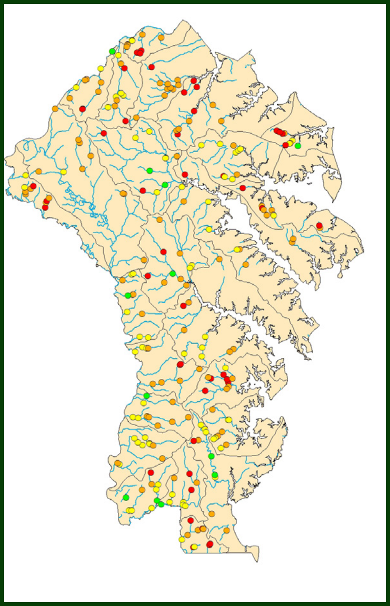

Aquatic Biological Assessment of the Watersheds of Anne Arundel County, Maryland: Round Two 2009 - 2013

Anne Arundel County, Maryland
Department of Public Works
Watershed, Ecosystem, and Restoration Services

Aquatic Biological Assessment of the Watersheds of Anne Arundel County, Maryland: Round Two 2009 - 2013

Prepared for:

Anne Arundel County
Department of Public Works
Watershed, Ecosystem, and Restoration Services
Ecological Assessment Program

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Executive Summary

In 2004, a Countywide Biological Monitoring and Assessment Program for Anne Arundel County, Maryland was developed to assess the biological condition of the County's streams at multiple scales (i.e., site-specific, primary sampling unit (PSU), and countywide). Under the Countywide Biological Monitoring and Assessment program, biology (i.e., benthic macroinvertebrates) and stream habitat, as well as geomorphological and water quality parameters, are assessed at approximately 240 sites throughout the entire County over a 5-year period using a probabilistic, rotating-basin design. Round One of the County's Biological Monitoring and Assessment Program occurred between 2004 and 2008. This effort summarizes the findings of Round Two (2009 – 2013) of the County's Biological Monitoring and Assessment Program, with a discussion of the results at both countywide and PSU scales.

Based on the Benthic Index of Biotic Integrity (BIBI) for coastal plain streams, Anne Arundel County streams during the Round Two assessment period were generally in poor biological condition. Countywide BIBI results indicate that only 5% of the streams in the County were in "Good" condition, 32% were rated "Fair", 43% were rated "Poor", and 20% were classified as "Very Poor", which is consistent with findings of the Round One survey during the previous five year period from 2004 to 2008 (Hill and Pieper, 2011). There was no significant difference in average biological conditions between Round One and Round Two surveys. Physical habitat conditions in County streams were generally rated "Partially Degraded" using the MBSS Physical Habitat Index (PHI) method, and "Partially Supporting" using the U.S. EPA's Rapid Bioassessment Protocol (RBP), which are also similar to Round One results.

Biological conditions at the PSU scale resulted in six PSUs rated as "Fair," 17 rated "Poor" and one rated "Very Poor." Only five PSUs saw significant differences in BIBI scores between Round One and Round Two. Marley Creek and Stocketts Run both saw BIBI scores decrease, which was generally attributed to degrading water quality conditions. Three PSUs (West River, Sawmill Creek, and Cabin Branch) saw BIBI scores increase in Round Two, which was attributed to depressed BIBI scores in 2008 resulting from severe drought conditions. Physical habitat results using the PHI resulted in 20 PSUs rated as "Partially Degraded," three rated as "Degraded," and only one PSU rated as "Minimally Degraded." RBP physical habitat rated 16 PSUs as "Partially Supporting," seven as "Supporting," and one was rated "Non-Supporting." Geomorphic assessment data indicate that the majority of streams assessed were classified as Rosgen "E" type (23%), "F" type (22%), or "G" type (20%) channels followed by "C" (10%), "DA" (7%), and "B" (3%) type channels with the remaining 15% of streams either classified as "Transitional" or the stream type could not be determined. Water quality data suggest that many PSUs have pH values consistently below the minimum limit specified in COMAR of 6.5 (29% of sites), and several of the more developed PSUs had highly elevated conductivity levels (46% of sites). Analysis of land use and imperviousness show 11 PSUs having predominantly developed land use and the remaining 13 PSUs dominated by forested land use. Impervious surface percentages at the PSU scale ranged from 2.9% to 35.5%.

Nonparametric Kendall rank correlations found significant correlations between a number of biotic and abiotic variables. Both the RBP and PHI physical habitat indices were positively correlated with BIBI scores ($p < 0.05$), while neither was significantly correlated to the BIBI in the rural PSUs. BIBI scores were

moderately correlated (negatively) to percent imperviousness ($p < 0.05$) and percent developed ($p < 0.05$) land use variables, and correlated (positively) with percent forested ($p < 0.05$) and percent agriculture ($p < 0.001$) variables. Specific conductivity was negatively associated with EPT Taxa ($p < 0.001$) and Percent Intolerant ($p < 0.001$) metrics, but only correlated at the 0.05 level with the BIBI. Several geomorphic variables were significantly correlated with biotic variables, but the findings may be an artifact of intercorrelation with drainage area. Numerous biological and physical habitat variables demonstrated strong positive correlations with drainage area, suggesting BIBI and RBP index scores are influenced by drainage area size. This evaluation is useful for understanding factors that affect stream quality, for improving water-quality management programs, for predicting stream response, and for documenting changing conditions over time in Anne Arundel County.

Acknowledgements

The principal authors of this document were Colin Hill, Megan Crunkleton and Michael Pieper of KCI Technologies, Inc. Aquatic Resources Center completed benthic macroinvertebrate sample sorting and primary identification and Freshwater Benthic Services completed QC taxonomic identifications in 2009. Environmental Services and Consulting completed benthic macroinvertebrate sample sorting and primary identification and Aquatic Resources Center completed QC taxonomic identifications from 2010-2013. County staff instrumental in program management and quality assurance are Janis Markusic and Christopher Victoria in the Department of Public Works; Watershed, Ecosystem, and Restoration Services. Annual sampling, data preparation, and reporting were conducted by Tetra Tech, Inc. in 2009, and KCI Technologies, Inc. from 2010-2013.

The appropriate citation for this report is:

Hill, C. R., Crunkleton, M.C. and M.J. Pieper. 2014. Aquatic Biological Assessment of the Watersheds of Anne Arundel County, Maryland: Round Two 2009 – 2013. Anne Arundel County Department of Public Works, Watershed, Ecosystem, and Restoration Services, Annapolis, Maryland.

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1 Introduction

In 2003, the Anne Arundel County Office of Environmental & Cultural Resources (now the Department of Public Works, Watersheds, Ecosystems, and Restoration Services) incorporated physical, chemical, and biological assessments into their stream monitoring program in an effort to document and track changes in the ecological condition of Countywide stream resources. Prior to 2003, the County used a combination of water chemistry sampling, stream inspection, stormwater sampling, and a limited amount of biological sampling to support environmental decision-making. For example, several programs focused at the site- or stream-specific scale (e.g., Town Center Monitoring Program, Church Creek water quality monitoring) were implemented to monitor the chemical and physical conditions (and later biological conditions) in selected County streams. In 2001, the County initiated a series of watershed studies and watershed management plans which included systematic stream assessments, targeted biological monitoring and the development of the stream assessment tool (SAT) and the watershed management tool (WMT). However, the County found that information necessary to adequately characterize the biological condition of its major watersheds and to satisfy the needs and goals of the County's planning and management efforts were lacking. A comprehensive biological monitoring and assessment program would allow managers to:

- Document the ecological status of Anne Arundel County watersheds;
- Contribute to understanding dominant stressors and stressor sources affecting stream and watershed ecology;
- Track ecological health trends in the County's watersheds over time, and
- Have monitoring data be an integral part of resource management in the County.

Consequently, a Biological Monitoring and Assessment Program for Anne Arundel County, Maryland was developed by Hill and Stribling (2004) with the input of County staff and a technical advisory group comprised of local, State, and Federal government officials as well as representatives from academia. Under the Countywide Biological Monitoring and Assessment Program, biology and stream habitat, as well as geomorphological and water quality parameters, are assessed at approximately 240 sites throughout the entire County (i.e., 10 sites per Primary Sampling Unit or PSU) over a 5-year period using a randomized rotating-basin design. Further information describing the Countywide Biological Monitoring and Assessment Program design can be found in Hill and Stribling (2004).

This report summarizes the results of Round Two (2009 – 2013) of the County's Biological Monitoring and Assessment Program and compares stream health conditions with the baseline conditions established in Round One (2004 – 2008). In addition, this report examines the interactions and associations between biotic and abiotic variables to determine which factors are influencing the chemical, physical, and biological integrity of the County's streams.

2 Methods

2.1 Field Methods

Both field sampling and data analysis methods were developed to be directly comparable to Department of Natural Resources' Maryland Biological Stream Survey (MBSS), and complementary to those in place in Prince George's, Montgomery, and Howard Counties in Maryland (Hill and Stribling, 2004). Primary data collected include site location (latitude and longitude), pH, dissolved oxygen, water temperature and conductivity, benthic macroinvertebrates, and physical habitat index (PHI) following MBSS methodologies (Kazyak, 2001; DNR, 2007). Physical habitat assessment using USEPA's Rapid Bioassessment Protocols (RPB; Barbour et al., 1999) for Low Gradient streams was also performed. A geomorphic monitoring component was added in 2005, which includes stream cross-sectional measurement, stream gradient, and a modified Wolman pebble count based on the procedures describe by Harrelson (1994) and Rosgen (1996). Biological data were analyzed using the revised (2005) version of the MBSS Coastal Plain BIBI (Southerland et al., 2005).

A more detailed description of the sampling and analysis methods can be found in the annual Biological Monitoring and Assessment Program Annual Reports (Crunkleton, et al., 2013; Crunkleton, et al., 2012; Crunkleton, et al., 2011; Crunkleton, et al., 2010; Victoria, et al., 2011). Specific information regarding the sampling and analysis methods, including the standard operating procedures (SOPs), can be found in the *Documentation of Method Performance Characteristics for the Anne Arundel County Biological Monitoring Program* (Hill et al., 2010) and the *Quality Assurance Project Plan for Anne Arundel County Biological Monitoring and Assessment Program* (Hill et al., 2011).

2.2 Quality Assurance/Quality Control

A primary goal of the County is to produce biological assessments of its water resources with objective and defensible data. As a result, a comprehensive Quality Assurance Project Plan (QAPP) for ensuring the collection of such data was developed simultaneously with the Countywide Biological Monitoring and Assessment Program initially by Tetra Tech in 2004, and was updated by KCI in 2011. The QAPP followed U. S. Environmental Protection Agency requirements for developing project plans (USEPA, 1995) and describes the biological stream assessment protocol including data collection methods (SOPs), the technical rationale behind the procedures, and the series of activities and reporting procedures that are used to document and communicate data quality.

To provide a guideline for ongoing data quality assessments associated with the County's Biological Monitoring Program and to help enhance defensibility of data and assessments, a method performance characteristic framework was developed and outlined in *Documentation of Method Performance Characteristics for the Anne Arundel County Biological Monitoring Program* (Hill et al., 2005, Hill and Pieper, 2010). In this guidance document, five performance quality characteristics (precision, accuracy, bias, representativeness, and completeness) were evaluated, either quantitatively or qualitatively, for each of six methods making up the biological assessment protocol for Anne Arundel County: field sampling, laboratory sorting and subsampling, taxonomic identification and enumeration, data entry, metric calculation, and site assessment. From the results of the performance characteristic evaluation, quantitative measurement quality objectives (MQOs) were developed for each of the six biological assessment components, which help to define criteria for acceptable data quality.

As part of the routine QA/QC process, performance characteristics are calculated for each annual monitoring event and compared to the stated MQOs to determine the acceptability and comparability of each data set. Detailed QA/QC results from each Round Two monitoring year can found in the Biological Monitoring and Assessment Program's Annual Reports (Crunkleton et al., 2010, 2011, 2012, 2013; Victoria et al., 2011).

2.3 Land Use/Land Cover and Impervious Analysis

Drainage areas to each sampling site were delineated during the analysis phase of each individual Round Two sampling year using geographic information system (GIS) data. The County's land cover GIS data is a hybrid land use/land cover dataset, but primarily represents land cover and is referred to in this report as such. The County's impervious GIS data is a polygon file that represents roadways, building footprints, and parking lots. From these data, the land cover and impervious surfaces in each sampling site's drainage area were calculated. Area and percent area of land cover and imperviousness for each sampling site's drainage area was calculated. Land cover and imperviousness for each PSU was determined following the same procedures. The calculation of impervious area did not account for treated vs. untreated imperviousness nor connected vs. disconnected impervious area.

For those sites sampled in 2009 and 2010, land cover was evaluated using countywide land cover and impervious data layers from 2007. Sites sampled from 2011 through 2013 were evaluated using 2011 land cover and impervious data layers.

To better summarize the land use characteristics, data from the County's land cover layers were combined into four primary land use classes as shown below in Table 1. These land use classes are utilized to characterize site drainage areas and PSU, and are utilized in much of the analysis. References to *land use* in this report refer to these combined land use classes.

Table 1. Combined Land Use Classes

Land Use Class	Land Cover Type
Developed	Airport, commercial, industrial, transportation, utility, residential (1/8-ac., ¼-ac., ½-ac., 1-ac., and 2-ac.)
Forested	Forested wetland, residential woods*, and woods
Agriculture	Pasture/hay, row crops
Open	Open space, open wetland, water

*not present in 2011 Land Cover layer

2.4 Data Analysis

Round Two data were analyzed to investigate associations between chemical, physical, and biological, parameters in order to better understand stressors impacting Anne Arundel County streams. While a detailed stressor identification following the USEPA Stressor Identification (SI) process (USEPA, 2000) for all of the County's impaired waters or PSUs was beyond the scope of this report, an attempt was made to apply the general SI framework by analyzing associations between measurements of the candidate causes and effects. Following the SI recommendations for the use of statistics to analyze observational data in the stressor identification process, data were primarily analyzed using summary statistics to evaluate measurements of potential stressors and correlations to quantify relationships between stressor and response variables. However, it should be noted that correlation does not necessarily indicate causation given that stressors often covary with each other and with natural environmental variables, and a strong relationship between a candidate cause and a biological variable may be due to a factor other than the candidate cause (USEPA, 2000). Correlation analysis indicates only the probability that an apparent relationship is due to sampling variance, and to strengthen the case for causality consideration must be given to other possible underlying variables and to whether the relationship holds in other populations (Bewick et al., 2003).

2.4.1 *Box Plots*

Univariate box plots, also referred to as box-and-whisker plots, were generated in XLSTAT (Addinsoft, 2010) to show the distribution of values for each PSU including the following summary statistics; minimum, first quartile (i.e., value for which 25% of the values are less), median, mean, third quartile (i.e., value for which 75% of the values are less), and maximum, as well as anomalous values including outliers, and extreme outliers. Generally, an outlier is a data point that lies an abnormal distance from other values in a random sample from a population (NIST/SEMATECH, 2011). A standard outlier is a value that falls within the lower and upper limits of the distribution; the lower limit being the lower quartile minus 1.5 times the interquartile range, and the upper limit being the upper quartile plus 1.5 times the interquartile range. Similarly, an extreme outlier is a value that falls beyond the upper and lower limits and within the range between the lower quartile minus three times the interquartile range and the upper quartile plus three times the interquartile range.

PSUs with smaller (i.e., tighter) boxes and 'whiskers' indicate a smaller range of values, while larger (i.e., looser) boxes and 'whiskers' indicate a larger range of values.

2.4.2 *Correlations*

Correlation, one of the most commonly used techniques for investigating the relationship between two quantitative variables, quantifies the strength of the relationship between a pair of variables (Bewick et al., 2003). Simple linear correlation analysis relies on assumptions that both variables being compared are normally distributed and the linear plot is homoscedastic (i.e., uniform variance). However, a Shapiro-Wilk goodness of fit test (Shapiro and Wilk, 1965) revealed that the BIBI data do not fit a normal distribution (p 0.001, $\alpha = 0.05$). Consequently, a non-parametric correlation analysis using the Kendall rank correlation coefficient (Kendall, 1955), was performed on the data set using XLSTAT version 2010.3.07 (Addinsoft, 2010). The Kendall rank correlation coefficient, or Kendall's tau (τ), evaluates the degree of similarity between two sets of ranks given to a same set of objects and provides a set of binary values, which are then used to compute a correlation coefficient (Abdi, 2007).

Correlations were performed to determine which environmental variables show strong associations with biological, physical, and water quality response indicators. The Kendall tau correlation coefficient quantifies the strength of the linear relationship between a pair of variables. Values of the coefficient range from -1 to 1. Negative values indicate an inverse relationship between the two values (i.e., when one variable increases the other decreases), while positive values indicate a positive relationship (i.e., both variables increase). The absolute value of the number indicates the strength of the association, with larger absolute values indicating stronger associations between the two variables. The significance level (also called the p-value) is a statement of probability regarding the likelihood that the differences in two variables after the application of a given statistical test are related to interactions between the variables themselves instead of being related to chance, with smaller values indicating a stronger likelihood of a non-random relationship. A significance level of 0.05 (i.e., 95% probability that the observed relationship is not due to chance) was used as a cutoff for significant correlations, and p-values of less than 0.001 (i.e., 99.95% probability) defined highly significant correlations. For a simplified discussion of results, correlations are defined as weak (τ <0.1), moderate (τ = 0.1 to 0.3), or strong (τ >0.3).

2.4.3 *Benthic Macroinvertebrate Taxa Analysis*

Analysis was performed on the raw benthic macroinvertebrate taxa data to evaluate which, if any, taxa may be unique to sites categorized as 'good' by the BIBI. A taxa list was assembled for all sites that received BIBI scores of 4.00 or greater, representing the population of taxa from minimally-impaired sites. A taxa list was also assembled for all sites that received BIBI scores of less than 2.00, which represented the population of taxa from highly impaired sites. The two lists were then compared for overlap and taxa were selected that were unique to only minimally-impaired sites. The resulting list of minimally-impaired taxa was compared against another taxa list comprised of sites that received biological condition ratings of 'poor' (BIBI scores between 2.00 – 2.99). The final list was then comprised of taxa that either remained unique to unimpaired sites (BIBI scores of 3.00 or greater) or those that occurred at only a single impaired site. Taxa that were found to be unique but were identified to a higher taxonomic level than the genus level target (e.g., family, tribe) were also omitted from the list. Thus, the final list is comprised only of genera that are unique, or relatively unique, to unimpaired streams.

2.4.4 *Comparison of Round One and Round Two Results*

To compare statistical differences between mean index values from two time periods (e.g., Round One and Round Two), this report uses the method recommended by Schenker and Gentleman (2001). This is the same method used by the MBSS to evaluate changes in condition over time, and is considered a more robust test than the commonly used method, which examines the overlap between the associated confidence intervals around two means (Roseberry Lincoln et al., 2007). In this method, the 95% confidence interval for the difference in mean values $Q_1 - Q_2$ is estimated using the following formula:

$$(Q_1 - Q_2) \pm 1.96[SE_1^2 + SE_2^2]^{1/2}$$

where Q_1 and Q_2 are two independent estimates of the mean of a variable (i.e., BIBI, RBP, PHI) and SE_1 and SE_2 are the associated standard errors. The null hypothesis that $(Q_1 - Q_2)$ is equal to zero was tested (at the 5 percent nominal level) by examining whether the 95 percent confidence interval contains zero.

The null hypothesis that the two means are equal was rejected if and only if the interval did not contain zero (Schenker and Gentleman, 2001), resulting in a statistically significant difference between those two values.

3 Round Two Results

Results of Round Two sampling in Anne Arundel County from 2009 to 2013 are discussed by parameter (i.e., land use/land cover, biology, physical habitat, water quality, and geomorphology) at two different scales, the Countywide scale and PSU scale, in the following sections. Individual site assessment results are reported in the Biological Monitoring and Assessment Program's annual reports (Crunkleton, et al., 2010, 2011, 2012, and 2013; Victoria, et al., 2011).

3.1 Primary Sampling Unit Characterization

As outlined in *Design of the Biological Monitoring and Assessment Program for Anne Arundel County, Maryland*, the County was subdivided into 24 subwatershed PSUs (Hill and Stribling, 2004). To better understand the PSUs discussed in the following sections, a table containing summary characteristics for each PSU (i.e., drainage area, land use types, year sampled, etc.) has been compiled (Table 2). In addition, Countywide results are also included to provide a way to compare individual PSU results with overall conditions observed in the County throughout Round Two sampling. Countywide land use and imperviousness are calculated based on County level data. Condition ratings for the County are based on mean values for all Countywide sites (n = 240). Percentage and proportion results at the Countywide scale (e.g., total proportion of Rosgen stream types, percentage of biological conditions, percentage of physical habitat conditions, etc.) are based on the individual site results (n = 240).

3.2 Land Use/Land Cover and Imperviousness

For a description of land cover types that comprise each land use category see Section 2.3 *Land Use/Land Cover and Imperviousness Analysis.* Complete land cover data for each PSU is included in Appendix A.

Figure 1 shows the proportion of land use classes for each PSU. A total of 11 PSUs were predominantly comprised of developed land use, ranging from 45.8% in Piney Run to 66.3 % in Upper Magothy. Similar to land use in Round One, only two PSUs, Upper Patuxent and Cabin Branch were less than 20% developed. Forested land use was dominant in the remaining 13 PSUs, which ranged from 37.6% in Lyons Creek to 75.1% in Upper Patuxent. Four PSUs had the smallest proportion of forested land (less than 30%) including Sawmill Creek, Lower Patapsco, Upper Magothy, and Lower Magothy (21.8, 25.6, 28.6, and 28.7, respectively). There were no PSUs with agriculture or open land comprising the dominant land use. The highest percentage of agricultural land use occurred in Lyons Creek (31.3%), followed by Rock Branch (22.8%), Cabin Branch (21.8%), Hall Creek (21.0%), and Middle Patuxent (20.8%). Open land use was the least dominant, with the highest proportions observed in Sawmill Creek (18.3%) and Stony Run (14.6%), due in large part to the open space surrounding Baltimore-Washington

Table 2. Characterization of Anne Arundel County Primary Sampling Units from 2009-2013.

PSU Name	PSU Code	Year Sampled	Drainage Area (acres)	Percent Impervious	Percent Developed	Percent Forested	Percent Agriculture	Percent Open	BIBI Rating	PHI Rating	RBP Rating
COUNTYWIDE	-	2009-2013	266,024	14.6	43.8	39.9	6.8	9.4	P	PD	PS
Bodkin Creek	6	2011	5,872	12.6	52.0	37.1	0.2	10.7	P	PD	S
Cabin Branch	23	2013	6,443	2.9	18.3	44.8	21.8	15.1	F	PD	PS
Ferry Branch	21	2010	8,038	5.3	23.0	47.2	19.1	10.7	P	PD	PS
Hall Creek	24	2012	3,168	4.3	27.9	45.7	21.0	5.3	P	PD	PS
Herring Bay	15	2010	14,595	6.2	28.3	53.6	10.2	7.9	F	PD	PS
Little Patuxent	17	2009	28,196	17.4	35.5	49.0	3.2	12.3	P	PD	PS
Lower Magothy	8	2013	12,697	19.1	64.4	28.7	0.6	6.3	P	PD	PS
Lower North River (South River)	12	2009	23,681	16.9	48.0	40.7	4.3	7.1	P	PD	PS
Lower Patapsco	3	2012	4,040	29.5	61.5	25.6	0.0	12.9	P	PD	NS
Lyons Creek	22	2013	6,154	4.4	24.3	37.6	31.3	6.8	F	PD	S
Marley Creek	5	2009	19,425	28.6	62.8	30.3	0.4	6.5	VP	D	PS
Middle Patuxent	18	2010	6,332	7.1	25.1	41.4	20.8	12.7	F	PD	PS
Piney Run	1	2012	4,868	21.4	45.8	43.7	0.1	10.5	P	D	PS
Rhode River	13	2012	8,737	5.2	26.0	54.1	11.3	8.6	P	PD	PS
Rock Branch	20	2009	6,131	3.6	22.2	46.7	22.8	8.3	F	PD	PS
Sawmill Creek	4	2010	11,044	35.5	59.9	21.8	0.0	18.3	P	D	PS
Severn River	10	2013	28,920	18.9	57.4	32.1	2.7	7.9	P	PD	S
Severn Run	9	2011	15,424	17.5	50.4	39.3	2.4	7.9	F	PD	PS
Stocketts Run	19	2013	8,714	4.9	28.9	43.9	17.5	9.7	P	PD	PS
Stony Run	2	2010	6,203	30.6	51.7	33.2	0.5	14.6	P	PD	S
Upper Magothy	7	2011	10,031	19.7	66.3	28.6	0.0	5.1	P	PD	S
Upper North River (South River)	11	2011	12,797	6.4	29.8	56.3	8.7	5.2	P	PD	S
Upper Patuxent	16	2011	6,957	5.1	15.2	75.1	0.9	8.8	P	MD	S
West River	14	2009	7,558	6.9	29.6	46.4	19.5	4.5	P	PD	PS

BIBI Ratings: G = Good, F = Fair, P = Poor, VP = Very Poor

PHI Ratings: MD = Minimally Degraded, PD = Partially Degraded, D = Degraded, SD = Severely Degraded

RBP Ratings: C = Comparable, S = Supporting, PS = Partially Supporting, NS = Non-Supporting

International (BWI) Airport in addition to Cabin Branch (15.1%), which is largely due to Jug Bay Wetland Sanctuary acreage. A map displaying land use throughout the County, based on the 2011 Land Cover layer, is shown in Figure 2.

Within each PSU, the dominant land use type (i.e., the largest land use category, by percent, found in the upstream drainage area) representing each site sampled is shown, as a percentage of total sites, in Figure 3. Similar to Round One results, one hundred percent of sites sampled in Upper Magothy, Stony Run, and Lower Magothy were predominantly developed land use. Ninety percent of sites in Bodkin Creek and Marley Creek were also dominated by developed land use. In contrast, three PSUs, Rhode River, Upper Patuxent, and West River, had 100% of sites dominated by forested land use. Additionally, three PSUs had 90% of sites that were predominantly forested (Herring Bay, Rock Branch, and Upper North River). Fifty percent of sites in Lyons Creek were dominated by agricultural land use, followed by 40% in Ferry Branch. The proportions of dominant land use types sampled differ slightly from the proportions that characterize each PSU, as shown in Figure 1, suggesting that land use within site-specific drainage areas may be more useful in explaining the overall biological condition of each PSU as opposed to land use at the PSU scale.

The percentage of impervious cover was quite variable, ranging from a maximum of 35.5% in Sawmill Creek to a minimum of 2.9% in Cabin Branch (Table 2). Two other PSUs, Lower Patapsco and Stony Run, had impervious cover equal to or exceeding 30% of their respective drainage areas. A total of three PSUs had impervious cover between 20% and 30% (Marley Creek, Piney Run, and Upper Magothy), and six more PSUs exceeded 13% (Lower Magothy, Severn River, Severn Run, Little Patuxent, Lower North River, and Bodkin Creek). The remaining 12 PSUs all had impervious cover that was below 10%, four of which had less than five percent impervious cover (Cabin Branch, Rock Branch, Hall Creek, and Lyons Creek). A map of impervious cover throughout the County, based on the 2011 impervious cover layer, is displayed in Figure 4.

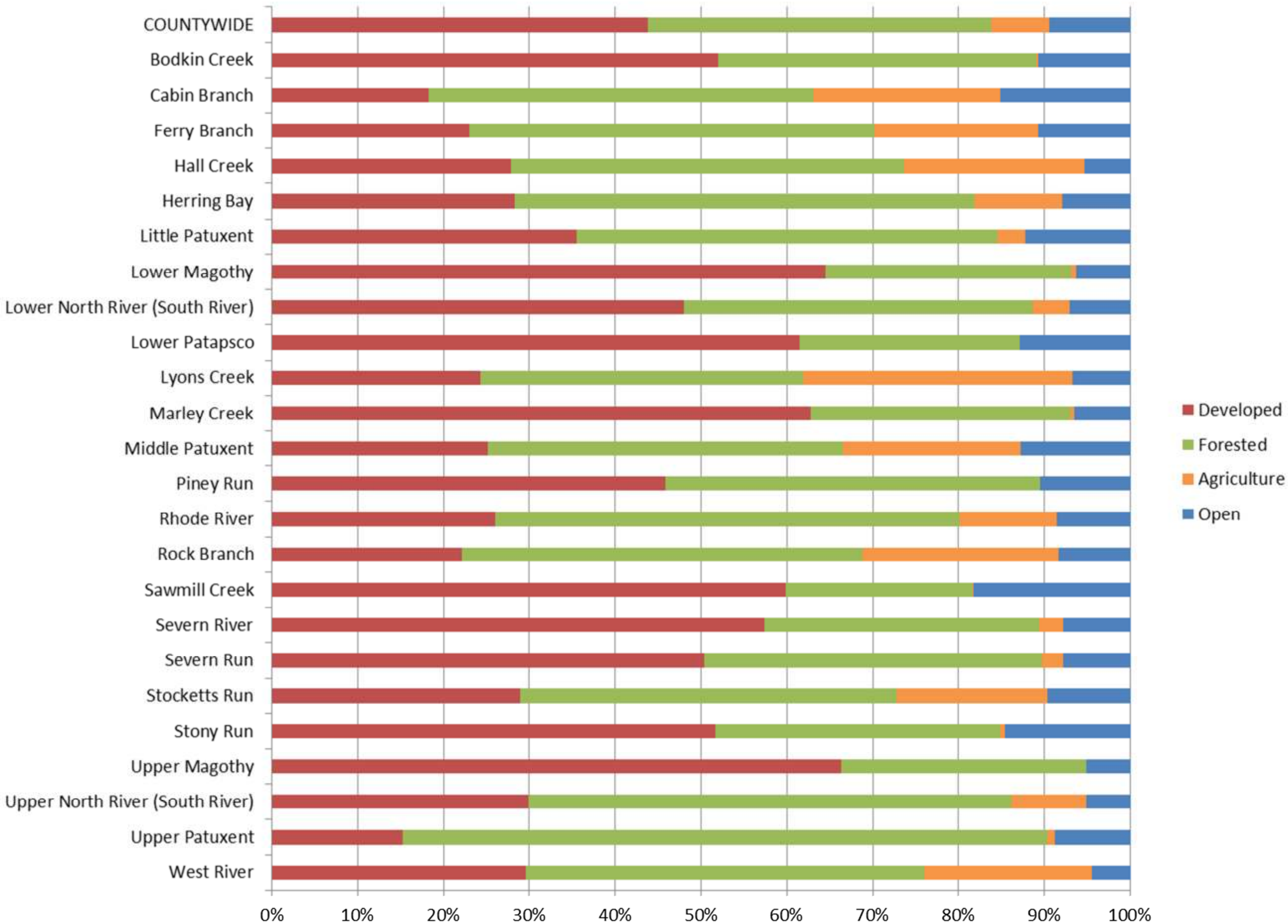

Figure 1. Percentage of Land Use Types for each PSU

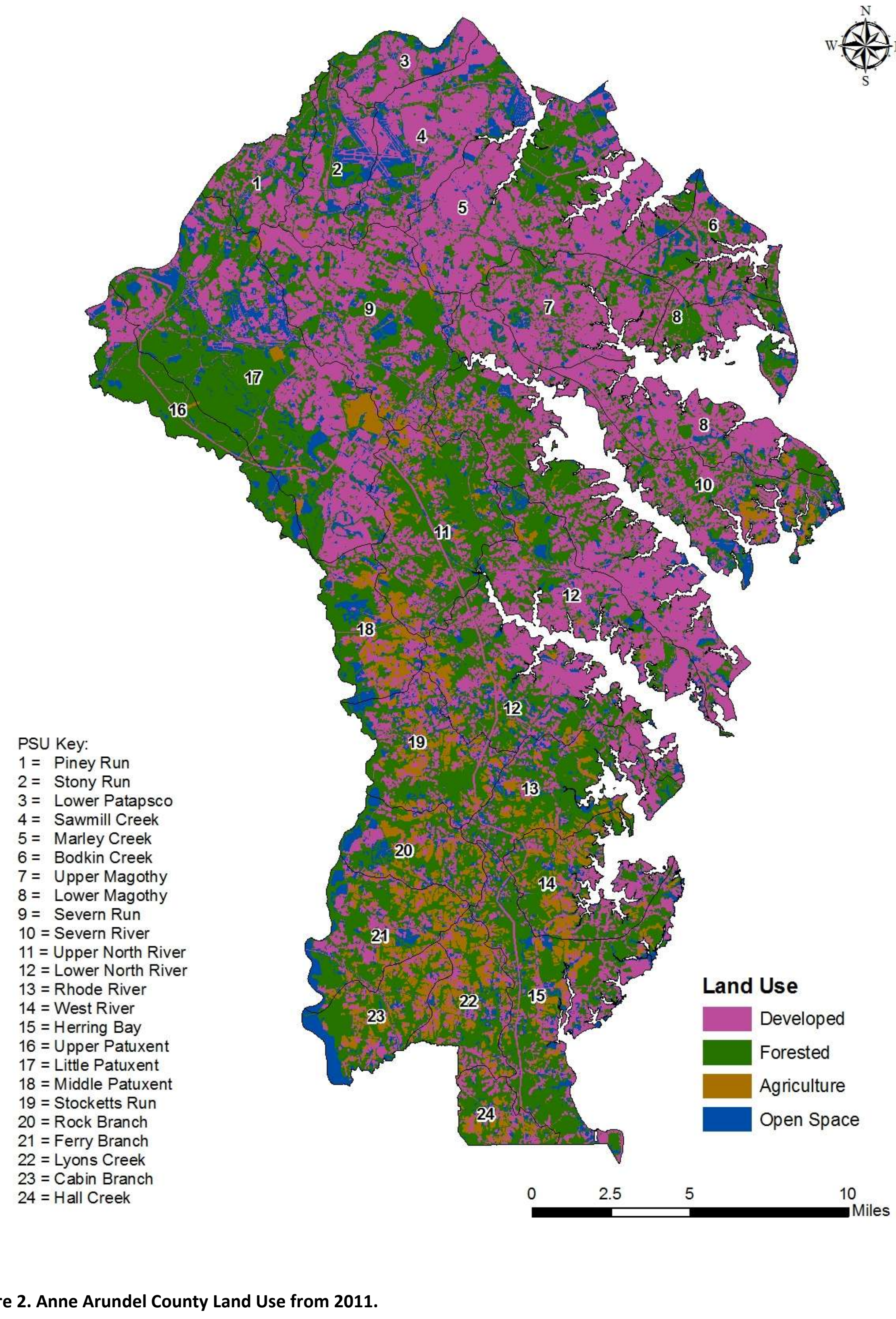

Figure 2. Anne Arundel County Land Use from 2011.

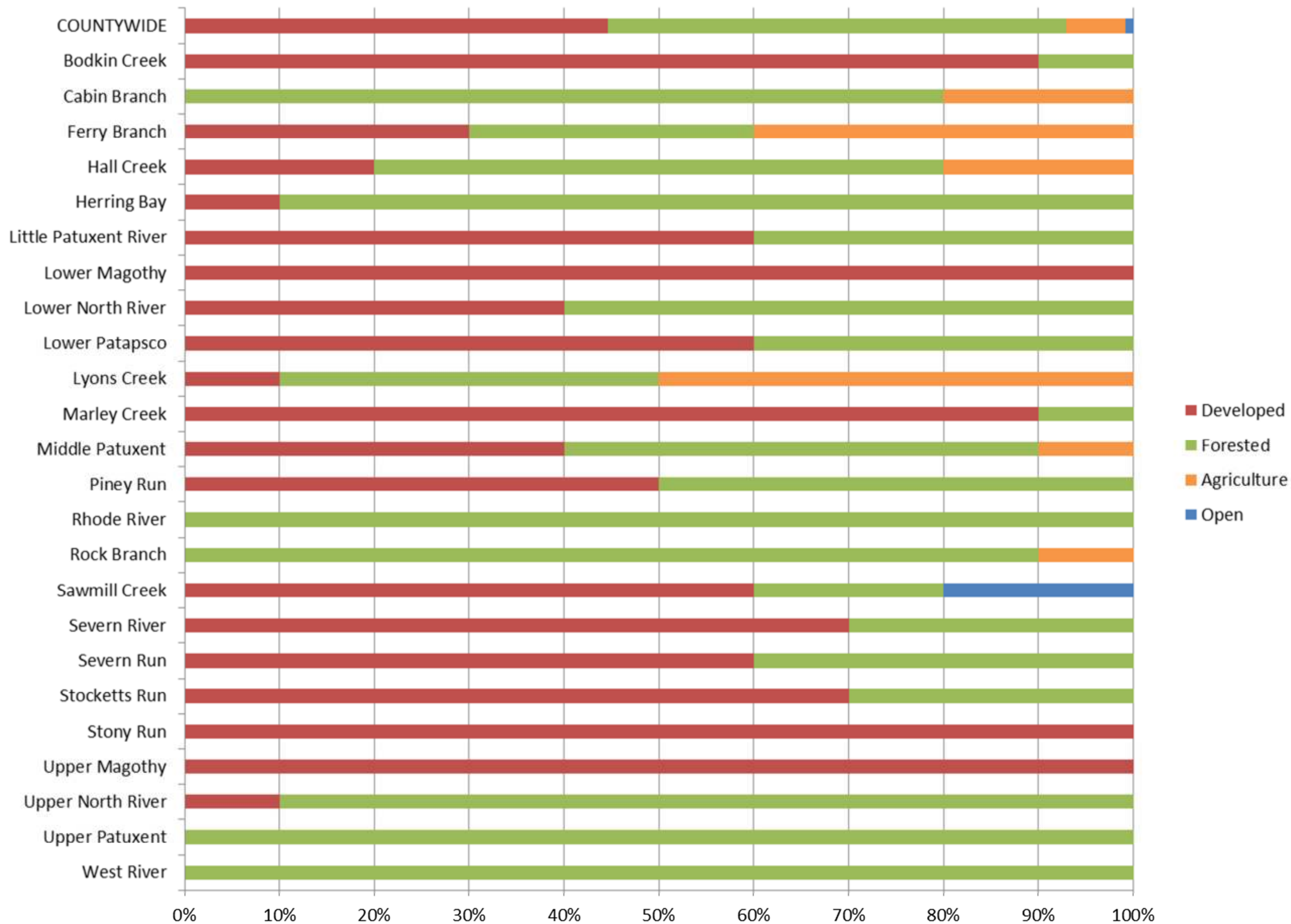

Figure 3. Dominant Land Use Draining to Each Site as a Proportion of Total Sites Sampled in Each PSU.

