quality metrics. The optimal models were selected based on the combination of predictors that produced the highest adjusted R^2 value.

Results

Macroinvertebrate Metrics

Following the identification and counting of macroinvertebrate families, four water quality metrics were calculated: HBI, VA-SCI, Shannon Diversity Index, and total abundance. There were no farms with the best water quality values for more than one metric (Appendix 2). Farm 9 had the best HBI score (3.7), farms 6 and 7 had the best VA-SCI scores (66), farm 6 had the highest Shannon Index (2.36), and farm 5 had the highest abundance (958 macroinvertebrates/m^2). Farm 4 had the worst water quality for HBI (8.0), VA-SCI (19), and Shannon Index (0.10). Farm 12 had the lowest abundance (71 macroinvertebrates/m^2). Scatterplots of the relationship between time since restoration and the macroinvertebrate metrics showed that Farm 4 was an outlier for three of the four metrics (Figure 3). The stream on Farm 4 was most likely a spring creek with atypical water chemistry. This sample was unusual compared to the other sites, so it was excluded from further analysis.

After Farm 4 was removed, macroinvertebrate and landscape metric distributions were analyzed. The macroinvertebrate metrics, HBI, VA-SCI, Shannon Diversity Index, and total abundance were all normally distributed, with HBI possessing an outlier on the high end (Figure 4). Based on the Biosurvey Category system of the VA-SCI, all but two farms (Farm 6 and 7) were classified as “Impaired” (Figure 4, Appendix 2).

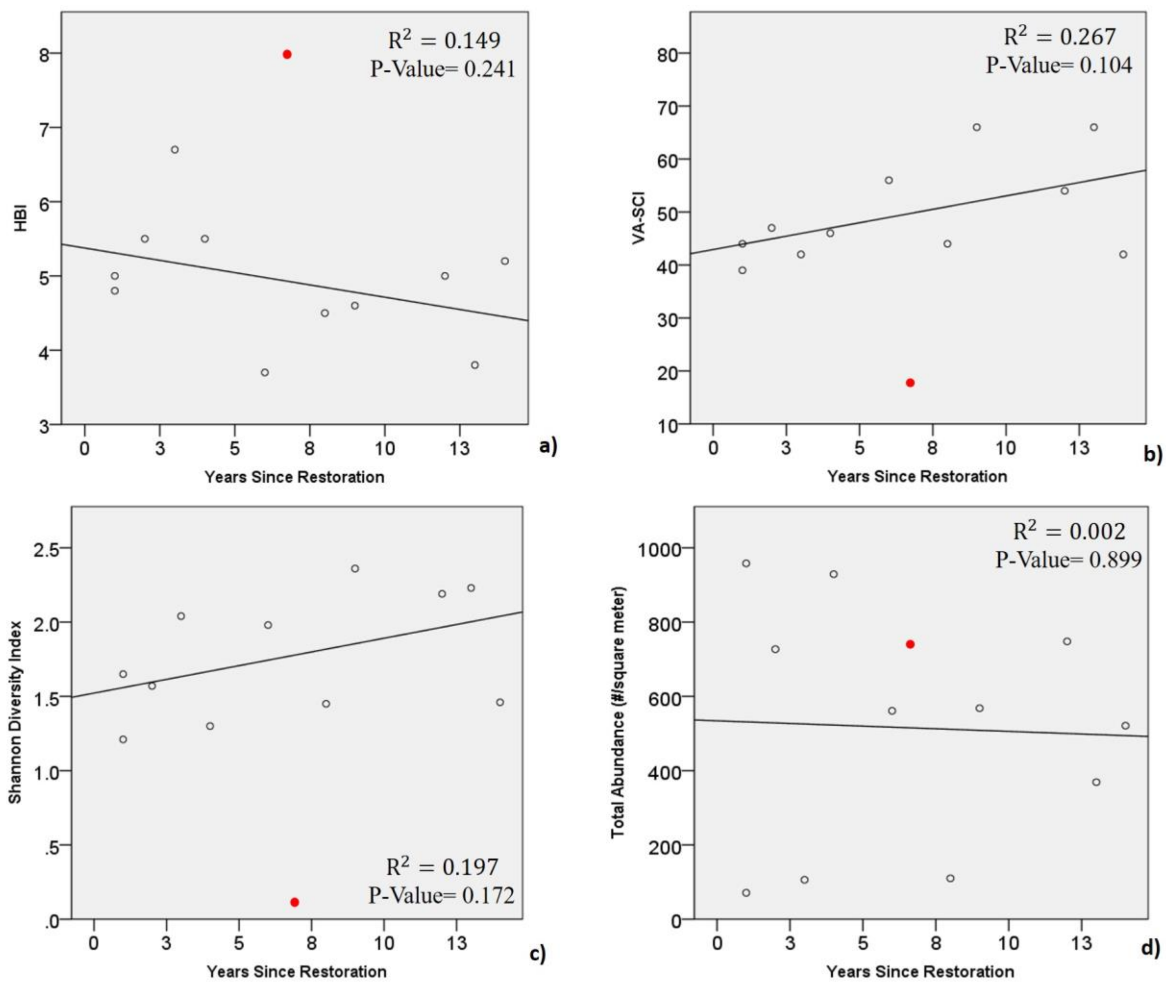


Figure 3. Scatterplots showing results of linear regressions of the number of years since restoration versus each of the water quality metrics for the 11 usable samples: a) HBI, b) VA-SCI, c) Shannon Diversity Index, and d) total abundance. Farm 4 was not included in the regressions but was overlaid on top of the scatterplots (red circle) to illustrate it as an outlier.

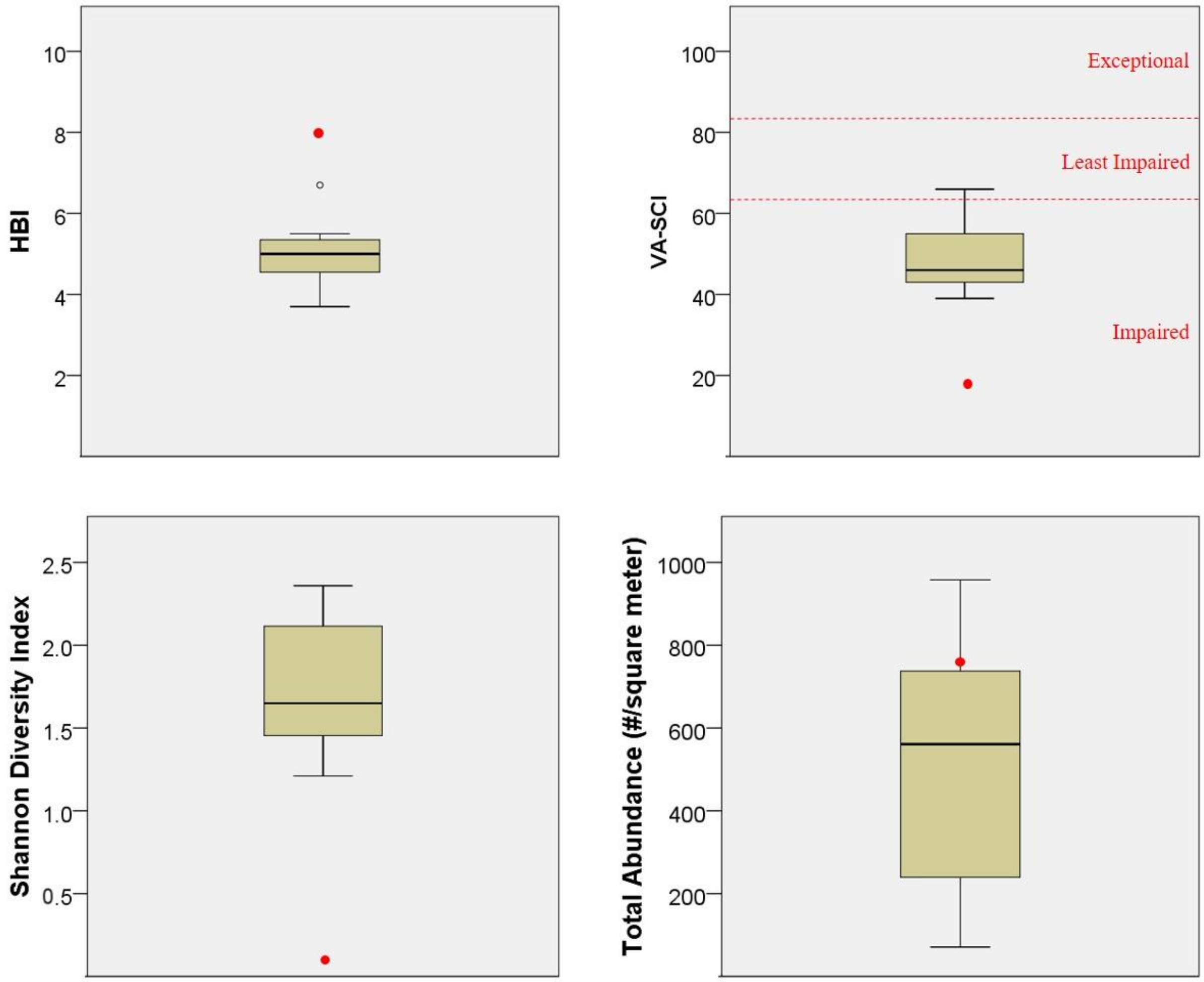


Figure 4. Box plots showing the distribution of the macroinvertebrate metrics with the outlier farm (Farm 4) removed. A VA-SCI score below 61.3 categorizes water as "Impaired." A score between 61.4- and 81.6 is "Least Impaired." A score of 81.7-100 is considered "Exceptional." Farm 4 was not included in the box plots but was overlaid (red circle) to illustrate it as an outlier.

Landscape Metrics

Because all of the watersheds were located within the Shenandoah Valley, there was some degree of overlap between their areas. Many watersheds were nested within larger watersheds (Figure 5). Watershed area ranged from approximately 540.9 hectares at the lowest to 47,204.1 hectares at the largest (Figure 5, Appendix 2). Many of the watersheds possessed extensive tributary systems while others had relatively few branch points (Figures 6-17, Appendix 2).

