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IMPERVIOUS SURFACE AND MACROINVERTEBRATES IN THE SOUTH ATLANTA METROPOLITAN AREA

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ABSTRACT

Studies utilizing volunteer stream monitoring data are rare, particularly in the Atlanta metropolitan area. This study investigated how the macroinvertebrate communities of 20 different stream sites in the south metropolitan Atlanta area were affected by the imperviousness of their surrounding watersheds. These sites were in a diverse landscape which included forests, wetlands, suburban day-use parks, and parking lots. Percentage impervious surface area was measured using a geographic information system analysis. Macroinvertebrates were collected using Georgia Adopt-A-Stream's volunteer monitoring protocols, and a water quality index (WQI) was calculated from these data. The relationship between WQI and imperviousness was curvilinear and best fit by a quadratic equation. In watersheds having more than 8% imperviousness, WQI clearly decreased.

Keywords: Georgia Adopt-A-Stream, macroinvertebrate, impervious surface, watershed, volunteer monitoring

INTRODUCTION

Although many professional stream ecologists have established a relationship between a stream's watershed characteristics and its macroinvertebrate community, data collected by volunteer citizen scientists have not frequently been used to examine this relationship. Volunteer stream monitoring programs can provide data with little to no funding, and sometimes for longer time periods and a broader geographic scale than government agencies are able. Despite the coarser taxonomic resolution and simpler biotic indices of volunteer protocols, a few studies have demonstrated that volunteers can provide scientifically valid data. Fore et al. (2001) reported that volunteers were as accurate at identifying macroinvertebrates as professionals when properly trained, and that their simple volunteer index was correlated with a professional multimetric index, if less precise. Engel and Voshell (2002) also found that volunteers are just as reliable as professionals when properly trained in collection and identification, but the simple volunteer index used by Virginia Save Our Streams did not correlate to professional indices, so they developed a new one. Using volunteer rapid assessment protocols in Georgia (Georgia Adopt-A-Stream 2009), Stahley and Kodani (2011) found that streams draining parking lots have less diverse macroinvertebrate communities dominated by tolerant species, compared to streams in forest preserves. Using one volunteer group's data, the current study investigated how several streams' watersheds affected the health of their macroinvertebrate communities. The strength of that relationship, any emergent patterns in the communities' response to watershed damage, and the shape of the response curve were key matters of interest in this study.

When discussing the health of a stream's macroinvertebrate community, impervious surfaces and urbanization go together. Arnold and Gibbons (1996) reviewed the history of impervious surfaces in the United States and pointed out that imperviousness increased in the mid-twentieth century as roads were paved and that it became associated with areas having high population density. Interestingly, they even mention that imperviousness could be studied more widely in the future with geographic information systems (GIS), and subsequently, the emergence of better coverage and lower costs has enabled deeper investigation. In New England, percentage impervious surface area within a watershed was 96–98% correlated with urban intensity (McMahon and Cuffney 2000; Coles et al. 2010). In Maryland they were 94% correlated (Utz et al. 2009). Allan (2004) warned that urbanization is complex, and that it can bring with it a complex mix of many intertwined factors such as higher stream temperatures, a mix of toxins, and habitat changes. Although it is not completely synonymous with urbanization, imperviousness can be thought of as a simple environmental index that can summarize all the complexity that comes with urban development, with its mix of land uses, various ways of managing storm water, and diverse sources of pollution (Arnold and Gibbons 1996).

One pattern that regularly emerges from the literature is that as damage to the watershed increases, pollution-sensitive taxa such as mayflies, stoneflies, and caddisflies decrease, whereas tolerant taxa such as midges increase (Paul and Meyer 2001; Georgia Adopt-A-Stream 2009). In Utah, Gray (2004) reported that the abundance of sensitive macroinvertebrates decreased while tolerant species increased as the area around the Provo River urbanized over 24 years. In a detailed study of the Piedmont, Highlands, and Coastal Plain regions of Maryland, Utz et al. (2009) found that even different species of macroinvertebrates within the same order or family can respond to imperviousness differently, depending on their regional location. Most stoneflies (Plectoptera) were negatively affected by urbanization in the Coastal Plain and Piedmont, but less than one third of the nonbiting midge flies (Chironomidae) were. In the Atlanta metropolitan area, Gregory and Calhoun (2007) reported that stoneflies had the strongest negative response to urbanization of any single taxon in their study (Spearman's rank coefficient R_s -0.86), followed closely by beetles (Coleoptera, R_s -0.69) and mayflies (Ephemeroptera, R_s -0.66), whereas midges and dipterans actually increased (both R_s +0.68).

Despite the varying responses of individual taxa, macroinvertebrate community metrics universally show a strong negative response to watershed damage. Studying agricultural, mixed-agricultural, mixed-urban, and urban streams in the Piedmont region of Maryland, Moore and Palmer (2005) reported a strong negative relationship between impervious surface and taxa richness (R^2 = 0.70). Ourso and Frenzel (2003) report that the Hilsenhoff family-level biotic index (Hilsenhoff 1988), a rapid assessment protocol used by professional benthologists to quickly evaluate a stream, is 72% correlated to impervious surface area. Being designed for volunteers, Georgia Adopt-A-Stream's (2009) macroinvertebrate index (referred to as the water quality index or WQI) only requires taxonomic identification of macroinvertebrates to order, and assigns pollution tolerant species 1 point, moderately tolerant species 2 points, and intolerant species 3 points. Despite being designed for use by volunteers, Georgia Adopt-a-Stream's WQI has been occasionally used by ecologists in publications (Barnett et al. 2007; Stahley and Kodani 2011). This study used Georgia Adopt-A-Stream's macroinvertebrate index to investigate the strength of the relationship between a stream's health and the impervious surface of the surrounding watershed.

In addition, some previous studies indicated that watersheds can sustain a certain amount of damage from impervious surfaces—a threshold—before damage to macroinvertebrate communities occurs. This threshold is usually small. In reviewing literature, Paul and Meyer (2001) found that some studies reported a threshold between 10 and 20% impervious surface area. Ourso and Frenzel (2003) studied urbanizing watersheds in Alaska, and found that percent impervious area as little as 5% negatively affected several physical, chemical, and biological factors within a stream. In China, Wang et al. (2012) also reported a 5% threshold for impervious surface damage to a stream macroinvertebrate community. In their study of streams in the Piedmont region of north central Georgia, Roy et al. (2003) suggested that sensitive taxa are lost above 15% urban land cover. On the other hand, in a very thorough study of urban intensity and macroinvertebrates in New England watersheds around Boston, Coles et al. (2010) found that only one group, collector-gatherers, showed a threshold response, but other indices such as EPT, noninsect taxa, and tolerance values conformed to linear models. Allan (2004) hypothesized that the relationship between the biological condition of a stream and an anthropogenic gradient could be linear, nonlinear, or a threshold. A goal of this current study was to determine the nature of Georgia Adopt-A-Stream's WQI response to impervious surface.