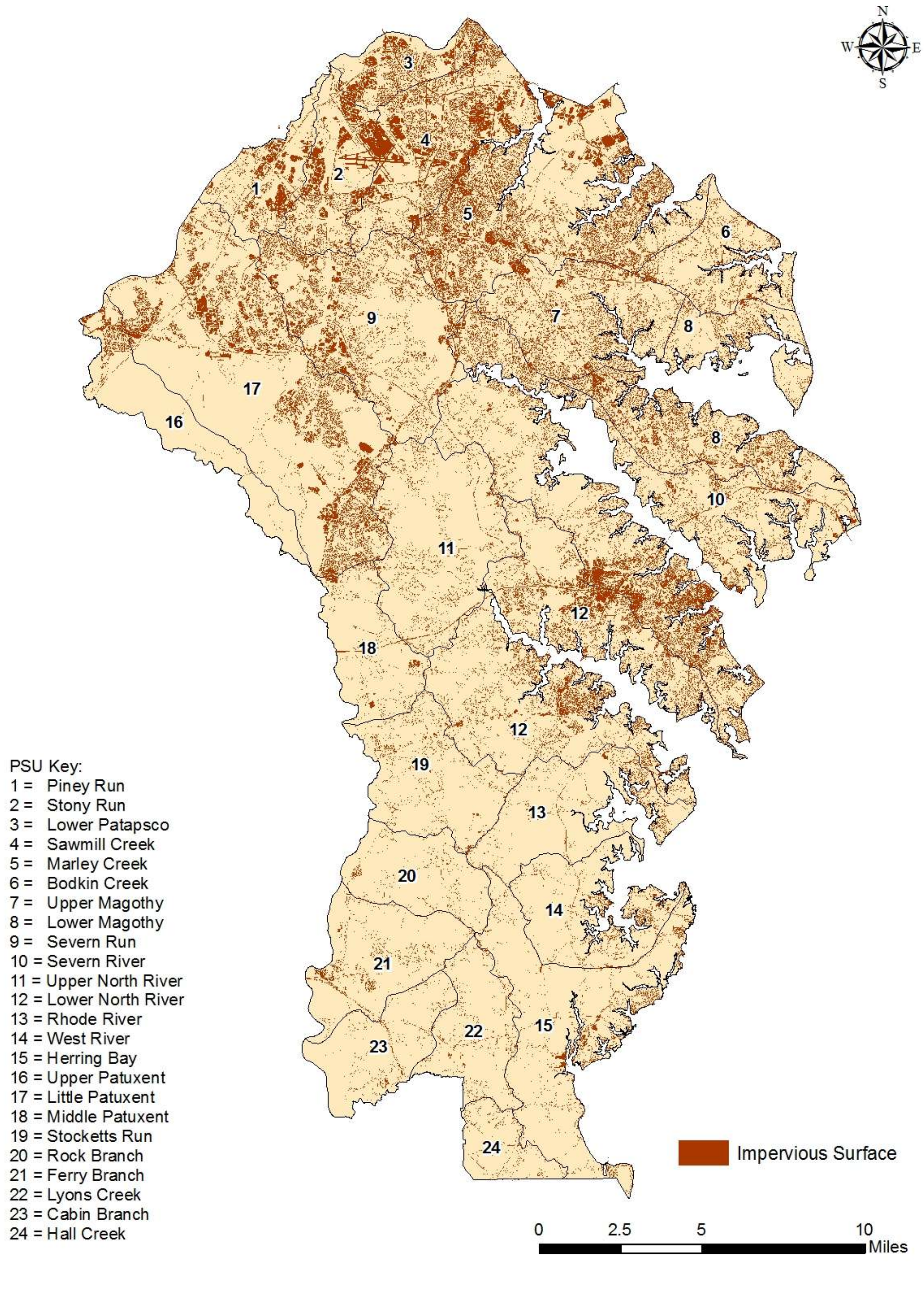

Figure 4. Anne Arundel County Impervious Surface from 2011

3.3 Biological Conditions

The biological condition of Anne Arundel County's streams was assessed using benthic macroinvertebrate indicators, namely the Benthic Index of Biotic Integrity (BIBI) developed by MBSS and specifically calibrated for Coastal Plain streams (Southerland et al., 2005). A comparison of mean BIBI scores along with relative rankings (1 = best, 24 = worst) for each PSU is included in Table 3. The overall condition of Anne Arundel County streams during the Round Two assessment period (2009-2013) was "Poor", with a mean BIBI score of 2.67 (standard deviation [SD] = 0.80).

Table 3. Mean BIBI Scores Ordered by Relative Rank for Anne Arundel County PSUs from 2009-2013

PSU	Sample	Mean BIBI	Std Dev	Rating	Rank
COUNTYWIDE	240	2.67	0.80	Poor	-
Cabin Branch	10	3.34	0.81	Fair	1
Middle Patuxent	10	3.32	0.58	Fair	2
Herring Bay	10	3.17	1.00	Fair	3
Severn Run	10	3.14	1.05	Fair	4
Rock Branch	10	3.03	0.74	Fair	5
Lyons Creek	10	3.00	0.98	Fair	6
Ferry Branch	10	2.91	0.47	Poor	7
Upper Magothy	10	2.91	0.59	Poor	8
West River	10	2.89	0.28	Poor	9
Severn River	10	2.77	0.63	Poor	10
Upper North River	10	2.74	0.88	Poor	11
Piney Run	10	2.69	0.90	Poor	12
Stony Run	10	2.69	0.98	Poor	13
Stocketts Run	10	2.60	0.91	Poor	14
Lower North River	10	2.60	0.59	Poor	15
Lower Patapsco	10	2.43	0.74	Poor	16
Bodkin Creek	10	2.40	0.92	Poor	17
Sawmill Creek	10	2.37	0.52	Poor	18
Little Patuxent River	10	2.34	0.27	Poor	19
Upper Patuxent	10	2.34	0.50	Poor	20
Hall Creek	10	2.20	0.81	Poor	21
Rhode River	10	2.17	0.45	Poor	22
Lower Magothy	10	2.17	0.59	Poor	23
Marley Creek	10	1.83	0.47	Very Poor	24

A total of six PSUs were rated "Fair" (25%), seventeen were rated "Poor" (71%), and one was rated "Very Poor" (4%; Figure 5). Cabin Branch had the highest mean BIBI score of 3.34, followed by Middle Patuxent (3.32), Herring Bay (3.17), Severn River (3.14), Rock Branch (3.03), and Lyons Creek (3.00), all of which were rated as having "Fair" biological conditions. On the opposite end of the spectrum, Marley Creek had the lowest BIBI score of 1.83, which was the only PSU rated "Very Poor."

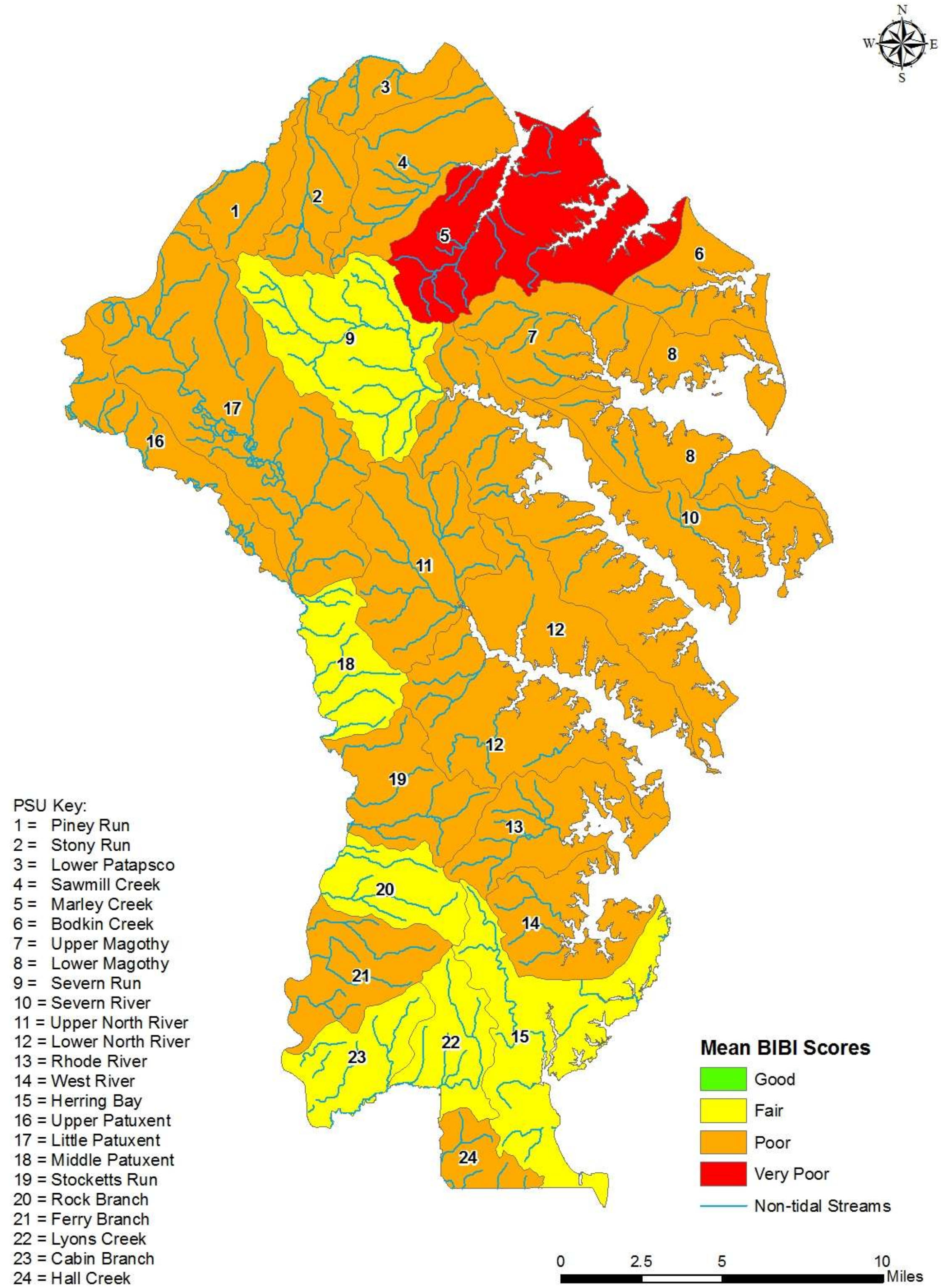

Figure 5. Average Biological Conditions for Primary Sampling Units.

Countywide biological assessment results indicate that only 5% of the streams in the County were in "Good" condition, 32% were rated "Fair", 43% were rated "Poor", and 20% were classified as "Very Poor" (Figure 6). These results are similar to findings from the Maryland Department of Natural Resources MBSS sampling efforts during their Round Three sampling period (2008-2009; DNR, 2013). Both assessments classified the majority of streams as being in either "Poor" or "Fair" biological condition; however, MBSS classified slightly more streams as being in "Very Poor" and "Good" condition (24% v. 20% and 12% v. 5%, respectively).

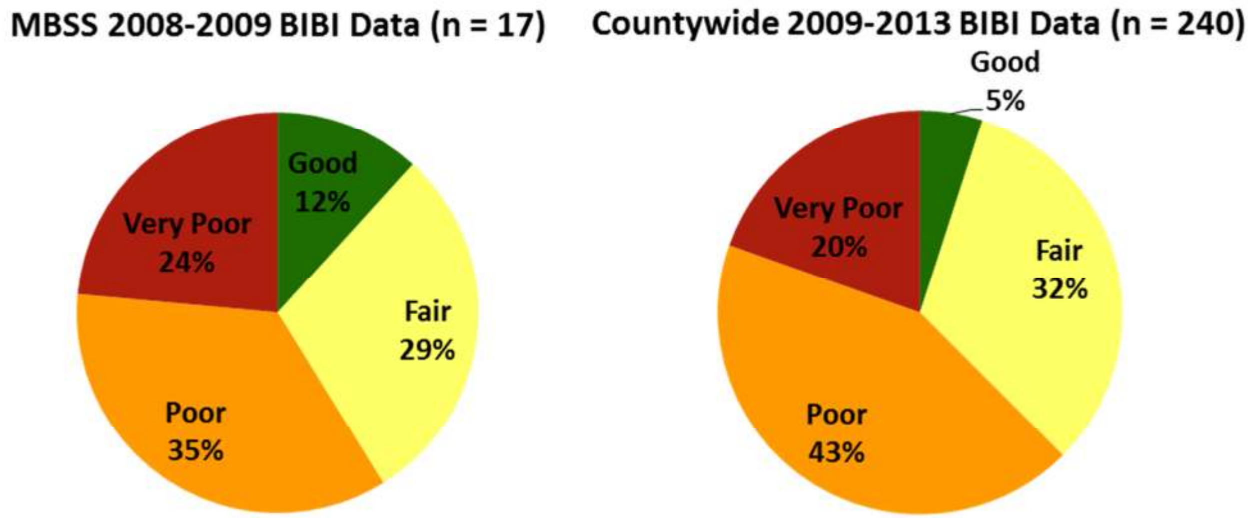

Figure 6. Comparison of Biological Conditions in Anne Arundel County Between MBSS Round 3 (2008-2009) and Countywide Round Two (2009-2013) Assessments.

A summary of site-specific biological condition ratings as a percentage of total sites within each PSU is displayed in Figure 7 and the distribution of sampling sites with their corresponding biological condition rating is displayed in Figure 8. Three PSUs (Cabin Branch, Herring Bay, and Severn Run) had over 10 percent of sites rated "Good" while six more PSUs had 10 percent of sites rated as "Good" (Bodkin Creek, Lyons Creek, Middle Patuxent, Piney Run, Rock Branch, and Upper North River). Only five PSUs (Ferry Branch, Little Patuxent River, Middle Patuxent, Rock Branch, and West River) had no sites rated as "Very Poor." Conversely, eight PSUs had 20 percent or more of sites rated as "Very Poor" and no sites rated as "Good." Moreover, two PSUs (Marley Creek and Sawmill Creek) had 100 percent of sites rated as either "Poor" or "Very Poor".

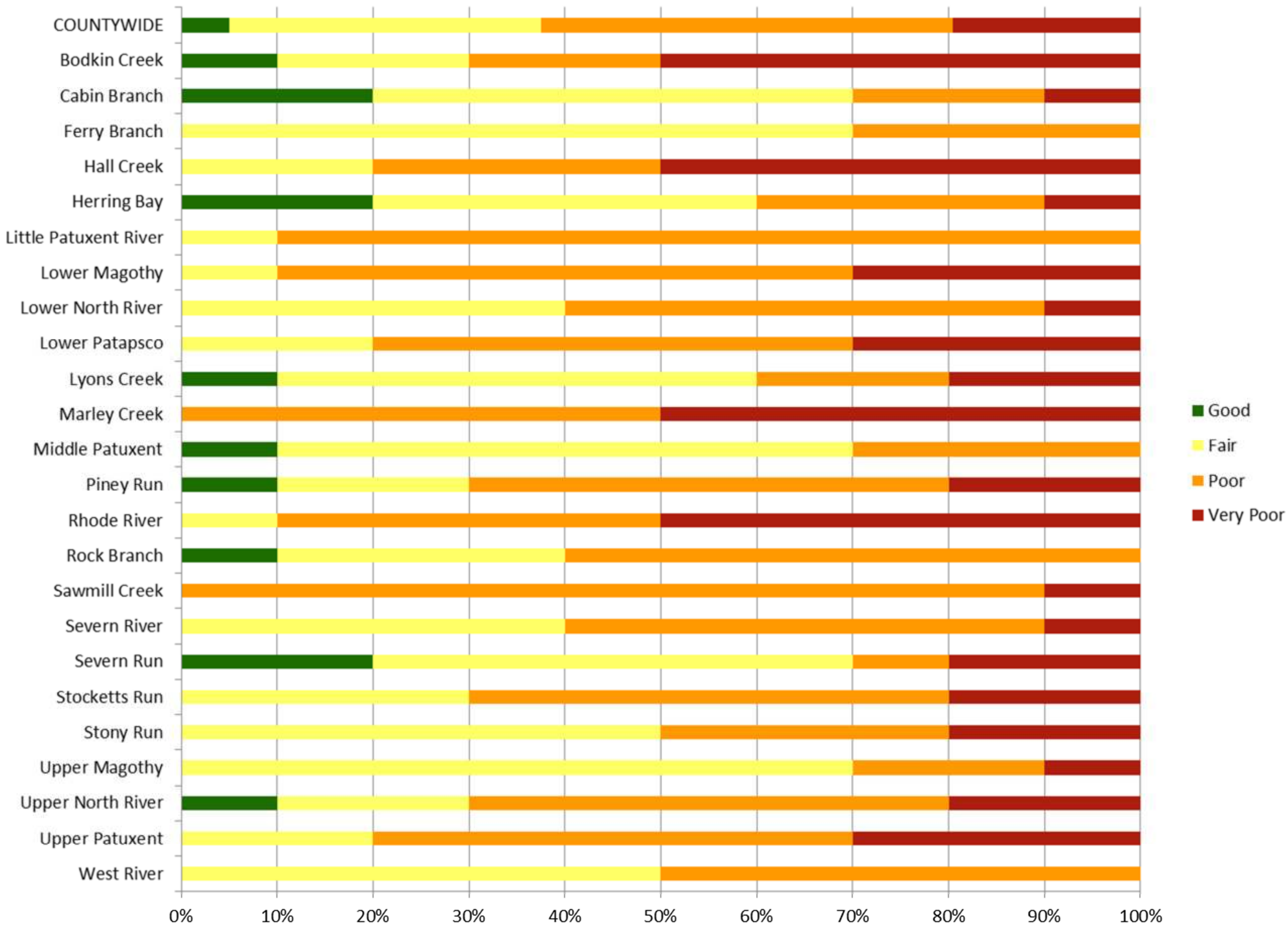

Figure 7. Biological Condition Ratings as a Percentage of Total Sites Within Each PSU.

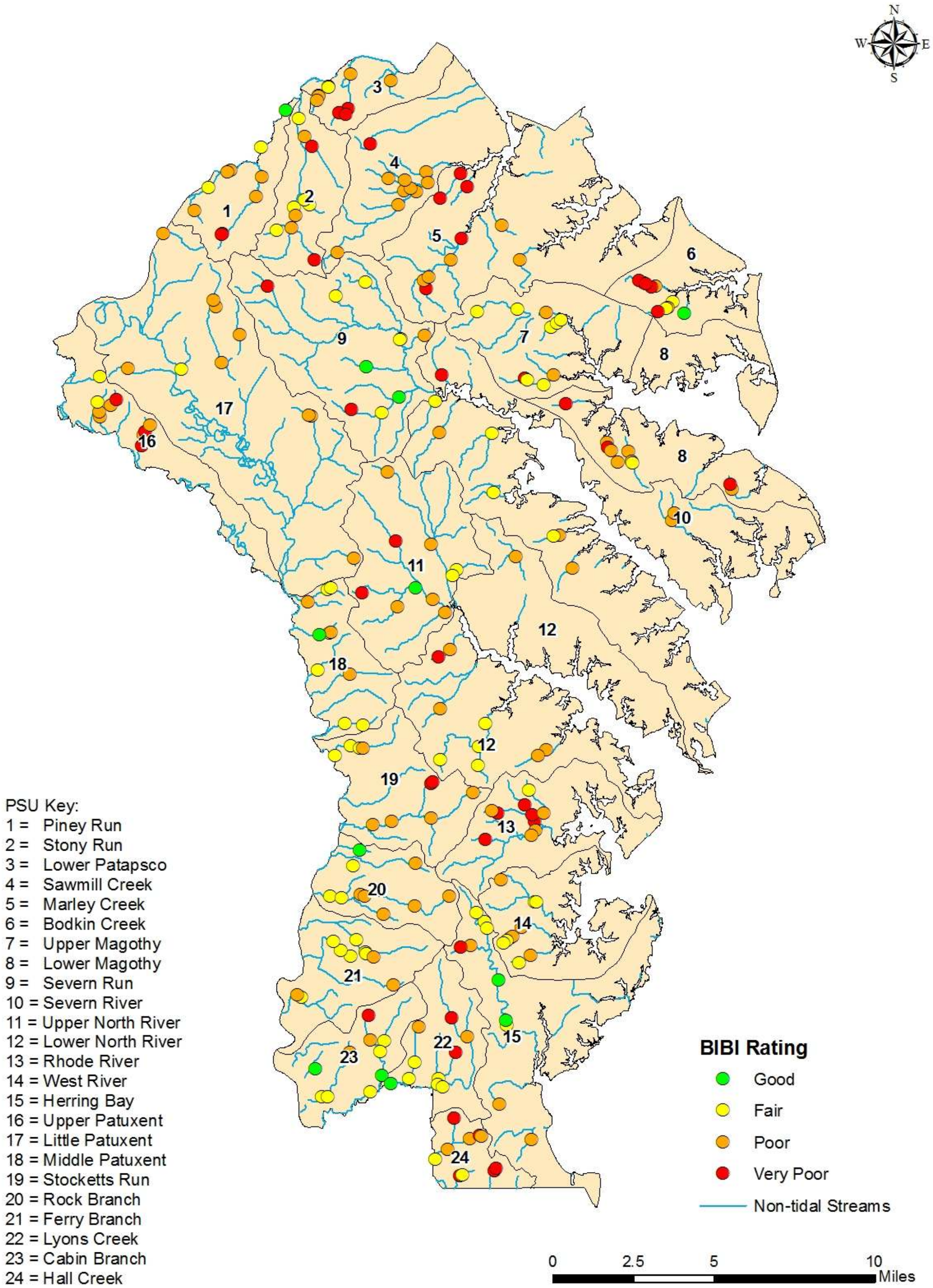

Figure 8. Countywide Biological Assessment (BIBI) Results from 2009-2013.

Box plots showing the distribution of BIBI scores for all sites sampled during Round Two ("ALL"; n = 240) in addition to each PSU are shown in Figure 9. For the Countywide analysis, scores ranged from a minimum of 1.00 (i.e., the lowest attainable score) to a maximum of 4.71 (maximum attainable is 5.00). Three quarters of sites had BIBI scores of less than or equal to 3.00, the threshold between "Fair" and "Poor" classifications. Sites rated as "Good" were primarily concentrated in the less developed southern portion of the County (Rock Branch, Cabin Branch, Lyons Creek, Herring Bay) or along the northeastern portion of the County (Piney Run, Severn Run, Upper North River, Middle Patuxent; Figure 8). The broadest range of BIBI scores (i.e., where the difference between the maximum and minimum values was greater than 2.5) occurred in Piney Run (PSU 01), Stony Run (02), Bodkin Creek (06), Severn Run (09), Upper North River (11), Herring Bay (15), Stocketts Run (19), Lyons Creek (22), Cabin Branch (23), and Hall Creek (24) PSUs, indicating greater variability between sites. In contrast, West River (PSU 14) and Little Patuxent (17) had the smallest range of BIBI scores (i.e., less than 1.0), indicating less variability between sites.

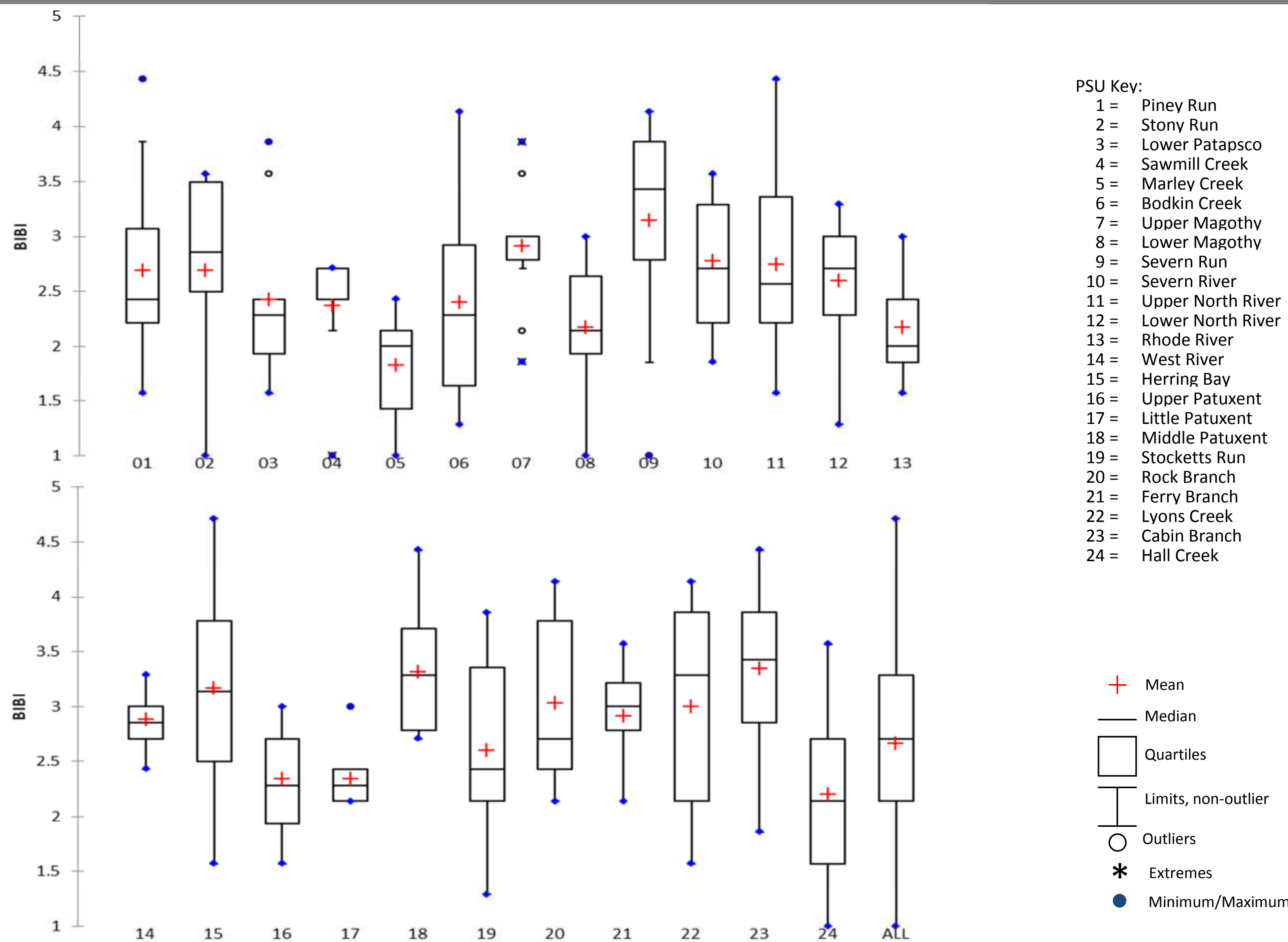

Figure 9. Box Plots of BIBI Scores.

3.4 Physical Habitat Conditions

The physical habitat condition of Anne Arundel County's streams was assessed using both the U.S. Environmental Protection Agency's Rapid Bioassessment Protocol (RBP) method (Barbour et al., 1999) and Maryland Biological Stream Survey's Physical Habitat Index (PHI; Paul et al., 2003). Results of each visual-based habitat assessment technique are presented separately in the following sections.

3.4.1 *RBP Habitat*

Mean RBP habitat scores and relative rankings (1 = best, 24 = worst) for each PSU are presented in Table 4. The overall physical habitat conditions in Anne Arundel County streams were rated "Partially Supporting" by the RBP (mean = 120.3, SD = 24.07). The majority of PSUs, 16 total, were rated as "Partially Supporting" (67%), seven were rated "Supporting" (29%), and one was rated "Non-Supporting" (4%; Figure 10). There were no PSUs with a mean physical habitat condition rating of "Comparable."

Table 4. Mean RBP Habitat Scores Ordered by Relative Rank for Anne Arundel County PSUs from 2009-2013

PSU	Sample Size	Mean RBP	Std Dev	Rating	Rank
COUNTYWIDE	240	120.3	24.07	Partially Supporting	-
Upper Magothy	10	141.6	14.10	Supporting	1
Upper Patuxent	10	139.9	23.33	Supporting	2
Severn River	10	137.5	19.81	Supporting	3
Bodkin Creek	10	136.0	29.71	Supporting	4
Upper North River	10	131.6	26.14	Supporting	5
Lyons Creek	10	126.7	21.52	Supporting	6
Stony Run	10	125.5	22.78	Supporting	7
Rhode River	10	124.7	19.26	Partially Supporting	8
Piney Run	10	124.2	17.10	Partially Supporting	9
Severn Run	10	123.9	36.74	Partially Supporting	10
Middle Patuxent	10	123.0	16.31	Partially Supporting	11
Sawmill Creek	10	122.9	35.27	Partially Supporting	12
Cabin Branch	10	118.6	20.32	Partially Supporting	13
Stocketts Run	10	118.6	19.36	Partially Supporting	14
Lower Magothy	10	117.0	28.84	Partially Supporting	15
Ferry Branch	10	115.3	8.97	Partially Supporting	16
Herring Bay	10	113.8	11.02	Partially Supporting	17
Little Patuxent River	10	113.5	18.89	Partially Supporting	18
Lower North River	10	110.0	16.42	Partially Supporting	19
Hall Creek	10	108.5	12.07	Partially Supporting	20
West River	10	108.2	9.26	Partially Supporting	21
Rock Branch	10	105.4	18.12	Partially Supporting	22
Marley Creek	10	103.0	30.17	Partially Supporting	23
Lower Patapsco	10	98.1	27.11	Non-Supporting	24

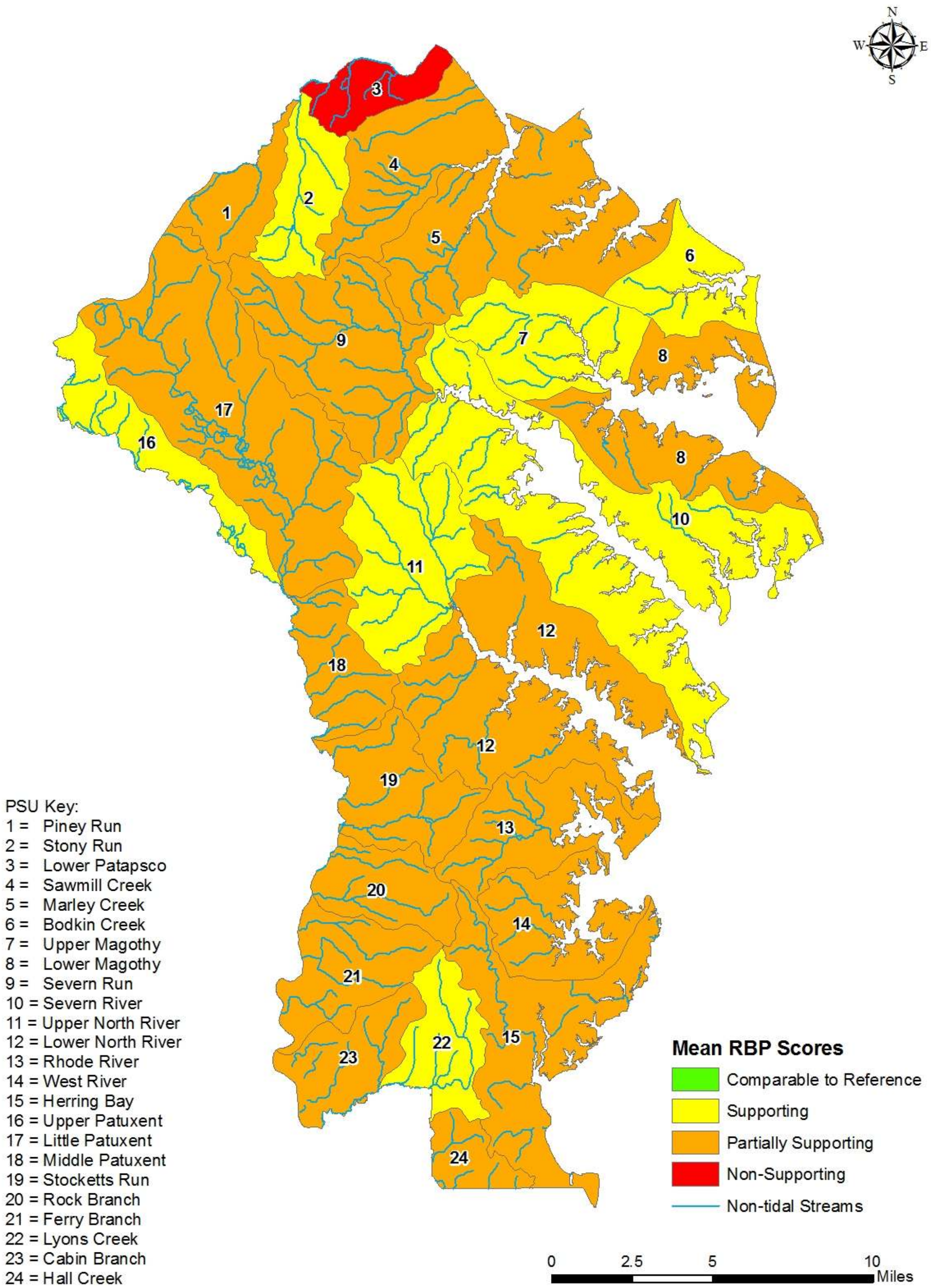

Figure 10. Average RBP Physical Habitat Conditions for Primary Sampling Units.

Upper Magothy had the highest mean RBP score of 141.6 with a physical habitat condition rating of “Supporting.” Six additional PSUs received a “Supporting” rating including Upper Patuxent (RBP = 139.9), Severn River (137.5), Bodkin Creek (136), Upper North River (131.6), Lyons Creek (126.7), and Stony Run (125.5). Conversely, Lower Patapsco received the lowest RBP score of 98.1 and was the only PSU classified as “Non-Supporting”. Marley Creek (103), Rock Branch (105.4), West River (108.2), and Hall Creek (108.5), all classified as “Partially Supporting”, were also ranked among the worst PSUs by the RBP habitat index.

Countywide RBP physical habitat assessment results indicate that only 10% of the streams in the County were rated “Comparable to Reference”, 33% were rated “Supporting”, 38% were rated “Partially Supporting”, and 19% were classified as “Non-Supporting” (Figure 11).

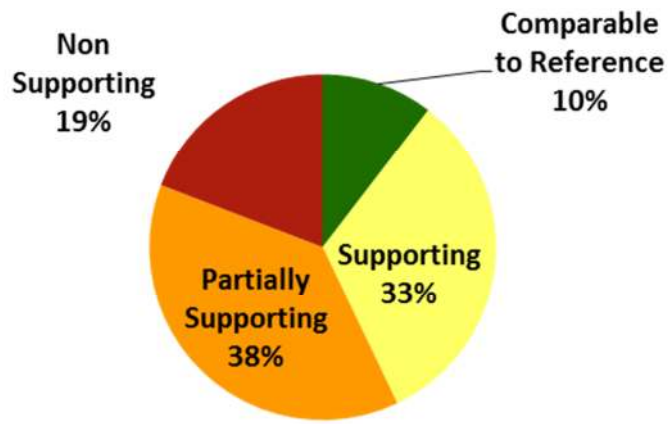

Figure 11. Countywide RBP Physical Habitat Conditions (2009-2013; n=240).

A summary of site-specific physical habitat conditions, as a percentage of total sites within each PSU, is displayed in Figure 12. Only two PSUs (Ferry Branch and Upper Magothy), had all sites rated as either “Comparable”, “Supporting”, or “Partially Supporting.” Eight PSUs had greater than 10% of sites rated as “Comparable” (Bodkin Creek, Lyons Creek, Severn River, Severn Run, Stony Run, Upper Magothy, Upper North River, and Upper Patuxent). On the other hand, two PSUs (Hall Creek and West River) had all sites rated as either “Non-Supporting” or “Partially Supporting”. Figure 13 shows the distribution of sampling sites with their corresponding RBP physical habitat condition rating.

Figure 14 shows the distribution of RBP scores within each PSU as box and whisker plots. PSUs with the lowest variability in RBP scores (i.e., less than 30 points between lowest and highest scoring sites) were West River (PSU 14), Herring Bay (15), and Ferry Branch (21). The broadest range of RBP scores (i.e., greater than 70 points between lowest and highest scores) were observed in Lower Patapsco (PSU 03), Sawmill Creek (04), Marley Creek (05), Bodkin Creek (06), Lower Magothy (08), Severn Run (09), Upper North River (11), and Upper Patuxent (16) PSUs; however, the minimum values in Sawmill Creek, Bodkin Creek and Lower Magothy PSUs were determined to be outliers based on the quartile distributions in each PSU.