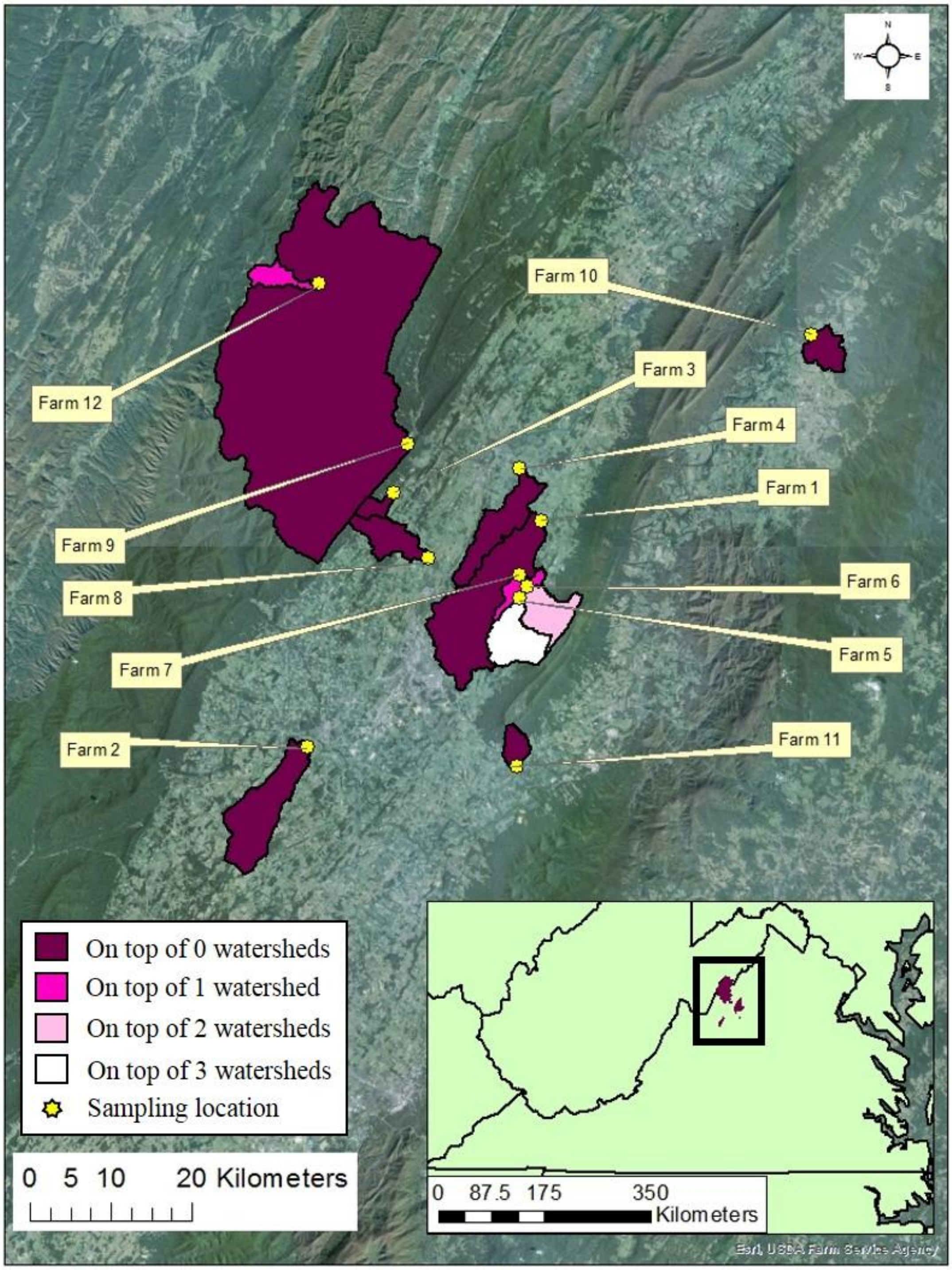


Figure 5. All watersheds sampled, their relative locations, and overlap. Increasingly lighter shades indicate watersheds combined within another watershed.

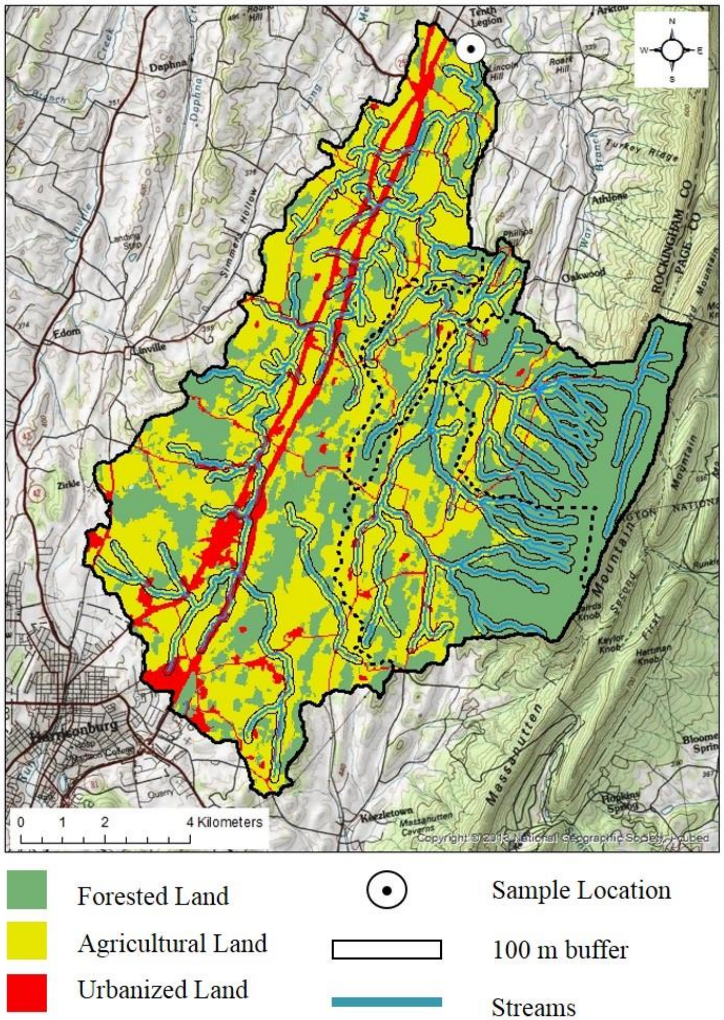


Figure 6. Farm 1 watershed and 100 m buffer surrounding the stream. Farm 1 contains Farms 7, 6, and 5 (dashed lines).

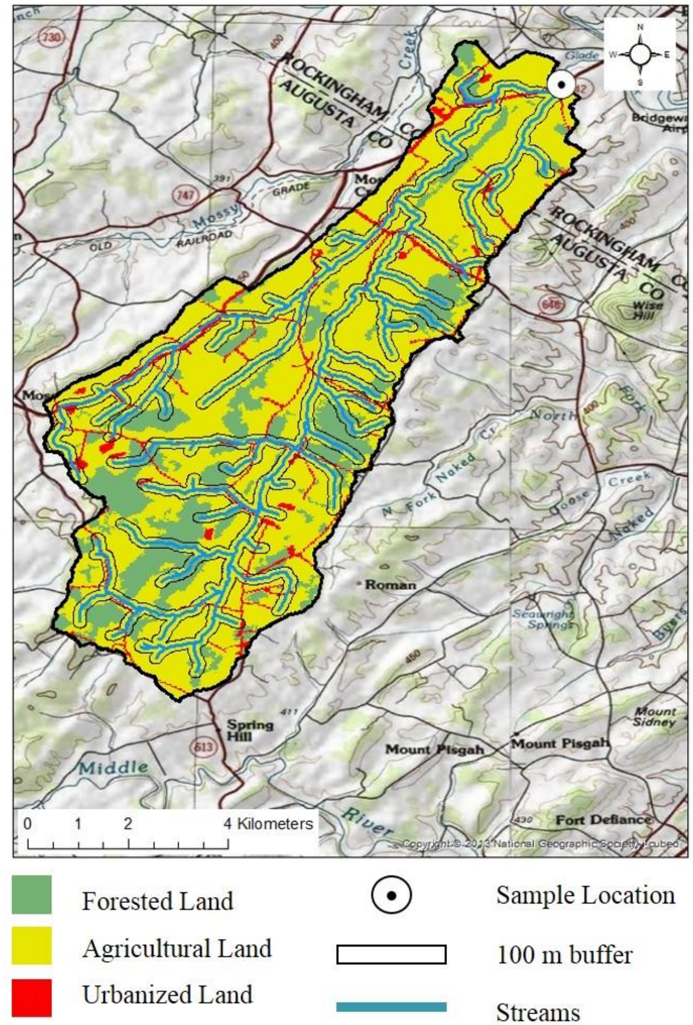
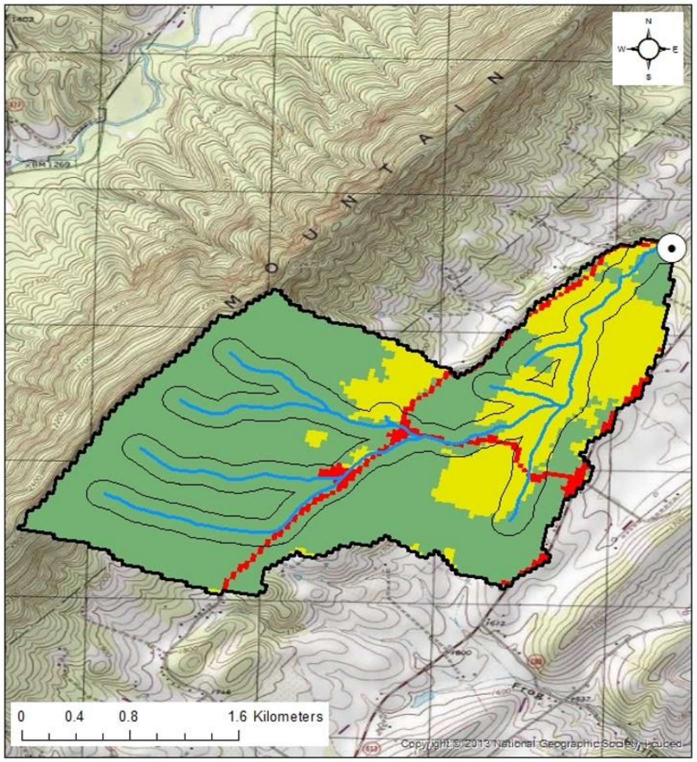
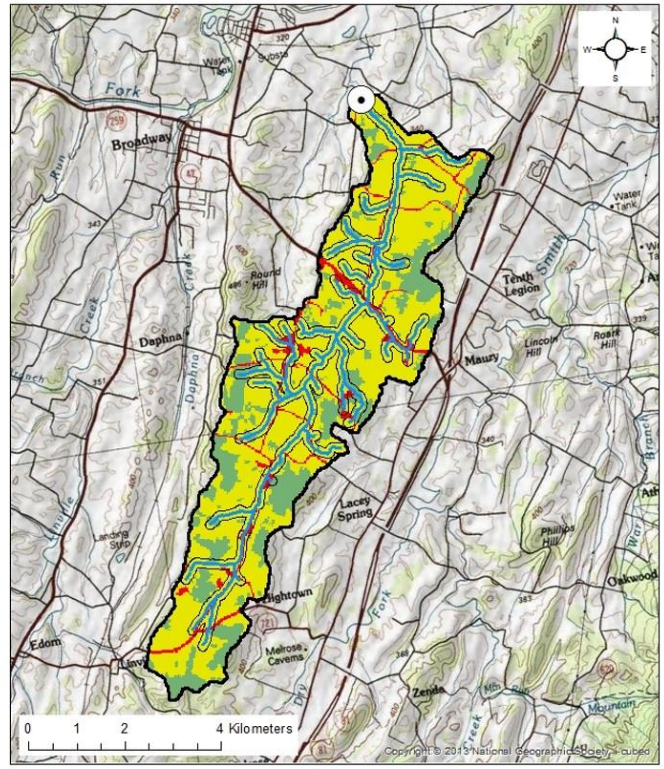