MATERIALS AND METHODS

Twenty research sites within Clayton, Henry, and Spalding Counties in the south Atlanta metropolitan area were visited from January 2007 through September 2014 (Figure 1). All sites were on small, wadeable streams, in a variety of environments including forests, wetlands, suburban day-use parks, housing subdivisions, and parking lots. Sites were visited from 1 to 8 times.

Macroinvertebrate samples were collected using the methods outlined in Georgia Adopt-A-Stream's (2015) volunteer sampling protocols. D-frame nets were used for capturing macroinvertebrates in muddy bottom streams, and kick seines in rocky bottoms streams. Samples were sorted to either class or order, and although protocol only required reporting rare (1–9), common (10–99), or dominant (≥ 100) taxa, the actual number of individuals within each taxon found was recorded. Noting actual numbers of individuals allowed for calculation of indices such as the percentage of mayflies, stoneflies, and caddis, commonly referred to as EPT, as well as percentages of individual taxa. Because recent changes to the Georgia Adopt-A-Stream (2015) collection protocol made a distinction between case-building (sensitive = 3 points) and net-spinning caddis (somewhat sensitive = 2 points), it made sense to try calculating an index similar to EPT, excluding net-spinners, henceforth referred to as MSC. Only one EPT and one MSC were calculated for each site, pooling all the data from all the site visits. WQI, a macroinvertebrate index reflecting water quality, was totaled as follows: 3 points was assigned for the presence of each sensitive taxon, 2 points for somewhat sensitive taxa, and 1 point for pollution tolerant taxa (Table I; Georgia Adopt-A-Stream 2015).

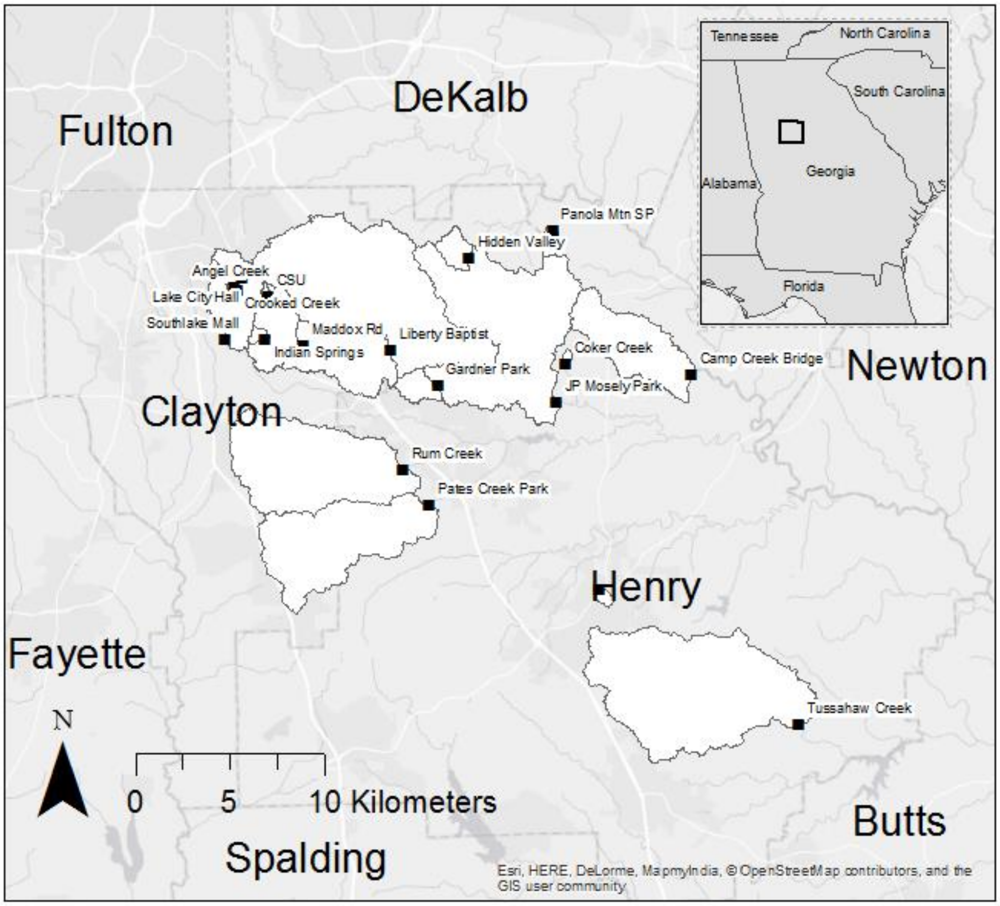

Figure 1. Watersheds examined in the current study. County names are in the large font, whereas site names are in the small font. For brevity, the Griffin Golf Course site, to the south in Spalding County is not shown.

Table I. Pollution Tolerance and Points of Georgia Adopt-A-Stream's WQI* (Georgia Adopt-A-Stream 2015)

Sensitive Taxa (3 points)	Somewhat Sensitive Taxa (2 points)	Tolerant Taxa (1 point)
Stonefly Nymphs	Common Net Spinning Caddisflies	Midge Fly Larvae
Mayfly Nymphs	Dobsonfly/Hellgrammite & Fishfly	Black Fly Larvae
Water Penny Larvae	Dragonfly & Damselfly Nymphs	Lunged Snails
Riffle Beetle Larvae and Adults	Crayfish	Aquatic Worms
	Crane Flies	Leeches
Aquatic Snipe Flies	Aquatic Sow Bugs	
Caddisflies (Case-building)	Scuds	
	Clams & Mussels	
Gilled Snails		

*Water quality rating (WQI) was calculated as the sum of all categories: excellent > 22, good 17–22, fair 11–16, and poor < 11.