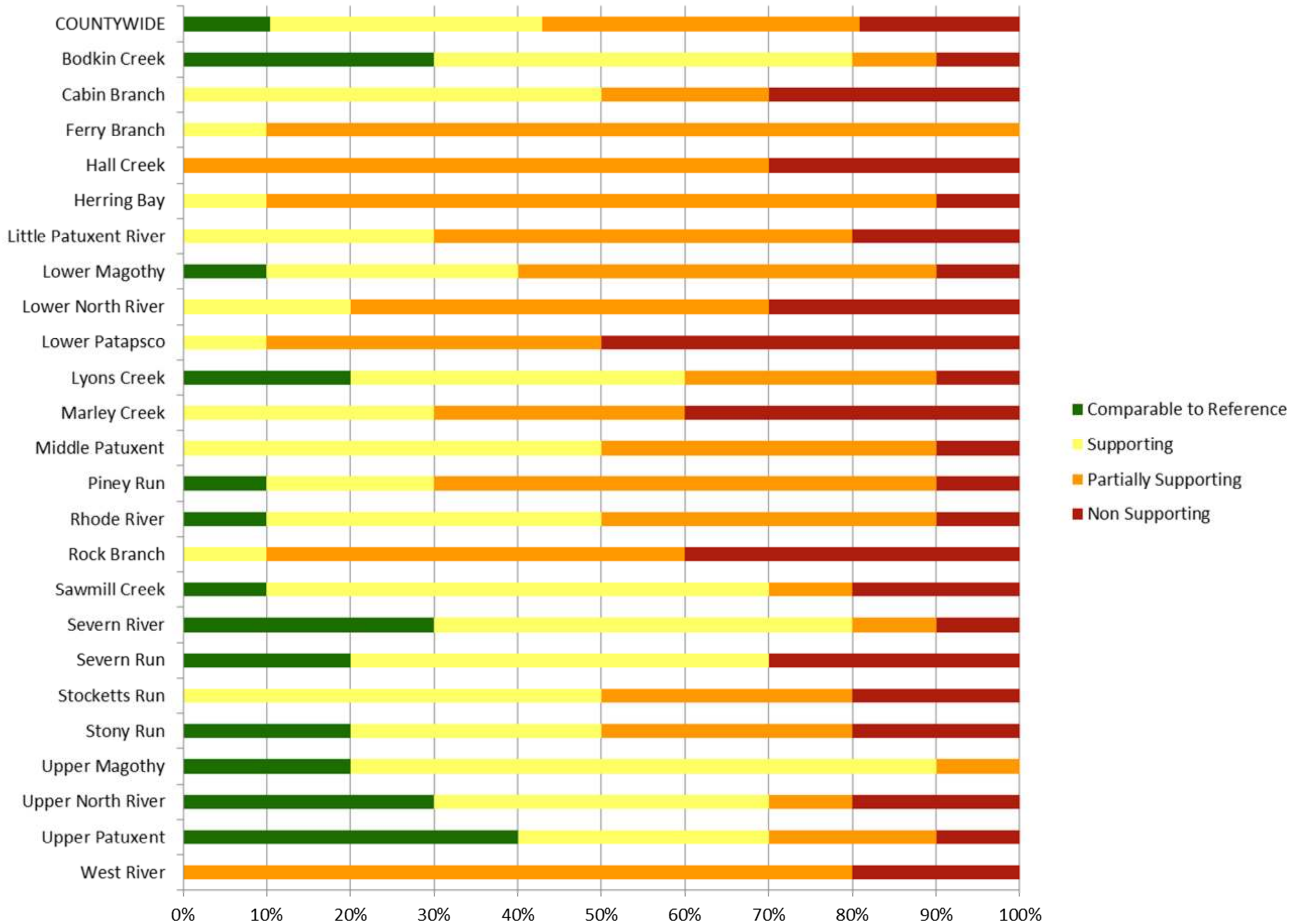

Figure 12. RBP Physical Habitat Conditions as a Percentage of Total Sites Within Each PSU

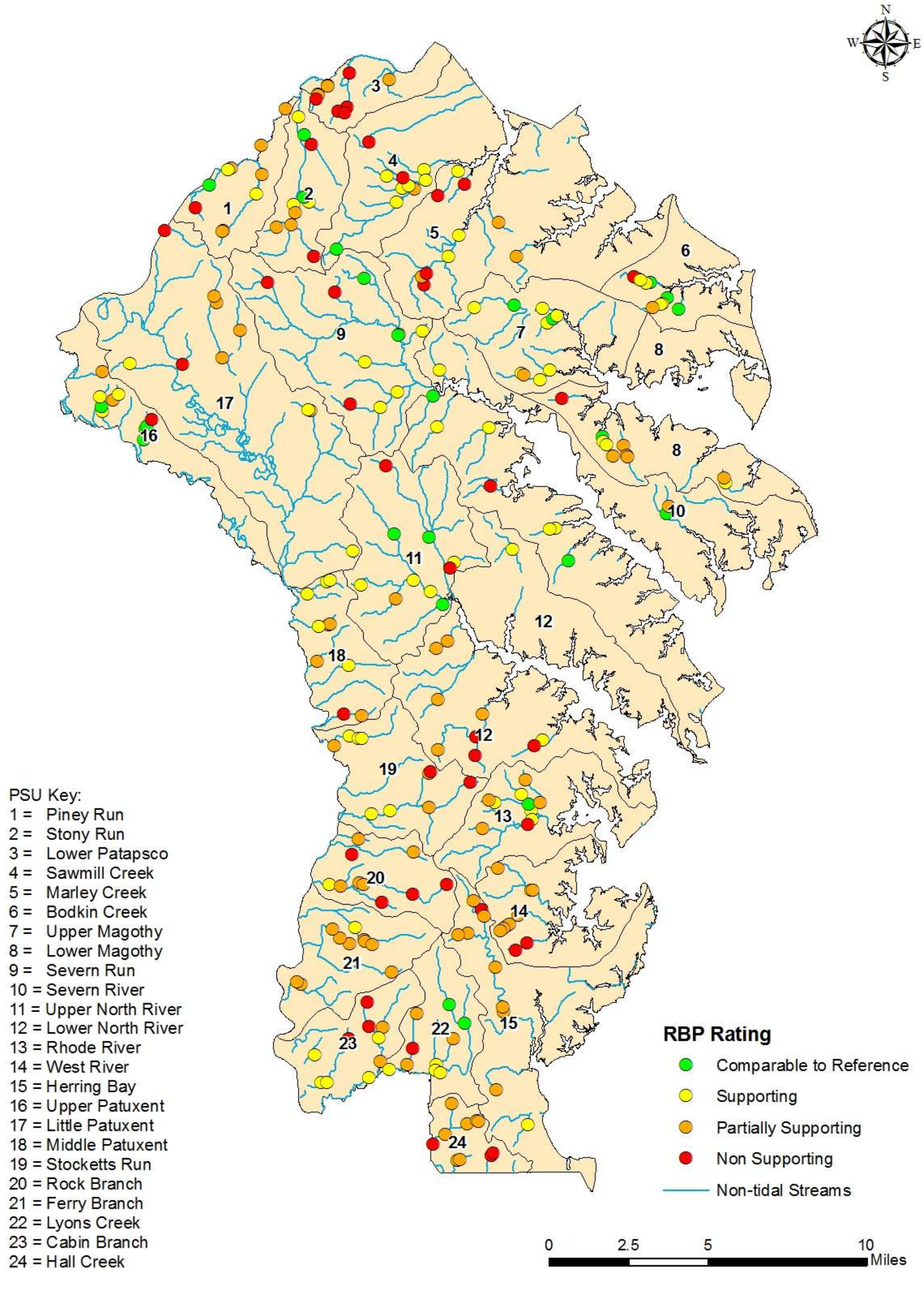

Figure 13. Countywide Physical Habitat Assessment (RBP) Results from 2009-2013.

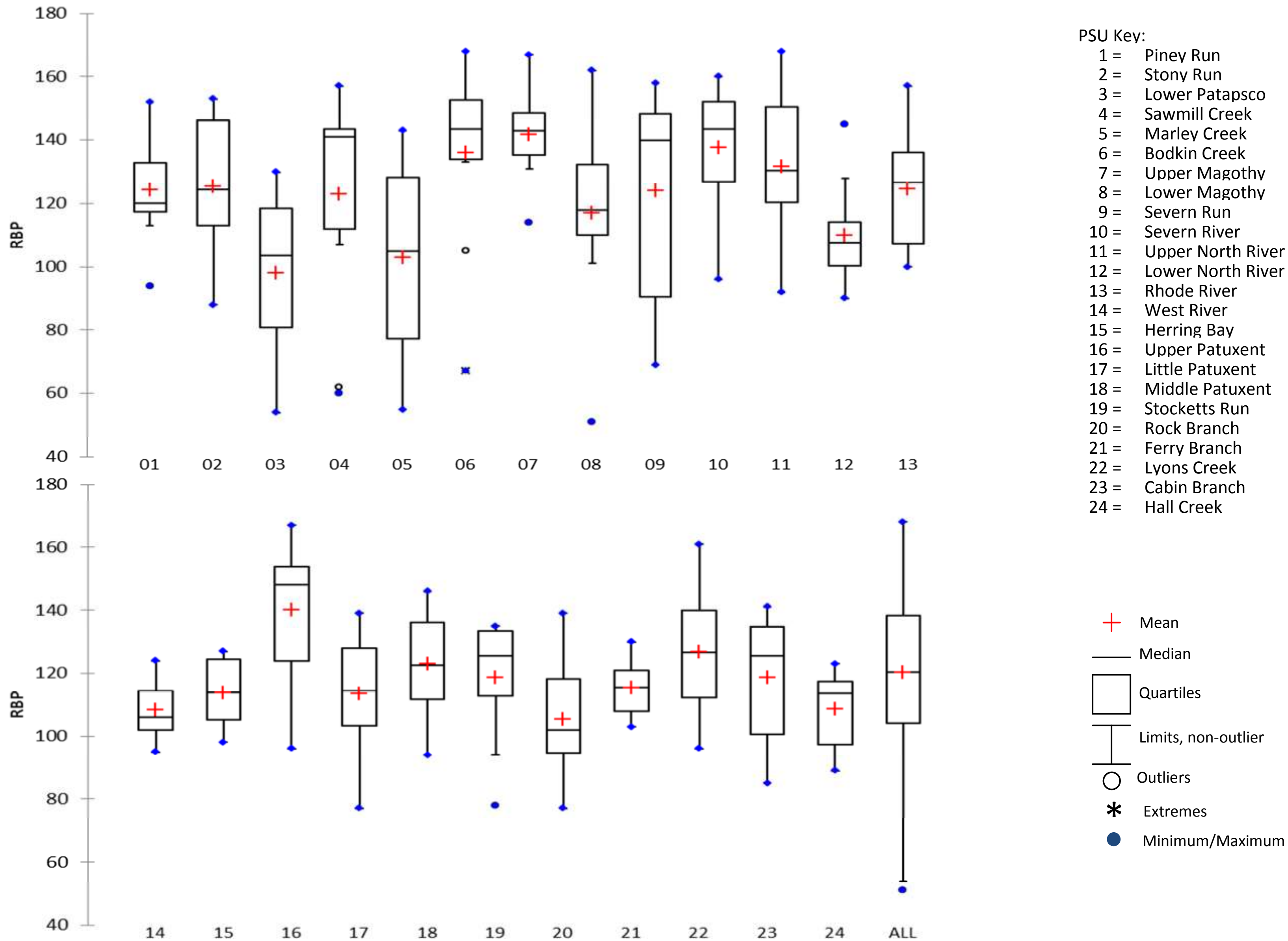

Figure 14. Box Plot of RBP Scores.

3.4.2 *PHI Habitat*

Physical habitat conditions of streams in Anne Arundel County are also assessed using the Physical Habitat Index (PHI) developed by MBSS and specifically calibrated for Coastal Plain streams (Paul et al., 2003). A comparison of mean PHI scores, along with relative rankings (1 = best, 24 = worst), for each PSU is displayed in Table 5. Overall physical habitat conditions in Anne Arundel County streams were rated “Partially Degraded” by the PHI, with a mean score of 69.5 (SD = 11.5). Twenty PSUs were rated as “Partially Degraded”, three were considered “Degraded”, and only one PSU was rated “Minimally Degraded” (Figure 15). Upper Patuxent had the highest mean PHI score of 85.3 and was rated “Minimally Degraded”, followed by Severn River (PHI = 75.2) and Middle Patuxent (PHI = 75.0), both classified as “Partially Degraded”. The lowest PHI score of 60.5 occurred in Marley Creek, which was classified as “Degraded”. Piney Run (64.5) and Sawmill Creek (64.5) were also classified as “Degraded” and round out the worst rated PSUs.

Table 5. Mean Physical Habitat Index Scores Ordered by Relative Rank for Anne Arundel County PSUs from 2009-2013

PSU	Sample Size	Mean PHI	Std Dev	Rating	Rank
COUNTYWIDE	240	69.5	11.5	Partially Degraded	-
Upper Patuxent	10	85.3	6.3	Minimally Degraded	1
Severn River	10	75.2	10.1	Partially Degraded	2
Middle Patuxent	10	75.0	10.4	Partially Degraded	3
Upper Magothy	10	73.0	5.9	Partially Degraded	4
Cabin Branch	10	72.4	10.1	Partially Degraded	5
Lyons Creek	10	71.9	6.1	Partially Degraded	6
Bodkin Creek	10	71.1	14.2	Partially Degraded	7
Severn Run	10	70.2	11.9	Partially Degraded	8
Upper North River	10	70.0	10.1	Partially Degraded	9
Rock Branch	10	69.5	10.3	Partially Degraded	10
Stony Run	10	68.7	15.1	Partially Degraded	11
Ferry Branch	10	68.6	10.1	Partially Degraded	12
Rhode River	10	68.4	10.3	Partially Degraded	13
Hall Creek	10	68.2	10.1	Partially Degraded	14
Stocketts Run	10	68.0	5.6	Partially Degraded	15
West River	10	67.5	13.0	Partially Degraded	16
Lower Magothy	10	67.3	10.6	Partially Degraded	17
Little Patuxent River	10	67.0	12.4	Partially Degraded	18
Herring Bay	10	66.3	7.3	Partially Degraded	19
Lower North River	10	66.3	10.8	Partially Degraded	20
Lower Patapsco	10	66.3	14.9	Partially Degraded	21
Sawmill Creek	10	65.8	16.3	Degraded	22
Piney Run	10	64.5	13.1	Degraded	23
Marley Creek	10	60.5	12.0	Degraded	24

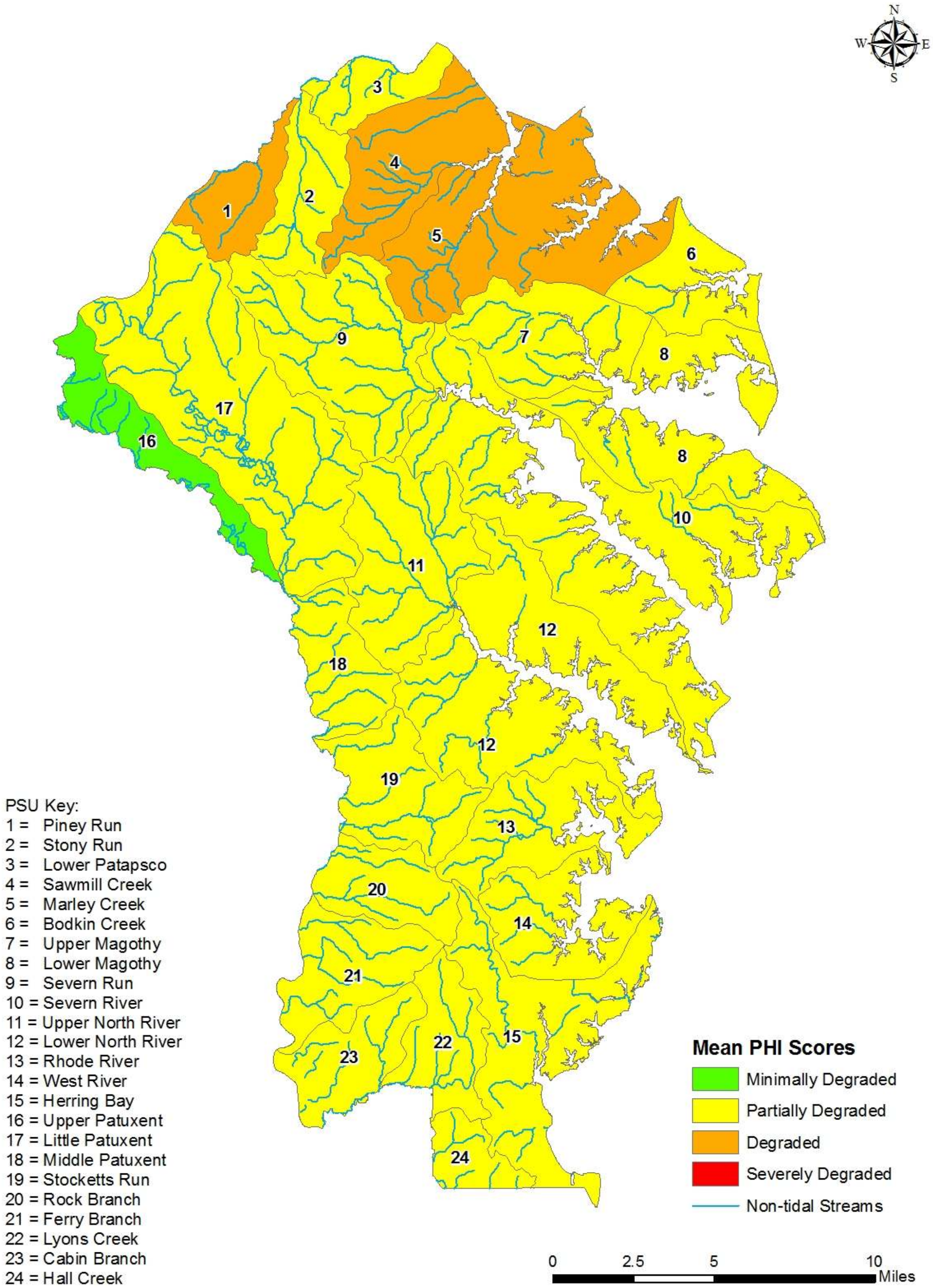

Figure 15. Average PHI Physical Habitat Conditions for Primary Sampling Units.

Countywide results indicate that 12% of the streams in Anne Arundel County had “Minimally Degraded” habitat, 51% had “Partially Degraded” habitat, and 37% had “Degraded” or “Severely Degraded” habitat (Figure 16).

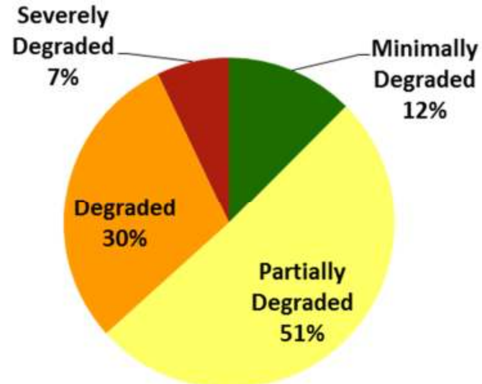

Figure 16. Countywide PHI Physical Habitat Conditions (2009-2013; n=240)

A summary of site-specific physical habitat conditions, as a percentage of total sites within each PSU, is displayed in Figure 17. Only one PSU, Upper Patuxent, had all sites rated as either “Minimally Degraded” or “Partially Degraded”. Five more PSUs (Cabin Branch, Middle Patuxent, Severn River, Upper Magothy, and Upper North River) had at least 10% of sites rated “Minimally Degraded” and no sites rated as “Severely Degraded”. In contrast, four PSUs (Ferry Branch, Lower Magothy, Marley Creek, and Rhode River) had at least 10% of sites rated as “Severely Degraded” and no sites rated as “Minimally Degraded”. Figure 18 shows the distribution of sampling sites with their corresponding physical habitat condition ratings for the PHI. Sites rated by the PHI as “Minimally Degraded” were primarily concentrated in the Severn River watershed and PSUs draining to the Patuxent River along the western border of the County.

Box plots displaying the distribution of PHI scores within each PSU are included in Figure 19. Countywide PHI scores ranged from minimum of 35.8 to a maximum of 95.4 on a 100-point scale. The broadest range of PHI scores (i.e., the difference between the maximum and minimum values was greater than 40) were observed in Stony Run (PSU 02), Lower Patapsco (03), Sawmill Creek (04), Marley Creek (05), and Bodkin Creek (06) PSUs. The smallest range of PHI scores (i.e., less than 20) were observed in Upper Magothy (07), Herring Bay (15), Upper Patuxent (16), Stocketts Run (19), and Lyons Creek (22), indicating less variability between sites.

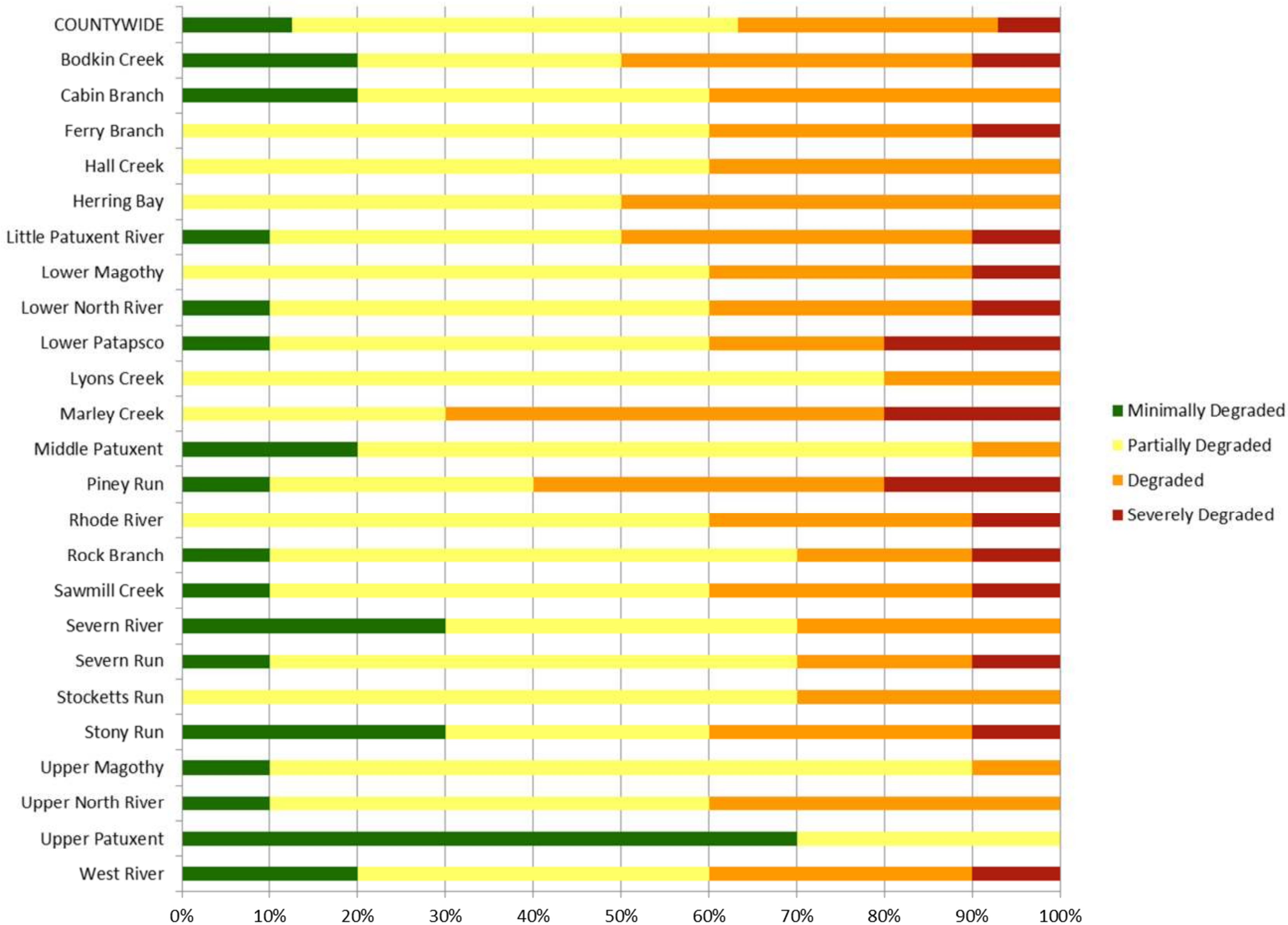

Figure 17. PHI Physical Habitat Conditions as a Percentage of Total Sites Within Each PSU.

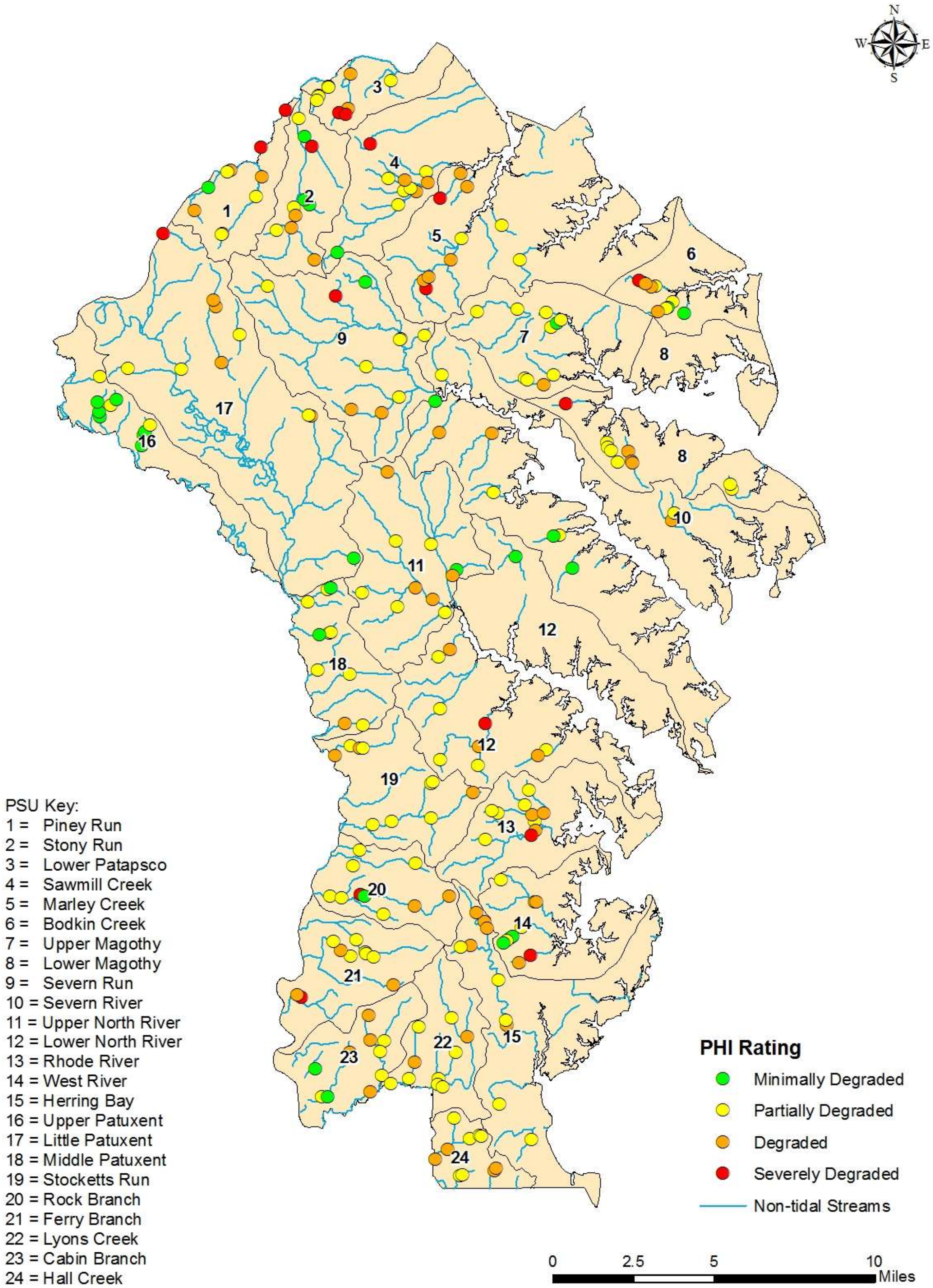

Figure 18. Countywide Physical Habitat Assessment (PHI) Results from 2009-2013.

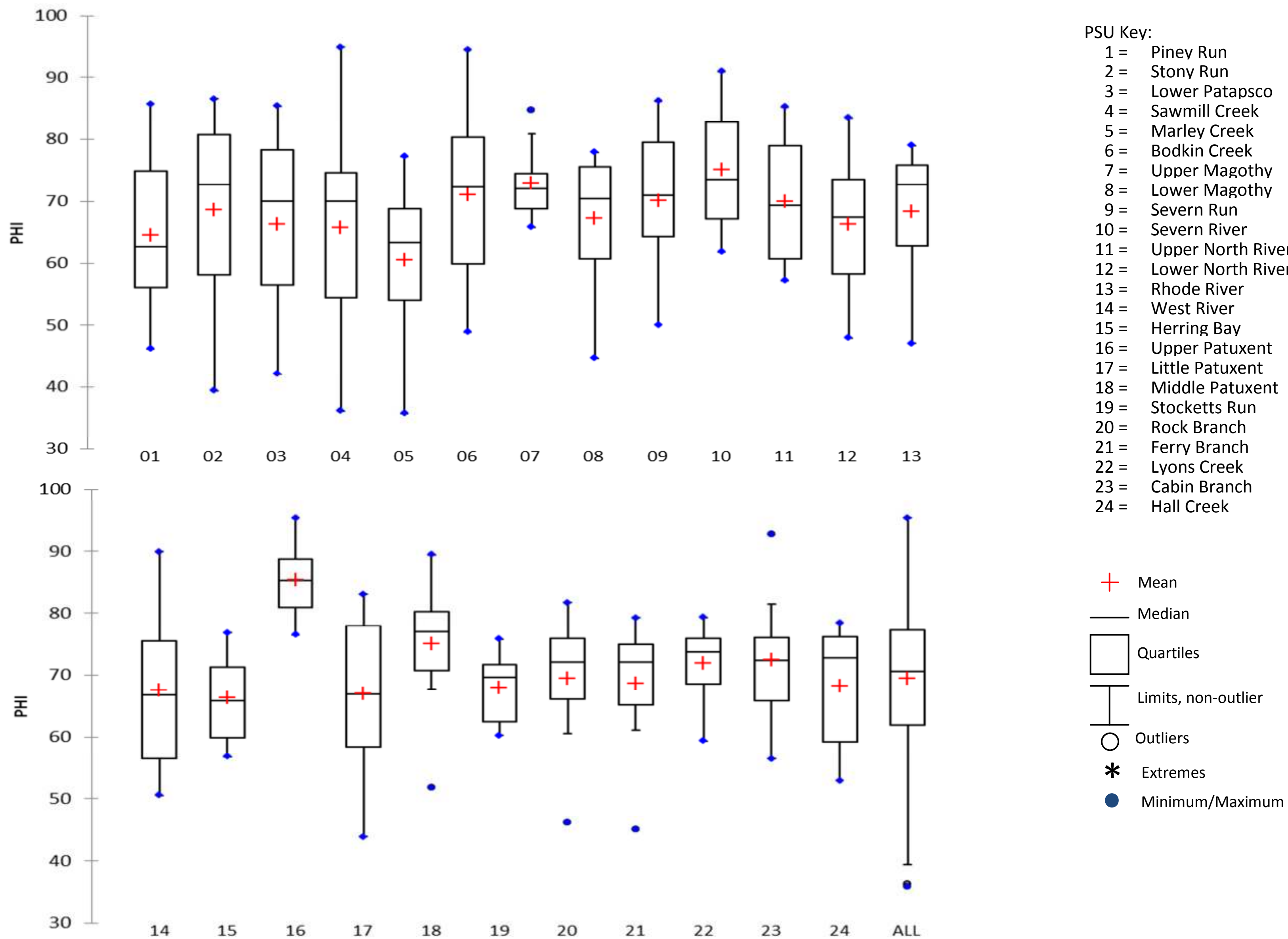

Figure 19. Box plot of PHI Scores

3.5 Water Quality Conditions

Although comprehensive water quality sampling is not a component of this monitoring program, supplemental *in situ* water quality measurements were performed during each site visit. A limited number of parameters were routinely measured (i.e., water temperature, dissolved oxygen (DO), pH, and specific conductivity), with supplemental turbidity data collected from 2010 through 2013. For the purposes of this report, only DO, pH, and conductivity results are summarized. Due to fluctuations in water temperature depending on the time of day and/or date sampled, this parameter was not considered useful in detecting trends between sampling units.

A comparison of DO values both within and across PSUs shows a broad range of values as well as numerous outliers and extreme outliers. For example, DO values in Bodkin Creek (PSU 06) ranged from a minimum of 3.27 mg/L to a maximum of 12.72 mg/L. Similar ranges between minimum and maximum DO values were observed in Lower Patapsco (PSU 03; min =3.79 mg/L, max = 11.88 mg/L) and Severn Run (PSU 09; min = 4.01 mg/L, max = 12.22 mg/L). A few measurements indicate DO values below the COMAR standard for Use I waters, which stipulate that DO concentrations should not fall below 5 mg/L at any time (COMAR, 2010). Low DO values (<5.0 mg/L) were measured in three PSUs including Bodkin Creek, Lower Patapsco, and Severn Run; which, as previously mentioned are the same PSUs with the largest range of DO values. However, it should be noted that low DO values in Lower Patapsco, Marley Creek, and Bodkin Creek PSUs were considered extreme outliers based on the quartile distributions. Furthermore, DO values (in mg/L) are largely dependent on water temperature, which can fluctuate considerably throughout the sampling period (March 1 – April 30), and to a lesser extent during each sampling day. As a result, the ability to detect trends among PSUs is challenging and the data should be interpreted with caution.

Box plots of pH values for each PSU are displayed in Figure 20. In general, the majority of PSUs were acidic (pH < 7), with only six PSUs (Piney Run, Stony Run, Sawmill Creek, Marley Creek, and Hall Creek) having mean pH values above 7.0. A total of eight PSUs (Bodkin Creek, Upper Magothy, Severn Run, Severn River, Upper North River, Lower North River, West River, and Upper Patuxent) had mean pH values at or below 6.5, which is the minimum threshold stated in COMAR (2010; Figure 21). It is unclear whether the observed low pH values are due to naturally acidic conditions (e.g., drainage from wetlands, acidic soils), anthropogenic disturbance (e.g., fertilizer runoff, acid deposition), or a combination of the two. One particular PSU, Upper Patuxent River, had a mean pH value of 4.89, and further investigation into the underlying soil types revealed a predominance of highly acidic soil types throughout that PSU as well is in several other PSUs including Bodkin Creek and Severn Run (Crunkleton et al., 2011).

Specific conductivity values were fairly consistent for the majority of PSUs (17 total), with the majority of mean values falling between the range of 100 µS/cm and 300 µS/cm (Figure 22). One particular PSU, Marley Creek, had a mean conductivity value that exceeded 600 µS/cm while several PSUs (Little Patuxent River, Lower North River, Lower Patapsco, Marley Creek, Piney Run, Sawmill Creek, and Stony Run) had sites with conductivity values that exceeded 600 µS/cm. Non-outlier values exceeding 1000 µS/cm were observed in Sawmill Creek and Marley Creek. In addition, values exceeding 1000 µS/cm were also observed in Lower North River and Little Patuxent; however, those measurements were considered outliers based on the quartile distributions. It should also be noted that one extreme outlier value of 8313 µS/cm (PSU 05) was removed from the data set because of the sites proximity to the tidal interface and likely tidal water influence on the measured values. While no COMAR standard for conductivity currently exists, a threshold for biological impairment in Maryland streams has been established at 247 µS/cm (Morgan et al., 2007). Thus, PSUs with mean values exceeding 300 µS/cm are not only indicative of increased anthropogenic disturbance, but also likely to see degraded biological conditions. Not surprisingly, mean conductivity values were highest in the more intensively developed PSUs in the northern part of the County, while values were lowest in the less developed southern portion of the County (Figure 23).