Figure 7. Farm 2 watershed and 100 m buffer surrounding the stream.



Forested Land
Agricultural Land
Urbanized Land
Sample Location
100 m buffer
Streams

Figure 8. Farm 3 watershed and 100 m buffer surrounding the stream.



Forested Land
Agricultural Land
Urbanized Land
Sample Location
100 m buffer
Streams

Figure 9. Farm 4 watershed and 100 m buffer surrounding the stream.

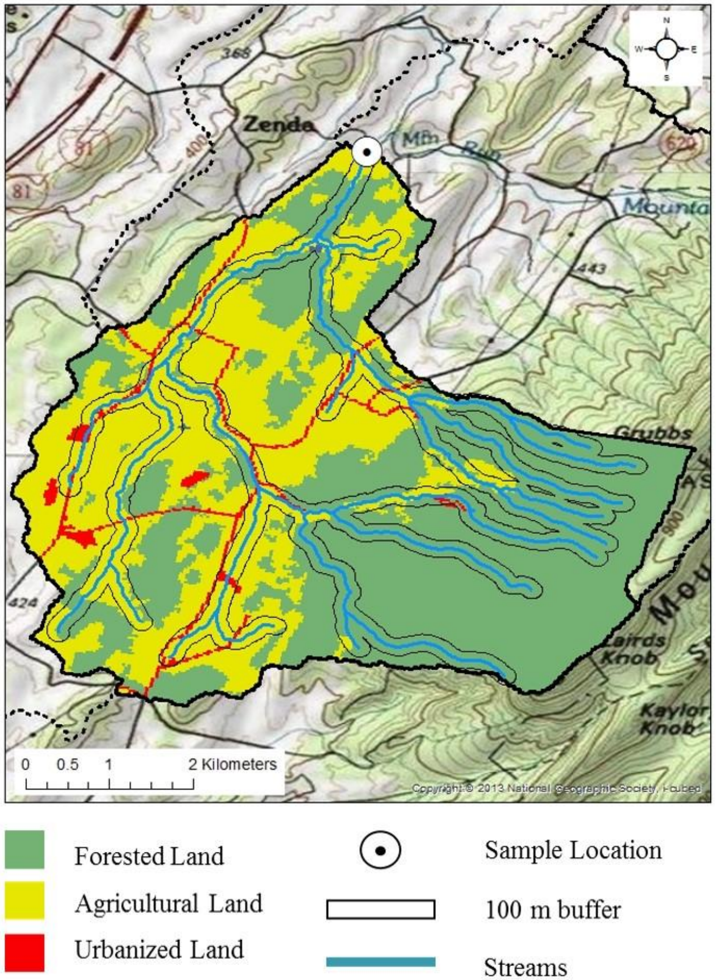


Figure 10. Farm 5 watershed and 100 m buffer surrounding the stream. Farm 5 is contained in Farms 6, 7, and 1 (dashed lines).

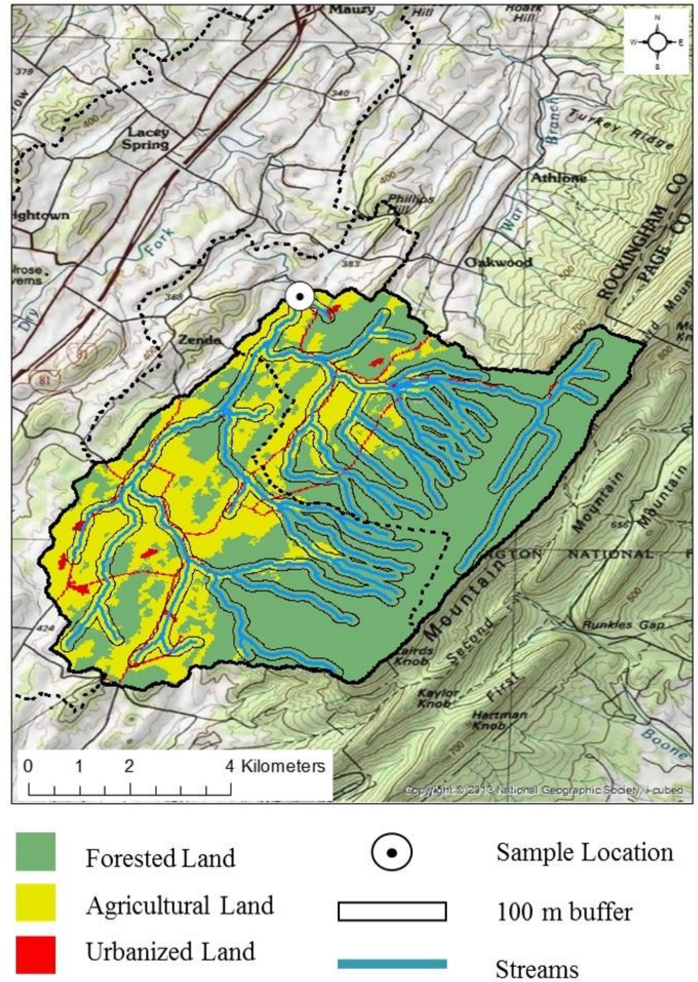


Figure 11. Farm 6 watershed and 100 m buffer surrounding the stream. Farm 6 is contains Farm 5 and is contained by Farms 7 and 1 (dashed lines).

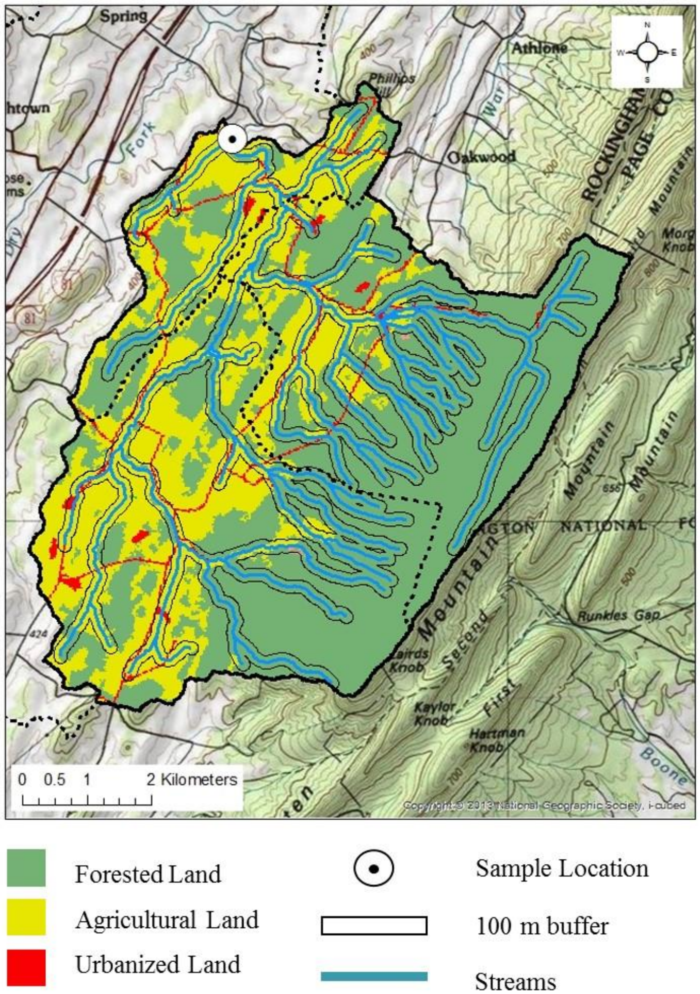


Figure 12. Farm 7 watershed and 100 m buffer surrounding the stream. Farm 7 contains Farms 6 and 5 and is contained by Farm 1 (dashed lines).