In cases when sites were visited multiple times, a separate WQI was calculated for each visit. After counting, the live macroinvertebrates were returned to their stream. Specimens were preserved in ethanol only if needed for further study, and Voshell's *A Guide to Common Freshwater Invertebrates of North America* (2002) was used to confirm taxonomic identification. SRI's ArcGIS 10.0 geographical information system was used to delineate watersheds for each study site (ESRI 2011). A digital elevation model was available free of charge from the National Elevation Dataset (NED), which enabled creation of a three-dimensional map of the study area (U.S. Geological Survey 2016). Data for impervious surfaces was available for free from the National Land Cover Database (USGS 2014)—this map layer allowed quantification of the percentage of each watershed that was impervious to water. All of our macroinvertebrate data were entered into the Georgia Adopt-A-Stream database (2015) and are freely available to the public, as well as the locations, descriptions, and maps for each study site. Coordinates for each study site are included in appendix I.

The data, which consisted of the sites' WQI and the percent imperviousness of the associated watershed, were analyzed in Minitab 17 Statistical Software (2010). Simple linear and polynomial regression models were explored by examining residuals, significance testing, and forward stepwise curve fitting as per Zar (2010).

RESULTS

To understand how the macroinvertebrate communities related to impervious surfaces, taxa were examined first individually, then in groups, and finally as a whole assemblage. Individual taxa exhibited different relationships to impervious surfaces, and the more interesting ones are shown in Figure 2. Three taxa seemed to exhibit a maximum tolerance for imperviousness: case-building caddis (<17%), stoneflies (<27%), and clams (<40%). It should be noted that even below their apparent maximum imperviousness, these three taxa were greatly variable in their occurrence from site to site. A level of imperviousness below 27%, for instance, was not a guarantee of finding stoneflies, although they never appeared above this level. Other taxa, notably mayflies, net-spinning caddis, and midges, could be found sporadically in watersheds of low, medium, and high levels of imperviousness. Mayflies were present irregularly at all levels of imperviousness, but were less abundant in watersheds with highest imperviousness. Midges were also found at almost every study site, but when sites had greater than 22% imperviousness, they consistently made up between 12 to 40% of the associated communities.

Percent EPT, the traditional index used to indicate water quality in macroinvertebrate studies, did not exhibit any clear pattern with regard to imperviousness (Figure 3). MSC, which included mayflies, stoneflies, and only the case-building caddis, had a somewhat triangular distribution. At low imperviousness, MSC could be high, medium, or low, but as imperviousness increased it appeared that MSC diminished.

In addition to EPT and MSC, macroinvertebrates data were also grouped according to pollution tolerance and graphed against imperviousness (Figure 4). Tolerant and moderately-tolerant taxa were found in all of the sites, whereas intolerant taxa were absent from two sites, both of which had higher imperviousness.

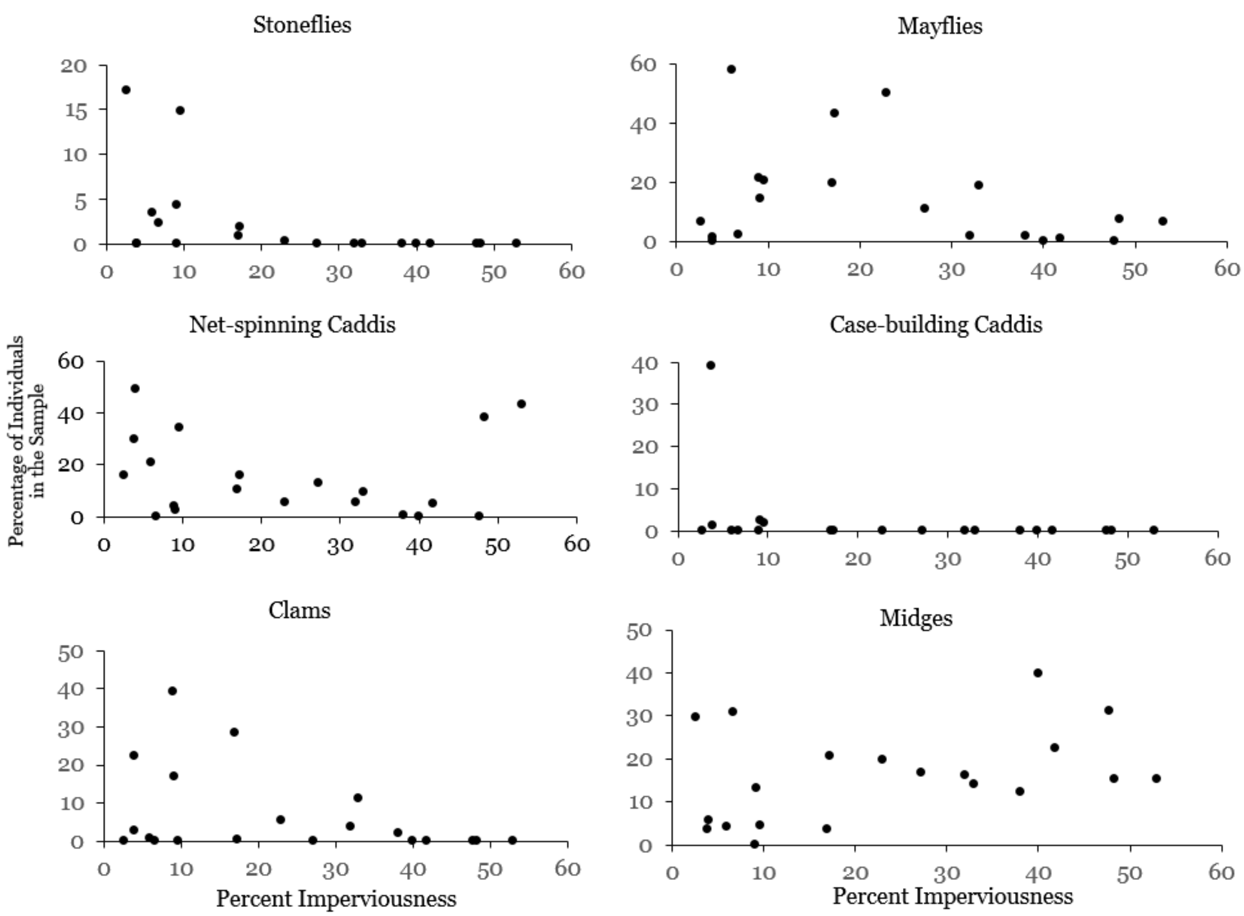

Figure 2. Percentage of selected taxa within rach macroinvertebrate community.