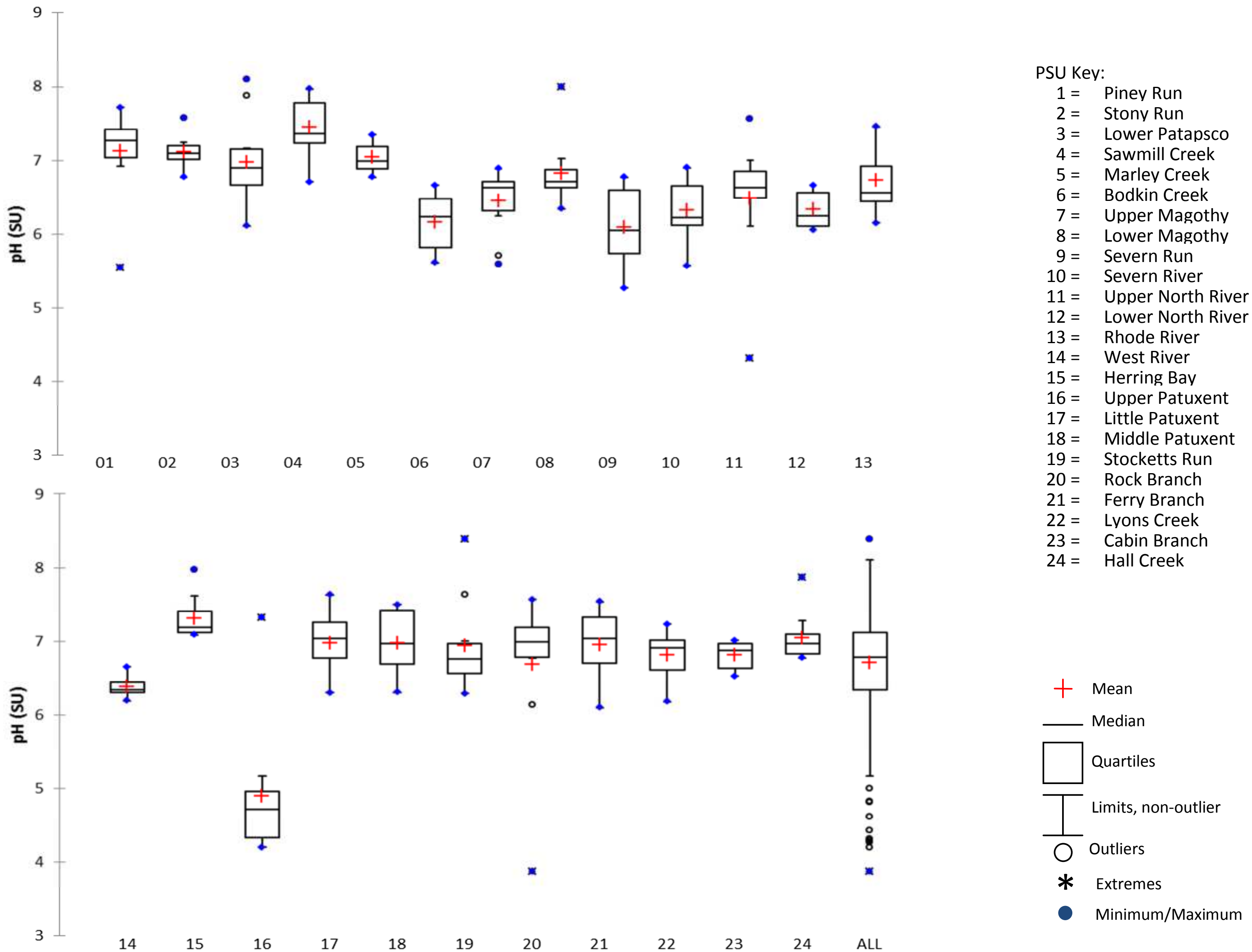

Figure 20. Box Plot pH Values.

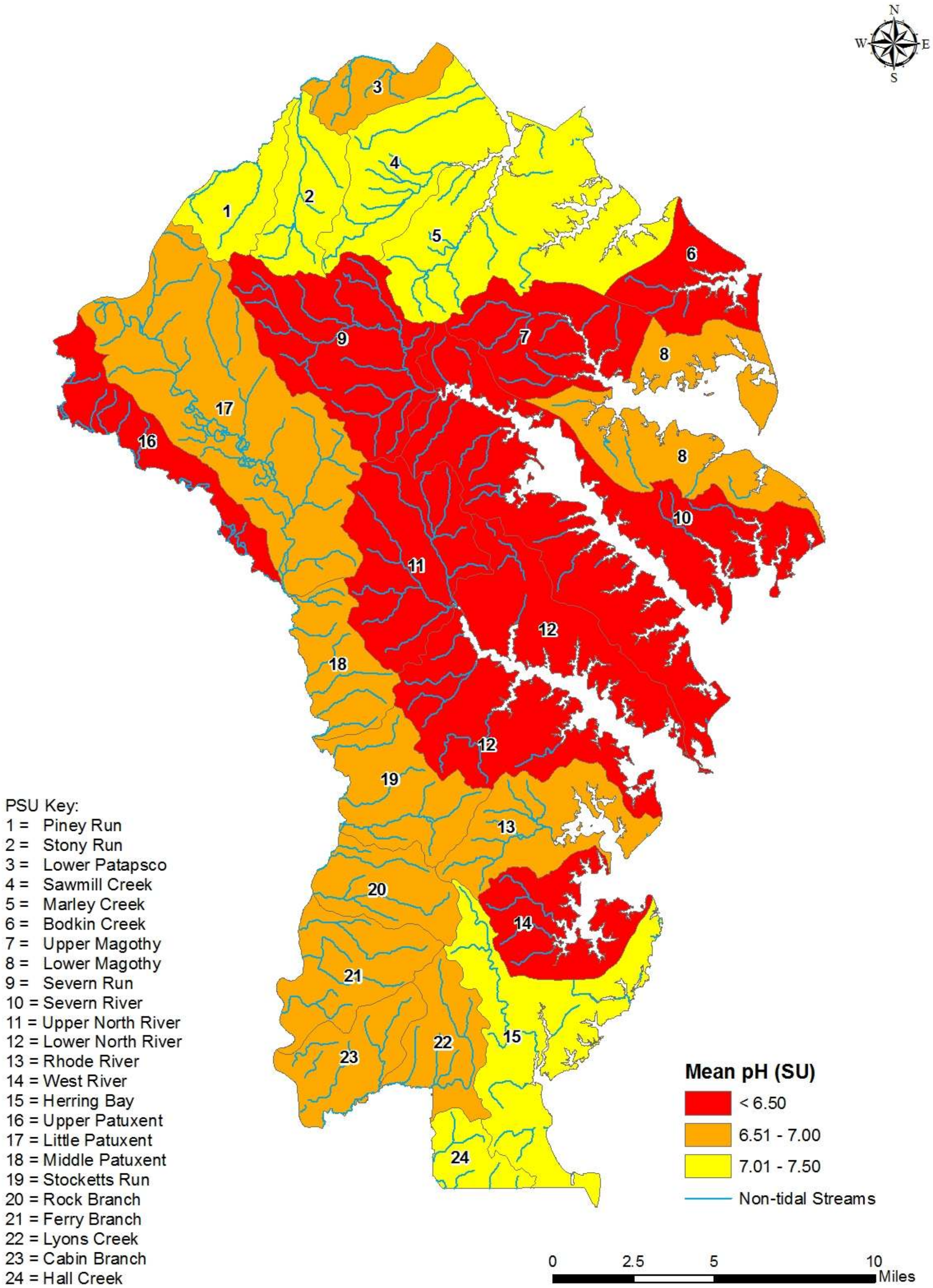

Figure 21. Average pH Values for Primary Sampling Units.

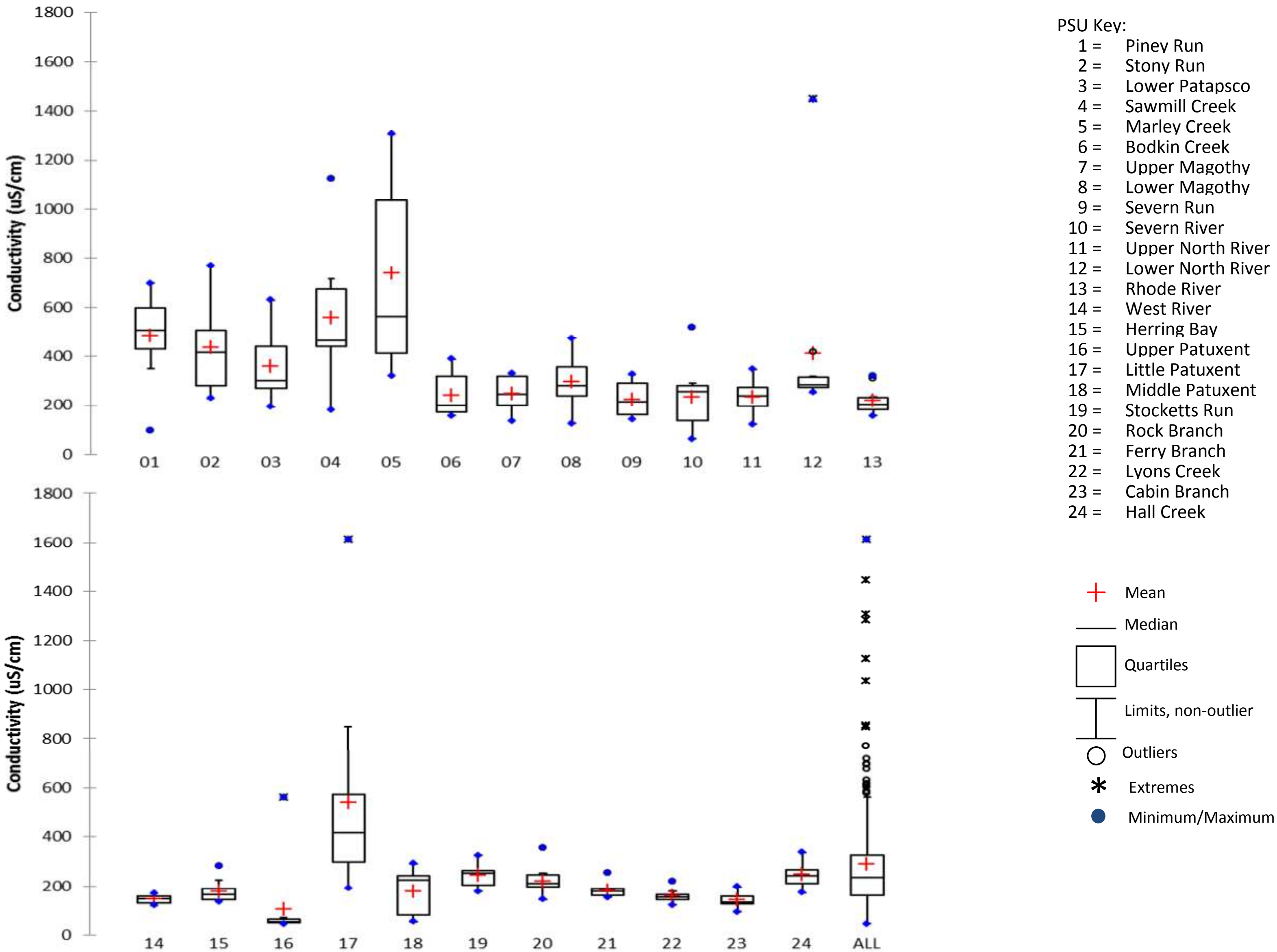

Figure 22. Box Plot of Specific Conductivity Values.

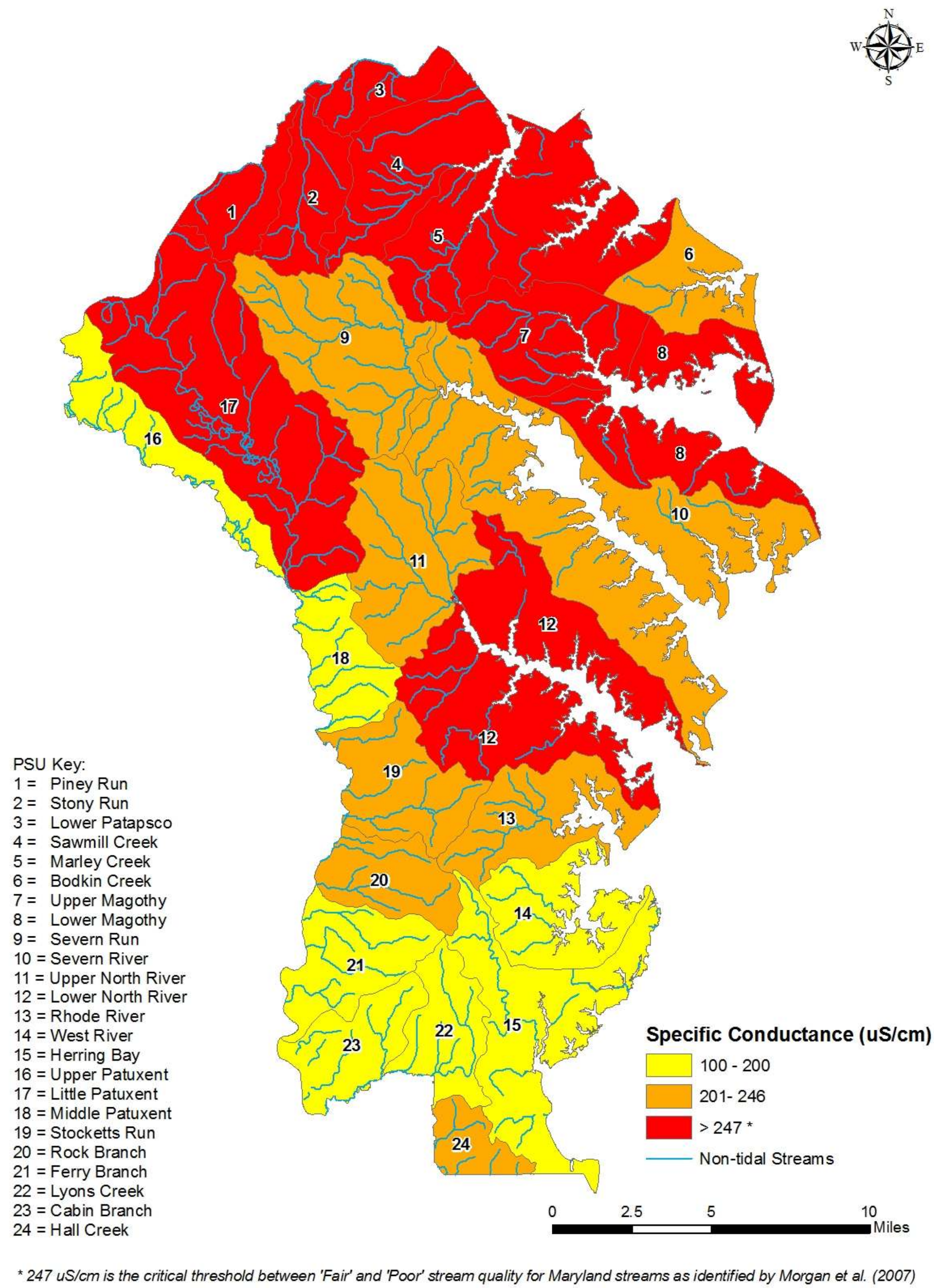

Figure 23. Average Conductivity Values for Primary Sampling Units.

3.6 Fluvial Geomorphology

The geomorphological characteristics of Anne Arundel County streams were primarily characterized using the Rosgen stream classification system for natural rivers (Rosgen, 1994, 1996). A map of Rosgen classification results for all sites assessed during Round Two is displayed in Figure 25. In Round Two, Rosgen channel type was not determined (i.e., classified as ND) for 31 sites because either geomorphic assessments were unable to be completed in the field due to anthropogenic constraints (e.g., pipe culvert, armored banks) or the resulting data were not sufficient, or representative, to allow for an accurate classification. Additionally, five sites were considered Transitional reaches (i.e., sites that were actively transitioning between two Rosgen channel types) and could not be classified as one specific type. Of the remaining 204 sites that were surveyed and assessed, the majority were classified as "E" type (23%), "F" (22%), and "G" (20%) channels followed by "C" (10%), "DA" (7%), and "B" (3%) channels (Figure 24). There were no sites classified as "A" or "D" types during the Round Two sampling effort.

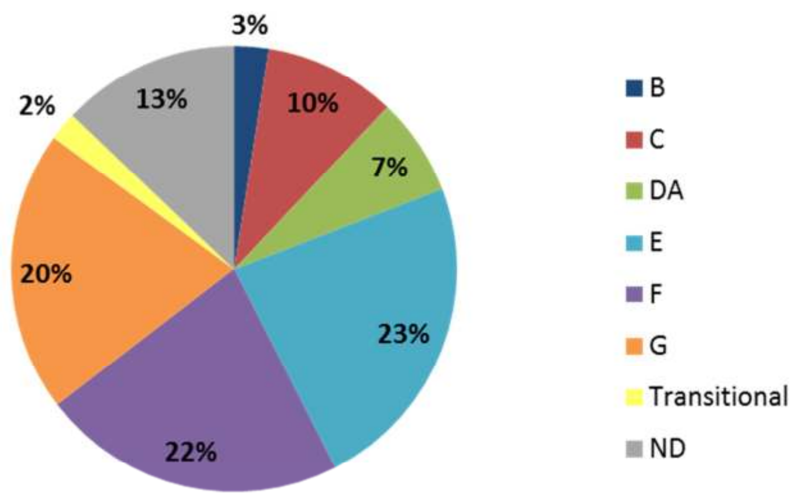

Figure 24. Distribution of Rosgen Stream Types in Sites Sampled from 2009-2013 (n=240).

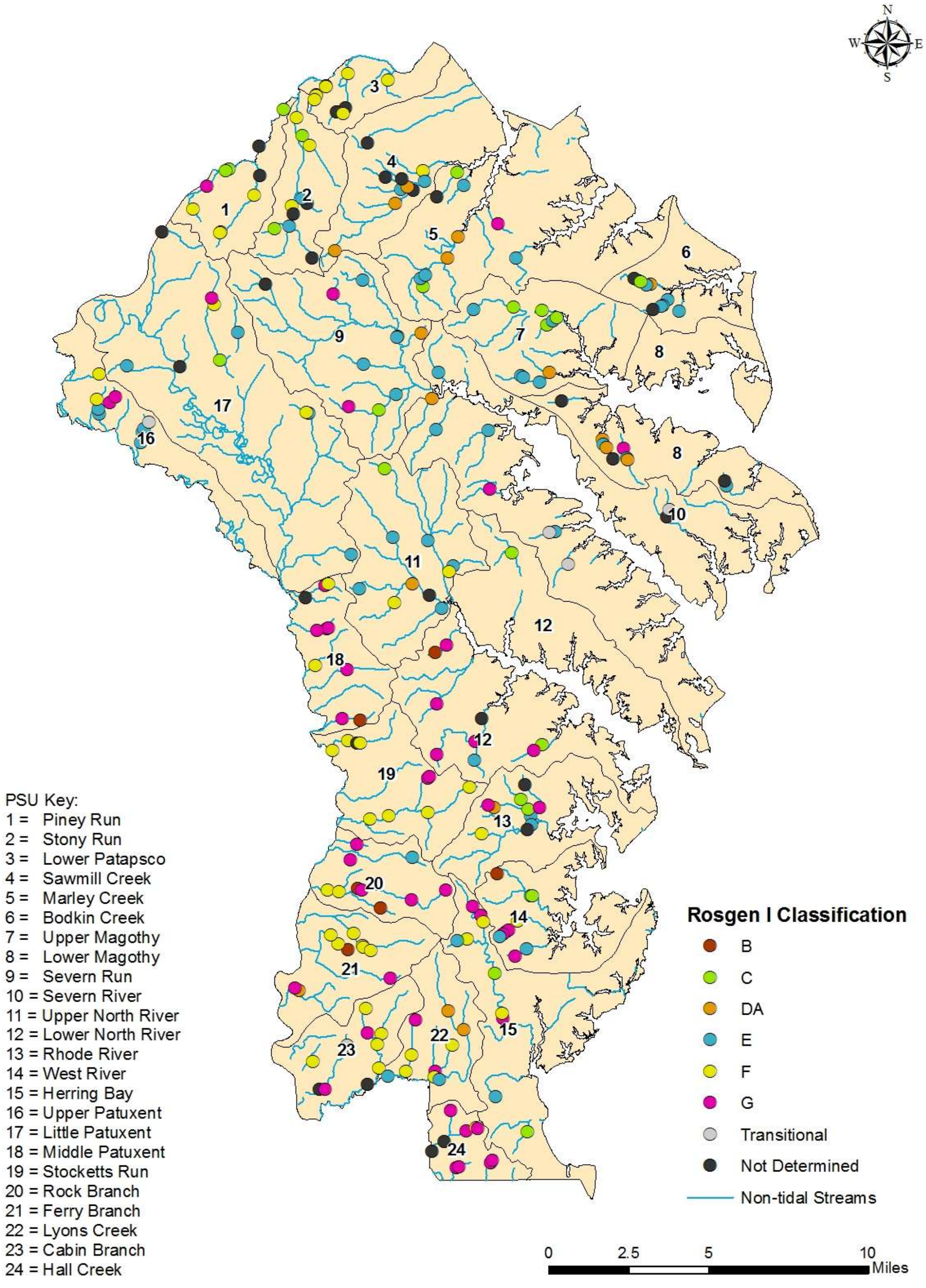

Figure 25. Countywide Geomorphic Classification (Rosgen) Results from 2009-2013.

The proportion of Rosgen stream types within each PSU is presented in Figure 26. Rosgen "E" type channels, typically considered very stable unless the stream banks are disturbed and significant changes in sediment supply and/or stream flow occur (Rosgen, 1996), were predominant in Bodkin Creek, Severn Run, Upper Magothy, Upper North River, and Upper Patuxent PSUs, where they comprised at least 50% of sites sampled. Other PSUs with predominantly "E" type channels include Marley Creek and Severn River. Although dominated by "E" channels, Upper Magothy also had the highest percentage of "C" type channels at 40%. In addition, Piney Run had a high percentage of "C" type channels (30%), although it was not the predominant stream type identified in the PSU. As the second most dominate channel type observed in Round Two, entrenched "F" type channels comprised at least 50% of sites in Cabin Branch, Ferry Branch, Lower Patapsco, and Stocketts Run PSUs. Streams sampled in Lyons Creek and Piney Run PSUs were also predominantly "F" type channels. "G" type channels, typically considered very sensitive to disturbance with a tendency to make significant adverse channel adjustments to changes in flow regime and sediment supply (Rosgen, 1996), comprised at least 50% of sites in Hall Creek, Lower North River, Middle Patuxent, and Rock Branch PSUs. The "G" type channel was also the predominant stream type identified in West River PSU. The "B" type channel was observed in Ferry Branch, Lower North River, Middle Patuxent, Rock Branch, and West River. Anastomosed "DA" type channels, were observed in 11 PSUs with the most sites in Lower Magothy and Sawmill Creek.

Figure 27 displays box plots of the four primary delineative parameters (i.e., entrenchment ratio, width/depth ratio, sinuosity, water surface slope) used in the Rosgen classification system. The box plots display the similarities and differences in the delineative parameter values measured throughout Anne Arundel County by channel type. As expected, entrenchment ratio and width/depth ratio were the most useful delineative parameters for classifying channels into different stream types. Channel sinuosity and water surface slope, on the other hand, showed a high degree of overlap between the different stream types.

The geomorphic assessment field data were compared to the Maryland Coastal Plain (MCP) regional relationships of bankfull channel geometry (McCandless, 2003) in order to determine how bankfull characteristics observed in the field compare to those predicted by the MCP. Comparisons of bankfull cross-sectional area, bankfull width, and mean bankfull depth are shown in Figure 28, Figure 29, and Figure 30, respectively. Although bankfull cross-sectional area values indicate that the field data points fall above and below the MCP curve, the field data trendline closely follows the MCP curve, especially where drainage area exceeds two square miles. A similar trend was observed for bankfull width values, where the field data fell both above and below the MCP curve, but the overall trendline resembled the MCP predictions; however, not as closely as bankfull cross-sectional area values. Field data of mean bankfull depth, on the other hand, were far more variable with many points falling further above and below the MCP than bankfull cross-sectional area and bankfull width even though both trendlines closely resembled one another. Relatively poor fit observed in the bankfull depth field data (R^2 = 0.4879) may be partly explained by the fact that riffles were not always present within the 75 meter sampling reach and features such as runs, which tend to be much deeper, may have been measured for cross-sectional dimensions. Overall, it appears that the field bankfull data are fairly consistent with the MCP relationships for sites with larger drainage areas (i.e., greater than two square miles); however, field measured bankfull width dimensions were more often slightly larger than the MCP predictions while mean depth measurements were more often slightly smaller than the MCP predictions.

It should also be noted that the MCP curves were developed using streams with drainage areas ranging from 0.3 to 89.7 square miles, with the majority of the data collected in watersheds greater than one square-mile and with low (0 - 3%) imperviousness. Thus, it is possible that stream channels with smaller drainage areas (<1 square mile) and higher percentages of imperviousness may simply exhibit greater variability in channel dimensions when compared to the MCP relationships, and consequently, it is not surprising that the field data deviated slightly from the MCP curve.

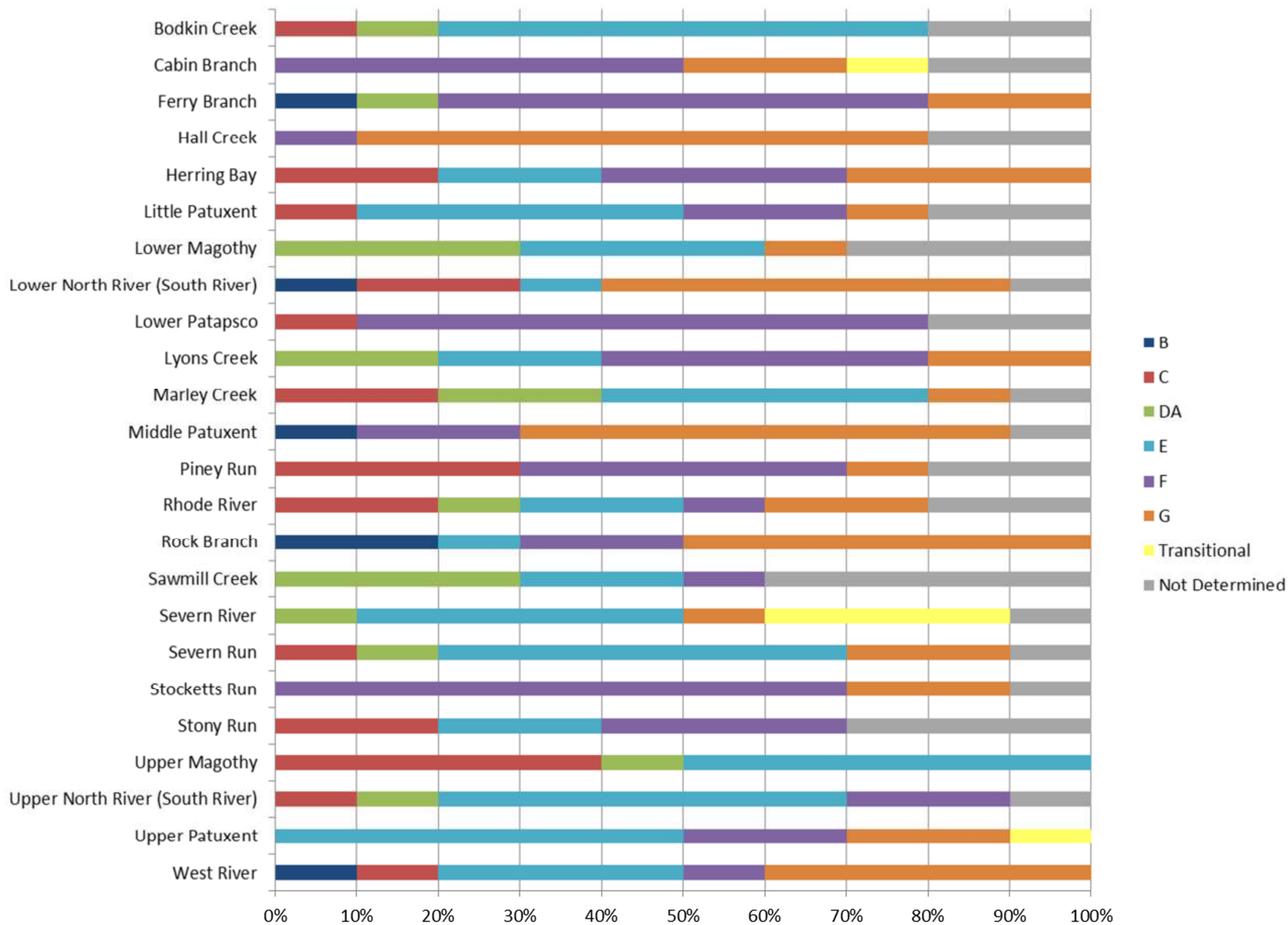

Figure 26. Proportion of Rosgen stream types identified within each PSU. ND indicates that Rosgen stream type was not determined.

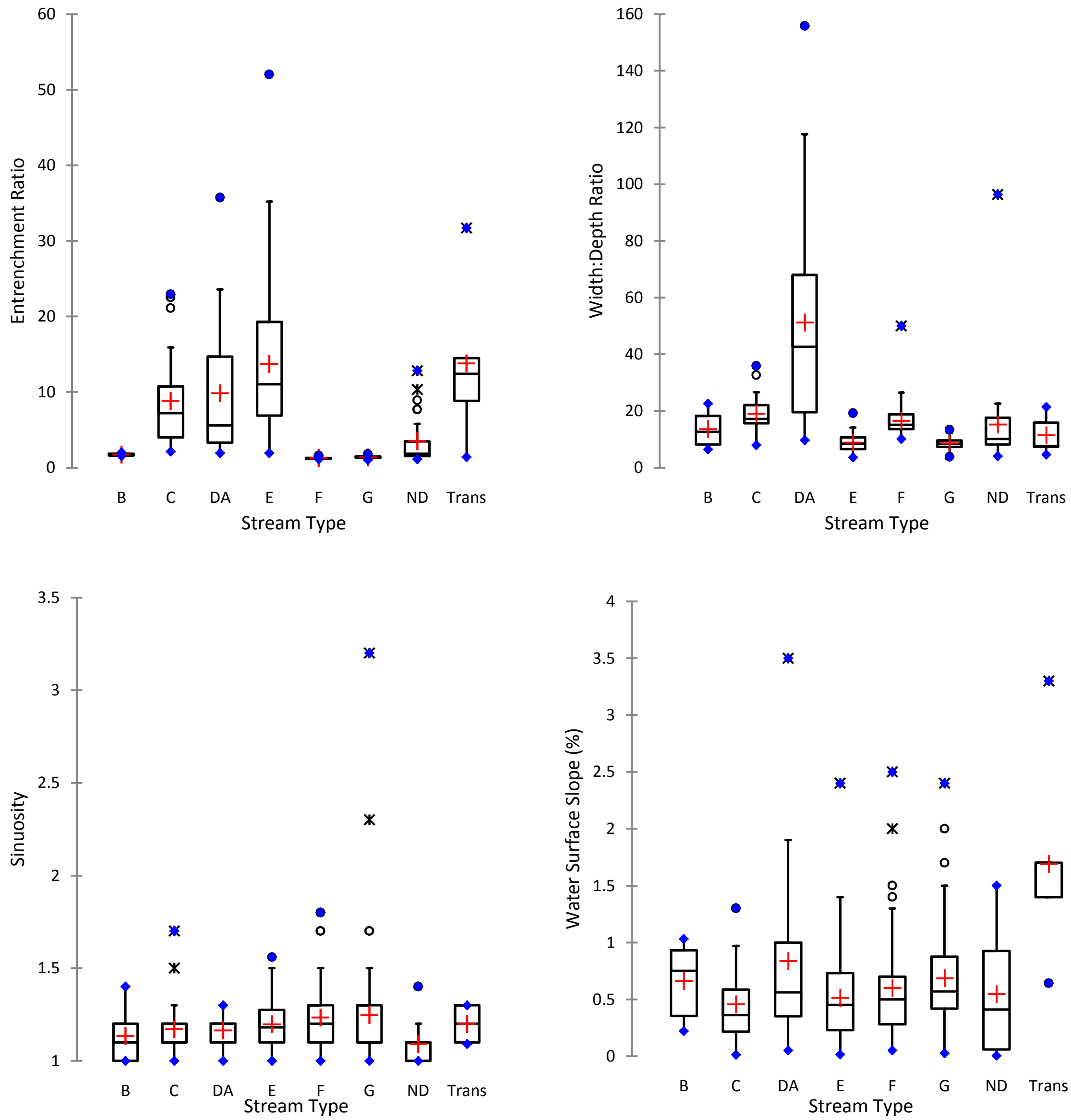

Figure 27. Box Plots of Geomorphic Parameters Used for Rosgen Stream Classification.

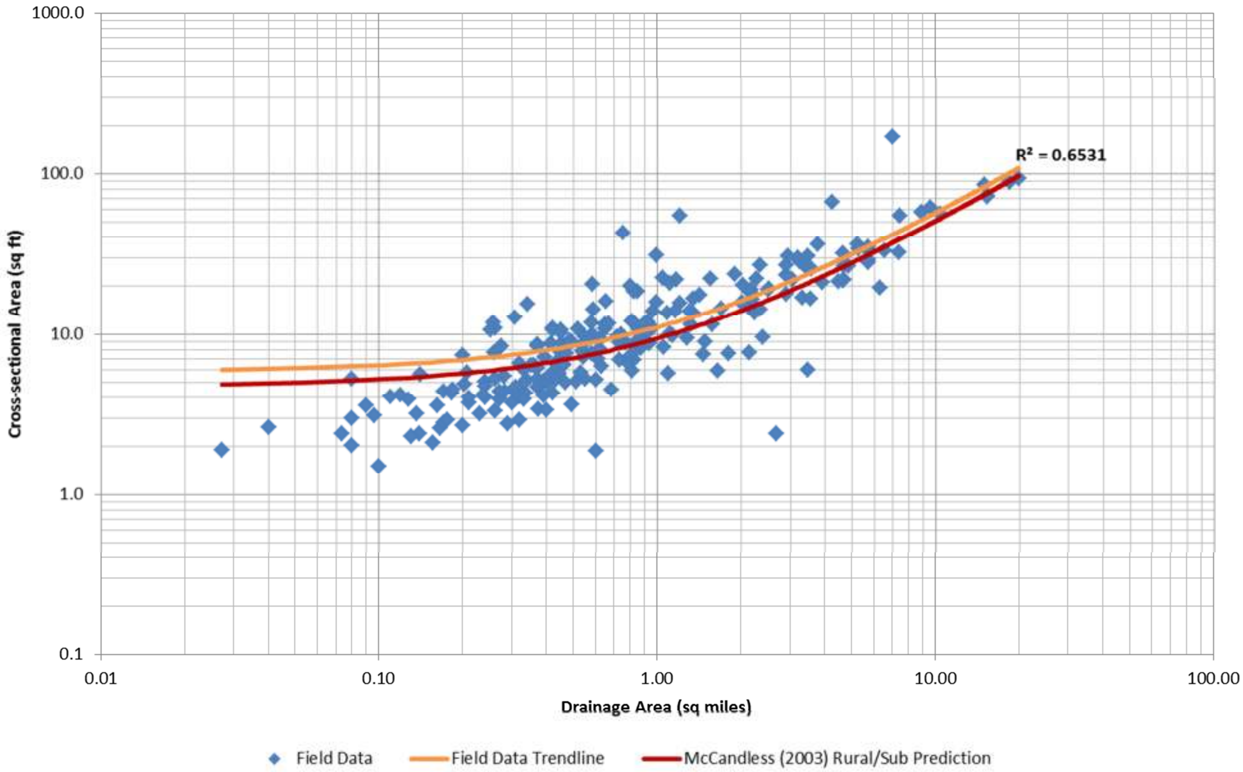

Figure 28. Comparison of the Bankfull Cross-Sectional Area - Drainage Area Relationship between Field Data and Regional Relationship Curve Data.

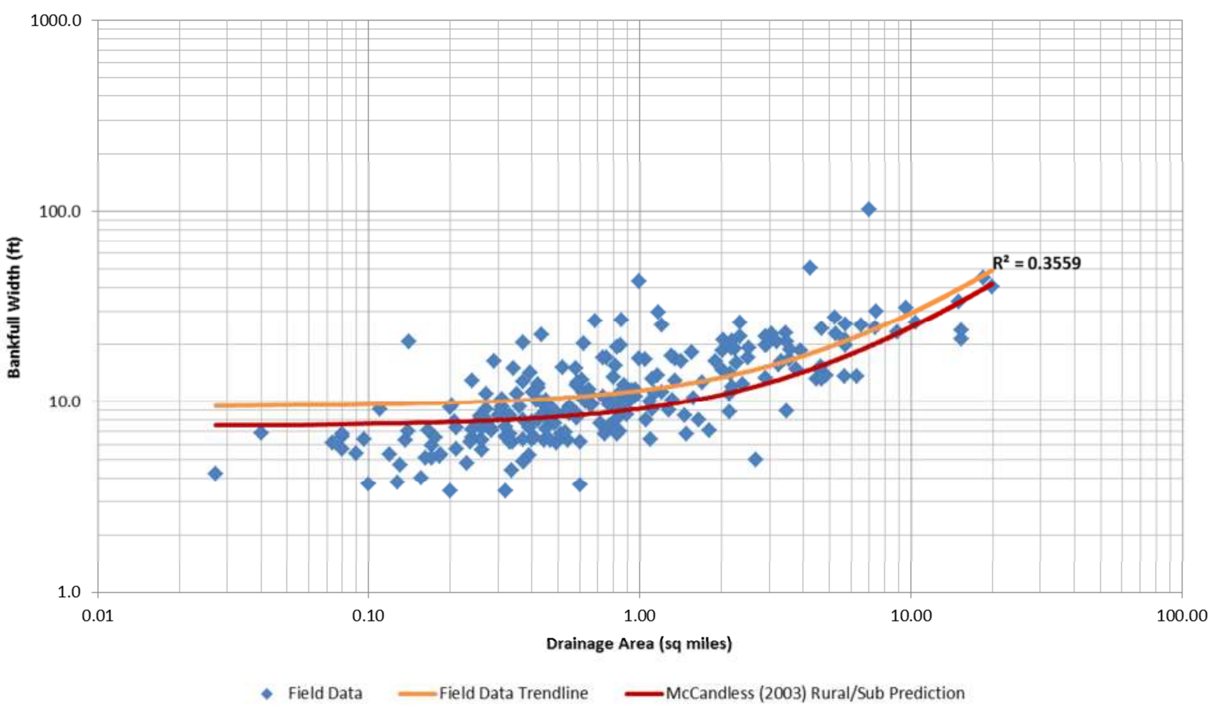

Figure 29. Comparison of the Bankfull Width - Drainage Area Relationship between Field Data and Regional Relationship Curve Data.