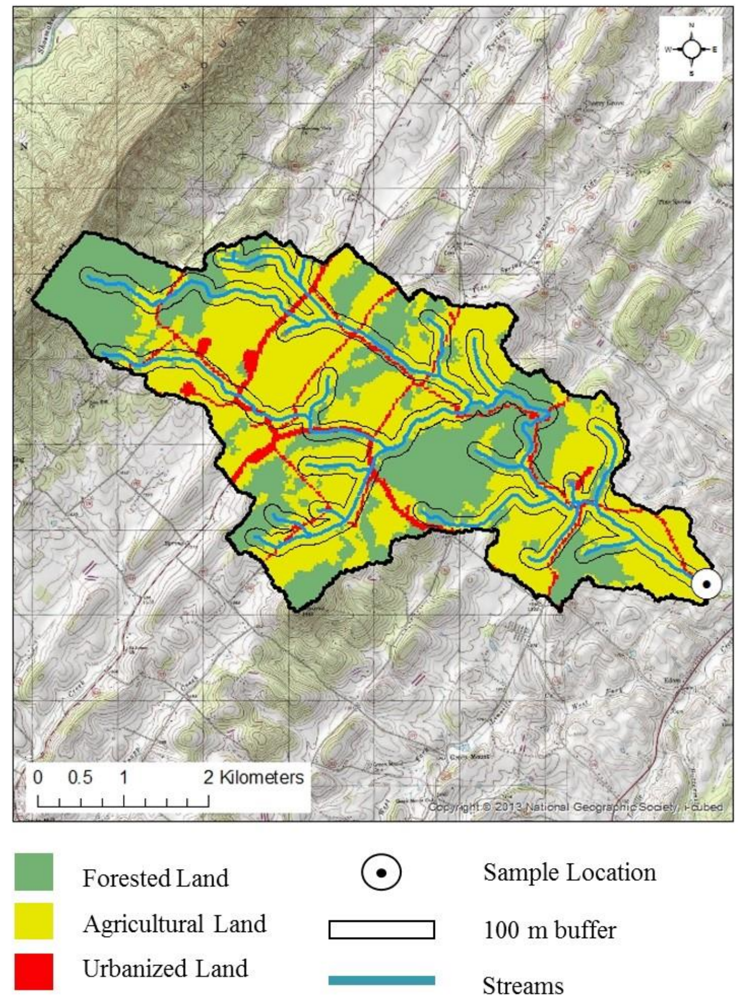


Figure 13. Farm 8 watershed and 100 m buffer surrounding the stream.

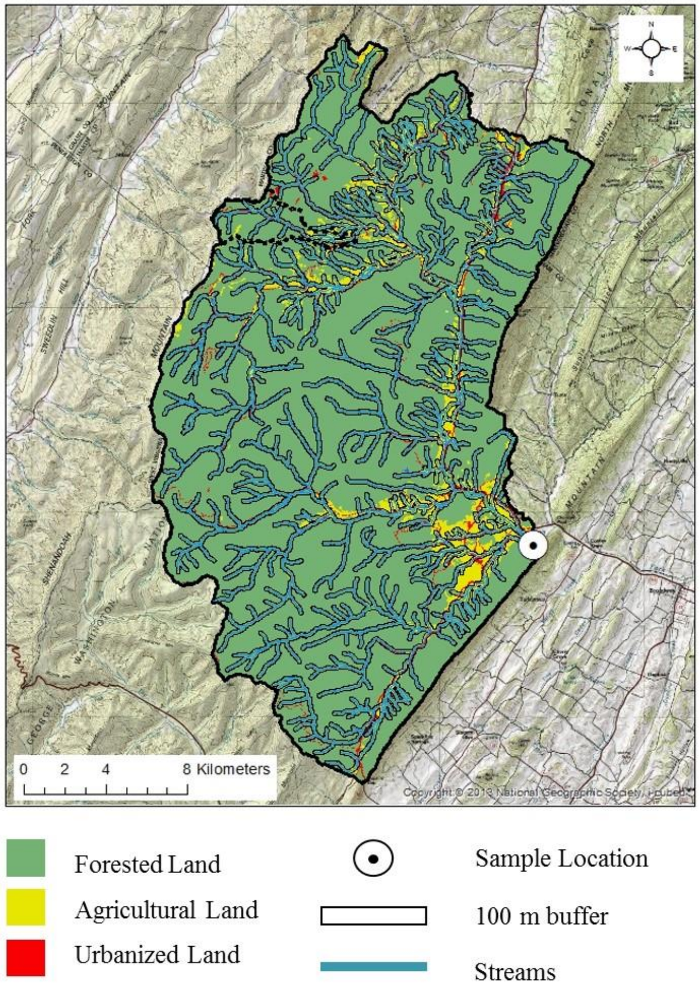


Figure 14. Farm 9 watershed and 100 m buffer surrounding the stream. Farm 9 contains Farm 12 (dashed lines).

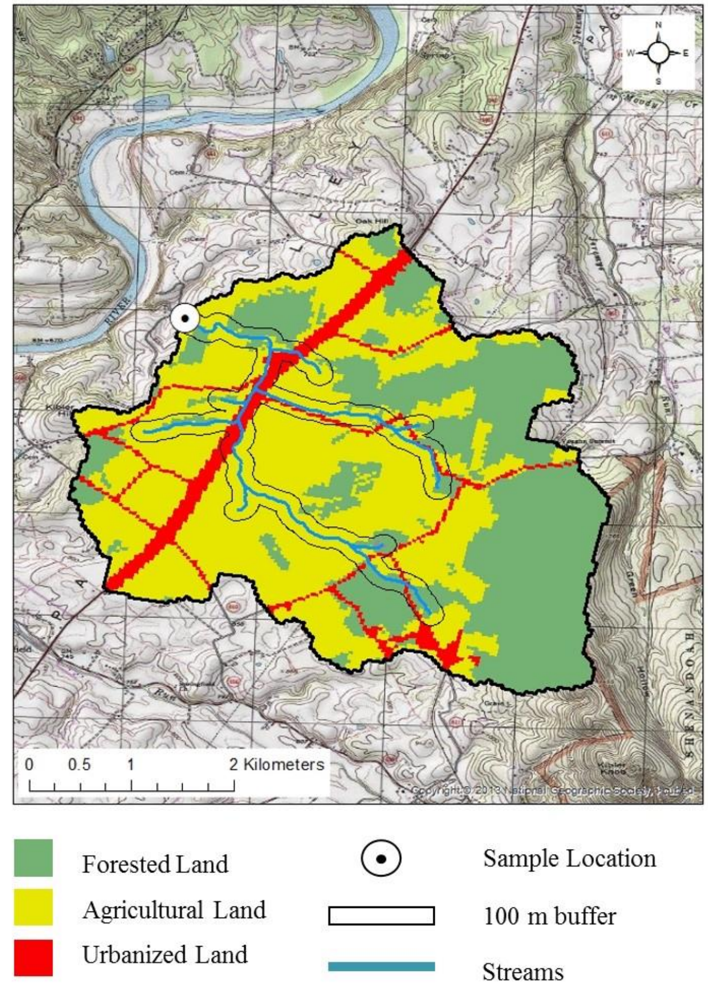


Figure 15. Farm 10 watershed and 100 m buffer surrounding the stream.

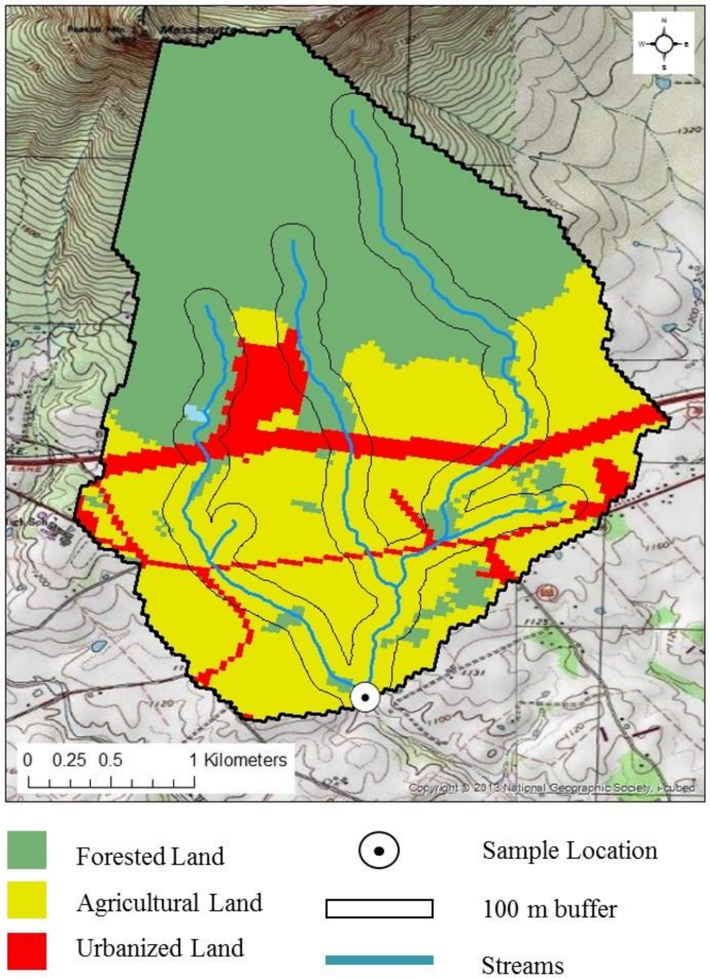


Figure 16. Farm 11 watershed and 100 m buffer surrounding the stream.

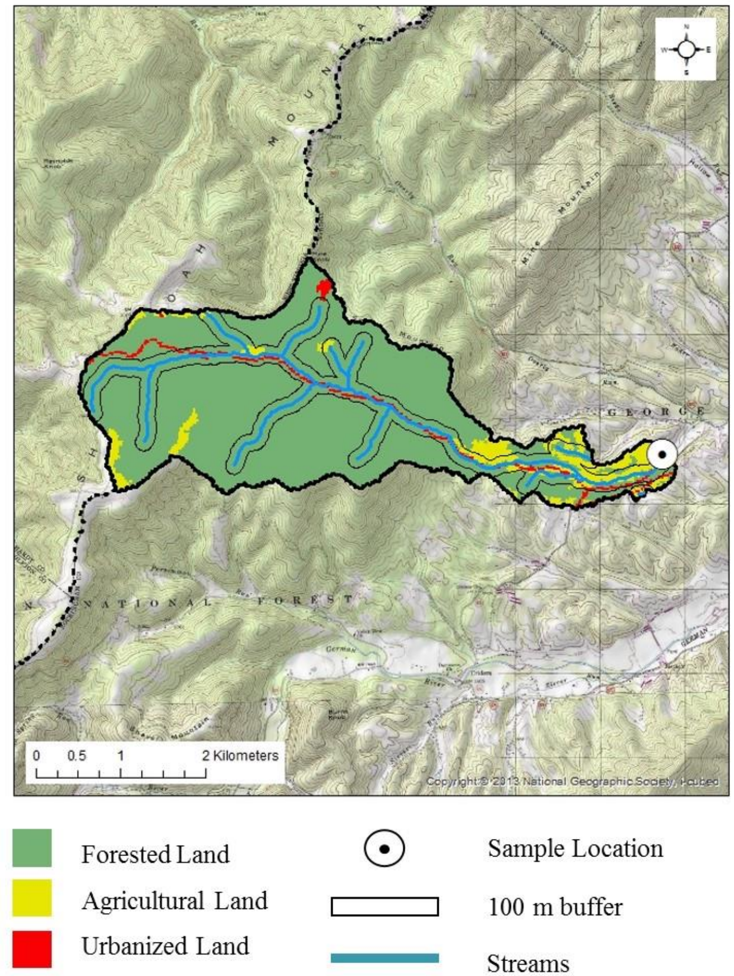


Figure 17. Farm 12 watershed and 100 m buffer surrounding the stream. Farm 12 is contained by Farm 9 (dashed lines).