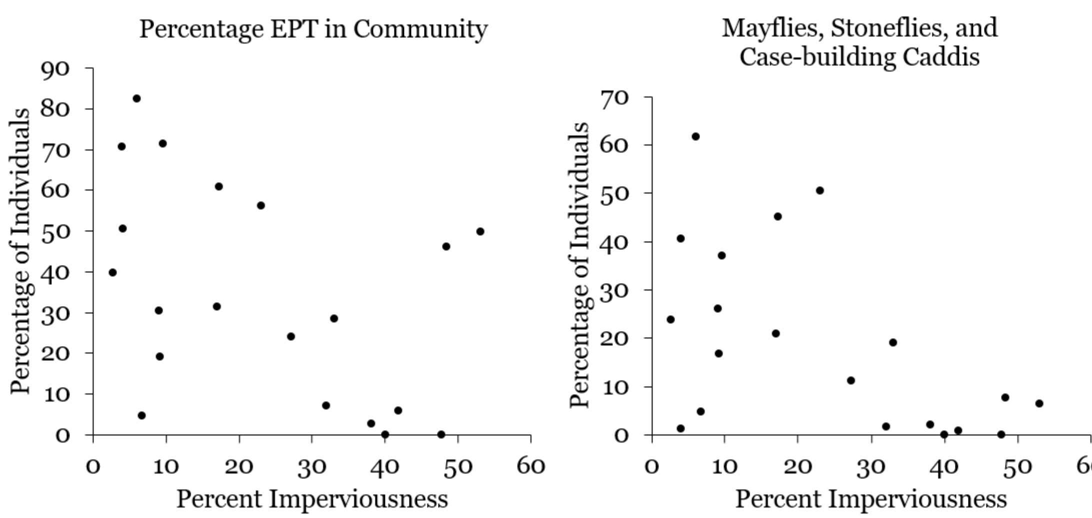

Figure 3. Comparison of EPT and MSC versus imperviousness. Percent EPT is the standard index which describes the preponderance of all mayflies, stoneflies, and caddis in a community. Percent MSC is similar, in that it includes mayflies and stoneflies, but only includes the case-building caddis.

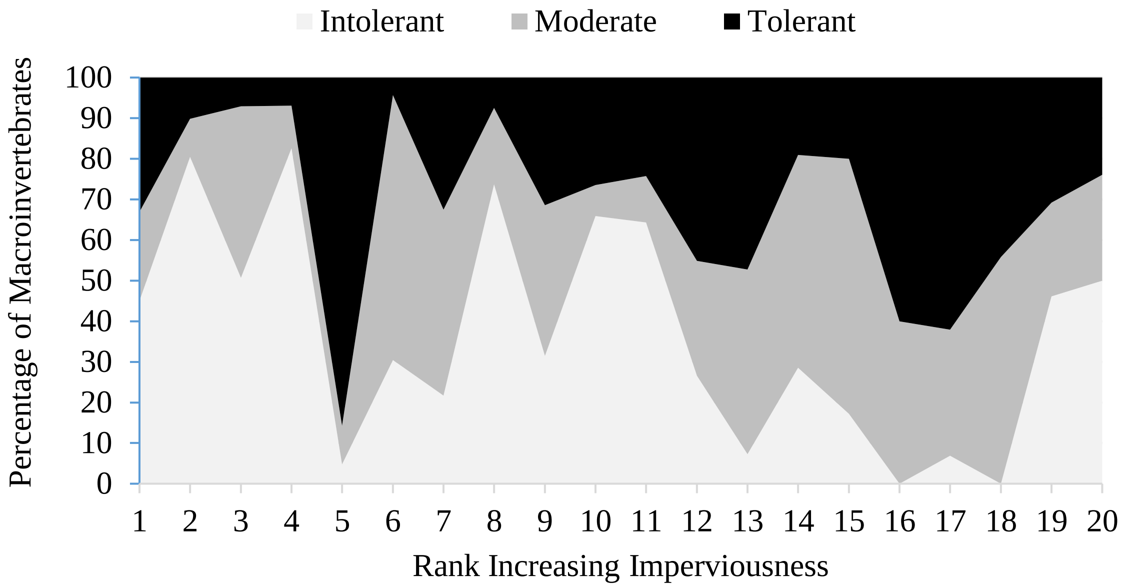

Figure 4. Pollution tolerance groups over a gradient of imperviousness.

The average macroinvertebrate WQI for study sites in this study ranged from 2.6 to 25.0 (Table II). Individual observations of WQI ranged from 0 to 25 (Table II). The water quality index measures the macroinvertebrate species richness at each study site, with pollution sensitive species receiving 3 points, somewhat-tolerant species receiving 2 points, and tolerant species receiving 1 point. Based on their average WQI, five of the sites rated as *poor*, seven were *fair*, another seven were *good*, and only one was *excellent*. Watershed imperviousness ranged from 3% to 53%. The watersheds for our sites varied greatly in size: Angel Creek at Reynolds Nature Preserve was the smallest at just 5 hectares, whereas Big Cotton Indian Creek at J.P. Mosely Park was the largest at 13,383 hectares.

For this study, there was no evidence for a meaningful relationship between WQI and watershed size, even when plotted as both a simple linear regression and quadratic regression (Figure 5). R^2 was only 0.16 for a linear model, and just 0.22 for curvilinear model. There were very few large watersheds sampled, but even for the smaller watersheds (those under 5,000 hectares in area), WQI ranged greatly and showed no apparent pattern. Multiple regression revealed that imperviousness was a significant factor, but watershed size was not (Table III).

When WQI was plotted against imperviousness, the residuals were nonnormal and followed a curvilinear trend, which suggested the possibility of a curvilinear function (Gotelli and Ellison 2013), and these issues were resolved with a quadratic model. Lowess regression of WQI against imperviousness produced a regression line similar to a quadratic function when F = 0.5 (the standard default for Lowess regressions) was selected (Appendix II). Stepwise regression (Zar 2010) was employed to find a polynomial equation (Table IV). First, a simple linear regression yielded a Y-intercept of 21.27 and a slope of -0.3452, both of which differed significantly from zero, so the null hypothesis was

Table II. Study Sites Ranked by Average WQI

Rank	Average WQI	Site Visits	Water Quality Rating	Percentage Watershed Imperviousness	Watershed Name (Size in ha)
1	25.0	1	Excellent > 22	6	Camp Creek (1,785)
2	22.0	2	Good 17–22	3	Panola Mountain (97)
3	20.0	7		10	Hidden Valley (279)
4	19.5	2		17	JP Mosely Park (13,383)
5	19.0	1		4	Pates Creek (3,194)
6	18.6	5		23	Stockbridge HS (8,036)
7	17.0	1		17	Rum Creek (3,759)
8	17.0	1		9	Tussahaw Creek (5,849)
9	16.6	6	Fair 11–16	4	Angel Creek (5)
10	16.3	3		38	Maddox Road (929)
11	14.5	2		9	Crooked Creek (29)
12	14.0	1		33	Southlake Mall (1,133)
13	13.0	1		7	Coker Creek (28)
14	12.0	2		32	Liberty Baptist (2,410)
15	11.0	1		53	Big Springs Park (64)
16	9.0	5	Poor < 11	27	Gardner Park (288)
17	6.0	1		40	Griffin Golf Course (73)
18	6.0	7		42	Indian Springs (69)
19	3.7	3		48	Lake City Hall (205)
20	2.6	9		48	Clayton State U (27)