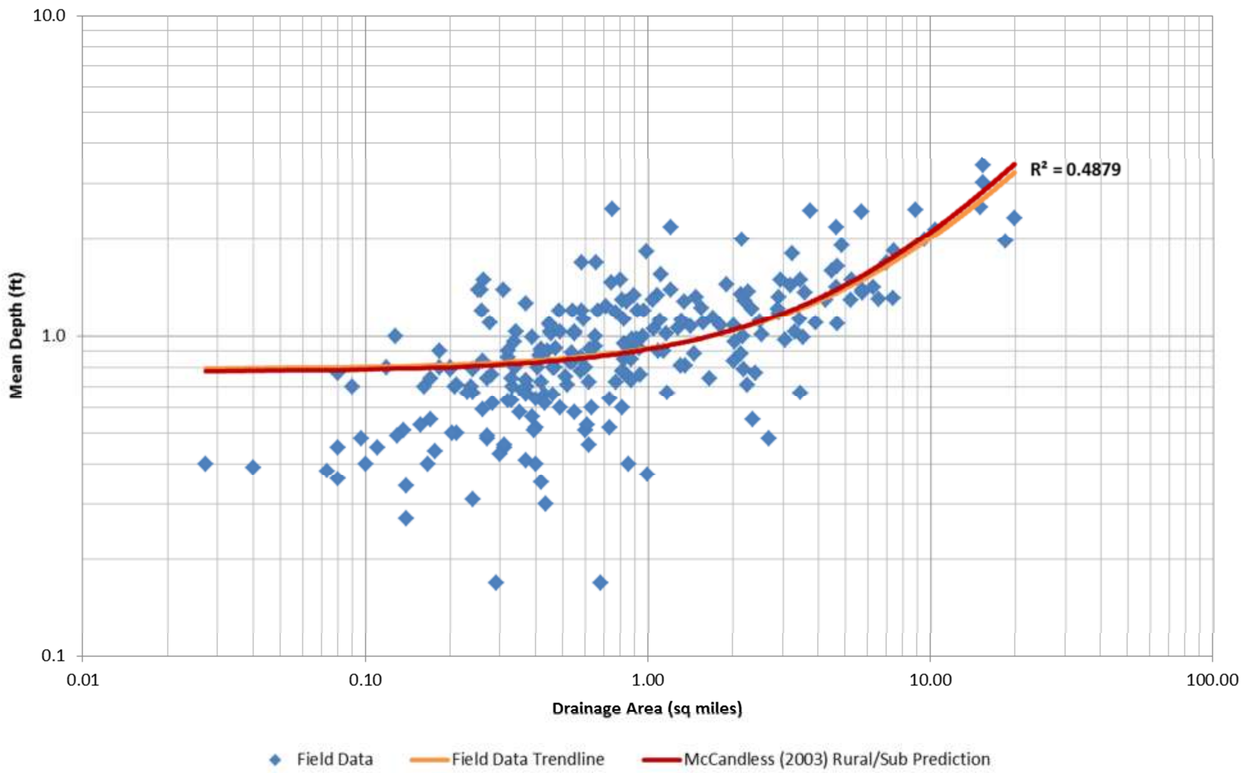

Figure 30. Comparison of the Mean Bankfull Depth - Drainage Area Relationship between Field Data and Regional Relationship Curve Data.

4 Round Two Data Analysis

4.1 Exploratory Trend Analysis

The following section describes the results of the exploratory trend analysis with a discussion of the patterns in biological data based on abiotic strata or classification types. Biological data were stratified by dominant land use class, drainage area class, imperviousness class, and Rosgen stream type and summarized using box plots.

Stratification by dominant land use class, at the scale of drainage area to each individual sampling location, showed a considerable overlap of interquartile ranges and highly similar mean and median BIBI scores (Figure 31). However, it should be noted that there were only three samples comprising the open land use class, which is an insufficient sample size for comparison with the other land use classes. Sites in the forested class do show an increased potential for higher BIBI scores as shown by the higher maximum and 3rd quartile values. In contrast, sites in the developed class have a decreased potential for higher BIBI scores and an increased potential for lower BIBI scores as shown by the lower 1st quartile values as compared to agriculture or forested site. These results suggest that dominant land use class alone is not a primary driver of biological condition. This is likely due to the fact that dominant land use may exert less of an influence on the biota than secondary, or even tertiary land uses. For example, a drainage area that is 50% forested, 45% developed, and 5% agriculture, would be classified as predominantly forested; however, the high percentage of developed land may have a greater influence on the stream biota than the forested land use. Furthermore, the proximity of land use type with respect to the sample station location may have a greater influence on the biota.

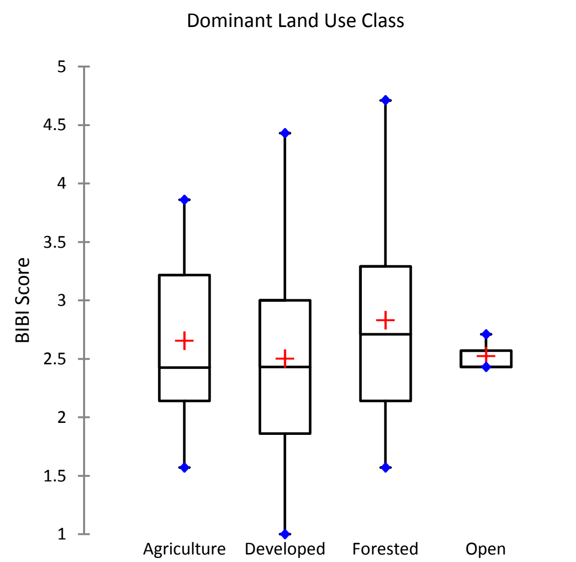

Figure 31. BIBI Data Stratified by Dominant Land Use Class.

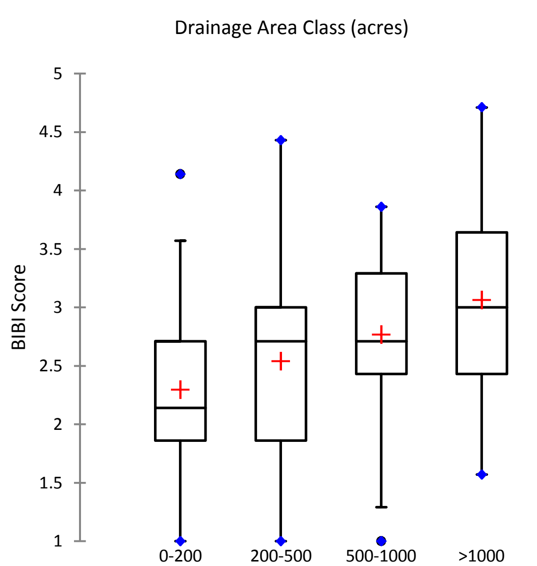

Figure 32. BIBI Data Stratified by Drainage Area Class.

To examine the influence of drainage area on BIBI scores, sites were stratified by drainage area classes with small streams classified as

<200 acres, medium streams as 200 – 500 acres, large streams as 500 – 1000 acres, and very large streams as >1000 acres in order to maintain a fairly consistent sample size between approximately 50 and 80 sites per class. While there is considerable overlap in interquartile ranges, a visible trend of increasing BIBI scores with each successive class as shown by the mean, 1st, and 3rd quartile values is apparent (Figure 32). This pattern is consistent with that observed in Round One, which suggests drainage area is likely influencing BIBI scores with a potential for streams with larger drainage areas to score higher than streams with smaller drainage areas.

Box plots of individual benthic macroinvertebrate metrics show a similar drainage area influence, especially for number of Ephemeroptera and percent Ephemeroptera metrics (Figure 33). For sites with less than 500 acres of drainage, a single Ephemeroptera taxon is considered an extreme outlier. A similar trend is observed with scraper taxa, whereby watersheds less than 500 acres have mean values of less than one (1). This may be due to some streams with smaller drainage areas being intermittent in nature, whereby biological communities are limited by low flow conditions during the dry season. In addition, streams with smaller drainage areas have less channel width and surface area per 75-meter

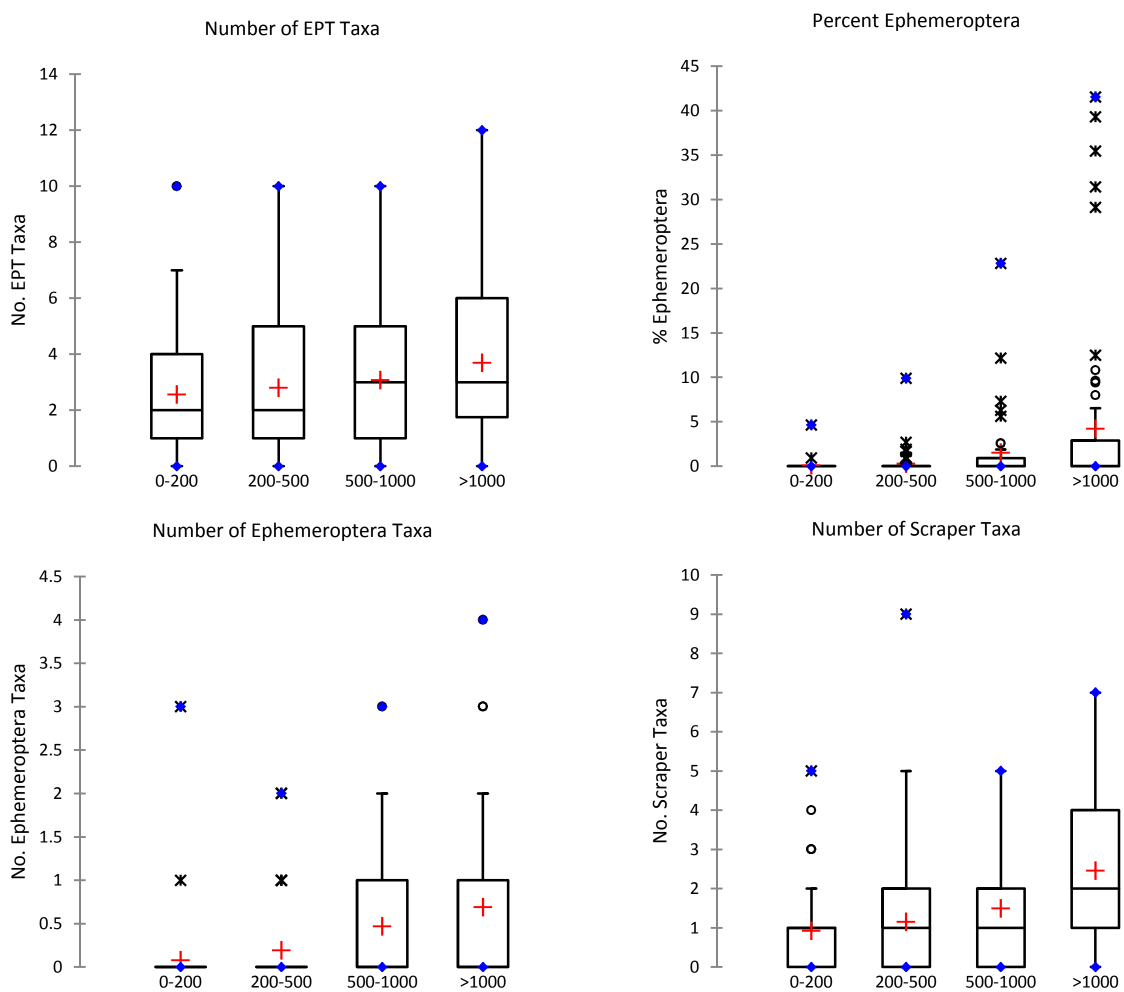

Figure 33. Box Plots of Benthic Macroinvertebrate Metrics Stratified by Drainage Area Class.

sampling reach, which likely limits the variety of microhabitats and current velocities available for biota as compared to larger, wider stream channels. Furthermore, the river continuum concept (RCC) (Vannote et al., 1980; Minshall et al., 1985) predicts that macroinvertebrate assemblage composition shifts as stream order increases. For example, the functional feeding group composition of macroinvertebrate assemblages should shift from the shredder-dominated headwaters via scraper dominated middle reaches to the collector-dominated lower reaches of large rivers (Vannote et al., 1980).

While the underlying cause of this trend is unclear, the implications should be noted. For two metrics in particular, number of Ephemeroptera taxa and number of scraper taxa, the scoring thresholds are extremely narrow, whereby the absence of either taxa results in a score of ‘1’, a single taxon yields a score of ‘3’, and two or more taxa results in a score of ‘5’. Thus, sites with less than 500 acres of drainage consistently received scores of ‘1’ for the Ephemeroptera Taxa metric in all but rare instances (i.e., extreme outliers), and nearly one half received scores of ‘1’ for scraper taxa. Consequently, sites having drainage areas less than 500 acres frequently score lower than sites with larger drainage areas primarily due to the absence of these two ‘rare’ taxa groups, which may result in a bias toward lower BIBI scores for smaller streams since the BIBI is not scaled to drainage area as is MBSS’s PHI and fish index of biotic integrity (FIBI).

Stratification of BIBI data by percent impervious class showed a reduction in BIBI scores (mean, max, and 3rd quartile) among sites where imperviousness exceeded 30%, and a considerable reduction across the board above 40% (Figure 34), indicating a pronounced influence of drainage area imperviousness on biota. A closer look at individual benthic macroinvertebrate metrics shows the percentage of intolerant (i.e., pollution sensitive) taxa decline sharply as imperviousness exceeds 10% and number of EPT taxa declines as imperviousness exceeds 20% (Figure 35). These findings are consistent with the Round One report (Hill and Pieper, 2011) and also with the Impervious Cover Model (ICM), which describes a strong relationship between watershed impervious cover and the decline of a suite of stream indicators (Schueler, 1994; CWP, 2003). As noted by Schueler (2008), the reformulated ICM is no longer expressed as a best fit line but rather a wedge that is widest at the lowest levels of imperviousness and narrowest at the highest levels, which represents the observed variability in the response of stream indicators to impervious cover and prevents the misconception that streams draining low impervious cover will automatically have good habitat conditions and a high quality benthic macroinvertebrate assemblage. This data set also shows a broad

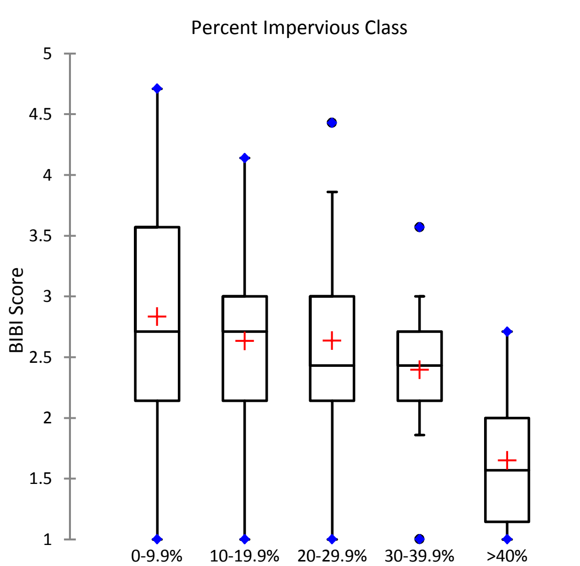

Figure 34. BIBI Data Stratified by Percent Impervious Class.

range of scores for the lowest classes of impervious cover and the narrowest range for the highest class, supporting the notion that stream quality gradually decreases with increasing imperviousness.

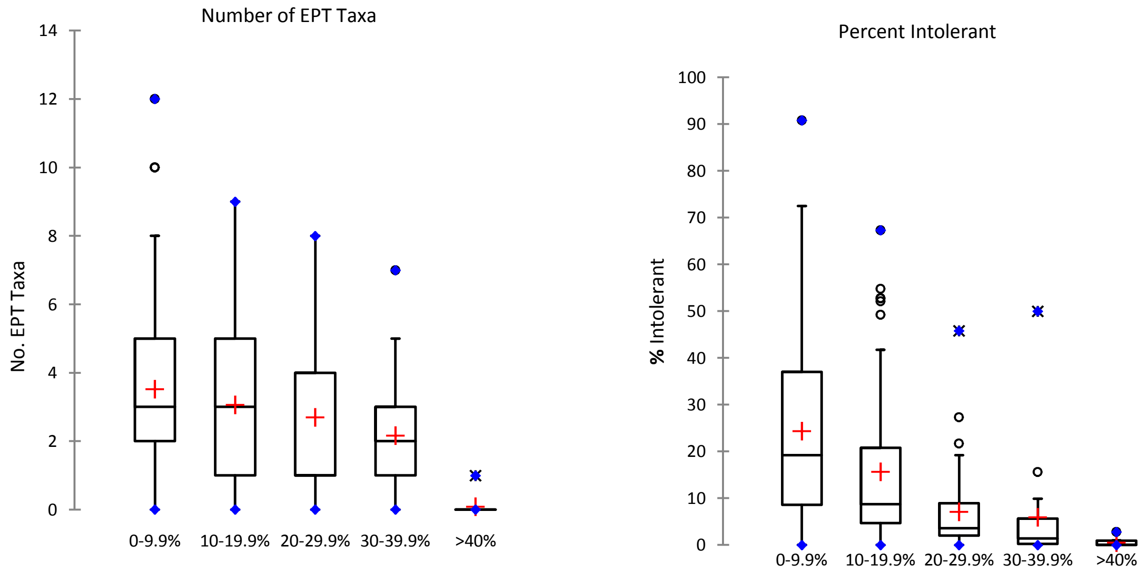

Figure 35. Box Plots of Percent Intolerant and EPT Taxa Metrics Stratified by Imperviousness Class.

A comparison of BIBI scores among Rosgen stream types was also conducted to determine the influence of geomorphic classification on biological condition. Stratification of BIBI data by Rosgen Level I stream type not only showed a large amount of overlap between channel types but also yielded results that were contrary to the expected outcome (Figure 36). Based on the notion that both “F” and “G” type streams are incised channels with little to no floodplain access and are considered the least stable stream types in terms of erosion potential, it was expected that BIBI scores would be lowest for these channel types and highest for the more stable stream types (i.e., “B”, “C”, “E” and “DA”). However, this data set shows the highest mean, 3rd quartile, and maximum values were all obtained from “F” type streams. These results are consistent with the Round One report, which found F type streams generally have higher BIBI values.

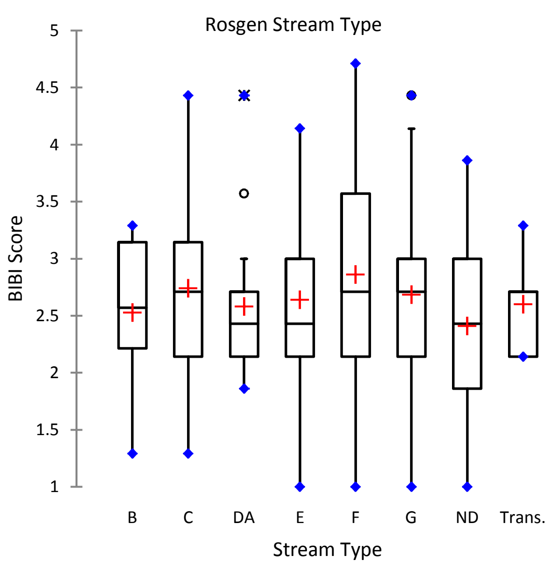

Figure 36. BIBI Data Stratified by Rosgen Stream Type.

Box plots of percent developed and agricultural land use stratified by Rosgen stream type shows that there are considerable differences in predominant land use between “F” and “G” streams as compared to “C”, “E”, and “DA” streams (Figure 37). It should be noted that only six streams were classified as “B” type, and the small sample size limits the ability to draw meaningful conclusions about this stream type. Both “F” and “G” streams occurred more frequently in drainages with generally less developed land than "C", "E", and "DA" type streams. Furthermore, "C" and "E" type streams occurred more frequently in drainages with far less agriculture land use than "F" and "G" streams. These results are consistent with findings from the Round One report (Hill and Pieper, 2011), and suggest that perhaps the differences in stressors between agricultural and developed land uses are likely influencing the biota more than Rosgen stream type. Moreover, the land use changes that caused the "F" and "G" streams to downcut and become incised may have occurred due to historic land use changes (e.g., clear cutting, ditching, intensive agriculture); and more recent land use changes, such as the conversion of farm land back to forests in some of these areas, may have enabled some streams to begin to recover resulting in more stable "F" and "G" streams.

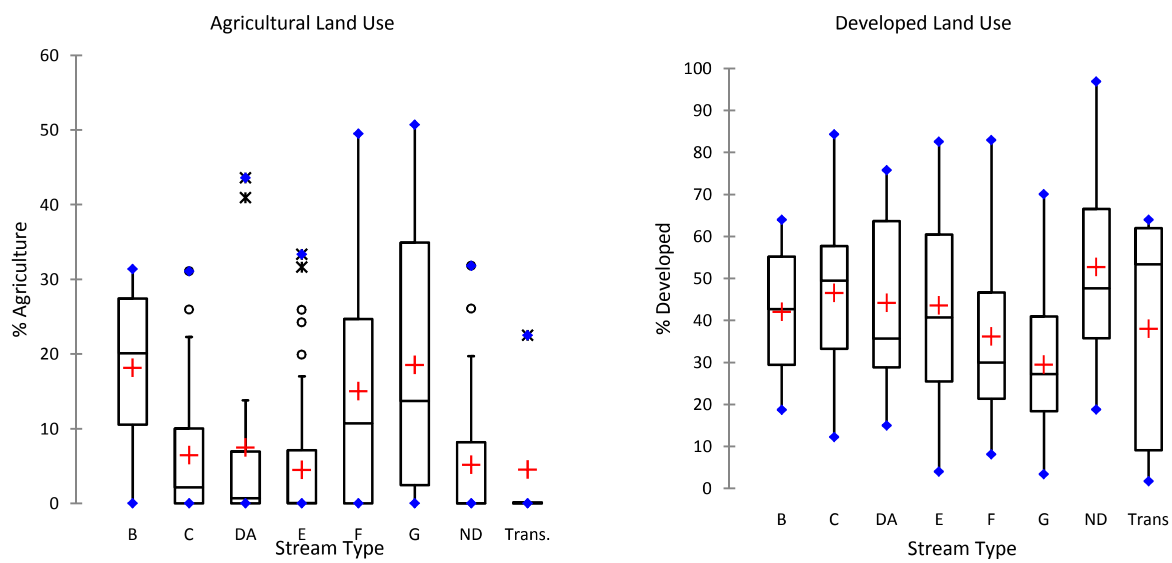

Figure 37. Percent Agriculture and Developed Land Use Stratified by Rosgen Stream Type.

In the more developed watersheds the abundance of "C", "E", and "DA" channels may be the result of an aggradation phase caused by an increased sediment supply typical of urbanization (Paul and Meyer, 2001). In the aggradation phase, sediment fills the channel and generally decreases stream depth, which decreases the channel capacity and leads to greater flooding and overbank sediment deposition, ultimately raising bank heights (Wolman, 1967.) Thus, rather than perceiving all "C" and "E" type streams throughout the County as 'stable' streams, it is important to also note the stream process before making a final determination on whether the stream is truly stable or evolving toward a less stable phase. Only through continued monitoring can one ultimately determine the evolutionary trajectory of these systems.

4.2 Correlations

The following section describes the results of the correlation analysis with a discussion of the associations between biotic and abiotic variables. Complete correlation matrices are included in Appendix B.

4.2.1 *Physical Habitat Variables*

4.2.1.1 RBP Habitat Index

The BIBI score was highly significantly correlated (p-values less than 0.001) with several individual habitat metrics including epifaunal substrate/available cover, pool substrate, and pool variability (Table 6). The overall RBP habitat index score (τ = 0.15, p <0.05), pool channel flow, channel alteration, and riparian zone width were also moderately positively correlated. Bank stability was the only metric that was negatively correlated with the BIBI and several metrics. This is likely due the fact that many urbanized channels have hardened/stabilized banks, which is supported by the positive correlation between bank stability and percent impervious and percent developed land cover (Table 7). Four individual macroinvertebrate metrics, Number of Taxa, EPT Taxa, Percent Intolerant, and Scraper Taxa were also correlated with RBP index score. Epifaunal substrate/available cover was consistently correlated with all macroinvertebrate metrics, with the exception of Percent Climbers which was not significantly correlated with any RBP habitat variable.

The overall RBP index score was significantly correlated with only one land use characteristic, percent forested land cover (Table 7). Two individual habitat parameters, channel alteration and combined riparian vegetative zone width, were significantly correlated with numerous land use characteristics (Table 7), which is consistent with findings from the Round One Report (Hill and Pieper, 2011). Both parameters were negatively correlated (p <0.001) with percent imperviousness, and percent developed, and highly positively correlated (p <0.001) with percent forested and moderately positively correlated (p <0.05) with percent agriculture.

The RBP as well as individual parameters were compared against geomorphic variables to determine which geomorphic measures are most strongly associated with physical habitat conditions (Table 8). It should be noted however, that numerous geomorphic measures were highly significantly correlated with drainage area, as were numerous habitat parameters. Therefore, to avoid potentially significant correlations that may be the result of covariance, this discussion will focus on dimensionless geomorphic variables (i.e., entrenchment ration and width/depth ratio) and sinuosity, which were not correlated with drainage area. Entrenchment ratio was strongly positively correlated with RBP score as well as several individual parameters including bank stability, vegetative protection, and channel flow, and moderately positively correlated with pool substrate, and sediment deposition. Two additional parameters, pool variability and epifaunal substrate, were positively correlated at the 0.05 level. Width/depth ratio was highly significantly correlated with bank stability (p <0.001) and was also positively correlated (p <0.05) with vegetative protection, pool variability and RBP score. While a strong positive correlation between measured sinuosity and visually assessed channel sinuosity parameter was expected, sinuosity was also highly significantly correlated (p <0.001) with overall RBP score as well as riparian zone width, and significantly correlated (p <0.05) with channel alteration, pool substrate, and pool variability.

Table 6. Correlation coefficients (Kendall τ) for physical habitat variables versus benthic macroinvertebrate metric and index scores.

Variable	No. Taxa	No. EPT Taxa	% Ephem	No. Ephem Taxa	% Intolerant	No. Scraper Taxa	% climbers	BIBI
RBP Habitat Variables								
Bank Stability	-0.02	**-0.13**	**-0.13**	**-0.14**	-0.08	0.00	0.05	**-0.10**
Vegetative Protection	0.07	-0.04	-0.08	-0.09	0.04	0.05	0.05	0.00
Channel Flow	0.05	0.06	0.05	0.05	**0.11**	**0.14**	0.01	**0.14**
Channel Alteration	**0.13**	**0.21**	0.09	0.09	**0.25**	-0.07	0.01	**0.15**
Channel Sinuosity	0.01	**0.10**	-0.01	0.00	**0.09**	**0.16**	0.00	0.09
Pool Substrate	**0.14**	**0.12**	**0.17**	**0.17**	0.05	**0.18**	0.09	**0.19**
Pool Variability	**0.16**	**0.10**	**0.19**	**0.18**	0.01	**0.28**	0.09	**0.21**
Riparian Zone Width	**0.12**	**0.15**	**0.12**	**0.11**	**0.20**	-0.05	0.06	**0.12**
Sediment Deposition	**-0.09**	0.00	0.03	0.03	0.07	0.09	-0.08	0.01
Epi. Substrate/Avail. Cover	**0.29**	**0.30**	**0.18**	**0.18**	**0.12**	**0.16**	0.09	**0.30**
RBP Score	**0.13**	**0.10**	0.07	0.06	**0.10**	**0.16**	0.08	**0.15**
PHI Habitat Variables								
Instream Habitat	**0.29**	**0.25**	**0.17**	**0.17**	0.08	**0.14**	**0.12**	**0.27**
Epifaunal Substrate	**0.15**	**0.25**	**0.22**	**0.21**	**0.12**	**0.32**	0.04	**0.29**
Bank Stability	-0.01	**-0.13**	**-0.13**	**-0.14**	-0.08	0.00	0.05	**-0.10**
Percent Shading	**0.12**	**0.14**	-0.01	0.00	**0.14**	**-0.13**	0.08	0.06
Remoteness	0.03	**0.17**	**0.11**	**0.11**	**0.19**	-0.02	0.04	**0.13**
# Woody Debris/Rootwads	**0.14**	0.04	**0.15**	**0.14**	-0.05	**0.13**	**0.14**	**0.14**
Instream Habitat Score	**0.20**	**0.22**	-0.02	-0.02	**0.17**	-0.01	0.06	**0.15**
Epifaunal Substrate Score	**0.09**	**0.24**	**0.10**	**0.10**	**0.16**	**0.23**	0.01	**0.21**
Bank Stability Score	-0.01	**-0.13**	**-0.13**	**-0.14**	-0.08	0.00	0.05	**-0.10**
Shading Score	**0.12**	**0.14**	-0.01	0.00	**0.14**	**-0.13**	0.08	0.06
Remoteness Score	0.03	**0.17**	**0.11**	**0.11**	**0.20**	-0.02	0.04	**0.13**
Woody Debris Score	0.01	-0.03	**-0.10**	-0.10	0.02	-0.08	0.05	-0.07
PHI Score	**0.13**	**0.21**	0.01	0.01	**0.19**	0.02	0.08	**0.14**

Values in bold are different from 0 with a significance level alpha=0.05
Highlighted values indicate significance at 0.001 level

Table 7. Correlation coefficients (Kendall τ) for physical habitat variables versus land use variables.

Variable	% Impervious	%Developed	%Forested	%Open	%Agriculture	Drainage area
RBP Habitat Variables						
Bank Stability	**0.18**	**0.12**	0.00	0.03	**-0.26**	0.02
Vegetative Protection	**0.10**	0.08	0.04	0.00	**-0.19**	0.01
Channel Flow	-0.04	-0.04	**0.10**	0.01	-0.03	**0.25**
Channel Alteration	**-0.27**	**-0.26**	**0.29**	-0.09	**0.17**	0.04
Channel Sinuosity	0.00	0.01	0.05	0.04	-0.08	0.02
Pool Substrate	0.02	-0.01	0.02	0.03	-0.02	**0.30**
Pool Variability	0.05	0.01	-0.01	0.06	0.01	**0.41**
Riparian Zone Width	**-0.23**	**-0.21**	**0.20**	-0.05	**0.11**	-0.01
Sediment Deposition	0.03	0.03	0.04	0.01	-0.07	0.09
Epi. Substrate/Avail. Cover	-0.02	**-0.09**	**0.10**	0.06	0.03	**0.34**
RBP Score	0.02	-0.02	**0.09**	0.03	-0.08	**0.21**
PHI Habitat Variables						
Instream Habitat	-0.02	**-0.09**	**0.10**	0.04	0.04	**0.37**
Epifaunal Substrate	-0.01	-0.07	0.08	0.06	0.00	**0.28**
Bank Stability	**0.18**	**0.13**	-0.01	0.03	**-0.26**	0.02
Percent Shading	**-0.17**	**-0.14**	**0.12**	**-0.13**	**0.09**	**-0.25**
Remoteness	**-0.31**	**-0.32**	**0.25**	**-0.11**	**0.16**	-0.01
# Woody Debris/Rootwads	0.04	0.05	-0.05	0.05	0.08	**0.25**
Instream Habitat Score	-0.05	**-0.09**	**0.11**	-0.03	-0.07	-0.08
Epifaunal Substrate Score	-0.03	-0.07	**0.09**	0.01	-0.06	0.02
Bank Stability Score	**0.18**	**0.13**	-0.01	0.03	**-0.26**	0.02
Shading Score	**-0.17**	**-0.14**	**0.12**	**-0.13**	**0.09**	**-0.25**
Remoteness Score	**-0.31**	**-0.32**	**0.25**	**-0.11**	**0.16**	-0.01
Woody Debris Score	0.00	0.04	-0.02	-0.07	-0.05	**-0.32**
PHI Score	**-0.13**	**-0.15**	**0.18**	**-0.09**	-0.03	**-0.15**

Values in bold are different from 0 with a significance level alpha=0.05
Highlighted values indicate significance at 0.001 level

4.2.1.2 PHI Habitat Index

The PHI score was strongly correlated with RBP score (τ = 0.44, p <0.001), but was only moderately correlated at the 0.05 level with BIBI score (τ = 0.14, p <0.05). Two individual PHI parameters, epifaunal substrate and instream habitat, were highly significantly correlated with BIBI score, while remoteness and woody debris/rootwads were moderately correlated at the 0.05 level (Table 6). Because several metrics are scaled to drainage area, both the raw (i.e., non-scaled) PHI metric values as well as the scored metrics are included in Table 6. It should be noted, however, that although woody debris counts were moderately positively correlated with all but two macroinvertebrate metrics and the overall BIBI score, the woody debris metric score was either not correlated or negatively correlated (i.e., Percent

Ephemeroptera) to individual metrics and the BIBI. These findings are similar to those observed in Round One, where the correlations with macroinvertebrate metrics were not consistent between the raw woody debris counts and calculated woody debris scores, suggesting the PHI scoring process that scales the scores based on drainage area (i.e., smaller drainage areas score higher than larger drainage areas for an equivalent amount of woody debris) may be overcompensating for drainage area differences. This is supported by the fact that woody debris counts are highly positively correlated with drainage area, while woody debris scores are highly negatively correlated with drainage area (Table 7).

Land use characteristics correlated much better with the PHI habitat index, as compared to the RBP index (Table 7), which is consistent with findings from Round One (Hill and Pieper, 2011). The overall PHI score was negatively correlated ($p <0.001$) with percent developed land and drainage area and positively correlated ($p <0.001$) with percent forested land cover. The PHI score was also negatively correlated ($p <0.05$) with percent imperviousness and percent open land. These results are somewhat expected given that remoteness, which is an indirect measure of proximity to roads, is highly significantly correlated with percent developed, percent forested, and percent imperviousness. In addition to remoteness, percent shading was also correlated with nearly all land use characteristics, with percent impervious, percent developed, and percent open being negatively correlated, and percent forested being positively correlated. It is also worth noting that bank stability is the only metric that showed a highly significant negative correlation with percent agriculture. In contrast, bank stability showed a highly significant positive correlation to percent impervious, which further supports the notion that bank stability scores can be easily skewed by artificial hardening and stabilization efforts while providing little biological benefit as demonstrated by the negative correlations with many macroinvertebrate metrics and the BIBI (Table 6).

The PHI as well as individual parameters were compared against geomorphic variables to determine which geomorphic measures are most strongly associated with physical habitat conditions (Table 8). Because numerous geomorphic measures were significantly correlated with drainage area, as were numerous habitat parameters, this discussion will focus primarily on the dimensionless geomorphic variables (i.e., entrenchment ration and width/depth ratio) and sinuosity, which were not correlated with drainage area, as well as metric scores that have been scaled to drainage area and were not also correlated with drainage area (i.e., instream habitat, epifaunal substrate, bank stability, remoteness. The overall PHI score was highly significantly correlated with one only geomorphic variable, sinuosity. Instream habitat and epifaunal substrate scores were highly significantly correlated with sinuosity and D50, while instream habitat score was also moderately correlated with water surface slope. Bank stability score was strongly positively correlated ($p <0.001$) with several geomorphic variables including entrenchment ratio, and flood-prone width, while being moderately positively correlated with width/depth ratio.

Table 8. Correlation coefficients (Kendall τ) for physical habitat variables versus geomorphic variables.