From the watershed delineation and creation of stream buffers in ArcMap, various landscape variables were calculated both within the entire watershed and restricted to within the buffer. Most landscape metrics were evenly distributed (Figures 18 and 19); however, impervious surface data in the watersheds were skewed (Figure 18a). The average percentage of impervious surface among all watersheds and buffers was not above 3%. Road density was also very low among the watersheds, peaking at approximately 5 km roads per square kilometer. Percent of urbanized land was consistently less than ten percent in each watershed (Appendix 2). Thus, the watersheds sampled had relatively low amounts paved roads and developments compared to surrounding areas.

Average slope in both the watersheds and buffers did not rise above 17%. Relief greatly varied among the watersheds, ranging from a change of 176 meters (Farm 2) to almost 900 meters (Farm 9) (Appendix 2). Within both the watersheds and the buffers the percent of agricultural and forested land comprised the majority of land use. The percent of agricultural land within the watersheds reached almost 75% at the highest (Farm 2), and the percent of forested land within the watersheds reached almost 90% (Farm 9). Average canopy cover greatly varied in both the watersheds and buffers (Appendix 2) and appeared to be related to land use percentages.

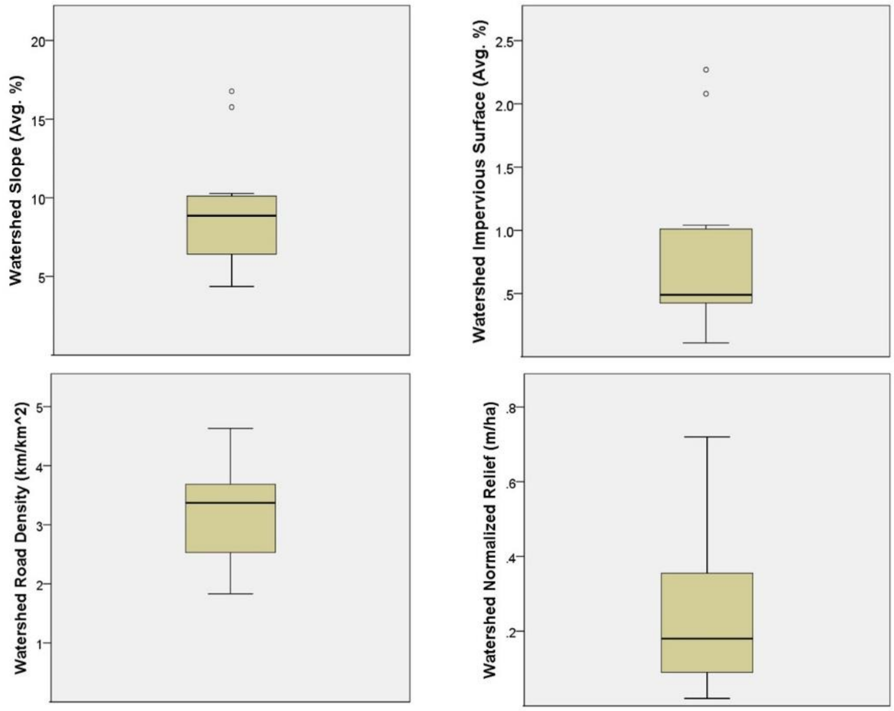


Figure 18a. Box plots showing the distribution of values among the watersheds for the following variables: slope, impervious surface, road density, and normalized relief.

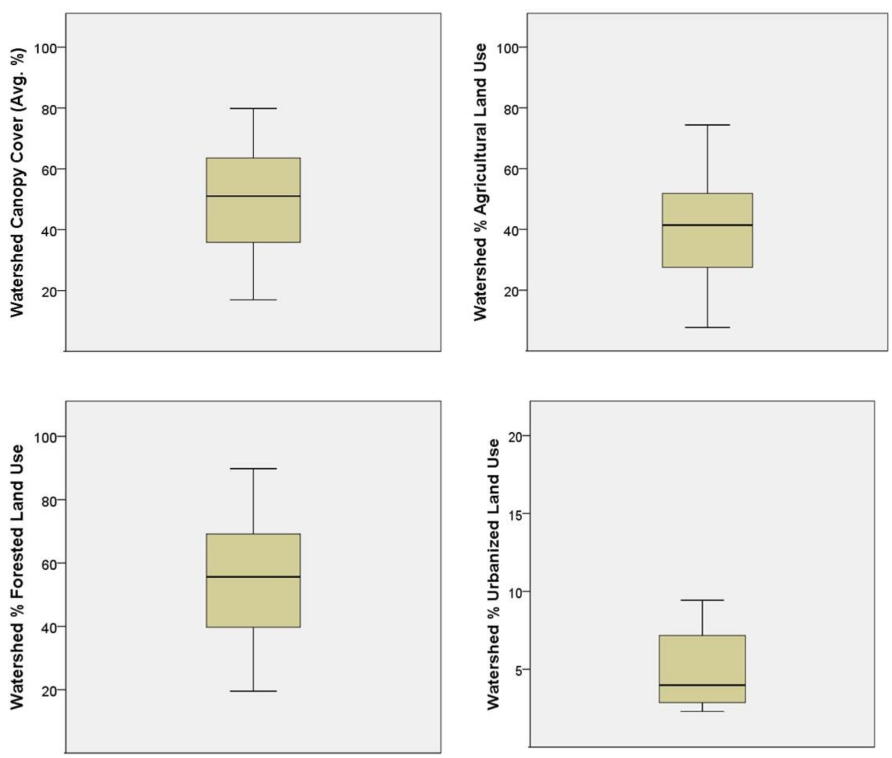


Figure 18b. Box plots showing the distribution of values among the watersheds for the following variables: canopy cover, agricultural land use, forested land use, and urbanized land use.

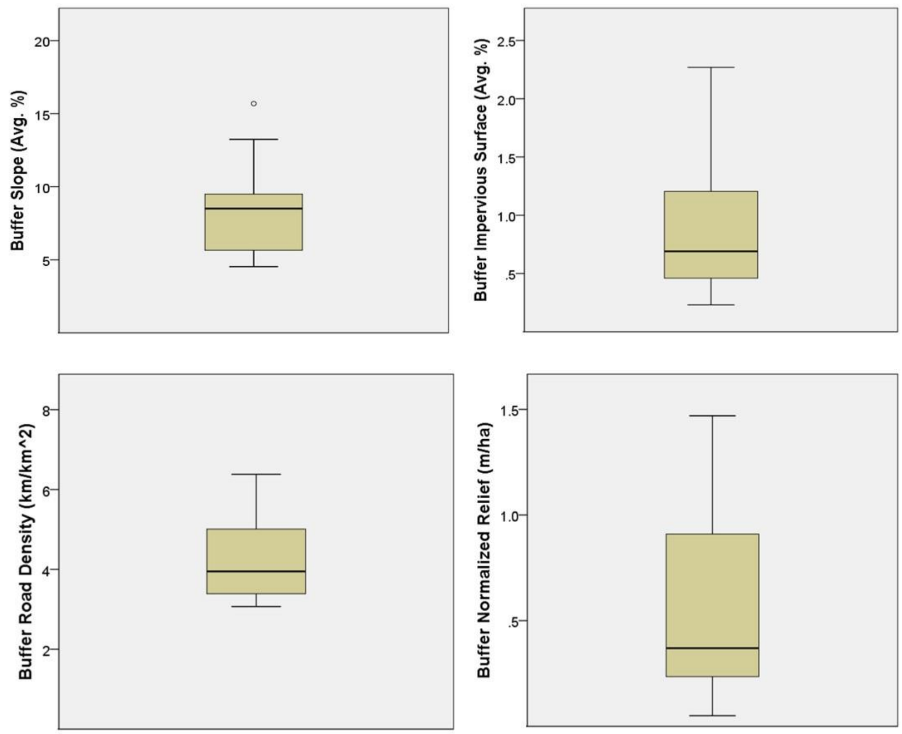


Figure 19a. Box plots showing the distribution of values among the buffers for the following variables: slope, impervious surface, road density, and normalized relief.

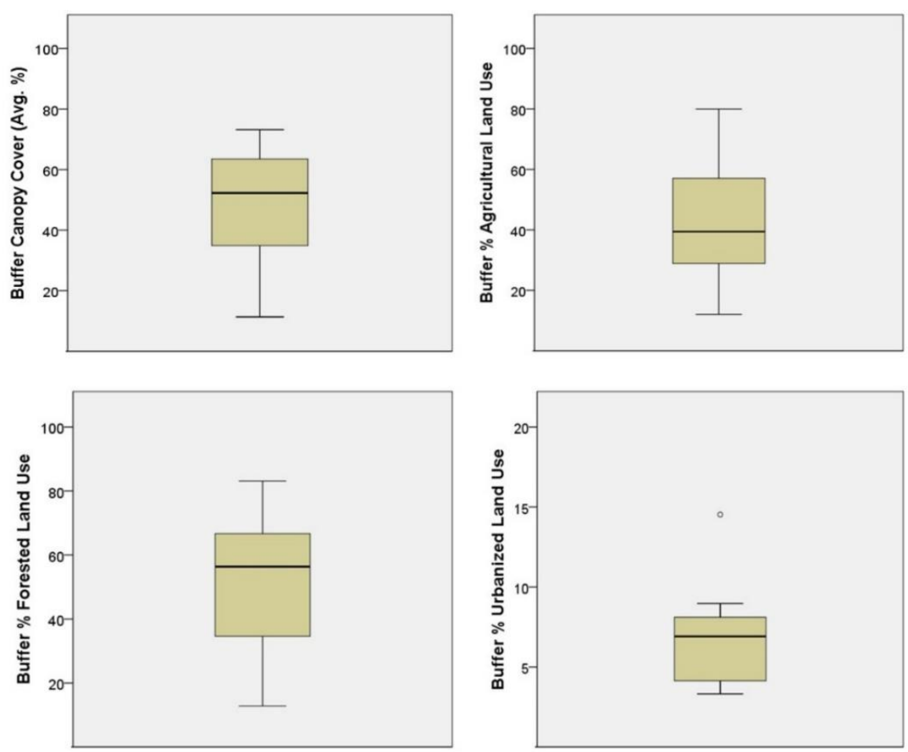


Figure 19b. Box plots showing the distribution of values among the buffers for the following variables: canopy cover, agricultural land use, forested land use, and urbanized land use.