Table III. Multiple Regression of WQI versus Watershed Size and Imperviousness

Source	DF	Adj SS	Adj MS	*F*-Value	*P*-Value
Regression	2	488.67	244.34	17.24	< 0.001*
Watershed Size	1	43.61	43.61	3.08	0.097
Imperviousness	1	368.52	368.52	26.00	< 0.001*
Error	17	240.95	14.17	--	--
Total	19	729.63	--	--	--

*Indicates significant at $\alpha = 0.05$

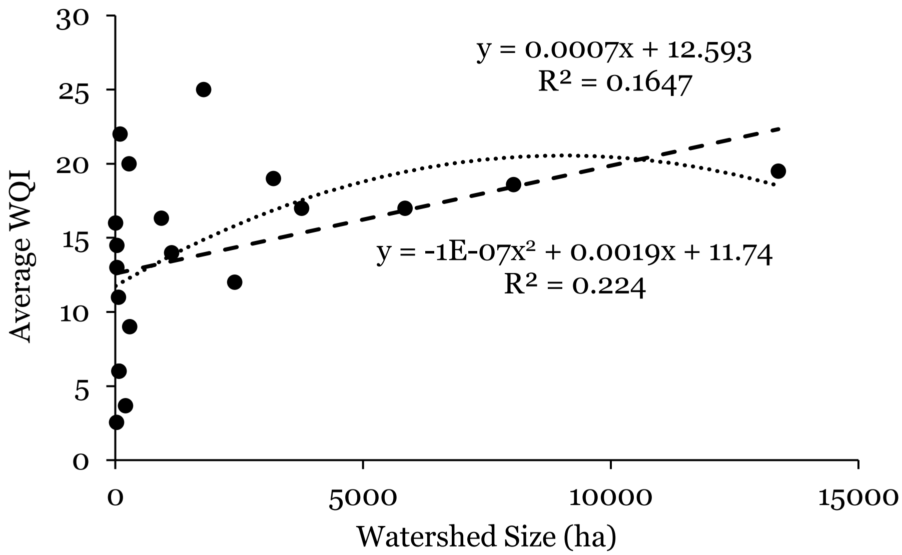

Figure 5. Average WQI as a function of watershed size.

Table IV. Coefficients for Terms in the Stepwise Regression

Regression Equation	Term	Coefficient	SE Coefficient	*t*-Value	*P*-Value
Linear	Constant	21.27	1.30	16.42	< 0.001*
	Imperviousness	-0.3452	0.0410	-8.42	< 0.001*
Quadratic	Imperviousness^2	-0.00950	0.00343	-2.77	0.008*
Cubic	Imperviousness^3	0.000030	0.000320	0.09	0.925†

†Note that the cubic term is not significant.

*Indicates significant at $\alpha = 0.05$

rejected, and both terms were determined to be important for the regression. In the second step, the coefficient of the imperviousness^2 term was tested and was also significantly different from zero. Lastly, in the third step, the imperviousness^3 term did not reject the null hypothesis, meaning adding this term did not significantly improve the regression model, so the stepwise process was complete.

Table V shows the regression analysis for the quadratic equation. The Imperviousness term was not significant, but Zar (2010) recommends leaving this in the quadratic equation for the best fit line because it affects the calculation of residuals. With a probability of 0.009, the test for lack-of-fit rejected the null hypothesis of linearity. Four observations were identified as outliers, and their removal did affect the probability of the summary statistics. Removing the outliers decreased S, the standard error of the regression, from 4.74 to 3.65 (Frost 2014), R^2 increased from 60.45% to 76.64%, and most interestingly, the test for lack-of-fit ended up with a probability of 0.065, thus confirming the quadratic model.

Some interesting trends appeared in the plot of WQI versus percent imperviousness (Figure 6). First, it is important to note that at each site, WQI was highly variable between site visits. The best fit line took a path which increased very slightly through the sites with imperviousness ranging from 3 to 8%, reached a peak WQI value of 17.4 at 8% imperviousness, and then decreased strongly as it moved through sites with higher imperviousness.

Table V. Regression Analysis for the Quadratic Equation
Y = –0.00714 Imperviousness^2 + 0.046 Imperviousness + 18.10.

Source	DF	ADJ SS	ADJ MS	*F*-Value	*P*-Value
Regression	2	1955.86	977.929	43.56	< 0.001*
Imperviousness	1	1.61	1.609	0.07	0.790
Imperviousness^2	1	113.79	113.788	5.07	0.028*
Error	57	1279.74	22.452	--	--
Lack-of-Fit	16	633.99	39.624	2.52	0.009*
Pure Error	41	645.76	15.750	--	--
Total	59	3235.60	--	--	--
Model Summary: S = 4.74; R^2 = 60.45%; R^2 (adj) = 59.06%; R^2 (pred) = 55.83%					

Four outliers removed
Y = – 0.0102 Imperviousness^2 + 0.167 Imperviousness + 17.92.

Source	DF	ADJ SS	ADJ MS	*F*-Value	*P*-Value
Regression	2	2309.96	1154.98	86.92	< 0.001*
Imperviousness	1	19.01	19.01	1.43	0.237
Imperviousness^2	1	203.03	203.03	15.28	< 0.001*
Error	53	704.25	13.29	--	--
Lack-of-Fit	15	296.16	19.74	1.84	0.065
Pure Error	38	408.09	10.74	--	--
Total	55	3014.21	--	--	--
Model Summary: S = 3.65; R^2 = 76.64%; R^2 (adj) = 75.75%; R^2 (pred) = 74.04%					