Variable	Entrenchment Ratio	Bankfull Width	Mean Depth	Width: Depth Ratio	Bankfull Area	Water Surface Slope	Bankfull Discharge	Sinuosity	Flood-Prone Width	D50
RBP Habitat Variables										
Bank Stability	**0.37**	**0.09**	**-0.15**	**0.18**	-0.05	-0.06	**-0.18**	0.00	**0.36**	-0.01
Vegetative Protection	**0.34**	0.06	**-0.15**	**0.16**	-0.06	-0.03	**-0.21**	0.07	**0.34**	0.00
Channel Flow	**0.34**	**0.10**	0.06	-0.01	**0.10**	***-0.25***	0.02	-0.02	***0.35***	**-0.16**
Channel Alteration	0.09	-0.04	0.02	-0.08	-0.01	-0.09	-0.03	**0.13**	0.06	-0.06
Channel Sinuosity	0.03	0.03	-0.02	0.02	0.01	0.05	-0.03	**0.61**	0.07	0.07
Pool Substrate	**0.19**	***0.26***	***0.17***	0.08	***0.26***	**-0.11**	**0.15**	**0.11**	***0.33***	***0.24***
Pool Variability	**0.11**	***0.36***	***0.27***	**0.11**	***0.37***	**-0.16**	***0.22***	**0.10**	***0.33***	***0.24***
Riparian Zone Width	0.04	-0.03	-0.01	-0.04	-0.02	-0.01	-0.03	**0.21**	0.03	-0.04
Sediment Deposition	**0.28**	0.01	-0.06	0.01	-0.04	0.02	-0.01	0.07	**0.24**	-0.05
Epi. Substrate/Avail. Cover	**0.11**	***0.28***	***0.26***	0.05	***0.31***	**-0.10**	***0.22***	**0.15**	***0.27***	***0.29***
RBP Score	**0.31**	***0.18***	0.03	**0.11**	**0.12**	**-0.10**	-0.02	**0.21**	***0.40***	0.08
PHI Habitat Variables										
Instream Habitat	**0.12**	***0.30***	***0.30***	0.05	***0.35***	**-0.13**	***0.26***	**0.12**	***0.30***	***0.28***
Epifaunal Substrate	0.07	***0.24***	**0.11**	**0.12**	***0.21***	-0.08	***0.21***	**0.17**	***0.23***	***0.28***
Bank Stability	**0.37**	0.09	**-0.15**	**0.18**	-0.05	-0.05	**-0.17**	0.01	**0.36**	0.00
Percent Shading	**-0.11**	***-0.21***	-0.04	***-0.17***	**-0.15**	0.09	**-0.15**	**0.11**	***-0.22***	-0.06
Remoteness	-0.01	-0.07	-0.03	-0.06	-0.06	0.02	-0.07	**0.14**	-0.02	-0.01
# Woody Debris/Rootwads	**0.13**	***0.20***	***0.28***	-0.04	***0.28***	***-0.16***	***0.20***	0.07	***0.20***	0.01
Instream Habitat Score	0.09	-0.04	-0.02	-0.04	-0.04	**0.17**	-0.08	**0.20**	0.06	**0.20**
Epifaunal Substrate Score	0.04	0.05	-0.07	0.08	-0.01	0.09	0.00	**0.23**	**0.09**	**0.23**
Bank Stability Score	**0.37**	0.09	**-0.15**	**0.18**	-0.05	-0.05	**-0.17**	0.01	**0.36**	0.00
Shading Score	**-0.11**	***-0.21***	-0.04	***-0.17***	**-0.15**	0.09	**-0.15**	**0.11**	***-0.22***	-0.06
Remoteness Score	-0.01	-0.07	-0.03	-0.06	-0.06	0.02	-0.07	**0.14**	-0.02	-0.01
Woody Debris Score	0.04	**-0.23**	**-0.13**	**-0.12**	**-0.22**	**0.18**	**-0.23**	**0.13**	**-0.12**	**-0.12**
PHI Score	0.06	**-0.11**	**-0.12**	-0.04	**-0.13**	**0.12**	***-0.18***	**0.25**	0.01	**0.10**
Drainage Area	0.08	**0.55**	**0.49**	**0.12**	**0.68**	**-0.40**	**0.53**	-0.07	**0.39**	**0.17**

Values in bold are different from 0 with a significance level alpha=0.05

Highlighted values indicate significance at 0.001 level

Italicized values indicate both variables are strongly correlated with drainage area

4.2.2 *Water Chemistry Variables*

The water quality analysis performed is limited in scope. The sampling conducted represents only a snapshot of conditions in time and is not fully representative of the mean or range of conditions that the biota are subject. Additionally, several parameters (i.e., dissolved oxygen and temperature) are influenced by daily cycles of ambient temperature and stream metabolism. Nevertheless, several individual macroinvertebrate metrics showed significant correlations with water chemistry parameters (Table 9). Both Number of EPT Taxa and Percent Intolerant metrics were highly significantly correlated (negatively) with conductivity, which is consistent with findings from the Round One report (Hill and Pieper, 2011). Percent Intolerant was also highly significantly correlated (negatively) to pH; however, since pH is also significantly correlated with conductivity (see Appendix B) the result is likely due to intercorrelation between conductivity and pH. Conductivity was also moderately negatively correlated ($p < 0.05$) with Percent Ephemeroptera, Number of Ephemeroptera, and BIBI score. Other statistically significant ($p < 0.05$) water quality parameter associations include dissolved oxygen being weakly positively correlated with EPT Taxa and BIBI score, and turbidity being moderately correlated (negatively) with Number of Taxa and EPT Taxa metrics.

4.2.3 *Geomorphic Variables*

Contrary to findings from the Round One report (Hill and Pieper, 2011), Round Two geomorphic data yielded some significant correlations with the overall BIBI score as well as several individual macroinvertebrate metrics (Table 9). Three variables (mean depth, bankfull area, and estimated bankfull discharge) were highly significantly correlated with the overall BIBI score. Bankfull width and D_{50} were also positively correlated ($p < 0.05$), while entrenchment ratio was negatively correlated ($p < 0.05$). Three metrics Percent Ephemeroptera, Ephemeroptera Taxa, and Scraper Taxa, were either correlated or ($p < 0.05$) or highly significantly correlated ($p < 0.001$) with at least six different geomorphic variables. However, it should be noted that these three macroinvertebrate metrics, as well as the BIBI score, are also highly significantly correlated with drainage area, and nearly all geomorphic variables are also very strongly correlated ($p < 0.001$) with drainage area (Table 10), with the exception of entrenchment ratio, width/depth ratio and sinuosity. This suggests the results are likely due to intercorrelation between drainage area and geomorphic variables given that they are not independent variables (i.e., mean depth, bankfull area, and bankfull discharge variables are dependent on catchment drainage area). Nonetheless, geomorphic variables such as width, depth, and estimated discharge are likely potential drivers of the drainage area effect observed with benthic macroinvertebrate metrics and the BIBI score. In contrast, one macroinvertebrate metric, Percent Intolerant, was negatively correlated to numerous geomorphic variables including bankfull width, width/depth ratio, bankfull area, floodprone width, and D50; however, these results are likely due to intercorrelation given that those same geomorphic variables are also positively correlated with Percent Impervious (Table 10), which is strongly negatively correlated with Percent Intolerant (Table 9).

Associations between bed surface materials and biological variables and found negative correlations between the percentage of silt/clay substrate and Number of Taxa ($p < 0.001$), Number of EPT Taxa ($p < 0.001$), and the overall BIBI ($p < 0.05$). In contrast, the percentage of sand substrate was positively correlated with Number of Taxa ($p < 0.001$), Number of EPT Taxa ($p < 0.05$), Percent Climbers ($p < 0.05$), and the overall BIBI ($p < 0.05$). These results suggest that stream biota are being influenced by bed surface materials, especially fine sediments (i.e, particles ≤0.062 mm).

Table 9. Correlation coefficients (Kendall τ) for water chemistry, geomorphic, and land use variables versus benthic macroinvertebrate metric and index scores.

Variable	No. Taxa	No. EPT Taxa	% Ephem	No. Ephem Taxa	% Intolerant	No. Scraper Taxa	% climbers	BIBI
Water Quality Variables								
Conductivity	0.02	**-0.17**	**-0.12**	**-0.11**	**-0.38**	0.05	**0.15**	**-0.15**
Dissolved Oxygen	0.07	**0.09**	0.04	0.04	0.00	0.03	0.05	**0.09**
pH	-0.02	-0.07	**0.12**	**0.12**	**-0.19**	**0.12**	0.07	0.02
Turbidity	**-0.11**	**-0.14**	0.02	0.01	-0.04	-0.03	-0.03	-0.09
Water Temperature	**-0.11**	-0.01	0.04	0.04	0.07	0.07	-0.07	0.01
Geomorphic Variables								
Entrenchment Ratio	-0.01	**-0.13**	**-0.10**	**-0.11**	-0.06	-0.06	0.01	**-0.09**
Bankfull Width	**0.10**	0.01	**0.17**	**0.17**	**-0.15**	**0.24**	**0.13**	**0.14**
Mean Depth	**0.19**	**0.11**	**0.23**	**0.23**	-0.05	**0.13**	**0.15**	**0.22**
Width: Depth Ratio	-0.05	-0.08	-0.02	-0.02	**-0.11**	**0.12**	-0.01	-0.05
Bankfull Area	**0.17**	0.06	**0.24**	**0.23**	**-0.12**	**0.22**	**0.16**	**0.20**
Water Surface Slope	**-0.10**	0.02	**-0.17**	**-0.16**	0.04	-0.05	-0.06	-0.09
Bankfull Discharge	**0.11**	**0.11**	**0.25**	**0.23**	-0.09	**0.23**	0.08	**0.20**
Sinuosity	0.04	0.09	-0.07	-0.06	0.08	0.05	0.01	0.05
Flood-Prone Width	0.04	**-0.10**	0.04	0.03	**-0.11**	0.09	0.08	0.01
D50	**0.13**	**0.14**	0.05	0.05	**-0.10**	**0.20**	0.07	**0.11**
Bed % Silt/Clay	**-0.18**	**-0.19**	-0.06	-0.07	0.02	-0.06	-0.08	**-0.13**
Bed % Sand	**0.17**	**0.13**	0.02	0.02	0.04	-0.06	**0.13**	**0.10**
Bed % Gravel	0.02	0.06	0.03	0.03	-0.03	**0.12**	-0.02	0.04
Bed % Cobble	-0.04	-0.06	-0.05	-0.04	**-0.13**	0.04	0.04	-0.08
Bed % Boulder	-0.04	-0.04	**-0.14**	**-0.14**	**-0.14**	-0.03	0.01	**-0.13**
Land Use/ Drainage Area Variables								
Drainage Area	**0.15**	0.08	**0.27**	**0.26**	-0.07	**0.24**	**0.10**	**0.22**
%Impervious	0.02	**-0.21**	**-0.17**	**-0.17**	**-0.41**	**0.17**	0.03	**-0.15**
%Developed	-0.01	**-0.21**	**-0.18**	**-0.18**	**-0.34**	**0.12**	-0.02	**-0.15**
%Forested	0.03	**0.20**	**0.10**	0.10	**0.35**	**-0.12**	0.02	**0.13**
%Open	0.00	-0.06	0.08	0.08	**-0.14**	0.08	0.01	-0.01
%Agriculture	0.09	**0.17**	**0.26**	**0.26**	**0.17**	0.02	0.03	**0.19**

Values in bold are different from 0 with a significance level alpha=0.05

Highlighted values indicate significance at 0.001 level

4.2.4 *Land Use Variables*

In Round Two, land use variables (i.e., developed, agriculture, forested, open) correlated well with biological data. Drainage area was positively correlated with all but two metrics (EPT taxa and % Intolerant) including the BIBI (Table 9), which is consistent with findings from the Round One Report (Hill and Pieper, 2011). Both percent impervious and percent developed were strongly negatively correlated with the Percent Intolerant metric and moderately negatively correlated with three other metrics (i.e., EPT Taxa, Ephemeroptera Taxa, and Percent Ephemeroptera) as well as the BIBI score. The similarity in associations is not surprising given the strong positive correlation between percent impervious and percent developed ($\tau = 0.82$). In contrast, percent forested was strongly positively correlated with the Percent Intolerant metric, and moderately positively correlated with EPT Taxa, Percent Ephemeroptera, and the BIBI score. Percent agriculture was highly significantly correlated (positively) with four metrics (i.e., EPT Taxa, Percent Ephemeroptera, Ephemeroptera Taxa, and Percent Intolerant) as well as the BIBI score. These findings are consistent with the previous studies concluding that streams draining developed, or urban, watersheds tend to be more degraded than those draining agricultural or forested watersheds (Crawford and Lenat 1989, Wang et al. 2000). Interestingly, Number of Scraper Taxa was negatively correlated with percent forested and positively correlated with percent developed and percent impervious, which is contrary to the expected response to increasing perturbation. However, the five most prevalent scraper taxa found in the County (both abundance and frequency) have tolerance values of 7 or greater and are considered tolerant taxa. Of the 29 scraper taxa found in the County during Round 2, 45% are considered tolerant, while only 21% are considered intolerant.

Conductivity and pH were the water quality indicators that showed the strongest correlations with land use characteristics (Table 10). Both conductivity and pH were strongly positively correlated ($p < 0.001$) with percent impervious and moderately correlated ($p < 0.05$) with percent developed, and strongly negatively correlated with percent forested ($p < 0.001$). Additionally, pH was highly significantly correlated with percent open and negatively correlated with percent agriculture. However, it should be noted that conductivity and pH are strongly positively correlated ($\tau = 0.503$); therefore, it is not clear whether the strong associations observed for pH are the result of intercorrelation with conductivity or true responses to land use characteristics. Conductivity, on the other hand, has previously showed a strong link with land use characteristics in the Round One Report (Hill and Pieper, 2011). Conductivity is often observed in elevated levels in developed, or urbanized, watersheds and has been shown to be strongly correlated with urban land use (Rasmussen et al., 2009). Furthermore, the results are consistent with a study examining the relationship between stream chemistry and watershed land cover in the Mid-Atlantic region, where concentrations of chloride and base cations, which collectively influence conductivity, were strongly related to watershed land cover (Herlihy et al. 1998).

Table 10. Correlation coefficients (Kendall τ) for water chemistry and geomorphic variables versus land use variables.

Variable	Drainage area	%Impervious	%Developed	%Forested	%Open	%Agriculture
Water Chemistry Variables						
Conductivity	0.08	**0.40**	**0.19**	**-0.36**	**0.22**	-0.13
Dissolved Oxygen	**0.14**	**-0.14**	-0.07	0.10	**-0.14**	**0.20**
pH	**0.18**	**0.42**	**0.15**	**-0.30**	**0.26**	**-0.17**
Turbidity	-0.04	-0.02	0.01	0.04	-0.02	**-0.24**
Water Temperature	-0.02	**0.26**	**0.14**	**-0.18**	0.14	**-0.25**
Geomorphic Variables						
Entrenchment Ratio	0.08	**0.13**	**0.13**	-0.02	0.02	**-0.16**
Bankfull Width	**0.55**	**0.13**	0.07	**-0.10**	**0.12**	0.07
Mean Depth	**0.49**	0.01	-0.01	-0.02	0.07	**0.13**
Width: Depth Ratio	**0.12**	**0.10**	0.07	-0.08	0.06	-0.01
Bankfull Area	**0.68**	**0.09**	0.03	-0.08	**0.11**	**0.12**
Water Surface Slope	**-0.40**	0.03	0.02	-0.01	-0.04	**-0.12**
Bankfull Discharge	**0.53**	0.05	0.00	-0.05	**0.11**	**0.14**
Sinuosity	-0.07	0.04	0.05	-0.01	0.03	**-0.13**
Flood-Prone Width	**0.39**	**0.17**	**0.13**	-0.04	0.07	**-0.11**
D50	**0.17**	**0.18**	**0.10**	**-0.10**	0.08	-0.09

Values in bold are different from 0 with a significance level alpha=0.05
Highlighted values indicate significance at 0.001 level

4.2.5 *Biological Index Associations*

In Round Two, several patterns have emerged between the biological data and other environmental variables that were not evident in the Round One analysis. For instance, land use variables appear to be good predictors of biological conditions with moderate to strong associations with the BIBI and individual macroinvertebrate metrics. Percent forested and agriculture were positively correlated with BIBI scores and percent developed and percent impervious were negatively correlated, which were the expected responses, suggesting that land use categories are generally useful predictors of overall biological conditions. These results are not consistent with findings from Round One, where land use variables were generally not well correlated with biological data (Hill and Pieper, 2011). These differences are likely due to more consistency in the methods used to perform the land use analysis in Round Two as well as improved impervious and land cover layers available.

Two individual macroinvertebrate metrics, Number of EPT Taxa and Percent Intolerant Urban, showed the strongest correlations with land use variables, which remain consistent with findings in Round One (Hill and Pieper, 2011). The Number of EPT Taxa metric (the number of taxa in the insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Tricoptera (caddisflies)), which are generally intolerant taxa, is predicted to decrease in response to increasing perturbation (Barbour et al., 1999).

EPT Taxa richness is used in most macroinvertebrate bioassessments in the United States and almost always shows a negative correlation with measures of urban intensity (Kerans and Karr, 1994). Similarly, the Percent Intolerant Urban metric (the percentage of organisms considered intolerant to urbanization) is also predicted to decrease in response to increasing perturbation (Southerland et al., 2005). Therefore, it is not surprising that these two metrics appear to respond better than the others to land use types, such as percent developed, which are associated with urban stressors and increased perturbation. Furthermore, these same two metrics were the most strongly correlated to specific conductivity. Conductivity was positively correlated with only one metric, Percent Climbers; however, this may be due to the inverse relationship between Percent Intolerant and Percent Climbers ($\tau = -0.133$), suggesting that climber taxa may occupy an increasing proportion of the benthic macroinvertebrate community as intolerant individuals are lost due to increasing conductivity.

The positive relationship between individual macroinvertebrate metrics and percent agriculture observed in Round Two is consistent with findings from Round One, and does not necessarily imply that nutrient enrichment from agricultural practices is enhancing biological communities. Positive relationships between agricultural land and IBI scores in freshwater streams have been documented in other studies as well (e.g., Volstad et al., 2003; Wang et al., 2000), and may be due to the interdependency between percent agriculture land and percent developed land use. Furthermore, streams in agricultural watersheds usually remain relatively unimpaired until the extent of agriculture is relatively high (i.e., more than 30% – 50%; Allan, 2004), and only one PSU, Lyons Creek, had over 30% agricultural land use. As a result, not only were agricultural impacts on the biological community likely insignificant, but also the increase in agricultural land was typically coupled with a decrease in developed land, which exerts a disproportionately larger influence on streams (Paul and Meyer, 2001).

Round Two geomorphic data correlated well with the overall BIBI score as well as several individual macroinvertebrate metrics, contrary to findings from the Round One report where geomorphic variables were not well correlated with the overall BIBI score or individual macroinvertebrate metrics (Hill and Pieper, 2011). Three variables were highly significantly correlated with the overall BIBI score (mean depth, bankfull area, and estimated bankfull discharge), and four more were positively correlated at the 0.05 level (bankfull width, entrenchment ratio, D_{50}, and percent sand bed material), while two were negatively correlated at the 0.05 level (percent silt/clay bed material, percent boulder bed material). However, it should be noted that nearly all geomorphic variables are also strongly correlated with drainage area, which suggests these results are possibly due to intercorrelation between drainage area and geomorphic variables. What is not yet clear, however, is the influence drainage area has on the biological conditions and whether or not the geomorphic differences (e.g., depth, width) are what is essentially driving the 'drainage area effect'.

While the overall BIBI score was not strongly correlated with any of the water quality variables, several physical habitat parameters were highly significantly correlated. The individual RBP habitat variables that were most strongly correlated with BIBI included pool substrate, pool variability, and epifaunal substrate/available cover. Total RBP habitat score, which was highly significantly correlated with the BIBI score in the Round One report (Hill and Pieper, 2011), was only correlated at the 0.05 level in Round Two. Two PHI habitat parameters, instream habitat and epifaunal substrate, were highly significantly correlated to the BIBI score, and the overall PHI was correlated at the 0.05 level. While some studies have shown that integrated habitat scores are poorly correlated with stream quality (Roesner and Bledsoe, 2003), strong correlations between macroinvertebrate indicators and visual habitat parameters have been reported in cases when habitat evaluations are adapted for a specific region (Fend et al., 2005). The results of this analysis support the latter, suggesting a strong association between select visual habitat assessment parameters and BIBI scores in Anne Arundel County.

The highly significantly correlation between drainage area and biological indicators was again observed in Round Two. The BIBI score and five other metrics were positively correlated with drainage area. Number of EPT Taxa and Percent Intolerant were the only two metrics not correlated with drainage area. These results support the notion that drainage area, or perhaps stream order, is exerting some influence on biological community composition. Since drainage area was also significantly correlated with RBP habitat score and a number of geomorphic variables, it is likely that physical habitat is more diverse, and heterogeneous in larger stream systems, which provides an increased potential for full colonization by benthic macroinvertebrate communities. What is unclear is whether this influence of drainage area on the BIBI is more widespread across Maryland, or simply confined to the western coastal plain given the deficiency of larger stream networks due to the predominance of first order streams, which drain directly to the flooded river valleys of the Chesapeake Bay.

4.2.6 *Rural PSU Associations*

To evaluate whether stream biota in rural, minimally developed watersheds in the south and western part of the County are responding differently to abiotic drivers as compared to the more developed PSUs in the northern part of the County, correlations were run using data from the following PSUs: Middle Patuxent, Stocketts Run, Rhode River, Rock Branch, West River, Ferry Branch, Herring Bay, Cabin Branch, Lyons Creek, and Hall Creek. These PSUs are all categorized as having less than 30 percent developed land, greater than 10 percent agricultural land use, and less than 10 percent imperviousness. Contrary to what was found among the entire data set, land use variables did not correlate well with biological variables in the rural PSUs (Table 11). Aside from drainage area, the BIBI score was not significantly correlated with any land use variable. Only one metric, Percent Intolerant, was significantly correlated ($p < 0.05$) with multiple land use variables. Percent Intolerant was negatively correlated with Percent Impervious, Percent Open, and Percent Agriculture, and was positively correlated with Percent Forested land use. This suggests that land use variables are generally not useful predictors of biological conditions within this portion of the County, likely due to more homogeneous land use conditions (i.e., predominantly forested and agriculture) as compared to the more developed areas.

Table 11. Correlation coefficients (Kendall τ) for biological variables versus land use in rural PSUs.

Variable	No. Taxa	No. EPT Taxa	% Ephem	No. Ephem Taxa	% Intolerant	No. Scraper Taxa	% climbers	BIBI
%Impervious	-0.05	-0.13	0.01	0.03	**-0.15**	0.15	-0.09	-0.07
%Developed	-0.10	-0.14	-0.01	0.01	-0.13	0.10	**-0.13**	-0.08
%Forested	-0.02	0.04	0.01	-0.01	**0.24**	**-0.20**	0.01	-0.01
%Open	-0.05	-0.03	0.08	0.08	**-0.15**	0.04	-0.06	-0.01
%Agriculture	0.10	0.03	0.05	0.06	**-0.15**	0.12	0.09	0.07
Drainage area	0.07	0.10	**0.36**	**0.33**	-0.05	**0.27**	0.02	**0.28**

Values in bold are different from 0 with a significance level alpha=0.05

Highlighted values indicate significance at 0.001 level

Similar to what was found among the entire data set, water quality variables showed some limited associations with biological variables in the rural PSUs (Table 12). However, it should be noted that that the water quality data is synoptic in nature and does not represent the breadth of potential water quality experienced by the macroinvertebrates. Conductivity remains a meaningful predictor of biological response with a highly significant negative correlation with Percent Intolerants, and correlations at the 0.05 level with EPT Taxa and the overall BIBI score. Turbidity also exhibited a strong influence on biological conditions as it was negatively correlated with Total Taxa, EPT Taxa, Scraper Taxa, and the overall BIBI score, suggesting that increased turbidity, possibly from agricultural runoff or bank erosion, is a predominant stressor contributing to biological impairment in these PSUs.

Table 12. Correlation coefficients (Kendall τ) for biological variables versus water quality in rural PSUs.

Variable	No. Taxa	No. EPT Taxa	% Ephem	No. Ephem Taxa	% Intolerant	No. Scraper Taxa	% climbers	BIBI
Conductivity	-0.09	**-0.17**	-0.07	-0.05	**-0.24**	-0.04	0.10	**-0.17**
Dissolved Oxygen	-0.08	0.04	-0.04	-0.04	-0.07	0.06	0.00	-0.04
pH	0.00	-0.03	0.14	0.14	-0.11	0.08	-0.03	0.05
Turbidity	**-0.21**	**-0.26**	-0.01	-0.03	-0.08	**-0.21**	-0.02	**-0.17**
Water Temperature	0.02	-0.05	0.03	0.00	-0.01	**0.15**	-0.07	0.04

Values in bold are different from 0 with a significance level alpha=0.05

Highlighted values indicate significance at 0.001 level

Generally, correlations between biological variables and both physical habitat and geomorphic variables in Rural PSUs were consistent with those observed for the entire data set (Appendix B). The BIBI was most strongly correlated with epifaunal substrate and instream habitat metrics, and to a lesser extent pool substrate and pool variability. The BIBI was strongly correlated with bankfull width, mean depth, and bankfull area, which is consistent with the overall data set; however, it should be noted that those geomorphic variables as well as the BIBI are strongly correlated with drainage area.

Correlations between biological variables and bed surface materials found strongly positive correlations between the number of EPT Taxa and the 16^{th}, 35^{th}, 50^{th}, and 65^{th} percentiles of cumulative particle size distribution (i.e., D16, D35, D50 and D65, respectively; Table 13). The overall BIBI was correlated at the 0.05 level with 16^{th}, 35^{th}, 50^{th}, 65^{th} and 84^{th} percentiles of cumulative particle size distribution. Total Taxa was also correlated at the 0.05 level with the D16, D50, and D65, while Scraper Taxa was correlated with the D50 and D65. These results suggest that stream biota in these watersheds are being influenced by bed surface materials, especially EPT Taxa. Moreover, the percentage of silt/clay substrate was strongly negatively correlated with EPT Taxa and negatively correlated at the 0.05 level with Total Taxa and the BIBI score, suggesting that increasing percentages of the finest substrate particles (≤0.062 mm) is a key driver of biological impairment in these watersheds. These results are consistent with findings from a study by Kaller and Hartman (2004), in which seven Appalachian streams with different levels of sediment accumulation found consistent negative relationships with the finest substrate particles (<0.25mm) that exceeded 0.8-0.9% of riffle substrate composition and EPT taxa richness.

Table 13. Correlation coefficients (Kendall τ) for biological variables versus bed surface materials in rural PSUs.

Variable	**No. Taxa**	**No. EPT Taxa**	**% Ephem**	**No. Ephem Taxa**	**% Intolerant**	**No. Scraper Taxa**	**% climbers**	**BIBI**
Bed Surface D16	**0.17**	**0.33**	0.04	0.05	0.07	0.05	-0.01	**0.18**
Bed Surface D35	0.12	**0.33**	0.06	0.07	0.06	0.13	-0.03	**0.19**
Bed Surface D50	**0.14**	**0.30**	0.09	0.11	0.02	**0.21**	-0.03	**0.22**
Bed Surface D65	**0.18**	**0.27**	0.10	0.11	0.04	**0.24**	-0.04	**0.23**
Bed Surface D84	0.12	**0.18**	0.09	0.09	0.09	**0.20**	-0.04	**0.18**
Bed Surface D95	0.09	0.12	0.02	0.03	0.03	**0.16**	-0.07	0.09
Bed Surface % Silt/Clay	**-0.20**	**-0.31**	-0.05	-0.06	-0.05	-0.10	-0.02	**-0.19**
Bed Surface % Sand	**0.16**	**0.15**	-0.03	-0.04	-0.01	-0.07	**0.19**	0.07
Bed Surface % Gravel	0.10	**0.22**	0.08	0.08	0.05	**0.21**	-0.06	**0.16**
Bed Surface % Cobble	0.10	0.05	0.13	0.17	0.00	0.07	**0.18**	0.11
Bed Surface % Boulder	0.07	0.07	-0.12	-0.12	0.03	**-0.19**	-0.03	-0.05

Values in bold are different from 0 with a significance level alpha=0.05
Highlighted values indicate significance at 0.001 level

4.1 Benthic Macroinvertebrate Taxa Analysis

A review of benthic macroinvertebrate taxa found at all sites receiving a biological condition rating of 'good' (BIBI score ≥ 4.00) was conducted to evaluate which taxa are unique to high quality streams in the County. Only seven taxa were found that were truly unique to unimpaired sites and were not found at any site that had been classified as either 'poor' or 'very poor' (Table 14). All but one taxa, *Eurylophella*, were present at only a single 'good' site and four of those taxa (i.e., *Anopheles, Arigomphus, Centroptilum, Dromogomphus*) had only a single specimen present, which suggests that these four taxa may simply be very rare with regards to occurrence and abundance. *Sweltsa*, an intolerant stone fly, is one of only two macroinvertebrate taxa that have been designated as cold water obligates by Maryland DNR (Kashiwagi & Prochaska, 2011). Cold water obligates are defined as genera with a 99th percentile of specimens occurring at or below a temperature threshold of 22° Celcius, and are potential surrogate indicators for brook trout water temperatures (Kashiwagi & Prochaska, 2011). It should also be noted that Maryland DNR currently does not have any records of *Sweltsa* occurring in Anne Arundel County, although records do exist in nearby Prince George's and Charles Counties. Even though *Swelta* was found at only one site in Round Two (R2-23-01), it's presence within the Jug Bay Wetland Sanctuary is a promising sign of the benefits of land conservation and preservation.

Table 14. Taxa Unique to Unimpaired Sites

Order	Family	Genus	Tolerance Value	No. of Organisms Found	No. of 'Good' Sites with Taxa Present
Diptera	Culicidae	*Anopheles*	N/A	1	1
Diptera	Dixidae	*Dixella*	5.8	2	1
Ephemeroptera	Baetidae	*Centroptilum*	2.3	1	1
Ephemeroptera	Ephemerellidae	*Eurylophella*	4.5	4	2
Odonata	Gomphidae	*Arigomphus*	2.2	1	1
Odonata	Gomphidae	*Dromogomphus*	2.2	1	1
Plecoptera	Chloroperlidae	*Sweltsa*	1.9	30	1

N/A indicates information is not available

An additional five taxa were primarily unique to unimpaired sites but were found to occur at only one 'poor' site (Table 15). It should be noted that none of these taxa were found at sites with BIBI scores below 2.43. While these taxa can be generally associated with unimpaired biological conditions, they are not unique to 'good' sites as their presence has been observed, albeit rarely, in streams designated as having 'poor' biological conditions.

Table 15. Taxa Primarily Occurring at Unimpaired Sites but Present at a Single Impaired Site

Order	Family	Genus	Tolerance Value	No. of Organisms Found	No. of 'Good' Sites with Taxa Present
Diptera	Chironomidae	*Alotanypus*	6.6	1	1
Ephemeroptera	Baetidae	*Acerpenna*	2.6	27	8
Ephemeroptera	Baetidae	*Baetis*	3.9	56	3
Odonata	Gomphidae	*Hagenius*	2.2	1	1
Plecoptera	Perlidae	*Eccoptura*	0.6	2	1
Trichoptera	Leptoceridae	*Triaenodes*	5	2	2

Unfortunately, numerous sensitive taxa from the orders Ephemeroptera (mayflies), Plecoptera (stoneflies), Tricoptera (caddisflies), and Megaloptera (alderflies, dobsonflies, fishflies) were also present at several 'Poor' sites precluding their designation as unique taxa to high quality streams. The combination of few truly unique taxa and unique taxa that are rare among even mimimally impacted streams, would likely not yield any useful metrics for discriminating between impaired and unimpaired streams with a high level of confidence. In other words, a metric comprised of unique taxa may score some 'good' sites poorly, while scoring some 'poor' sites better.

5 Comparison of Round One and Round Two Results

5.1 Biological and Physical Habitat Comparison

This section presents a brief comparison of the biological and physical habitat assessment results between Round One and Round Two. Statistical comparisons of BIBI, RBP, and PHI index scores between Rounds One and Two are shown in Table 16.

Table 16. Comparison of Biological and Physical Habitat Index Scores Between Round One and Round Two

Index	Round Two		Round One		Upper	Lower	Significant Difference? (Direction)
	Mean	SE	Mean	SE	95% CI	95%CI	
BIBI	2.67	0.05	2.61	0.05	0.08	-0.20	No
RBP	120.31	1.55	115.87	1.35	-0.41	-8.48	YES (increase)
PHI	69.46	0.74	67.47	0.77	0.10	-4.08	No

Mean BIBI scores for the County did not change significantly between sampling rounds. Although the median and third quartile values improved slightly in Round Two, the first quartile and mean BIBI score remained virtually unchanged (Figure 38). A statistically significant difference in the average RBP habitat scores for the County was observed between sampling rounds. While the first quartile remained relatively unchanged, the mean, median, and third quartiles were all slightly higher in Round Two, even though minimum scores were considerably lower in Round Two (Figure 39). Average PHI scores for the County did not significantly change between sampling rounds even though mean, median, and the first and third quartile values were all slightly higher in Round Two (Figure 40). Given that neither the PHI nor the BIBI changed, it is likely that the small, but significant, change noted in RBP scores between Round One and Round Two does not reflect an improvement in the physical habitat conditions within the County's streams and riparian zones during this time span but rather is an artifact of the qualitative nature of a visually-based assessment methodology. In other words, the observed difference is more likely attributed to sampler bias that is inherent in any rapid, visually-based habitat assessment procedure.

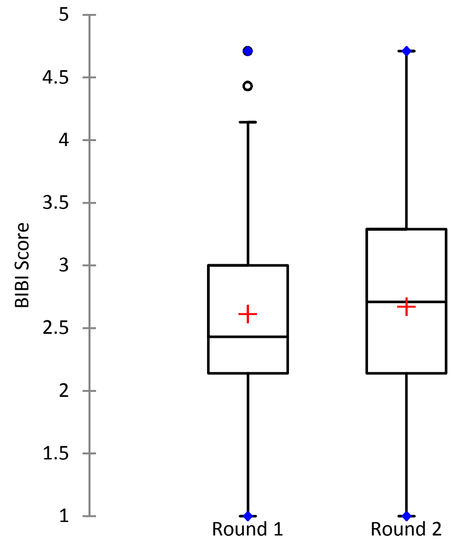

Figure 38. Comparison of Round 1 and Round 2 BIBI Scores

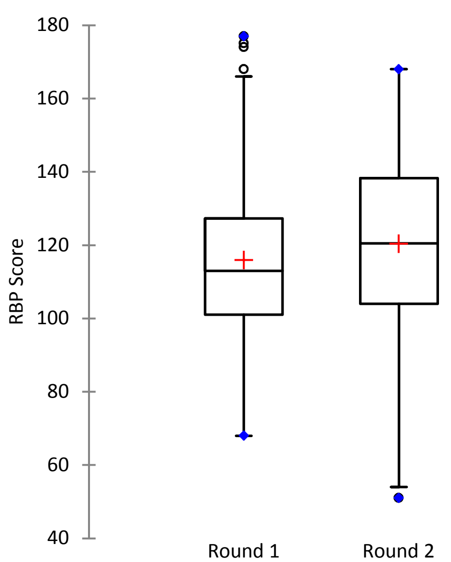

Figure 39. Comparison of Round 1 and Round 2 RBP Scores

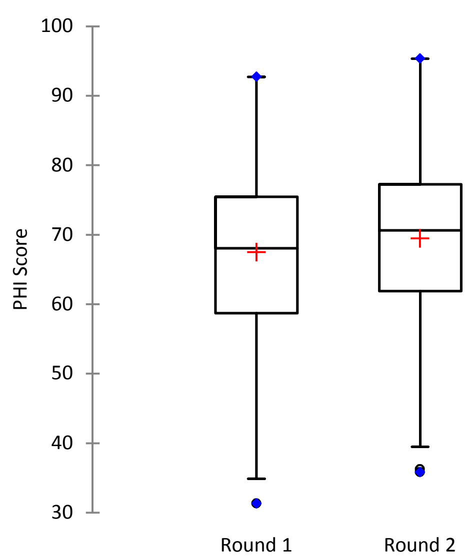

Figure 40. Comparison of Round 1 and Round 2 PHI Scores

At the PSU level, BIBI scores changed significantly for a total of five PSUs between rounds Table 17. Three PSUs (i.e., West River, Sawmill Creek, and Cabin Branch) had mean BIBI scores that significantly increased in Round Two. Conversely, the Marley Creek and Stocketts Run PSUs had mean BIBI scores that were significantly lower in Round Two. Surprisingly, there were no significant differences in either RBP or PHI habitat scores among the PSUs with statistically significant changes in BIBI scores, suggesting that the observed changes were not the result of improved or degraded physical habitat conditions in any of these PSUs.

Table 17. Comparison of PSU BIBI Scores Between Round One and Round Two

Year	PSU #	PSU Name	Round Two		Round One		Upper	Lower	Significant Difference? (Direction)
			Mean IBI	SE	Mean IBI	SE	95% CI	95%CI	
2009	17	Little Patuxent River	2.34	0.09	2.09	0.25	0.26	-0.78	No
2009	12	Lower North River	2.60	0.19	2.63	0.17	0.52	-0.47	No
2009	5	Marley Creek	1.83	0.15	2.57	0.17	1.19	0.29	Yes (Decrease)
2009	20	Rock Branch	3.03	0.24	2.43	0.31	0.16	-1.36	No
2009	14	West River	2.89	0.09	1.86	0.10	-0.77	-1.28	Yes (Increase)
2010	2	Stony Run	2.69	0.31	2.37	0.22	0.43	-1.07	No
2010	4	Sawmill Creek	2.35	0.16	1.92	0.13	-0.02	-0.84	Yes (Increase)
2010	15	Herring Bay	3.17	0.32	2.80	0.34	0.54	-1.28	No
2010	18	Middle Patuxent	3.32	0.19	2.94	0.22	0.19	-0.95	No
2010	21	Ferry Branch	2.91	0.15	3.20	0.26	0.87	-0.29	No
2011	6	Bodkin Creek	2.40	0.29	2.43	0.19	0.71	-0.65	No
2011	9	Severn Run	3.14	0.33	2.80	0.23	0.45	-1.14	No
2011	7	Upper Magothy	2.91	0.19	2.86	0.21	0.49	-0.60	No
2011	11	Upper North River	2.74	0.28	3.34	0.15	1.22	-0.01	No
2011	16	Upper Patuxent	2.34	0.16	2.37	0.12	0.42	-0.36	No
2012	24	Hall Creek	2.20	0.26	2.77	0.24	1.25	-0.11	No
2012	3	Lower Patapsco	2.43	0.23	2.69	0.19	0.85	-0.34	No
2012	1	Piney Run	2.69	0.28	2.69	0.25	0.75	-0.75	No
2012	13	Rhode River	2.17	0.14	1.97	0.11	0.15	-0.55	No
2013	23	Cabin Branch	3.34	0.25	2.31	0.16	-0.44	-1.62	Yes (Increase)
2013	8	Lower Magothy	2.11	0.17	2.20	0.15	0.53	-0.36	No
2013	22	Lyons Creek	3.00	0.31	2.77	0.25	0.55	-1.01	No
2013	10	Severn River	2.77	0.2	3.09	0.27	0.98	-0.35	No
2013	19	Stocketts Run	2.60	0.29	3.51	0.28	1.69	0.13	Yes (Decrease)

Consequently, for each of the aforementioned PSUs several additional abiotic variables that have been shown to be strongly associated with the BIBI score (i.e., percent impervious, drainage area, conductivity) were compared between rounds to determine if any significant differences were observed that could help explain the shift in BIBI scores. No statistically significant differences were observed for percent imperviousness or drainage area in any of the PSUs examined. Statistically significant differences were observed in conductivity values for two PSUs (Marley Creek and Stocketts Run) between sampling rounds (Table 18). Marley Creek saw mean conductivity values jump from 299.40 µS/cm in Round One (2006) to 738.67 µS/cm in Round Two (2009; Figure 41). Similarly, Stocketts Run saw mean conductivity values jump from 171.40 µS/cm in Round One (2005) to 242.73 µS/cm in Round Two (2013; Figure 41). These increases in conductivity support the notion that changing water quality conditions are most likely responsible for the observed shift in biological conditions within these PSUs. Since neither PSU showed statistically significant differences in the percentage of impervious surface or drainage area to each sampling location, the changes in water quality conditions are not likely attributed to changes in land use between rounds. It is plausible that differences in salt usage for roadway de-icing between sampling years may be responsible for the observed differences in stream conductivity, and subsequently decreased BIBI scores. For instance, SHA reports higher statewide salt usage in 2009 (222,230 tons) when Marley Creek was sampled in Round Two as compared to 2006 when it was sampled during Round One (157,508 tons; SHA, 2014). However, it should be noted that data are not available at the countywide level, nor are data available for municipal salt usage, which may differ considerably from SHA's rates of application.