Figures 20-22 illustrate representative GIS output of landscape variables measured: relief, percent impervious surface, road density, percent canopy cover, and average slope. Farm 9 was chosen to represent these variables, as it was the largest watershed surveyed and often produced landscape metric measurements that were at the extreme end compared to the other farms sampled (Figures 20-22, Appendix 2). Land cover (% agriculture, % forest, and % urban) are shown in Figures 6-17. Visual interpretation of landscape metrics in GIS for both the watersheds and buffers helped make comparisons to determine potential patterns among the landscape variables between the farms.

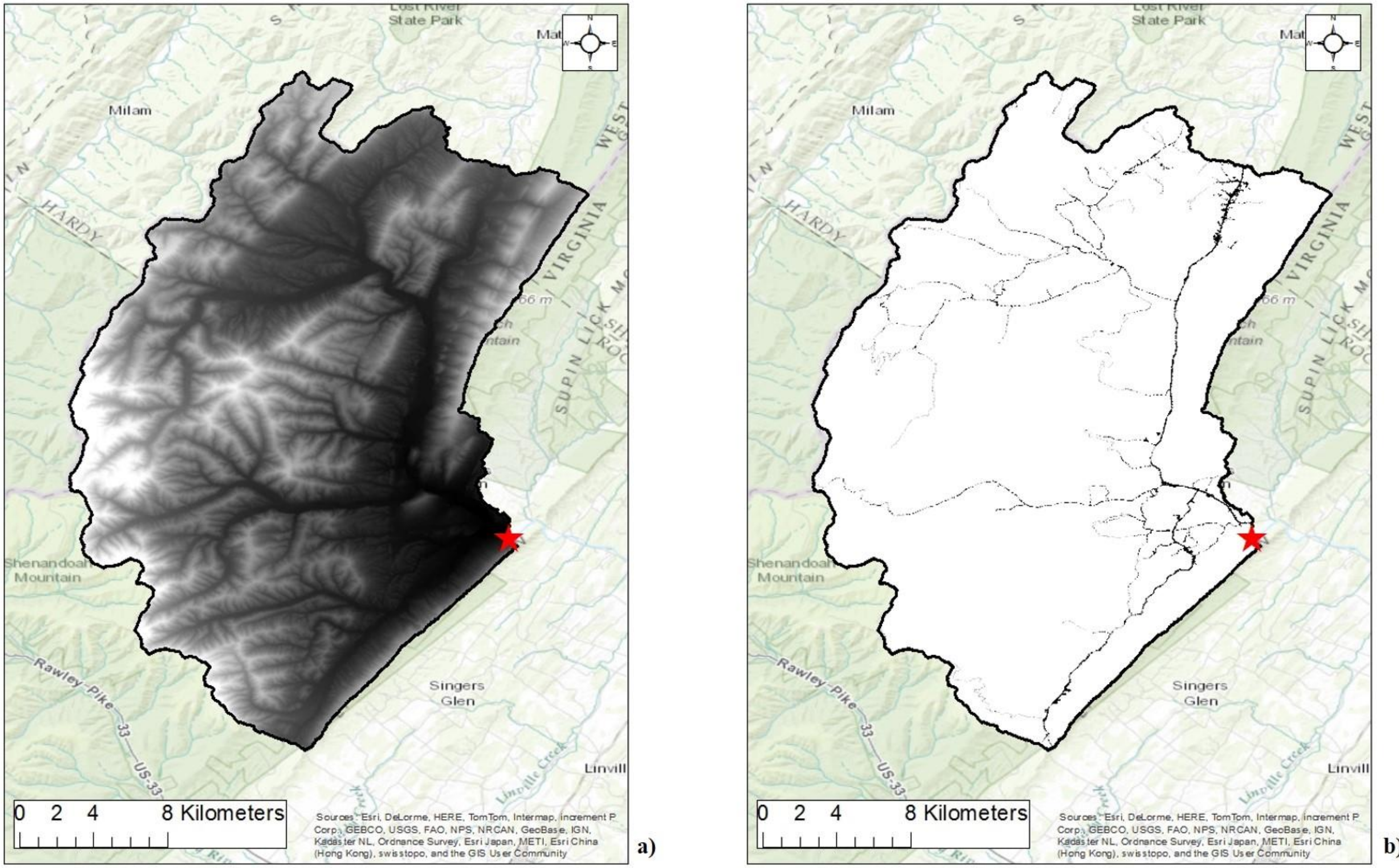


Figure 20. Relief and percentage of impervious surface for Farm 9. a) Overall relief (898 meters) was calculated from an elevation raster. Lighter colors represent higher elevations while darker colors represent lower elevations. b) Average percentage of impervious surface was 0.19%. Lighter colors represent a lower percentage of impervious surface while darker colors represent a higher percentage of impervious surface. The red star indicates the sampling location.

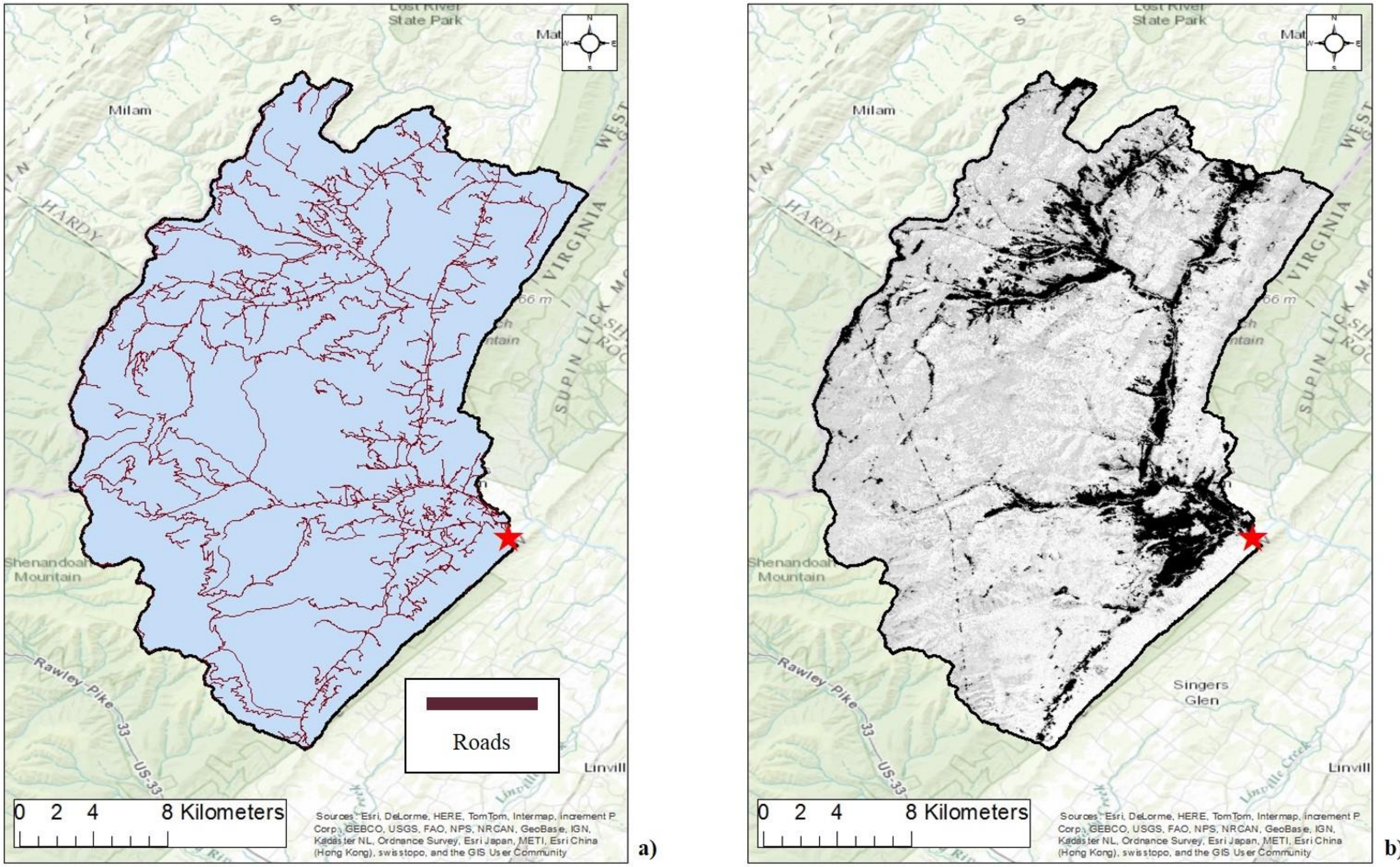


Figure 21. Road density and percentage of canopy cover for Farm 9. a) Road density was 1.83 km/km^2. b) Average percentage of canopy cover was 79.9%. Lighter colors represent a higher percentage of canopy cover while darker colors represent a lower percentage of canopy cover. The red star indicates the sampling location.