*Indicates significant at $\alpha = 0.05$

DISCUSSION

Interpretation of the Regression

These data, which included multiple observations over the study period for several of the sites, not only produced an R^2 value typical of all regressions, but also allowed for testing the goodness-of-fit. When the data in this study had 4 outlying observations removed, the sum of squares for the lack-of-fit test decreased by half and the associated probability rose to 0.065. It is therefore concluded that the quadratic model fit the data. Not only did WQI and impermeable surface have a strong relationship, but the quadratic model provided a better fitting line for the data than either the linear or cubic models, and provided a relatively high coefficient of determination (R^2=0.77), and fit the curve nicely (Figure 6). Furthermore, including all of the data in the regression, with several individual WQIs for each site rather than averaging all of them to provide a single Y for each X, was the correct thing to do. Zar (2010, 349) points out that with more values of Y at each X, statistical power is improved. Alternatively, means that grouped all the observations for each study site could have been reported, thus eliminating all of the

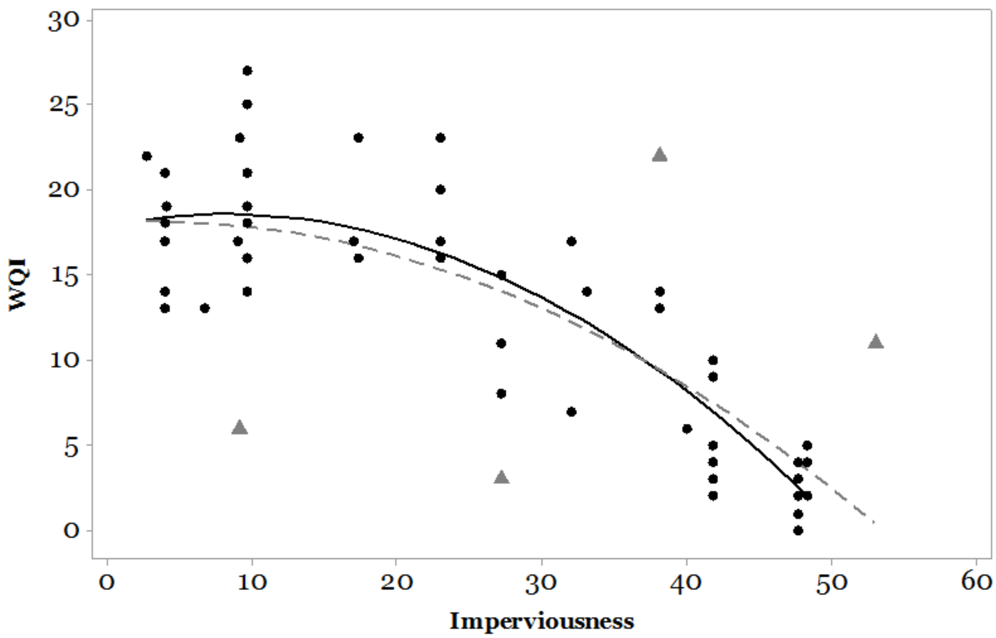

Figure 6. Macroinvertebrate WQI versus watershed imperviousness. There were 60 observations over 20 sites. Four observations were identified as outliers (shown as triangles). Regressions were fitted with outliers (dashed line) and without (solid line).

outliers, but this would result in fewer observations overall, with a loss of both information and the ability to test for linearity (Freund 1971; Zar 2010, 349). Naturally, the WQI for each site varied from time to time, and the S statistic, also known as the standard error of the regression, provided a clue as to how much. S was 3.65, which is about 30% of the overall average WQI of 11.8. About 95% of observations should fall within two times this value, which would be 7.3. Thus, the 95% confidence interval, being 7.3, was narrower than the value of the overall mean of 11.8—certainly a better situation than if it were wider. Still the WQI within each study site varied quite a bit over time, as evidenced by Hidden Valley (Table VI) which had a minimum WQI of 14 (fair) and a maximum of 27 (excellent). Even larger variation in WQI has been reported in another study in Georgia—Barnett et al. (2007) reported WQIs that ranged from 2 (poor) to 23 (excellent) for one particular site on the Alapahoochee River. The question of the effects of time, particularly of seasonality and year-to-year variation on a stream's macroinvertebrates, is a very valid one, but it will have to wait until enough data have been collected. With just 60 observations spread over nine years at 20 different sites, this particular set of data is not up to the task, but with more data, the question of these temporal factors could be answered.

So, if impervious surface cannot by itself entirely explain a site's WQI, then what else might contribute? Watershed size did not appear to affect WQI, as the very few large watersheds examined had WQI values well within the range of the many small ones (Figure 5), and a multiple regression analysis failed to detect size as a statistically significant factor (Table III). Another examination of individual taxa may provide a clue. In figure 2, it was clear that some macroinvertebrates were highly affected by imperviousness, and some were not. Despite being a "sensitive" taxon, in this study mayflies defied explanation and sometimes appeared where imperviousness was high. Anecdotally, my students and I found mayflies clinging onto branches within the stream with some degree of predictability. It is reasonable that the abundance of mayfly-harboring woody debris may be more reliably predicted by the presence of a protected stream buffer with a mature canopy, or perhaps even stream restoration efforts, rather than simple watershed imperviousness. Georgia Adopt-A-Stream recently introduced an in-stream assessment protocol, so future volunteer data will include a stream habitat score that will be based upon characteristics such as stream buffer, vegetative cover, and substrate variety. In addition to habitat quality, meteorological variables in the environment, such as temperature and rainfall, as well as in-stream changes in habitat such as erosion could change a stream's WQI from season to season and year to year.

The Relationship Between Impervious Surface and Macroinvertebrates

For this particular study, the relationship between impervious surface and the macroinvertebrate community index appeared to be curvilinear, with the vertex of the curve at 8% imperviousness. As such, these data supported Allan's (2004) hypothesis that a stream's condition could possibly respond in a nonlinear fashion to anthropogenic changes in the environment. Consistent with previous findings (Stahley and Kodani 2011), knowledge of streamside land use had some predictive power of the macroinvertebrate community for small watersheds, but it is impossible to accurately predict a site's macroinvertebrate index just by knowing its associated streamside habitat. With an R^2 of 0.632, the Georgia Adopt-A-Stream macroinvertebrate index correlates reasonably well with percent impervious area. This compared favorably with Ourso and Franzel's (2003) reported correlation index of $R^2 = 0.7266$ for the Hilsenhoff family-level biotic index (HFBI), a rapid assessment protocol, frequently used by professional benthologists to quickly evaluate a stream's health (Hilsenhoff 1988). This is also in agreement with Moore and Palmer (2005), who found macroinvertebrate diversity strongly related to percent imperviousness with their R^2 of 0.70. That so many studies have reported similar coefficients of determination again says that impervious surface must be important, but clearly it does not explain all of the variation in a stream's macroinvertebrate community.