Table 18. Comparison of PSU Conductivity Values Between Round One and Round Two

PSU	Round Two		Round One		Upper	Lower	Significant Difference? (Direction)
	Mean Cond	SE	Mean Cond	SE	95% CI	95%CI	
Cabin Branch	143.53	10.82	168.80	13.81	59.65	-9.12	No
Marley Creek	738.67	129.98	299.40	42.15	-171.44	-707.09	Yes (Increase)
Sawmill Creek	558.80	79.46	465.50	80.67	128.63	-315.23	No
West River	146.30	5.38	151.20	13.96	34.23	-24.43	No
Stocketts Run	242.73	14.23	171.40	14.49	-31.52	-111.14	Yes (Increase)

Of the three PSUs where BIBI scores were observed to have increased in Round Two, no trends were observed regarding these three particular variables. However, it is important to note that all three PSUs were sampled in the same year (2008) during the Round One sampling effort. Not surprisingly, the spring 2008 sampling period was preceded by unusually low precipitation and flow conditions that persisted in Maryland through the fall and winter of 2007 and into the spring of 2008. In fact, Anne Arundel County was in a severe drought in October of 2007 with moderate drought conditions continuing into March, the start of the 2008 sampling season (NDMC, 2014). In October of 2007, USGS reported record low flows on numerous streams and rivers in central Maryland and the eastern shore including the Patuxent River, Piscataway Creek, Winters Run, the Choptank River and Nassawango Creek (Baltimore Sun, 2007). Furthermore, the aquatic biota at MBSS Sentinel Sites in the coastal plain (western shore) decreased slightly in 2008, a year after the 2007 drought (Becker et al., 2010), although the FIBI decreased more considerably than the BIBI. Given that BIBI scores also decreased, and more considerably during the same time period at MBSS Sentinel Sites in the coastal plain - eastern shore (Becker et al., 2010), it is highly plausible that BIBI scores were depressed in West River, Sawmill Creek, and Cabin Branch PSUs as a result of the drought conditions. Becker et al. (2010) also noted that stream biota at Sentinel Sites typically recover quickly (i.e., within a year) once precipitation and flow conditions return to normal. Thus, it is even likely that West River, which was sampled in 2008 during Round One, could recover within a year and the mean BIBI score could significantly improve by 2009, when it was sampled again for Round Two.

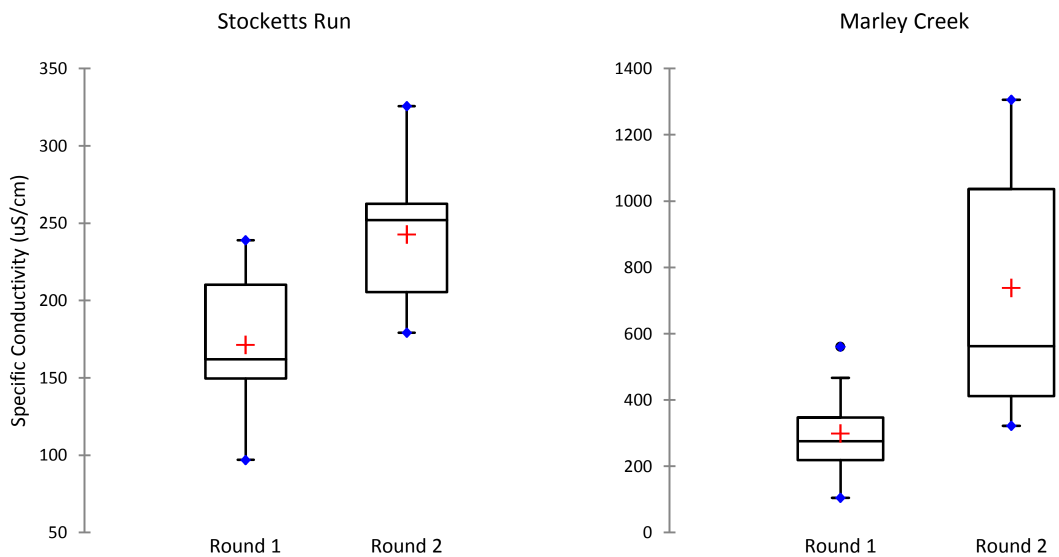

Figure 41. Comparison of Specific Conductivity Values between Round One and Round Two

5.2 Cross Section Comparison

To evaluate geomorphic changes in channel dimensions over time and determine whether those changes may have impacted BIBI scores, a brief analysis was conducted for Round One sites that were revisited during the Round Two sampling effort. Due to the random site selection process, only two of the 190 stream reaches surveyed in Round One were re-surveyed in Round Two by chance. Therefore, the findings are limited in nature and should be applied only to the individual streams assessed, and they do not necessarily represent broader countywide relationships between geomorphic processes and biological responses.

One cross section was re-surveyed in the Lower Magothy PSU (R1-08-11a; R2-08-10) and another cross section was re-surveyed in the Herring Bay PSU (R1-15-19a; R2-15-10). However, it should be noted that while there was always overlap between the Round One and Round Two sampling reaches, the upper and lower extents of the sampling reaches (i.e., 0m and 75m mark) for benthic macroinvertebrate sampling were not co-located between sampling rounds. Nevertheless, the cross-section was contained within both sampling reaches allowing for a direct comparison of cross-sectional dimensions over time.

Cross section surveys were analyzed for top of bank cross-sectional area using a consistent elevation from the baseline survey. Results of the cross-sectional comparison are show in Table 19. Complete survey data as well as cross-sectional overlays can be found in Appendix D.

Very little change was observed at the Lower Magothy site, with no more than a 4% deviation in channel cross-sectional dimensions. Over a six-year period, cross-sectional area, mean depth, and max depth all increased slightly, while width and width-depth ratio decreased slightly. It should be noted that there was some minor undercutting observed along the right bank during the 2013 survey (Appendix D, Figure D-1). However, the results of the comparison suggest that the stream is generally stable and shows no signs of either aggradation or degradation, only minor lateral migration. Not surprisingly, there was no change observed in the overall biological condition of "Poor" between 2007 (BIBI = 2.43) and 2013 (BIBI = 2.71).

The Herring Bay site, on the other hand, showed considerable changes in channel cross-sectional dimensions over a five-year timespan. Cross-sectional area, mean depth, and max depth all decreased by more than 20%, while the width increased by 12.5% and the width-depth ration increased by more than 60%. An overlay of the two surveys (Appendix D, Figure D-2), appears to show a channel bottom that has aggraded by nearly one foot between 2005 and 2010. While it is possible that the bed features may have migrated longitudinally downstream, without a full longitudinal profile of the reach, this is only speculation. Regardless, there was no change observed in the overall biological condition of "Good" between 2005 (BIBI = 4.43) and 2010 (BIBI = 4.43), and this stream remains among the highest scoring for biological condition in the entire County.

Table 19. Comparison of Cross-sectional Dimensions for Sites Re-surveyed in Round Two.

Top of Bank Measures	*Lower Magothy Site*			*Herring Bay Site*		
	2007	2013	% Increase	2005	2010	% Increase
Cross-sectional area (ft.sq.)	24.9	25.1	1.0	37.6	29.8	-20.8
Width (ft)	14.3	14.3	-0.4	17.8	20.0	12.5
Mean depth (ft)	1.7	1.8	1.4	2.1	1.5	-29.1
Max depth (ft)	3.0	3.2	3.8	2.9	2.2	-24.4
Width-depth ratio	8.3	8.1	-1.8	8.4	13.5	60.7

6 Conclusions and Recommendations

The current ecological status of County streams at the conclusion of Round Two can best be described as poor, with nearly two-thirds (63%) of the County's streams in "Poor" or "Very Poor" condition, which is generally consistent with what was observed during Round One (Hill and Pieper, 2011). Previous biological monitoring efforts by the MBSS yielded similar conclusions for the ecological status of Anne Arundel County streams in 1994 - 1997 (Millard et al., 2001), in 2000 - 2004 (Kazyak et al., 2005), and again in 2006 – 2009 (DNR, 2013). There was no statistically significant difference in the average biological condition of Anne Arundel County's streams between Round One and Round Two.

A total of 75% of the County's PSUs are considered as being in an impaired biological condition, being rated as either "Poor" or "Very Poor" by the BIBI. However, the ecological status of individual PSU's varies broadly throughout the County ranging from "Fair" to "Very Poor", based on mean BIBI scores. The PSUs rated in the best biological condition are Cabin Branch, Middle Patuxent, Herring Bay, Severn Run, Rock Branch, and Lyons Creek, all of which were rated "Fair". Interestingly, none of the top-rated PSUs for biological condition from Round One (Stocketts Run, Upper North River, Ferry Branch, and Severn River) were rated "Fair" in Round Two. Of the top-rated PSUs for biological condition, only Stockett's run saw a statistically significant decrease in the mean BIBI score, which can primarily be attributed to a change in water quality conditions as indicated by increased conductivity values measured throughout the PSU. In contrast, only one PSU, Marley Creek, was rated in the worst biological condition of "Very Poor" during Round Two. None of the three PSUs rated as "Very Poor" in Round One (West River, Sawmill Creek, and Rhode River), were rated "Very Poor" in Round Two, although it should be noted that all three of these PSUs were sampled in 2008 following extensive and lengthy drought conditions that possibly depressed BIBI scores. Nonetheless, the ecological status of streams presented in these reports is based on a single biological assemblage (i.e., benthic macroinvertebrates), and the overall ecological status may differ with the inclusion of data from additional biotic assemblages (e.g., fish, periphyton, herpetofauna) residing within these streams.

The observed trend in PSU conditions can be partially explained by a general lack of adequate habitat for benthic macroinvertebrates resulting from past and current land use changes. Because Anne Arundel County lies within the Coastal Plain region, many stream bottoms are composed primarily of sand and silt, which, in general, make poor habitat for benthos, and productive habitats such as woody debris and rootwads have been significantly reduced due to logging practices (Millard et al., 2001). Furthermore, land use change within watersheds and corresponding stream disturbances are often associated with the conversion of rural agricultural land use to urban land use (Paul and Meyer, 2001). These changes become more evident when connected rural areas and undeveloped buffers become fragmented and more interspersed (Kennen et al., 2005).

While degraded physical habitat conditions explain some of the impaired biological conditions in Anne Arundel County, many streams with "Supporting/Partially Supporting" or "Comparable/Minimally Degraded" habitat conditions were not always substantiated by a healthy benthic macroinvertebrate community, which is often an indication of degraded water quality conditions. However, given the very limited range of water chemistry data collected at part of this survey, it is difficult to determine the nature and extent of water quality impairment throughout the County. Only one parameter, specific conductivity, provided a useful measure of water quality impairment and correlated strongly with impervious cover. Stream conductivity is affected by inorganic dissolved solids such as chloride, nitrate, sulfate, and phosphate anions or sodium, magnesium, calcium, iron, and aluminum cations (Southerland et al., 2007), many of which are generally found at elevated concentrations in urban streams (Paul and Meyer, 2001). In fact, conductivity levels in the County were highest in PSUs with a high percentage of impervious surfaces (i.e., greater than 19%). Increased stream ion concentrations in urban systems typically results from runoff over impervious surfaces, passage through pipes, and exposure to other anthropogenic infrastructure (Cushman, 2006). While elevated conductivity may not directly affect stream biota, its constituents (e.g., chloride, metals, and nutrients) may be present at levels that can cause considerable biological impairment. Certainly, more detailed water quality sampling would be necessary to identify the nature and extent of chemical stressors throughout the County and would aid in locating, and ultimately, mitigating stressor sources impacting the biota.

While the direct causes of biological impairment may not always be evident, the relative rankings of PSU conditions and observed trends over time can assist managers in developing a prioritized list of PSUs requiring protection or restoration of stream resources. Management practices that affect environmental variables and that appear to be important for Anne Arundel County streams include protection of stream corridors, measures that reduce the effects of impervious surfaces associated with urbanization, reduction of dissolved solids in stream water, improvement of buffer conditions particularly related to buffer continuity, and improvement of streambed substrate conditions by reducing sediment loads to streams. However, because of the complexity of stream systems, especially urban streams, and connectivity of various factors affecting stream quality, improvement in any single environmental variable may not result in measurable improvements in overall stream quality (Rasmussen et al., 2009). Instead, a more holistic approach that focuses on treating multiple stressors and utilizes the cumulative effects of environmental improvements is recommended to improve the overall quality of the County's stream resources.

6.1 Stressor Relationships

Biological communities respond to a combination of environmental factors, commonly referred to as stressors. Stressors can be organized according to the five major determinants of biological integrity in aquatic ecosystems, which include water chemistry, energy source, habitat structure, flow regime, and biotic interactions (Karr et al., 1986; Angermeier and Karr, 1994, Karr and Chu, 1998). Water chemistry stressors include changes in chemical water quality conditions (e.g., DO, pH, temperature, turbidity, alkalinity, hardness), changes in water's ability to dissolve or adsorb chemical constituents (e.g., nutrients, toxics, organics, inorganics, sediment) and changes affecting the interactions between water quality constituents. Energy source stressors include changes affecting the food web including nutrients and organic material inputs, seasonal cycles, primary and secondary production, and sunlight. Habitat structure stressors include any alteration of physical habitat including bank stability, current, gradient, instream cover, vegetative canopy, substrate, sinuosity, width, depth, pool/riffle ratios, riparian and wetland vegetation, sedimentation, and channel morphology. Flow regime stressors are those affecting or modifying flows and include precipitation, seasonal flow patterns, land use conditions, runoff, flow velocity, ground water, and daily and seasonal extremes. And lastly, biotic interactions that may be classified as stressors include competition, predation, and parasitism from both native and introduced species as well as disease and reproduction stress.

The cumulative effects of human activities within the County's watersheds often result in an alteration of at least one, if not several, of these factors with detrimental consequences for the aquatic biota. Determining which specific stressors are responsible for the observed degradation within a stream or

PSU is a challenging task, given that many stressors co-exist and that both synergistic and antagonistic effects can occur among these stressors. Furthermore, an added challenge in identifying the stressors affecting stream biota is that the water quality and physical habitat data collected by the County's monitoring program are not comprehensive (i.e., they do not include all possible stressors), and virtually no data are available regarding biotic interactions and energy sources and only limited data regarding flow regime variables, such as land use and impervious cover. Stressor relationships with stream biotic components, and their derived indices (i.e., BIBI), are often difficult to partition from complex temporal–spatial data sets primarily due to the potential array of multiple stressors working from the reach to landscape scale in small streams (Helms et al. 2005; Miltner et al. 2004; Morgan and Cushman 2005; Volstad et al. 2003; Morgan et al., 2007). Therefore, it should be noted that the current level of analysis will not identify stressors for all of Anne Arundel County's impaired watersheds, nor will the stressors identified include all the stressors present. And while a stressor identification approach for identifying likely stressors affecting biologically impaired watersheds has been developed and adopted by MDE, the lack of parameters collected as part of this program to predict the six general candidate causes of degradation identified by MDE (i.e., flow regime, terrestrial sediment, energy source, oxygen consuming and thermal waste, inorganic pollutants, and organic pollutants; Southerland, et al., 2007), which overlap the aforementioned determinants of biological integrity in aquatic ecosystems, has rendered it impractical to implement this approach at this time. However, the addition of supplemental data parameters to the sampling program may open the door for this type of stressor identification in the future.

Impervious Cover

The numerous parameters measured as part of the Countywide Biological Monitoring and Assessment Program do address, at least in part, many common stressors, or stressor surrogates, to Maryland's streams such as impervious cover, sedimentation, and habitat degradation. As expected, the percentage of impervious cover draining to a sampling station appears to be a dominant stressor source affecting the biological condition of streams in Anne Arundel County. The relationship between imperviousness and ecological condition has been thoroughly studied and is well documented (Paul and Meyer, 2001; Schueler, 2008; Meyer et al., 2005; Walsh et al., 2005). While the relationship holds that high levels of imperviousness consistently lead to poor biological health, the contrary is not always true; low levels of imperviousness do not necessarily translate to good biological health. Other stressors not associated with imperviousness such as degraded physical habitat condition, siltation, or legacy land use may be factors limiting the biological community. As an example, Rhode River with only 5.2 percent imperviousness, suffers from 'Partially Degraded/Partially Supporting' physical habitat conditions which limits the biological potential of these streams in the absence of high imperviousness.

Many streams in Anne Arundel County, particularly in the well-developed northern and eastern portions of the County, exhibit many symptoms of the "Urban Stream Syndrome" including altered channel morphology, reduced biotic richness, decreased dominance of sensitive species, and elevated concentrations of contaminants (Paul and Meyer, 2001; Meyer et al., 2005). However, the biological response to impervious cover was not always consistent throughout the County. For instance, of the 12 sites rated "Good" for biological condition, three had drainage areas that exceeded 10% imperviousness, and one site in Piney Run had a drainage area with 23% imperviousness, although it should be noted that this site had the largest drainage area in all of Round Two at 12,681 acres. This unexpected response to high percentages of imperviousness can be explained by three primary factors: 1) impervious cover may be a source of different types of stressors (e.g., metals, oils, sediments) under different settings (e.g., rooftop, roadside, or parking lot runoff) resulting in considerable differences in water quality, or even quantity during storm events, depending on specific location; 2) hydrologic alteration affects may be partially mitigated by stormwater management facilities or other best management practices (BMPs), or even naturally occurring landscape features such as wetlands or forested buffers; and 3) the increased flow and overall volume of water in sites with large drainage areas may have an enhanced capacity to buffer the effects of stormwater runoff as compared to smaller streams, as implicated by the fact that all sites in Round Two with greater than 6,000 acres of drainage had biological condition ratings of 'Good' or 'Fair' despite conductivity values that exceeded the impairment threshold of 247 µS/cm. Further investigation into which factors enable certain streams with high imperviousness to maintain sufficient physical habitat quality and healthy benthic macroinvertebrate communities (e.g., stormwater management, wetland connectivity, continuous buffers, etc.) would be beneficial for watershed planners as it may shed some light onto which techniques are most effective at reducing the impacts of high imperviousness.

Legacy Effects

While impervious cover, and its associated stressors (e.g., toxic contaminants, nutrients, sediments, hydrologic alterations), can be used to explain the degraded biological conditions in the more developed PSUs, it is not a useful predictor in the less developed southern and western portions of the County where imperviousness is typically below 10 percent. With the exception of Lyons Creek, physical habitat was rated as "Partially Supporting" by the RBP, suggesting that physical habitat condition is a limiting factor to the biota in this region of the County. Furthermore, two-thirds of the streams sampled in this region of the County were classified as incised "F" and "G" type streams, which are generally considered unstable stream types. In some of the more heavily forested PSUs with less than 30% developed land (e.g., Upper Patuxent, Herring Bay, Hall Creek, Ferry Branch, Rhode River), this impaired physical habitat and geomorphic instability is likely a result of legacy effects, which are the consequences of past disturbances that continue to influence environmental conditions long after the initial appearance of the disturbance (Allan, 2004). Historically, nearly all of Anne Arundel County has experienced deforestation, followed by intensive agriculture which significantly altered the landscape (Schneider, 1996). These drastic land use changes likely altered the structure and function of the stream ecosystems to a considerable extent, some of which have yet to fully recover. This notion is supported by Harding and others (1998), who found that that past land use activity, in particular agriculture, may result in long-term modifications to and reductions in aquatic diversity, regardless of reforestation of riparian zones. What is not clear, however, is how long these legacy effects will persist in these subwatersheds, and consequently, what can be done to improve the biological condition of these streams.

Nutrients

Although not measured as part of this monitoring program, nutrients are likely a predominant stressor in the less developed, but more agricultural, southern and western portions of the County. Total phosphorus (TP), ammonia (NH_3), and nitrite-nitrogen (NO_2), are all potential stressors of concern. Water quality sampling by MBSS (2000 – 2004) found that 28% of the County's streams had TP concentrations at high levels associated with biological impacts (i.e., ≥ 0.07 mg/L), the majority of which were located in the southern part of the County (Kazyak et al., 2005). Similar results were found in Round 3 MBSS sampling (2007-2009) where 18% of the County's streams had high TP concentrations and another 41% had moderately high levels (i.e., 0.025 mg/L - 0.07 mg/L; DNR, 2013). MBSS data from Round 3 also showed high concentrations of ammonia (i.e., > 0.07 mg/L), and nitrite-nitrogen (i.e., > 0.01 mg/L) at 47% and 18% of sites sampled in the County, respectively. Furthermore, MBSS found high ammonia concentrations at 77% of sites located throughout the entire Lower Western Shore Tributary Basin, which was the highest percentage of stream miles with high ammonia concentrations in all of Maryland (Versar, 2011). These results, coupled with the continued impaired biological conditions observed in Round One of this sampling program, suggest that nutrients continue to be a potential stressor of concern in this portion of the County. However, more data are clearly needed to determine not only the nature and extent of nutrient pollution but also the associations with biological conditions in County streams. Only then can the sources of this stressor be determined and mitigated.

In addition to nutrients, there is also the possibility of persistent water quality impacts from agriculture resulting from pesticides and herbicides entering streams in these relatively undeveloped PSUs. However, there is currently a lack of water quality data to test this hypothesis, and only nutrients have thus far been identified as a water quality stressor related to agricultural land use in the County.

6.2 Recommendations for Future Program Development

Compatibility with MBSS

At the inception of the sampling program in 2004, Anne Arundel County had an underlying goal of being compatible with DNR's MBSS methodology. The MBSS program continues to evolve and refine their sampling design, field procedures, and data analysis protocols, with the most recent field sampling protocols having been updated in 2007. While no changes have occurred to the benthic macroinvertebrate collection methods implemented herein, additional surveys have been added to the data collection efforts (i.e., vernal pool search, invasive vegetation search), which may be of interest to the County. The County should continue to update their methods in the future to stay current with the latest MBSS sampling protocols, especially with regard to benthic macroinvertebrate sampling. In addition, the County should continue to ensure that all personnel collecting macroinvertebrate samples have been certified by MBSS in benthic macroinvertebrate sample collection procedures.

Water Quality Sampling

MBSS currently conducts water quality grab sampling during the spring index period, which enables DNR to conduct a more detailed assessment of water quality stressors affecting biological condition such as acidification and nutrients (DNR, 2005). For example, MBSS was able to identify inverse relationships between the total nitrogen/total phosphorus ratio and EPT taxa and between total phosphorus and EPT taxa (DNR, 2005). Because identifying stressors is critical to the development of management actions that can restore or protect the desired condition of streams, it is recommended that the County consider the addition of water quality grab sampling to their program to determine whether there are other chemical stressors affecting the biota. Water quality sampling should evaluate additional parameters such as nutrients, chloride, and metals, which may potentially be of concern. While this would add considerable costs to the monitoring program, the added benefit would greatly enhance the County's ability to indentify predominant water quality stressors and sources. Additionally the program would be positioned well to monitor changes in water chemistry as it relates to tracking progress towards meeting total maximum daily load (TMDL) requirements, both for specific impaired water bodies and for the Chesapeake Bay-wide TMDL.

Fish Community Assessments

MBSS conducts fish sampling during the summer index period, which provides additional information regarding stream biodiversity. Fish species exhibit diverse morphological, ecological, and behavioral adaptations to their natural habitat and, consequently, are particularly effective indicators of the condition of aquatic systems (Karr et al., 1986; Fausch et al., 1990; Simon and Lyons, 1995; McCormick et al., 2001). Given that fish assemblages respond differently to some stressors than benthic macroinvertebrate assemblages, data from fish sampling can assist in identifying stressors that may be impacting specific streams as well as provide an improved understanding of the biological condition of streams throughout the County via the combined index of biotic integrity (CIBI), which incorporates both BIBI and fish IBI (FIBI) results into a single biological index. Furthermore, fish sampling data can be used to evaluate biotic interactions, particularly the effects of non-native and invasive species on native fauna. Given that MBSS has identified non-native aquatic species as a predominant stressor occurring in 56% of the County's stream miles (Kazyak et. al., 2005), it is recommended that the County consider the addition of fish sampling to their program to not only allow for a more comprehensive assessment of the biological condition of the County's streams, but also to assist in the identification of additional stressors impacting their streams. Furthermore, the addition of fish sampling will allow for improved data sharing between the County and State agencies (i.e., DNR, MDE), which is essential to the protection and preservation of the Chesapeake Bay.

Geomorphic Assessments

While Rosgen Level II assessments provide useful information for characterizing the overall channel morphology, stream classification was not shown to be a useful predictor of biological condition or current land use characteristics. It is likely that the dominant geomorphological processes in these PSUs (i.e., erosion, transport, or deposition) are more important to the condition of the benthic macroinvertebrate communities than the current stream type as classified by the Rosgen approach. Perhaps a more rapid assessment of each reach using the channel evolution model (CEM; Schumm et al. 1984, Simon and Hupp 1986, and Simon 1989) would provide sufficient data regarding the geomorphological processes in each stream. The CEM identifies distinct stages of a channel's progression from a pre-modified condition through incising, widening, aggrading, re-stabilizing, and back to a quasi-equilibrium state, which may be observed in one reach overtime or various stages may be observed within an entire drainage network at a given time. Otherwise, streams surveyed in Round One or Round Two should be re-visited and cross sections should be surveyed again after a period of time (e.g., 5 – 10 years) so that changes in channel dimensions can be quantified and determinations made regarding the dominant process occurring in each stream. Due to the random site selection process, only two of the 190 stream reaches surveyed in Round One were re-surveyed in Round Two by chance; therefore, a concerted effort would be required to re-survey a subset of sites from earlier rounds and collect biological data concurrently to evaluate relationships between geomorphic processes and biological responses.

Additional Stressor Analysis

Further analysis of the Round Two data using multivariate analysis techniques such as principal component analysis (PCA) or nonparametric multidimensional scaling (MDS) may provide additional insight regarding relationships between benthic macroinvertebrate community data and environmental variables. However, a recent multivariate analysis of the Round One data by Crunkleton and Gresens (2012) generally found similar associations between the benthic macroinvertebrate community data and environmental variables as were reported in the Round One report, suggesting that the less-labor intensive multimetric approach is effective in identifying the primary drivers of biological degradation throughout the County.

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Appendix A: Land Use and Land Cover Data

Table A-1. Toal Acres Per Land Cover Type for Each Primary Sampling Unit and Countywide Based on 2011 Anne Arundel County Land Cover Layer. Note: PSUs shaded gray were calculated using 2007 land cover data.

Primary Sampling Unit	PSU Code	Airport	Commercial	Forested Wetland	Industrial	Open Space	Open Wetland	Pasture/Hay	Residential 1/2-acre	Residential 1/4-acre	Residential 1/8-acre	Residential 1-acre	Residential 2-acre	Residential Woods	Row Crops	Transportation	Utility	Water	Woods	Total Acres
COUNTYWIDE	N/A	1205.1	12560.0	285.8	5239.3	20848.5	1595.3	6013.2	10870.0	19494.9	20082.1	11596.5	23717.9		12072.3	9637.0	1931.1	2634.2	105638.0	265421.3
Piney Run	1		288.6	5.0	459.1	478.4		3.1	60.5	96.7	304.7	242.8	438.6			333.8	5.3	30.8	2120.4	4867.8
Stony Run	2	533.9	371.8	2.7	564.9	889.9	5.9		236.8	455.3	355.3	113.9	161.9		33.7	405.1	5.8	10.4	2055.6	6202.9
Lower Patapsco	3		356.3	27.6	405.5	346.0	49.6		27.0	550.0	680.5	117.0	44.4			271.4	32.2	124.5	1005.9	4037.8
Sawmill Creek	4	565.7	911.8		875.2	1976.4	3.0		81.9	1272.4	1693.5	156.3	251.3	51.4	4.5	729.5	75.0	40.2	2355.7	11043.6
Marley Creek	5		1352.5		932.0	1073.5	24.5	5.3	888.0	2010.0	4873.7	522.3	500.5		79.2	940.1	175.5	167.3	5874.0	19418.3
Bodkin Creek	6		199.4			435.0	33.4	10.3	489.6	466.0	205.9	996.7	573.3			123.6		162.4	2176.0	5871.6
Upper Magothy	7		548.5		9.6	470.0	5.8		1567.8	1864.4	270.5	1077.1	862.5		4.0	449.3		36.3	2865.4	10031.3
Lower Magothy	8		604.6	3.4	13.6	654.5	21.1	0.0	1998.1	2703.5	867.7	703.3	877.6		72.4	414.3		127.2	3635.8	12697.3
Severn Run	9		624.1	12.3	486.9	1168.3	6.7	160.5	587.6	1502.7	1725.2	740.1	1315.2		211.3	710.6	81.2	36.3	6055.1	15424.2
Severn River	10		2057.5	39.7	206.7	1913.7	70.9	278.3	2052.7	3949.0	1905.3	2115.6	3109.2		506.0	1141.0	48.9	290.0	9235.0	28919.6
Upper North River	11		157.3		22.6	549.8	57.1	498.6	174.9	88.1	139.3	1045.5	1566.4		609.6	389.2	236.2	54.6	7207.9	12797.2
Lower North River	12	24.7	1315.5		116.3	1352.5	101.8	312.4	1339.5	1875.5	1529.2	1283.8	2883.3	450.5	705.2	808.2	190.1	215.9	9176.8	23681.3
Rhode River	13		117.5		22.2	560.9	96.0	426.0	174.6	232.1	285.9	313.1	904.2		562.4	158.1	61.8	93.8	4728.3	8736.8
West River	14		144.4			280.6	36.8	471.2	293.3	129.4	266.1	259.6	929.0		1001.4	171.6	40.9	24.6	3505.5	7554.4
Herring Bay	15		242.6	3.2	19.2	696.7	313.4	506.9	165.4	112.0	910.2	310.6	1801.3		988.3	287.6	274.2	142.3	7820.9	14594.8
Upper Patuxent	16	13.8	190.9	102.6	5.8	482.0	49.4	1.6	2.7	205.8	171.5	11.1	80.8		59.2	199.0	177.7	79.8	5117.8	6951.2
Little Patuxent	17	65.9	2235.0	53.8	890.8	3170.7	145.0	479.0	158.7	1784.5	2551.1	184.5	513.2	209.3	435.0	1221.8	395.0	143.5	13558.6	28195.5
Middle Patuxent	18		151.8	3.8	17.4	716.5	4.1	407.4	81.4	66.6	11.4	142.5	969.3		907.3	150.3		86.5	2616.1	6332.3
Stocketts Run	19		95.6		23.1	814.7	1.2	654.4	116.1	72.7		288.2	1656.0		873.6	167.7	98.7	28.8	3822.7	8713.5
Rock Branch	20		26.2		216.1	456.7	8.7	279.4	20.5	63.2		181.7	764.4		1121.0	86.7		44.7	2862.1	6131.4
Ferry Branch	21		142.2		87.3	484.5	185.0	521.8	35.1	1.1	170.3	190.1	1043.5		1010.1	179.9		192.3	3794.5	8037.7
Lyons Creek	22		87.1	20.4	1.9	374.2	4.1	456.4	49.6	2.6		283.9	938.4		1469.9	131.2		37.6	2296.1	6153.6
Cabin Branch	23		12.2		6.7	191.5	270.1	400.7	34.2		57.7	122.4	806.0		1005.6	137.6		513.0	2885.4	6443.1
Hall Creek	24		30.7			154.0		245.0	2.3			76.4	666.6		421.8	75.0	32.8	14.7	1448.6	3167.9

Footnotes:

* Some water not included in LC classification, following acres were added manually to Water - Cabin Branch 486.05 ac (Jug Bay), Herring Bay 46.38 ac, Lower North River (South River) 138.18 ac, Middle Patuxent 53.52 ac (Patuxent River), Sawmill Creek 13.78 ac
* Residential woods added category for 2007 data

Table A-2. Percentage of Land Cover Types for Each Primary Sampling Unit and Countywide Based on 2011 Anne Arundel County Land Cover Layer. Note: PSUs shaded gray were calculated using 2007 land cover data.