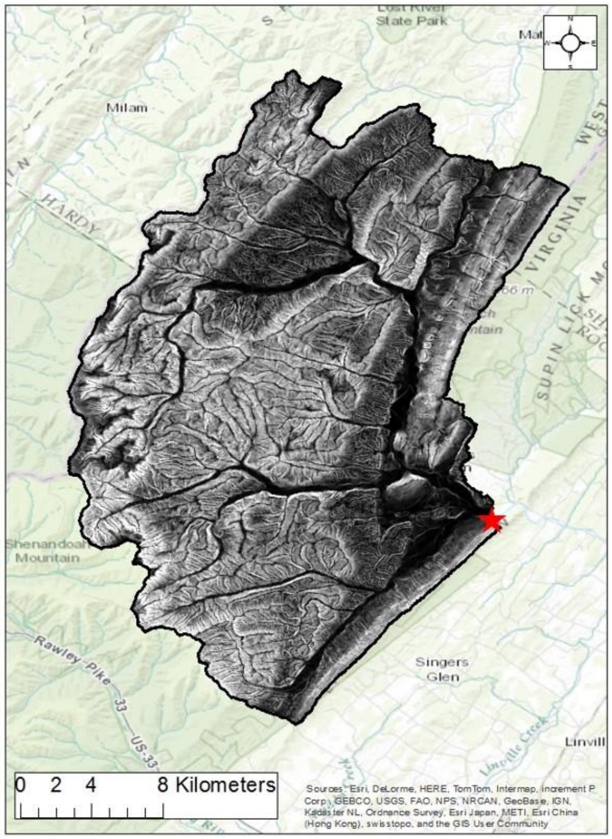


Figure 22. Slope for Farm 9. Average slope was 15.8%. Lighter colors represent greater percentages while darker colors represent lower percentages. The red star indicates the sampling location.

Regression Analysis

Single variable regression analyses showed that time since restoration did not significantly predict any of the metrics at the 0.10 level (Table 3). Single variable linear regressions were also performed for the landscape metrics. HBI was predicted by canopy cover, agricultural land use, forested land use, and relief ($p<0.10$) (Table 3). VA-SCI was only predicted by relief, and Shannon Diversity Index was only predicted by normalized relief. There were slight differences between the metrics with use of the watersheds versus the buffers;

however, overall, only a few significant relationships existed among the single variable regressions (Table 3).

Table 3. Adjusted R^2 values of the single variable regressions. Significant relationships at the 0.10 level are bolded.

	HBI	**VA-SCI**	**Shannon Diversity Index**	**Total Abundance**
Restoration Time	0.054	0.186	0.108	-0.109
Watershed				
Slope	**0.214**	-0.021	-0.082	-0.097
Impervious Surface	-0.085	-0.069	-0.110	-0.092
Canopy Cover	**0.444**	0.044	-0.097	-0.111
Agriculture %	**0.418**	0.004	-0.101	-0.106
Forest %	**0.397**	0.021	-0.096	-0.109
Urban %	0.022	0.061	-0.053	-0.092
Road Density	0.146	0.138	0.141	-0.111
Relief	**0.608**	**0.276**	0.003	-0.003
Area	0.156	0.008	0.015	-0.102
Normalized Relief	-0.110	0.052	**0.234**	-0.078
Buffer				
Slope	0.156	-0.019	-0.070	-0.101
Impervious Surface	-0.078	0.042	-0.031	-0.081
Canopy Cover	**0.494**	0.136	-0.066	-0.109
Agriculture %	**0.460**	0.074	-0.076	-0.111
Forest %	**0.435**	0.112	-0.055	-0.111
Urban %	0.030	**0.214**	0.095	-0.088
Road Density	0.011	**0.269**	**0.335**	-0.093
Relief	**0.436**	**0.325**	0.103	-0.024
Area	0.159	0.018	0.021	-0.104
Normalized Relief	-0.108	0.061	**0.209**	-0.074

A bivariate correlation test was conducted to determine if any landscape variables predicted the same effect before performing a multiple linear regression. The correlation test revealed which landscape variables were significantly correlated with one another ($p<0.05$) (Table 4). Because several of these variables were strongly correlated with one another, there were not many combinations available to incorporate into the model.

Table 4. List of significantly correlated variables (p-value > 0.05). Plus and minus signs indicate direction of correlation. Accordingly, if a pair was correlated, the variables were not used together as predictors in the multiple regression models.

Watershed	
Years Since Restoration	none
Watershed Slope	impervious surface (-), canopy cover (+), % agriculture (-), % forest (+), % urban (-), road density (-)
Impervious Surface	slope (-), canopy cover (-), % urban (+), road density (+)
Canopy Cover	slope (+), impervious surface (-), % agriculture (-), % forest (+), % urban (-)
% Agriculture	slope (-), canopy cover (-), % forest (-), % urban (+)
%Forest	slope (+), canopy cover (+), % agriculture (-), % urban (-)
%Urban	slope (-), impervious surface (+), canopy cover (-), % agriculture (+), % forest (-), road density (+)
Road Density	slope (-), impervious surface (+), % urban (+)
Relief	area (+)
Area	relief (+)
Normalized Relief	none
Buffer	
Years Since Restoration	none
Stream Channel Slope	impervious surface (-), canopy cover (+), % agriculture (-), % forest (+), relief (+)
Impervious Surface	slope (-), % forest (-), % urban (+), relief (-)
Canopy Cover	slope (+), % agriculture (-), % forest (+), % urban (-), relief (+)
% Agriculture	slope (-), canopy cover (-), % forest (-), relief (-)
%Forest	slope (+), impervious surface (-), canopy cover (+), % agriculture (-), % urban (-), relief (+)
%Urban	impervious surface (+), canopy cover (-), % forest (-), relief (-)
Road Density	normalized relief (+)
Relief	slope (+), impervious surface (-), canopy cover (+), % agriculture (-), % forest (+), % urban (-), area (+)
Area	relief (+)
Normalized Relief	road density (+)

From these results, two or three variables that were not significantly correlated were combined at a time using multiple linear regression to determine the best set of predictors for each water quality metric. Two of the macroinvertebrate metrics, HBI and VA-SCI, yielded statistically significant ($p<0.05$) sets of predictor variables. HBI could be predicted by time since restoration and forested land use within both the watershed (R^2=0.712) and buffer (R^2=0.748). VA-SCI could be predicted by time since restoration and impervious surface in the buffer (R^2=0.777) (Table 5). These sets of predictor variables strongly predicted their respective metrics ($p<0.01$). While the other sets of predictor variables were not significant at the 0.05 level, VA-SCI in the watersheds was predicted by time, normalized relief, and percent canopy cover at the 0.10 level (R^2=0.428) (Table 5). Overall, time since restoration, forested land use, percent canopy cover, percent impervious surface, and normalized relief appeared to best predict the HBI and VA-SCI macroinvertebrate metrics. There were no significant predictors for the Shannon Diversity Index and total abundance.

Table 5. Results of multiple linear regressions. The HBI has significant ($p<0.05$) predictors (bolded) in both the watersheds and buffers while the VA-SCI has significant predictors in the buffers.

Watersheds	**Predictors and Their Significance**	**Adjusted R^2**	**P-Value**
HBI	Time since restoration (0.011), Land use- forest (0.002)	0.712	**0.003**
VA-SCI	Time since restoration (0.089), Normalized relief (0.238), Canopy Cover (0.060)	0.428	0.078
Shannon Diversity Index	Time since restoration (0.372), Normalized relief (0.163)	0.225	0.148
Total Abundance	Time since restoration (0.754), Normalized relief (0.575)	-0.196	0.839
Buffers	**Predictors and Their Significance**	**Adjusted R^2**	**P-Value**
HBI	Time since restoration (0.008), Land use- forest (0.001)	0.748	**0.002**
VA-SCI	Time since restoration (0.001), Impervious surface (0.001)	0.777	**0.001**
Shannon Diversity Index	Time since restoration (0.392), Land use- forest (0.150), Normalized relief (0.130)	0.303	0.148
Total Abundance	Time since restoration (0.899)	-0.109	0.899

Discussion

The purpose of this study was to determine what factors influence the health of a stream following restoration and to determine if restoration practices result in better water quality. Macroinvertebrate sampling is one means of quantifying water quality over time through the calculation of various metrics. Literature review and the results of this study suggest that time since restoration alone may be insufficient in evaluating improvement in water quality. Instead, various landscape parameters surrounding a stream must be considered in regard to their effect on a stream habitat. Thus, the combination of macroinvertebrate survey and GIS analysis determined the best set of characteristics, time since restoration and specific landscape variables, which could be used to assess water quality.

The VA-SCI index has three water quality classifications: “Impaired” (VA-SCI 0-61.3), “Least impaired” (VA-SCI 61.4-81.7), and “Exceptional” (VA-SCI 81.8-100). Based on the VA-SCI index values, all but two of the streams were classified as “Impaired” (the others were “Least impaired”) (Figure 4). Thus, it may overall be concluded from the farms surveyed that many streams were still impaired, although it appears that greater length of time since restoration positively impacts water quality.

The bivariate correlation analysis showed that most of the landscape variables were significantly correlated. Several of these correlation pairs would naturally be associated with one another. For example, the two dominant land use characterizations, agriculture and forest, were negatively correlated within both the watershed and buffer zones. Additionally, canopy cover was negatively correlated with agricultural and urban land use and positively correlated with forested land use in both the watershed and buffer zones. Predictably, impervious surface was positively correlated with urban land use and road density in the watersheds. Relief and area were positively correlated among both the watersheds and buffers (Table 6). Thus, various interrelated landscape factors are correlated in their predictive powers over water quality, potentially highlighting areas to focus on when assessing the surrounding landscape.

The multiple linear regressions produced three sets of variables that significantly predicted two different metrics, HBI and VA-SCI (Table 5). Time since restoration was a significant contributor in each of these cases, forested land use in both the watersheds and buffers significantly predicted HBI, and percent impervious surface within the buffers predicted the VA-SCI. These predictor variables are influential for many possible reasons. Time is a very important factor because it accounts for greater interception of pollution as a result of riparian vegetation growth. We hypothesized that the greater length of time that a stream was buffered from pollutant infiltration has a positive impact on the quality of the water. The results of the multiple linear regression support this hypothesis.

The forest surrounding a stream could also have multiple impacts on the stream habitat and water quality. Forested land, undisturbed by agriculture or urbanization, intercedes more pollution and runoff than increasingly degraded and open landscapes. Increases in vegetation density and underground root systems provide a greater surface area for pollutants to be intercepted and cycled before reaching a stream. Similarly, a greater percentage of impervious surface surrounding a stream would result in less pollutant interception and increased runoff toward streams. Thus, both time and land cover characteristics highly impact the likelihood of pollutants reaching a body of water.