Recall that, as to the question of a minimum threshold of damage to a macroinvertebrate community, the literature reports varying results. Moore and Palmer (2005), found no damage threshold in their study of Maryland streams, whereas Paul and Meyer (2001) report a threshold of 10–20%. Studies in China (Wang et al. 2012) and Alaska (Ourso and Frenzel 2003), suggest a 5% threshold, but both include several study sites having very low percent impervious area, approaching 0%. In this study, only three study sites had imperviousness less than 5%—the Panola Mountain watershed had 3% imperviousness, Pates Creek and Angel Creek both had 4%with WQI varying greatly for each of these sites. Several authors (Gotelli and Ellison 2013; van Emden 2008; Zar 2010) caution against drawing conclusions outside the range of predictors or X values used to construct a regression model, so caution is warranted. Although WQI clearly decreased when imperviousness exceeded 8%, the question of exactly what happens in Georgia watersheds with imperviousness between 0 and 8% still remains. More data are needed.

Recommendations for Future Studies

There is clearly a need for further studies, and there are specific ways that future efforts could be focused to improve the understanding of how watersheds affect macroinvertebrate communities. First, in order to decisively settle the question of how imperviousness relates to a stream's macroinvertebrate community, data from two types of watersheds are needed: those that have nearly 0% imperviousness, and those that have imperviousness above 48%. This study was not able to test for the X or Y intercepts, but future studies could be directed towards finding such watersheds of interest, targeting them for data collection with this goal in mind. Second, in order to increase statistical power and account for seasonal variation, quarterly macroinvertebrate sampling should be sought out and encouraged. Third, in-stream habitat scores should be reported whenever possible, as these could also be used in improvement of the regression model. Fortunately, Georgia Adopt-A-Stream has recently implemented a habitat assessment protocol, and data are beginning to be recorded.

Finally, this study made use of volunteer data, which generally seems to be under-utilized—a point also defended by Fore et al. (2001). Although professional grade metrics for macroinvertebrate communities incorporate greater taxonomic precision, this study suggests that the Georgia Adopt-A-Stream water quality index can provide a reasonable estimation of a stream's health when compared to impervious surface within a watershed. Volunteer protocols typically trade some taxonomic resolution to reduce the time and expertise needed to monitor a stream. Such a trade-off is a good one because storm water managers can use these data to highlight areas that need further investigation—a wise idea if fiscal resources for professional crews are limited. Additionally, by involving citizen-scientists, volunteer monitoring programs can help to increase awareness of stream and watershed health. Lastly, scientists would do well to remember that volunteer data are still data. Just as a jigsaw puzzle requires many tiny pieces to see a whole picture, there are some valid and important questions that science can answer only with data carefully collected by volunteers who care about their local streams.

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REFERENCES

Allan, J.D. 2004. Landscapes and riverscapes: the influence of land use on stream ecosystems. Annu. Rev. Ecol. Evol. Syst., 35, 257–284.

Arnold, C.L., Jr. and C.J. Gibbons. 1996. Impervious surface coverage: the emergence of a key environmental indicator. J. of the American Planning Association, 62(2), 243–258.

Barnett J, D.L. Bechler, C. Denizman, J. Grable, J. Nienow, W. Tietjen, J. Turco, G.L. Wood. 2007. Water Quality and Aquatic Habitat Assessment for the Alapahoochee Watershed, Nonpoint Source Management Program, Section 319(h). Report submitted to the Environmental Protection Division, Department of Natural Resources, Georgia, USA.

Coles, J.F., T.F. Cuffney, G. McMahon, and C.J. Rosin. 2010. Judging a brook by its cover: the relationship between ecological condition of a stream and urban land cover in New England. Northeastern Naturalist, 17(1), 29–48.

Engel, S.R. and J.R. Voshell. 2002. Volunteer biological monitoring: can it accurately assess the ecological condition of streams? Am. Entomologist, 48(3), 164–177.

ESRI. 2011. ArcGIS Desktop: Release 10. Redlands, California: Environmental Systems Research Institute.

Fore L.S., K. Paulsen, and K. O'Laughlin. 2001. Assessing the performance of volunteers in monitoring streams. Freshwater Biol., 46, 109–123.

Frost, J. 2014. Regression Analysis: How to Interpret S, the Standard Error of the Regression. The Minitab Blog [Internet]. Accessed 13 December 2016. http://blog.minitab.com/blog/adventures-in-statistics/regression-analysis-how-to-interpret-s-the-standard-error-of-the-regression.

Fruend, R.J. 1971. Some observations on regressions with grouped data. The American Statistician, 25(3), 29–30.

Georgia Adopt-A-Stream. 2006. Aquatic Macroinvertebrate Field Guide for Georgia's Streams [Internet]. Accessed 2 January 2018. https://adoptastream.georgia.gov/sites/adoptastream.georgia.gov/files/related_files/document/Macro_Key.pdf.

Georgia Adopt-A-Stream. 2015. Biological and Chemical Stream Monitoring [Internet]. Accessed 2 January 2018. https://adoptastream.georgia.gov/sites/adoptastream.georgia.gov/files/related_files/document/MacroChemManual.pdf.

Gotelli, N.J. and A.M. Ellison. 2013. A primer of ecological statistics, second edition. Sinauer Associates, 614 pp.

Gray, L. 2004. Changes in water quality and macroinvertebrate communities resulting from urban stormflows in the Provo River, Utah, U.S.A. Hydrobiologia, 518, 33–46.

Gregory, M.B. and D.L. Calhoun. 2007. Physical, chemical, and biological responses of streams to increasing watershed urbanization in the piedmont ecoregion of Georgia and Alabama, 2003. US Geological Survey Scientific Investigations Report 2006-5101-B.

Hilsenhoff, W.L. 1988. Rapid field assessment of organic pollution with a family-level biotic index. J. N. Am. Benthological Soc., 7(1), 65–68.

Minitab 17 Statistical Software. 2010. [Computer software]. State College, Pennsylvania: Minitab, Inc. www.minitab.com.

McMahon, G. and T.F. Cuffney. 2000. Quantifying urban intensity in drainage basins for assessing stream ecological conditions. J. of the American Water Resources Association, 36(6), 1247–61.

Moore, A.A. and M.A. Palmer. 2005. Invertebrate biodiversity in agricultural and urban headwater streams: implications for conservation and management. Ecological Applications, 15(4), 1169–1177.

Ourso, R.T. and S.A. Frenzel. 2003. Identification of linear and threshold responses in streams along a gradient of urbanization in Anchorage, Alaska. Hyrdobiologia, 501, 117–131.

Paul, M.J. and J.L. Meyer. 2001. Streams in the urban landscape. Annual Review of Ecology and Systematics, 32(1), 333–365.

Roy, A.H., A.D. Rosemond, M.J. Paul, D.S. Leigh, and J.B. Wallace. 2003. Stream macroinvertebrate response to catchment urbanization (Georgia, U.S.A.). Freshwater Biol., 48, 329–346.

Stahley, A. and C.H. Kodani. 2011. Assessing small streams in the upper Ocmulgee watershed using the Georgia Adopt-a-Stream monitoring protocols. Georgia Journal of Science, 69(2), article 6. https://digitalcommons.gaacademy.org/gjs/vol69/iss2/6.

U.S. Geological Survey. 2014. NLCD 2011 Percent Developed Imperviousness (2011 Edition, amended 2014) - National Geospatial Data Asset (NGDA) Land Use Land Cover. http://www.mrlc.gov.

U.S. Geological Survey. 2016. The National Map. [Internet]. Accessed 20 December 2016. http://nationalmap.gov/3DEP/3dep_prodserv.html.

Utz, R.M., R.H. Hilderbrand, and D.M. & Boward. 2009. Identifying regional differences in threshold responses of aquatic invertebrates to land cover gradients. Ecological Indicators, 9(3), 556–567.

Van Emden, H. 2008. Statistics for Terrified Biologists. Blackwell Publishing, 343 pp.

Voshell, J.R. 2002. A Guide to Common Freshwater Invertebrates of North America. The McDonald and Woodward Publishing Company, 442 pp.

Wang, B.D., S. Liu, Y. Liu, D.L. Zhang, and L. Wang. 2012. Impacts of urbanization on stream habitats and macroinvertebrate communities in the tributaries of Qiangtang River, China. Hydrobiologia, 680, 39–51.

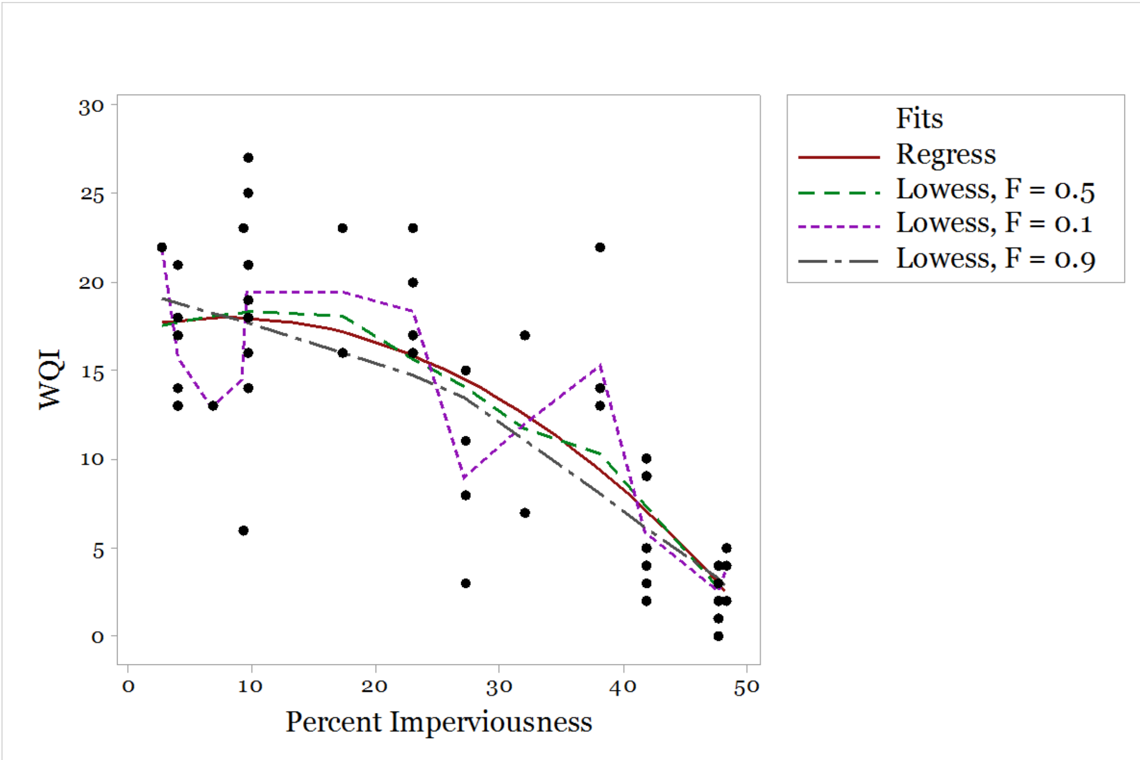
Zar, J.H. 2010. Biostatistical Analysis (5th Edition). Prentice Hall, 944 pp.

APPENDIX I

Coordinates of the Study Sites in UTM, Zone 16N,Number of Visits, Average, Minimum, and Maximum WQI

SiteName	Northing	Easting	Number of Visits	Average WQI	Minimum WQI	Maximum WQI
Angel Creek	3721119	745984	6	16	13	21
Big Springs Park	3705074	765296	1	11	--	--
Camp Creek Bridge	3716489	770203	1	25	--	--
Coker Creek	3717014	763525	1	13	--	--
Crooked Creek	3720905	746083	1	14.5	6	23
CSU	3720628	747780	8	2.6	0	4
Gardner Park	3715856	756738	5	9	3	15
Griffin Golf Course	3681154	754486	1	6	--	--
Hidden Valley	3722614	758377	7	20	14	27
Indian Springs	3718286	747574	7	6	2	10
JP Mosely Park	3715000	763054	2	19.5	16	23
Lake City Hall	3721601	746345	3	3.7	2	5
Liberty Baptist	3717781	754281	2	12	7	17
Maddox Rd	3717998	749585	3	16.3	13	22
Panola Mtn SP	3724099	762857	2	22	22	22
Pates Creek Park	3709583	756304	1	19	--	--
Rum Creek	3711424	754930	1	17	--	--
Southlake Mall	3718353	745483	1	14	--	--
Stockbridge HS	3716788	759552	5	18.6	16	23

APPENDIX II



Lowess regression of WQI vsersus imperviousness. The Lowess regression process does not provide a model equation for the data, but it produced a curve-fitted line notably similar to the quadratic model when the default value of F = 0.5 was selected. F = 0.9 produced what amounts to two straight lines, whereas F = 0.1 yielded a seemingly haphazard pattern.