This study incorporated both watershed and buffer analysis for a comparison of which areas provide a better estimate of water quality. There were two significantly predicted water quality metrics (HBI and VA-SCI) in the buffer area while there was only one (HBI) at the watershed scale. Because the strengths and types of predictor variables were similar between the watersheds and buffers, the buffers are most likely only slightly better estimates than the watersheds. This may be attributed to their close proximity to the streams. The immediate landscape characteristics surrounding a stream potentially have a stronger impact on macroinvertebrate assemblages than the landscape characteristics throughout the watershed.

The results of this study indicate the need for greater study in regard to environmental factors surrounding a stream. If time, land use, and impervious surface each indicate the health of streams, then perhaps these features should be explored and quantified in greater detail. In addition to the creation of riparian buffers as a form of restoration, landowners and planners may need to examine the influence of land usage and proximity of development when considering changes that need to be made to the landscape. To monitor the effectiveness of restoration efforts, it may be necessary to quantify water quality over time to determine if revitalization projects are worth the time and money that are invested in them.

Field observations highlighted several important factors that need to be considered when making generalizations and stream health evaluations. The weather the day before and during sampling influences the stream habitat. For example, heavy rainfall alters the stream bed by washing away sediments or by eroding substrates, potentially altering macroinvertebrate assemblages. Additionally, it is important to consider activities upstream of a sampling location. While pollutants may not enter streams as easily within a restored zone, they can still infiltrate a system from upstream flow. This could have been a factor that influenced the removal of Farm 4 from the final statistical analyses. In the field, it was observed that the landowner directly upstream of the sampling site allowed cattle to wade in the stream, most likely contributing pollutants which flowed downstream to the restored sampling site. Thus, landowners who choose to implement restoration projects may need to consider the influence of neighboring activity that could supersede their restoration efforts.

Potential sources of error or variation in the data may be explained by various factors. While GIS technology provides an excellent means of measuring and analyzing variables that could not as easily be performed in the field, it possesses certain limitations in regard to precision. For example, the raster datasets that were employed to assess land use, canopy cover, impervious surface, and relief were accurate down to a 30m x 30m resolution. Temporal error may also be a factor because the landuse data is current as of 2011 and was produced from older Landsat images. Thus, rasters with more precise resolutions and updated landscape data could result in better estimations of environmental features. Additionally, a buffer size of 100 m was chosen and constructed in GIS around the streams layer. This buffer model may not accurately depict the actual riparian buffer width in the field; therefore, measures of variables limited to the buffer zones may not have the same calculated impact as they do in reality.

The implications of this study result in the formation of several future research questions that further explore the best ways to assess stream restoration. While benthic macroinvertebrate sampling provides an assessment of tolerance to stream health, water quality can also be directly quantified via different measurements. For example, conductivity, temperature, and dissolved oxygen are each abiotic factors that contribute to macroinvertebrate assemblage. These measures are also more reliable throughout the year, while aquatic macroinvertebrates are primarily available during the warmer seasons. Additionally, riparian zone width, plant composition, and density impact the strength and frequency at which pollutants are intercepted. Transect construction could be utilized to assess buffer size while providing a way to sample the vegetation surrounding a stream. The integration of these factors could best provide researchers with a way of quantifying stream health over time, which in turn, helps land owners and planners make educated decisions in the pursuit of best management practices following a disturbance.

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Appendix 1. Letter sent to landowners.

Date

Hello,

As a participant in one of the Shenandoah Valley Soil & Water Conservation District's Cost Share programs, you have shown that you are concerned about protecting our agricultural resources and are committed to improving water quality in the Shenandoah Valley. We are writing you to let you know about an upcoming research project that will study the effect of various best management practices on water quality in local streams.

In cooperation with the Shenandoah Valley Soil & Water Conservation District, the JMU Department of Biology will be gathering data from waterways in the Shenandoah Valley to evaluate the effectiveness of agricultural best management practices involving streambank protection and restoration. Through the collection, enumeration, and identification of benthic macroinvertebrates, we will evaluate the health of these tributaries and determine if they are improving over time. Such information is vital toward understanding the relationship between landowners' activities and ecological sustainability.

In order to conduct our research, we need to visit your farm. Please read the information on the enclosed page about what we will be doing. If you are interested in contributing to this research by allowing us to collect samples on your property, please return the enclosed card with the appropriate contact information.

Your reply does not commit you to anything at this time. Please be assured that your participation is completely voluntary, and all research will be used confidentially for strictly scientific purposes. We will be glad to follow any particular instructions you might have while we are on the property.

Thank you for your time and consideration, and we look forward to your response. If you have any questions about this project, please contact us.

Sincerely,

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Appendix 1, cont.

Frequently Asked Questions:

What is the goal of the project?

- We aim to evaluate water quality in different types of best management practices and hope to make predictions about stream health over time.

What are you testing for?

- We will be collecting and identifying benthic macroinvertebrates.

Who will be on the property?

- Biology undergraduate research students from James Madison University

How long will testing take place?

- 1-2 hour sessions
- Various times throughout the year, typically in the months of April-October

Who will have access to the data and what will it be used for? Will it be available to the public?

- Data collection is strictly for scientific purposes. Only the student researchers and their professors will have access to this information. The combined data from multiple farms may be published in a report as part of a qualitative assessment of numerous sampling locations, but no individual results will be released.

Will I be able to see the data from my farm?

- Yes! We will be happy to share the results with you.

What parts of my property will the testers need access to?

- We request vehicle accessibility onto the property and walking access to the desired sampling sites in the stream.

What information will you need from me if I decide to participate in this project?

- At this time, we only request your permission to evaluate the accessibility of the desired sampling location. If suitable for our research purposes, we would further request your permission to collect invertebrate samples at that location.

Why should I participate? What's in it for me?

- We are conducting this research to assess the health of local tributaries. Agricultural land and developed areas often produce nonpoint sources of pollution that accumulate in these waterways. By conducting comparative analyses, we will be able to evaluate the effect land restoration, through the establishment of buffer zones, has on water quality. We will provide all participants with the results of this survey. These results may provide important environmental information regarding your land and land upstream of your property.

Appendix 2. Summary of all results of metric calculations and GIS analysis. Stream density in each watershed was calculated for comparison but was not incorporated into the regression.

Farm #	5	12	3	2	8	9	4	11	6	1	7	10
Sample #	55	64	53	52	58	60	54	62	56	51	57	61
Year Restored	2013	2014	2012	2011	2011	2009	2007	2007	2006	2002	2002	2001
Time between restoration and sampling year	1	1	2	3	4	6	7	8	9	12	13	14
HBI	5.0	4.8	5.5	6.7	5.5	3.7	8.0	4.5	4.6	5.0	3.8	5.2
VA-SCI	39	44	47	42	46	56	19	44	66	54	66	42
Shannon Diversity	1.21	1.65	1.57	2.04	1.30	1.98	0.10	1.45	2.36	2.19	2.23	1.46
Total Abundance (# macroinvertebrates/m^2)	958	71	727	106	929	561	763	110	568	748	369	521
Watersheds												
Slope (Average %)	8.9	16.8	9.9	5.0	7.2	15.8	5.3	6.0	10.3	6.8	9.7	4.4
Impervious Surface (Average %)	0.5	0.1	0.4	1.0	0.7	0.2	1.2	2.3	0.4	2.1	0.5	1.0
% Agriculture	41.4	9.1	23.6	74.4	57.6	7.7	71.7	42.4	31.5	49.8	35.2	53.8
% Forest	55.6	87.6	72.5	19.5	36.2	89.8	22.0	48.1	65.9	41.5	61.8	37.9
% Urban	2.8	2.9	4.0	6.0	6.1	2.3	6.3	9.4	2.6	8.5	2.9	8.2
Canopy Cover (Average %)	51.0	74.8	66.1	16.9	32.9	79.9	18.5	46.0	61.0	36.6	57.3	35.1
Road Density (km/km^2)	2.6	2.7	3.8	3.4	4.4	1.8	4.9	4.6	2.3	3.6	2.5	3.4
Relief (m)	640.4	431.9	365.8	176.1	472.8	898.1	180.3	538.8	647.6	688.5	659.4	221.2
Area (ha)	2440.7	958.1	540.9	4460.6	1821.8	47204.1	2875.9	751	4448.7	12591	5209.7	1214.3
Normalized Relief (Relief/Area) (m/ha)	0.26	0.45	0.68	0.04	0.26	0.02	0.06	0.72	0.15	0.05	0.13	0.18
Buffers												
Slope (Average %)	8.5	15.7	9.3	4.9	6.4	13.2	4.7	4.7	9.7	6.9	9.1	4.5
Impervious Surface (Average %)	0.6	0.2	0.7	1.0	0.7	0.4	1.9	2.2	0.5	1.4	0.5	2.3
% Agriculture	39.4	12.5	29.0	80.0	64.1	12.1	79.6	47.8	28.7	50.0	34.4	64.7
% Forest	56.4	80.5	65.6	12.8	26.9	83.1	10.5	42.8	67.8	42.3	61.9	20.4
% Urban	3.9	6.9	5.4	7.2	8.7	4.4	9.9	9.0	3.3	7.5	3.5	14.5
Canopy Cover (Average %)	52.3	67.9	63.0	11.3	25.6	73.2	9.7	41.0	64.0	38.9	58.6	31.0
Road Density (km/km^2)	3.6	6.2	4.5	4.0	6.4	3.2	6.2	5.1	3.1	3.9	3.1	4.9
Relief (m)	470.9	431.9	273.9	138.6	353.1	738.8	97.2	241.3	519.2	559.2	531.0	61.6
Area (ha)	733.7	293.4	189.6	1492.8	569.5	14120.9	793.6	204.4	1508	3348.6	1751.9	165.4
Normalized Relief (Relief/Area) (m/ha)	0.64	1.47	1.44	0.09	0.62	0.05	0.12	1.18	0.34	0.17	0.30	0.37
Total Length of Streams in Watershed (km)	39.2	15.9	10.0	78.3	30.7	750.9	41.9	11.3	80.1	178.6	93.2	9.1
Area of Watershed (ha)	2440.7	958.1	540.9	4460.6	1821.8	47204.1	2875.9	751	4448.7	12591	5209.7	1214.3
Stream Density (km/ha)	1.61	1.66	1.86	1.86	1.69	1.59	1.46	1.50	1.80	1.42	1.79	0.75