Primary Sampling Unit	PSU Code	Airport	Commercial	Forested Wetland	Industrial	Open Space	Open Wetland	Pasture/Hay	Residential 1/2-acre	Residential 1/4-acre	Residential 1/8-acre	Residential 1-acre	Residential 2-acre	Residential Woods	Row Crops	Transportation	Utility	Water	Woods
COUNTYWIDE	N/A	0.5%	4.7%	0.1%	2.0%	7.9%	0.6%	2.3%	4.1%	7.3%	7.6%	4.4%	8.9%	0.0%	4.5%	3.6%	0.7%	1.0%	39.8%
Piney Run	1	0.0%	5.9%	0.1%	9.4%	9.8%	0.0%	0.1%	1.2%	2.0%	6.3%	5.0%	9.0%	0.0%	0.0%	6.9%	0.1%	0.6%	43.6%
Stony Run	2	8.6%	6.0%	0.0%	9.1%	14.3%	0.1%	0.0%	3.8%	7.3%	5.7%	1.8%	2.6%	0.0%	0.5%	6.5%	0.1%	0.2%	33.1%
Lower Patapsco	3	0.0%	8.8%	0.7%	10.0%	8.6%	1.2%	0.0%	0.7%	13.6%	16.9%	2.9%	1.1%	0.0%	0.0%	6.7%	0.8%	3.1%	24.9%
Sawmill Creek	4	5.1%	8.3%	0.0%	7.9%	17.9%	0.0%	0.0%	0.7%	11.5%	15.3%	1.4%	2.3%	0.5%	0.0%	6.6%	0.7%	0.4%	21.3%
Marley Creek	5	0.0%	7.0%	0.0%	4.8%	5.5%	0.1%	0.0%	4.6%	10.4%	25.1%	2.7%	2.6%	0.0%	0.4%	4.8%	0.9%	0.9%	30.3%
Bodkin Creek	6	0.0%	3.4%	0.0%	0.0%	7.4%	0.6%	0.2%	8.3%	7.9%	3.5%	17.0%	9.8%	0.0%	0.0%	2.1%	0.0%	2.8%	37.1%
Upper Magothy	7	0.0%	5.5%	0.0%	0.1%	4.7%	0.1%	0.0%	15.6%	18.6%	2.7%	10.7%	8.6%	0.0%	0.0%	4.5%	0.0%	0.4%	28.6%
Lower Magothy	8	0.0%	4.8%	0.0%	0.1%	5.2%	0.2%	0.0%	15.7%	21.3%	6.8%	5.5%	6.9%	0.0%	0.6%	3.3%	0.0%	1.0%	28.6%
Severn Run	9	0.0%	4.0%	0.1%	3.2%	7.6%	0.0%	1.0%	3.8%	9.7%	11.2%	4.8%	8.5%	0.0%	1.4%	4.6%	0.5%	0.2%	39.3%
Severn River	10	0.0%	7.1%	0.1%	0.7%	6.6%	0.2%	1.0%	7.1%	13.7%	6.6%	7.3%	10.8%	0.0%	1.7%	3.9%	0.2%	1.0%	31.9%
Upper North River	11	0.0%	1.2%	0.0%	0.2%	4.3%	0.4%	3.9%	1.4%	0.7%	1.1%	8.2%	12.2%	0.0%	4.8%	3.0%	1.8%	0.4%	56.3%
Lower North River	12	0.1%	5.6%	0.0%	0.5%	5.7%	0.4%	1.3%	5.7%	7.9%	6.5%	5.4%	12.2%	1.9%	3.0%	3.4%	0.8%	0.9%	38.8%
Rhode River	13	0.0%	1.3%	0.0%	0.3%	6.4%	1.1%	4.9%	2.0%	2.7%	3.3%	3.6%	10.3%	0.0%	6.4%	1.8%	0.7%	1.1%	54.1%
West River	14	0.0%	1.9%	0.0%	0.0%	3.7%	0.5%	6.2%	3.9%	1.7%	3.5%	3.4%	12.3%	0.0%	13.3%	2.3%	0.5%	0.3%	46.4%
Herring Bay	15	0.0%	1.7%	0.0%	0.1%	4.8%	2.1%	3.5%	1.1%	0.8%	6.2%	2.1%	12.3%	0.0%	6.8%	2.0%	1.9%	1.0%	53.6%
Upper Patuxent	16	0.2%	2.7%	1.5%	0.1%	6.9%	0.7%	0.0%	0.0%	3.0%	2.5%	0.2%	1.2%	0.0%	0.9%	2.9%	2.6%	1.1%	73.6%
Little Patuxent	17	0.2%	7.9%	0.2%	3.2%	11.2%	0.5%	1.7%	0.6%	6.3%	9.0%	0.7%	1.8%	0.7%	1.5%	4.3%	1.4%	0.5%	48.1%
Middle Patuxent	18	0.0%	2.4%	0.1%	0.3%	11.3%	0.1%	6.4%	1.3%	1.1%	0.2%	2.3%	15.3%	0.0%	14.3%	2.4%	0.0%	1.4%	41.3%
Stocketts Run	19	0.0%	1.1%	0.0%	0.3%	9.3%	0.0%	7.5%	1.3%	0.8%	0.0%	3.3%	19.0%	0.0%	10.0%	1.9%	1.1%	0.3%	43.9%
Rock Branch	20	0.0%	0.4%	0.0%	3.5%	7.4%	0.1%	4.6%	0.3%	1.0%	0.0%	3.0%	12.5%	0.0%	18.3%	1.4%	0.0%	0.7%	46.7%
Ferry Branch	21	0.0%	1.8%	0.0%	1.1%	6.0%	2.3%	6.5%	0.4%	0.0%	2.1%	2.4%	13.0%	0.0%	12.6%	2.2%	0.0%	2.4%	47.2%
Lyons Creek	22	0.0%	1.4%	0.3%	0.0%	6.1%	0.1%	7.4%	0.8%	0.0%	0.0%	4.6%	15.2%	0.0%	23.9%	2.1%	0.0%	0.6%	37.3%
Cabin Branch	23	0.0%	0.2%	0.0%	0.1%	3.0%	4.2%	6.2%	0.5%	0.0%	0.9%	1.9%	12.5%	0.0%	15.6%	2.1%	0.0%	8.0%	44.8%
Hall Creek	24	0.0%	1.0%	0.0%	0.0%	4.9%	0.0%	7.7%	0.1%	0.0%	0.0%	2.4%	21.0%	0.0%	13.3%	2.4%	1.0%	0.5%	45.7%

Footnotes:

* Some water not included in LC classification, following acres were added manually to Water - Cabin Branch 486.05 ac (Jug Bay), Herring Bay 46.38 ac, Lower North River (South River) 138.18 ac, Middle Patuxent 53.52 ac (Patuxent River), Sawmill Creek 13.78 ac

* Residential woods added category for 2007 data

Appendix B: Kendall Correlation Matrices

Kendall Correlation Matrix: Physical Habitat Versus Land Use Variables

Variables	Bank Stability	Vegetative Protection	Channel Flow	Channel Alteration	Channel Sinuosity	Pool Substrate	Pool Variability	Riparian Zone Width	Sediment Deposition	Epi. Substrate/Avail. Cover	RBP Score	Instream Habitat	Epifaunal Substrate	Bank Stability	Percent Shading	Remoteness	# Woody Debris/Rootwads	Remoteness Score	Shading Score	Epifaunal Substrate Score	Instream Habitat Score	Woody Debris Score	Bank Stability Score	PHI Score	% Impervious	%Developed	%Forested	%Open	%Agriculture	Drainage area
Bank Stability	**1**																													
Vegetative Protection	**0.697**	**1**																												
Channel Flow	**0.259**	**0.327**	**1**																											
Channel Alteration	-0.036	**0.114**	**0.168**	**1**																										
Channel Sinuosity	0.042	**0.184**	**0.118**	**0.202**	**1**																									
Pool Substrate	**0.235**	**0.318**	**0.303**	**0.106**	**0.233**	**1**																								
Pool Variability	**0.135**	**0.237**	**0.304**	0.087	**0.256**	**0.646**	**1**																							
Riparian Zone Width	-0.039	**0.130**	0.074	**0.426**	**0.285**	**0.163**	**0.132**	**1**																						
Sediment Deposition	**0.271**	**0.272**	**0.382**	0.018	**0.138**	**0.318**	**0.254**	-0.038	**1**																					
Epi. Substrate/Avail. Cover	**0.151**	**0.255**	**0.257**	**0.243**	**0.231**	**0.578**	**0.590**	**0.176**	**0.206**	**1**																				
RBP Score	**0.440**	**0.587**	**0.482**	**0.290**	**0.380**	**0.578**	**0.520**	**0.307**	**0.407**	**0.543**	**1**																			
Instream Habitat	**0.138**	**0.229**	**0.267**	**0.222**	**0.198**	**0.589**	**0.621**	**0.166**	**0.201**	**0.907**	**0.517**	**1**																		
Epifaunal Substrate	**0.173**	**0.300**	**0.309**	**0.176**	**0.333**	**0.586**	**0.566**	**0.183**	**0.315**	**0.726**	**0.570**	**0.657**	**1**																	
Bank Stability	**0.985**	**0.694**	**0.258**	-0.032	0.047	**0.237**	**0.136**	-0.041	**0.265**	**0.153**	**0.440**	**0.143**	**0.180**	**1**																
Percent Shading	**-0.159**	-0.032	**-0.222**	**0.127**	0.061	**-0.141**	**-0.140**	**0.254**	**-0.140**	-0.060	-0.081	-0.077	-0.085	**-0.159**	**1**															
Remoteness	-0.066	0.078	**0.098**	**0.401**	**0.291**	**0.187**	**0.152**	**0.523**	0.021	**0.150**	**0.247**	**0.134**	**0.234**	-0.066	**0.130**	**1**														
# Woody Debris/Rootwads	-0.006	**0.108**	**0.134**	**0.106**	**0.126**	**0.289**	**0.331**	**0.126**	**0.092**	**0.334**	**0.251**	**0.346**	**0.240**	-0.007	0.008	**0.091**	**1**													
Remoteness Score	-0.065	0.080	**0.098**	**0.402**	**0.293**	**0.188**	**0.153**	**0.524**	0.023	**0.151**	**0.248**	**0.134**	**0.235**	-0.064	**0.133**	**0.999**	**0.091**	**1**												
Shading Score	**-0.158**	-0.031	**-0.219**	**0.128**	0.064	**-0.140**	**-0.137**	**0.256**	**-0.139**	-0.059	-0.080	-0.077	-0.081	**-0.159**	**0.997**	**0.135**	0.010	**0.137**	**1**											
Epifaunal Substrate Score	**0.170**	**0.314**	**0.217**	**0.171**	**0.352**	**0.467**	**0.410**	**0.204**	**0.296**	**0.541**	**0.505**	**0.474**	**0.780**	**0.179**	0.019	**0.262**	**0.157**	**0.264**	0.022	**1**										
Instream Habitat Score	**0.138**	**0.257**	**0.113**	**0.215**	**0.221**	**0.399**	**0.349**	**0.190**	**0.174**	**0.585**	**0.407**	**0.578**	**0.435**	**0.143**	**0.113**	**0.167**	**0.191**	**0.169**	**0.113**	**0.561**	**1**									
Woody Debris Score	-0.029	**0.089**	-0.070	0.081	**0.111**	0.008	-0.029	**0.123**	0.004	0.024	0.051	0.001	-0.021	-0.030	**0.228**	**0.094**	**0.446**	**0.095**	**0.230**	**0.111**	**0.249**	**1**								
Bank Stability Score	**0.985**	**0.694**	**0.258**	-0.032	0.047	**0.237**	**0.136**	-0.041	**0.265**	**0.153**	**0.440**	**0.143**	**0.180**	**1.000**	**-0.159**	-0.066	-0.007	-0.064	**-0.159**	**0.179**	**0.143**	-0.030	**1**							
PHI Score	**0.182**	**0.353**	**0.094**	**0.287**	**0.331**	**0.303**	**0.237**	**0.381**	**0.143**	**0.370**	**0.435**	**0.329**	**0.425**	**0.186**	**0.315**	**0.442**	**0.224**	**0.445**	**0.318**	**0.552**	**0.544**	**0.345**	**0.186**	**1**						
% Impervious	**0.181**	**0.096**	-0.044	**-0.267**	0.000	0.022	0.054	**-0.230**	0.025	-0.023	0.021	-0.021	-0.009	**0.183**	**-0.166**	**-0.308**	0.038	**-0.309**	**-0.166**	-0.031	-0.049	-0.002	**0.183**	**-0.129**	**1**					
%Developed	**0.125**	0.075	-0.036	**-0.257**	0.005	-0.008	0.007	**-0.214**	0.028	**-0.093**	-0.017	**-0.095**	-0.066	**0.128**	**-0.142**	**-0.316**	0.045	**-0.317**	**-0.142**	-0.072	**-0.092**	0.043	**0.128**	**-0.152**	**0.727**	**1**				
%Forested	-0.003	0.035	**0.101**	**0.291**	0.054	0.024	-0.011	**0.202**	0.036	**0.099**	**0.086**	**0.100**	0.084	-0.006	**0.119**	**0.250**	-0.047	**0.251**	**0.119**	**0.095**	**0.113**	-0.018	-0.006	**0.182**	**-0.476**	**-0.549**	**1**			
%Open	0.034	-0.003	0.006	-0.088	0.036	0.032	0.059	-0.055	0.010	0.061	0.026	0.043	0.056	0.032	**-0.131**	**-0.109**	0.047	**-0.111**	**-0.131**	0.012	-0.030	-0.066	0.032	**-0.093**	**0.209**	**0.125**	**-0.223**	**1**		
%Agriculture	**-0.260**	**-0.187**	-0.029	**0.167**	-0.076	-0.021	0.010	**0.113**	-0.067	0.033	-0.082	0.044	0.004	**-0.262**	**0.095**	**0.157**	0.082	**0.157**	**0.094**	-0.058	-0.074	-0.046	**-0.262**	-0.033	**-0.505**	**-0.442**	0.079	-0.049	**1**	
Drainage area	0.025	0.015	**0.253**	0.041	0.020	**0.303**	**0.411**	-0.007	0.086	**0.336**	**0.211**	**0.374**	**0.277**	0.024	**-0.251**	-0.012	**0.253**	-0.012	**-0.251**	0.021	-0.078	**-0.315**	0.024	**-0.150**	0.046	-0.012	-0.011	**0.116**	**0.163**	**1**

Values in bold are different from 0 with a significance level alpha=0.05

Highlighted values are different from 0 with a significance level alpha=0.001

Kendall Correlation Matrix: Physical Habitat Versus Biological Variables

Variables	No. Taxa	No. EPT Taxa	% Ephem	No. Ephem Taxa	% Intolerant	No. Scraper Taxa	% climbers	BIBI	Bank Stability	Vegetative Protection	Channel Flow	Channel Alteration	Channel Sinuosity	Pool Substrate	Pool Variability	Riparian Zone Width	Sediment Deposition	Epi. Substrate/Avail. Cover	RBP Score	Instream Habitat	Epifaunal Substrate	Bank Stability	Percent Shading	Remoteness	# Woody Debris/Rootwads	Remoteness Score	Shading Score	Epifaunal Substrate Score	Instream Habitat Score	Woody Debris Score	Bank Stability Score	PHI Score	Drainage Area
No. Taxa	1																																
No. EPT Taxa	0.381	1																															
% Ephem	0.190	0.367	1																														
No. Ephem Taxa	0.198	0.383	0.954	1																													
% Intolerant	0.101	0.393	0.181	0.178	1																												
No. Scraper Taxa	0.165	0.160	0.252	0.254	-0.022	1																											
% climbers	0.265	-0.013	0.004	0.010	-0.133	0.055	1																										
BIBI	0.489	0.632	0.550	0.562	0.340	0.410	0.148	1																									
Bank Stability	-0.017	-0.132	-0.128	-0.136	-0.080	0.000	0.053	-0.103	1																								
Vegetative Protection	0.068	-0.043	-0.082	-0.091	0.043	0.053	0.047	-0.004	0.697	1																							
Channel Flow	0.047	0.058	0.054	0.047	0.105	0.142	0.009	0.142	0.259	0.327	1																						
Channel Alteration	0.127	0.210	0.090	0.089	0.245	-0.075	0.006	0.151	-0.036	0.114	0.168	1																					
Channel Sinuosity	0.013	0.098	-0.006	-0.004	0.094	0.156	-0.005	0.091	0.042	0.184	0.118	0.202	1																				
Pool Substrate	0.136	0.122	0.170	0.166	0.047	0.179	0.087	0.191	0.235	0.318	0.303	0.106	0.233	1																			
Pool Variability	0.156	0.103	0.189	0.184	0.010	0.277	0.086	0.207	0.135	0.237	0.304	0.087	0.256	0.646	1																		
Riparian Zone Width	0.119	0.154	0.119	0.112	0.196	-0.047	0.056	0.124	-0.039	0.130	0.074	0.426	0.285	0.163	0.132	1																	
Sediment Deposition	-0.091	0.002	0.028	0.028	0.069	0.094	-0.075	0.012	0.271	0.272	0.382	0.018	0.138	0.318	0.254	-0.038	1																
Epi. Substrate/Avail. Cover	0.290	0.296	0.185	0.182	0.120	0.164	0.087	0.298	0.151	0.255	0.257	0.243	0.231	0.578	0.590	0.176	0.206	1															
RBP Score	0.130	0.099	0.069	0.059	0.097	0.159	0.077	0.145	0.440	0.587	0.482	0.290	0.380	0.578	0.520	0.307	0.407	0.543	1														
Instream Habitat	0.287	0.246	0.174	0.169	0.085	0.144	0.115	0.269	0.138	0.229	0.267	0.222	0.198	0.589	0.621	0.166	0.201	0.907	0.517	1													
Epifaunal Substrate	0.150	0.250	0.218	0.213	0.119	0.316	0.045	0.287	0.173	0.300	0.309	0.176	0.333	0.586	0.566	0.183	0.315	0.726	0.570	0.657	1												
Bank Stability	-0.015	-0.134	-0.132	-0.140	-0.084	-0.003	0.051	-0.103	0.985	0.694	0.258	-0.032	0.047	0.237	0.136	-0.041	0.265	0.153	0.440	0.143	0.180	1											
Percent Shading	0.120	0.137	-0.007	0.000	0.141	-0.130	0.082	0.062	-0.159	-0.032	-0.222	0.127	0.061	-0.141	-0.140	0.254	-0.140	-0.060	-0.081	-0.077	-0.085	-0.159	1										
Remoteness	0.035	0.167	0.108	0.109	0.194	-0.020	0.039	0.129	-0.066	0.078	0.098	0.401	0.291	0.187	0.152	0.523	0.021	0.150	0.247	0.134	0.234	-0.066	0.130	1									
# Woody Debris/Rootwads	0.136	0.042	0.148	0.143	-0.052	0.129	0.135	0.135	-0.006	0.108	0.134	0.106	0.126	0.289	0.331	0.126	0.092	0.334	0.251	0.346	0.240	-0.007	0.008	0.091	1								
Remoteness Score	0.035	0.167	0.108	0.109	0.195	-0.020	0.038	0.129	-0.065	0.080	0.098	0.402	0.293	0.188	0.153	0.524	0.023	0.151	0.248	0.134	0.235	-0.064	0.133	0.999	0.091	1							
Shading Score	0.120	0.138	-0.006	0.001	0.143	-0.128	0.081	0.064	-0.158	-0.031	-0.219	0.128	0.064	-0.140	-0.137	0.256	-0.139	-0.059	-0.080	-0.077	-0.081	-0.159	0.997	0.135	0.010	0.137	1						
Epifaunal Substrate Score	0.094	0.237	0.102	0.102	0.161	0.230	0.009	0.212	0.170	0.314	0.217	0.171	0.352	0.467	0.410	0.204	0.296	0.541	0.505	0.474	0.780	0.179	0.019	0.262	0.157	0.264	0.022	1					
Instream Habitat Score	0.200	0.219	-0.019	-0.017	0.169	-0.014	0.061	0.145	0.138	0.257	0.113	0.215	0.221	0.399	0.349	0.190	0.174	0.585	0.407	0.578	0.435	0.143	0.113	0.167	0.191	0.169	0.113	0.561	1				
Woody Debris Score	0.007	-0.026	-0.103	-0.100	0.018	-0.077	0.050	-0.066	-0.029	0.089	-0.070	0.081	0.111	0.008	-0.029	0.123	0.004	0.024	0.051	0.001	-0.021	-0.030	0.228	0.094	0.446	0.095	0.230	0.111	0.249	1			
Bank Stability Score	-0.015	-0.134	-0.132	-0.140	-0.084	-0.003	0.051	-0.103	0.985	0.694	0.258	-0.032	0.047	0.237	0.136	-0.041	0.265	0.153	0.440	0.143	0.180	1.000	-0.159	-0.066	-0.007	-0.064	-0.159	0.179	0.143	-0.030	1		
PHI Score	0.127	0.208	0.009	0.007	0.189	0.016	0.077	0.138	0.182	0.353	0.094	0.287	0.331	0.303	0.237	0.381	0.143	0.370	0.435	0.329	0.425	0.186	0.315	0.442	0.224	0.445	0.318	0.552	0.544	0.345	0.186	1	
Drainage Area	0.152	0.079	0.269	0.258	-0.073	0.238	0.103	0.223	0.025	0.015	0.253	0.041	0.020	0.303	0.411	-0.007	0.086	0.336	0.211	0.374	0.277	0.024	-0.251	-0.012	0.253	-0.012	-0.251	0.021	-0.078	-0.315	0.024	-0.150	1

Kendall Correlation Matrix: Biological Versus Water Quality & Land Use Variable:

Variables	**BIBI**	**No. Taxa**	**No. EPT Taxa**	**% Ephem**	**No. Ephem Taxa**	**% Intolerant**	**No. Scraper Taxa**	**% climbers**	**RBP_TOTAL**	**PHI**	**Conductivity**	**Dissolved Oxygen**	**pH**	**Turbidity**	**Water Temperature**	**% Impervious**	**%Developed**	**%Forested**	**%Open**	**%Agriculture**	**Drainage Area**
BIBI	**1**																				
No. Taxa	**0.489**	**1**																			
No. EPT Taxa	**0.632**	**0.381**	**1**																		
% Ephem	**0.550**	**0.190**	**0.367**	**1**																	
No. Ephem Taxa	**0.562**	**0.198**	**0.383**	**0.954**	**1**																
% Intolerant	**0.340**	**0.101**	**0.393**	**0.181**	**0.178**	**1**															
No. Scraper Taxa	**0.410**	**0.165**	**0.160**	**0.252**	**0.254**	-0.022	**1**														
% climbers	**0.148**	**0.265**	-0.013	0.004	0.010	**-0.133**	0.055	**1**													
RBP_TOTAL	**0.145**	**0.130**	**0.099**	0.069	0.059	**0.097**	**0.159**	0.077	**1**												
PHI	**0.138**	**0.127**	**0.208**	0.009	0.007	**0.189**	0.016	0.077	**0.435**	**1**											
Conductivity	**-0.147**	0.025	**-0.174**	**-0.119**	**-0.112**	**-0.378**	0.050	**0.153**	-0.066	**-0.126**	**1**										
Dissolved Oxygen	**0.090**	0.067	**0.090**	0.038	0.037	-0.004	0.027	0.053	-0.032	-0.044	0.071	**1**									
pH	0.015	-0.022	-0.071	**0.115**	**0.121**	**-0.186**	**0.119**	0.069	**-0.087**	**-0.124**	**0.275**	**0.093**	**1**								
Turbidity	-0.087	**-0.115**	**-0.140**	0.025	0.013	-0.039	-0.035	-0.032	**-0.124**	**-0.129**	-0.048	-0.090	0.092	**1**							
Water Temperature	0.013	**-0.112**	-0.008	0.043	0.036	0.065	0.067	-0.068	-0.053	-0.043	**-0.157**	**-0.246**	**0.102**	0.070	**1**						
% Impervious	**-0.155**	0.018	**-0.213**	**-0.174**	**-0.170**	**-0.406**	**0.167**	0.032	0.021	**-0.129**	**0.543**	-0.029	**0.190**	-0.069	**-0.131**	**1**					
%Developed	**-0.154**	-0.009	**-0.210**	**-0.183**	**-0.179**	**-0.342**	**0.120**	-0.024	-0.017	**-0.152**	**0.431**	-0.004	**0.104**	-0.052	**-0.147**	**0.727**	**1**				
%Forested	**0.125**	0.027	**0.199**	**0.100**	0.097	**0.355**	**-0.124**	0.020	**0.086**	**0.182**	**-0.301**	-0.031	**-0.189**	0.046	0.021	**-0.476**	**-0.549**	**1**			
%Open	-0.011	-0.002	-0.061	0.076	0.078	**-0.143**	0.085	0.008	0.026	**-0.093**	**0.186**	0.001	**0.153**	-0.005	0.028	**0.209**	**0.125**	**-0.223**	**1**		
%Agriculture	**0.194**	0.090	**0.172**	**0.261**	**0.264**	**0.171**	0.017	0.033	-0.082	-0.033	**-0.293**	**0.144**	0.068	0.072	**0.098**	**-0.505**	**-0.442**	0.079	-0.049	**1**	
Drainage Area	**0.223**	**0.152**	0.079	**0.269**	**0.258**	-0.073	**0.238**	**0.103**	**0.211**	**-0.150**	0.077	**0.141**	**0.183**	-0.036	-0.018	0.046	-0.012	-0.011	**0.116**	**0.163**	**1**

Values in bold are different from 0 with a significance level alpha=0.05

Highlighted values are different from 0 with a significance level alpha=0.001

Kendall Correlation Matrix: Biological Versus Geomorphic Variables

Variables	No. Taxa	No. EPT Taxa	% Ephem	No. Ephem Taxa	% Intolerant	No. Scraper Taxa	% climbers	BIBI	Entrenchment Ratio	Bankfull Width	Mean Depth	Width:Depth Ratio	Bankfull Area	Water Surface Slope	Bankfull Discharge	Sinuosity	Flood-Prone Width	D50	Bed Surface D16	Bed Surface D35	Bed Surface D50	Bed Surface D65	Bed Surface D84	Bed Surface D95	Bed Surface % Silt/Clay	Bed Surface % Sand	Bed Surface % Gravel	Bed Surface % Cobble	Bed Surface % Boulder	Drainage Area
No. Taxa	**1**																													
No. EPT Taxa	**0.381**	**1**																												
% Ephem	**0.190**	**0.367**	**1**																											
No. Ephem Taxa	**0.198**	**0.383**	**0.954**	**1**																										
% Intolerant	**0.101**	**0.393**	**0.181**	**0.178**	**1**																									
No. Scraper Taxa	**0.165**	**0.160**	**0.252**	**0.254**	-0.022	**1**																								
% climbers	**0.265**	-0.013	0.004	0.010	**-0.133**	0.055	**1**																							
BIBI	**0.489**	**0.632**	**0.550**	**0.562**	**0.340**	**0.410**	**0.148**	**1**																						
Entrenchment Ratio	-0.013	**-0.131**	**-0.104**	**-0.107**	-0.058	-0.058	0.012	**-0.094**	**1**																					
Bankfull Width	**0.100**	0.013	**0.170**	**0.169**	**-0.146**	**0.235**	**0.129**	**0.139**	-0.044	**1**																				
Mean Depth	**0.194**	**0.105**	**0.234**	**0.227**	-0.051	**0.132**	**0.151**	**0.217**	0.014	**0.284**	**1**																			
Width:Depth Ratio	-0.053	-0.084	-0.021	-0.018	**-0.107**	**0.115**	-0.010	-0.053	**-0.112**	**0.444**	**-0.276**	**1**																		
Bankfull Area	**0.168**	0.064	**0.239**	**0.230**	**-0.120**	**0.221**	**0.162**	**0.205**	-0.027	**0.655**	**0.631**	**0.096**	**1**																	
Water Surface Slope	**-0.100**	0.023	**-0.165**	**-0.158**	0.039	-0.055	-0.057	-0.089	**-0.105**	**-0.262**	**-0.302**	-0.025	**-0.335**	**1**																
Bankfull Discharge	**0.105**	**0.109**	**0.245**	**0.234**	-0.088	**0.233**	0.079	**0.201**	-0.077	**0.443**	**0.590**	-0.024	**0.668**	**-0.156**	**1**															
Sinuosity	0.040	0.087	-0.067	-0.064	0.082	0.047	0.006	0.049	-0.023	-0.047	-0.018	-0.056	-0.035	0.081	-0.034	**1**														
Flood-Prone Width	0.043	**-0.099**	0.041	0.034	**-0.114**	0.090	0.081	0.012	**0.586**	**0.382**	**0.179**	**0.164**	**0.326**	**-0.248**	**0.176**	-0.030	**1**													
D50	**0.132**	**0.143**	0.049	0.054	**-0.102**	**0.201**	0.067	**0.115**	**-0.162**	**0.202**	**0.134**	**0.099**	**0.210**	0.080	**0.189**	0.091	-0.003	**1**												
Bed Surface D16	**0.104**	**0.108**	-0.006	0.000	-0.073	0.062	0.064	0.042	**-0.124**	**0.167**	0.079	**0.107**	**0.162**	0.082	**0.179**	**0.103**	-0.004	**0.520**	**1**											
Bed Surface D35	**0.094**	**0.130**	-0.009	-0.004	-0.075	**0.146**	0.042	0.073	**-0.143**	**0.173**	**0.106**	**0.090**	**0.180**	0.085	**0.183**	0.084	-0.008	**0.674**	**0.772**	**1**										
Bed Surface D50	0.081	**0.122**	0.009	0.014	-0.085	**0.178**	0.025	0.081	**-0.170**	**0.181**	**0.120**	**0.089**	**0.192**	0.079	**0.189**	0.091	-0.022	**0.788**	**0.666**	**0.855**	**1**									
Bed Surface D65	**0.104**	**0.105**	0.013	0.015	-0.067	**0.190**	0.008	0.086	**-0.210**	**0.173**	**0.122**	**0.099**	**0.189**	**0.091**	**0.204**	**0.116**	-0.051	**0.679**	**0.576**	**0.721**	**0.832**	**1**								
Bed Surface D84	0.068	0.064	0.010	0.011	-0.046	**0.155**	0.006	0.059	**-0.243**	**0.156**	**0.136**	0.072	**0.189**	**0.098**	**0.225**	**0.103**	-0.087	**0.518**	**0.449**	**0.558**	**0.632**	**0.760**	**1**							
Bed Surface D95	0.020	0.014	-0.031	-0.030	-0.074	**0.097**	-0.035	-0.015	**-0.249**	**0.107**	**0.117**	0.053	**0.146**	**0.119**	**0.198**	0.055	**-0.119**	**0.418**	**0.374**	**0.451**	**0.500**	**0.608**	**0.793**	**1**						
Bed Surface % Silt/Clay	**-0.175**	**-0.188**	-0.063	-0.072	0.015	-0.061	-0.081	**-0.128**	**0.109**	**-0.096**	-0.071	-0.042	**-0.113**	-0.040	**-0.114**	**-0.117**	0.032	**-0.425**	**-0.681**	**-0.612**	**-0.547**	**-0.474**	**-0.338**	**-0.266**	**1**					
Bed Surface % Sand	**0.168**	**0.130**	0.016	0.018	0.041	-0.061	**0.128**	**0.102**	**0.167**	-0.060	-0.015	-0.084	-0.046	-0.087	**-0.121**	0.064	**0.115**	0.001	**0.146**	0.074	0.013	**-0.100**	**-0.242**	**-0.290**	**-0.363**	**1**				
Bed Surface % Gravel	0.015	0.062	0.034	0.032	-0.033	**0.118**	-0.018	0.038	**-0.314**	**0.158**	**0.145**	0.086	**0.190**	**0.129**	**0.239**	0.064	**-0.152**	**0.459**	**0.376**	**0.459**	**0.512**	**0.613**	**0.697**	**0.692**	**-0.240**	**-0.374**	**1**			
Bed Surface % Cobble	-0.039	-0.059	-0.050	-0.043	**-0.134**	0.044	0.042	-0.078	**-0.181**	**0.127**	0.053	**0.123**	**0.114**	0.101	**0.126**	0.009	-0.055	**0.232**	**0.250**	**0.283**	**0.284**	**0.350**	**0.441**	**0.518**	**-0.110**	**-0.268**	**0.378**	**1**		
Bed Surface % Boulder	-0.040	-0.043	**-0.135**	**-0.138**	**-0.144**	-0.034	0.007	**-0.125**	-0.074	0.006	0.017	0.010	0.013	0.095	0.020	0.034	-0.055	**0.154**	**0.257**	**0.258**	**0.251**	**0.260**	**0.305**	**0.316**	**-0.177**	**-0.164**	**0.201**	**0.417**	**1**	
Drainage Area	**0.152**	**0.079**	**0.269**	**0.258**	**-0.073**	**0.238**	**0.103**	**0.223**	**0.084**	**0.551**	**0.489**	**0.122**	**0.678**	**-0.403**	**0.533**	**-0.075**	**0.391**	**0.166**	**0.100**	**0.122**	**0.130**	**0.128**	**0.116**	**0.068**	**-0.070**	0.001	**0.085**	**0.048**	-0.022	**1**

Values in bold are different from 0 with a significance level alpha=0.05
Highlighted values are different from 0 with a significance level alpha=0.001

Kendall Correlation Matrix: Physical Habitat Versus Geomorphic Variables

Variables	Bank Stability	Vegetative Protection	Channel Flow	Channel Alteration	Channel Sinuosity	Pool Substrate	Pool Variability	Riparian Zone Width	Sediment Deposition	Epi. Substrate/Avail. Cover	RBP Score	Instream Habitat	Epifaunal Substrate	Bank Stability	Percent Shading	Remoteness	# Woody Debris/Rootwads	Remoteness Score	Shading Score	Epifaunal Substrate Score	Instream Habitat Score	Woody Debris Score	Bank Stability Score	PHI Score	Entrenchment Ratio	Bankfull Width	Mean Depth	Width:Depth Ratio	Bankfull Area	Water Surface Slope	Bankfull Discharge	Sinuosity	Flood-Prone Width	D50	Drainage area
Bank Stability	**1**																																		
Vegetative Protection	**0.697**	**1**																																	
Channel Flow	**0.259**	**0.327**	**1**																																
Channel Alteration	-0.036	**0.114**	**0.168**	**1**																															
Channel Sinuosity	0.042	**0.184**	**0.118**	**0.202**	**1**																														
Pool Substrate	**0.235**	**0.318**	**0.303**	**0.106**	**0.233**	**1**																													
Pool Variability	**0.135**	**0.237**	**0.304**	0.087	**0.256**	**0.646**	**1**																												
Riparian Zone Width	-0.039	**0.130**	0.074	**0.426**	**0.285**	**0.163**	**0.132**	**1**																											
Sediment Deposition	**0.271**	**0.272**	**0.382**	0.018	**0.138**	**0.318**	**0.254**	-0.038	**1**																										
Epi. Substrate/Avail. Cover	**0.151**	**0.255**	**0.257**	**0.243**	**0.231**	**0.578**	**0.590**	**0.176**	**0.206**	**1**																									
RBP Score	**0.440**	**0.587**	**0.482**	**0.290**	**0.380**	**0.578**	**0.520**	**0.307**	**0.407**	**0.543**	**1**																								
Instream Habitat	**0.138**	**0.229**	**0.267**	**0.222**	**0.198**	**0.589**	**0.621**	**0.166**	**0.201**	**0.907**	**0.517**	**1**																							
Epifaunal Substrate	**0.173**	**0.300**	**0.309**	**0.176**	**0.333**	**0.586**	**0.566**	**0.183**	**0.315**	**0.726**	**0.570**	**0.657**	**1**																						
Bank Stability	**0.985**	**0.694**	**0.258**	-0.032	0.047	**0.237**	**0.136**	-0.041	**0.265**	**0.153**	**0.440**	**0.143**	**0.180**	**1**																					
Percent Shading	**-0.159**	-0.032	**-0.222**	**0.127**	0.061	**-0.141**	**-0.140**	**0.254**	**-0.140**	-0.060	-0.081	-0.077	-0.085	**-0.159**	**1**																				
Remoteness	-0.066	0.078	**0.098**	**0.401**	**0.291**	**0.187**	**0.152**	**0.523**	0.021	**0.150**	**0.247**	**0.134**	**0.234**	-0.066	**0.130**	**1**																			
# Woody Debris/Rootwads	-0.006	**0.108**	**0.134**	**0.106**	**0.126**	**0.289**	**0.331**	**0.126**	**0.092**	**0.334**	**0.251**	**0.346**	**0.240**	-0.007	0.008	**0.091**	**1**																		
Remoteness Score	-0.065	0.080	**0.098**	**0.402**	**0.293**	**0.188**	**0.153**	**0.524**	0.023	**0.151**	**0.248**	**0.134**	**0.235**	-0.064	**0.133**	**0.999**	**0.091**	**1**																	
Shading Score	**-0.158**	-0.031	**-0.219**	**0.128**	0.064	**-0.140**	**-0.137**	**0.256**	**-0.139**	-0.059	-0.080	-0.077	-0.081	**-0.159**	**0.997**	**0.135**	0.010	**0.137**	**1**																
Epifaunal Substrate Score	**0.170**	**0.314**	**0.217**	**0.171**	**0.352**	**0.467**	**0.410**	**0.204**	**0.296**	**0.541**	**0.505**	**0.474**	**0.780**	**0.179**	0.019	**0.262**	**0.157**	**0.264**	0.022	**1**															
Instream Habitat Score	**0.138**	**0.257**	**0.113**	**0.215**	**0.221**	**0.399**	**0.349**	**0.190**	**0.174**	**0.585**	**0.407**	**0.578**	**0.435**	**0.143**	**0.113**	**0.167**	**0.191**	**0.169**	**0.113**	**0.561**	**1**														
Woody Debris Score	-0.029	**0.089**	-0.070	0.081	**0.111**	0.008	-0.029	**0.123**	0.004	0.024	0.051	0.001	-0.021	-0.030	**0.228**	**0.094**	**0.446**	**0.095**	**0.230**	**0.111**	**0.249**	**1**													
Bank Stability Score	**0.985**	**0.694**	**0.258**	-0.032	0.047	**0.237**	**0.136**	-0.041	**0.265**	**0.153**	**0.440**	**0.143**	**0.180**	**1.000**	**-0.159**	-0.066	-0.007	-0.064	**-0.159**	**0.179**	**0.143**	-0.030	**1**												
PHI Score	**0.182**	**0.353**	**0.094**	**0.287**	**0.331**	**0.303**	**0.237**	**0.381**	**0.143**	**0.370**	**0.435**	**0.329**	**0.425**	**0.186**	**0.315**	**0.442**	**0.224**	**0.445**	**0.318**	**0.552**	**0.544**	**0.345**	**0.186**	**1**											
Entrenchment Ratio	**0.370**	**0.344**	**0.337**	0.092	0.029	**0.188**	**0.107**	0.042	**0.276**	**0.113**	**0.307**	**0.125**	0.071	**0.369**	**-0.112**	-0.013	**0.126**	-0.012	**-0.112**	0.040	0.085	0.041	**0.369**	0.059	**1**										
Bankfull Width	**0.090**	0.061	**0.100**	-0.037	0.032	**0.262**	**0.358**	-0.032	0.011	**0.277**	**0.181**	**0.303**	**0.245**	0.088	**-0.212**	-0.072	**0.200**	-0.072	**-0.210**	0.049	-0.037	**-0.231**	0.088	**-0.106**	-0.044	**1**									
Mean Depth	**-0.146**	**-0.151**	0.062	0.016	-0.023	**0.172**	**0.266**	-0.008	-0.063	**0.260**	0.034	**0.300**	**0.110**	**-0.150**	-0.044	-0.033	**0.285**	-0.034	-0.045	-0.070	-0.020	**-0.126**	**-0.150**	**-0.115**	0.014	**0.284**	**1**								
Width:Depth Ratio	**0.176**	**0.156**	-0.012	-0.076	0.017	0.078	**0.114**	-0.042	0.012	0.050	**0.107**	0.045	**0.123**	**0.176**	**-0.172**	-0.062	-0.035	-0.061	**-0.171**	0.081	-0.039	**-0.122**	**0.176**	-0.035	**-0.112**	**0.444**	**-0.276**	**1**							
Bankfull Area	-0.047	-0.058	**0.096**	-0.011	0.011	**0.258**	**0.367**	-0.017	-0.038	**0.315**	**0.120**	**0.354**	**0.208**	-0.050	**-0.153**	-0.056	**0.283**	-0.057	**-0.153**	-0.010	-0.039	**-0.217**	-0.050	**-0.133**	-0.027	**0.655**	**0.631**	**0.096**	**1**						
Water Surface Slope	-0.056	-0.028	**-0.252**	-0.092	0.050	**-0.109**	**-0.157**	-0.014	0.023	**-0.099**	**-0.102**	**-0.129**	-0.083	-0.054	0.089	0.018	**-0.163**	0.019	0.089	0.086	**0.174**	**0.180**	-0.054	**0.123**	**-0.105**	**-0.262**	**-0.302**	-0.025	**-0.335**	**1**					
Bankfull Discharge	**-0.175**	**-0.212**	0.017	-0.026	-0.033	**0.148**	**0.224**	-0.033	-0.008	**0.219**	-0.018	**0.265**	**0.209**	**-0.175**	**-0.147**	-0.069	**0.201**	-0.070	**-0.147**	0.001	-0.082	**-0.232**	**-0.175**	**-0.177**	-0.077	**0.443**	**0.590**	-0.024	**0.668**	**-0.156**	**1**				
Sinuosity	0.001	0.070	-0.018	**0.129**	**0.609**	**0.109**	**0.102**	**0.213**	0.070	**0.148**	**0.209**	**0.118**	**0.170**	0.006	**0.114**	**0.139**	0.072	**0.140**	**0.114**	**0.229**	**0.200**	**0.134**	0.006	**0.252**	-0.023	-0.047	-0.018	-0.056	-0.035	0.081	-0.034	**1**			
Flood-Prone Width	**0.362**	**0.344**	**0.352**	0.057	0.071	**0.333**	**0.327**	0.033	**0.240**	**0.273**	**0.397**	**0.299**	**0.232**	**0.359**	**-0.220**	-0.021	**0.199**	-0.020	**-0.219**	**0.094**	0.059	**-0.121**	**0.359**	0.010	**0.586**	**0.382**	**0.179**	**0.164**	**0.326**	**-0.248**	**0.176**	-0.030	**1**		
D50	-0.005	-0.002	**-0.158**	-0.060	0.067	**0.236**	**0.241**	-0.042	-0.048	**0.287**	0.081	**0.282**	**0.281**	-0.002	-0.059	-0.013	0.011	-0.013	-0.060	**0.233**	**0.202**	**-0.121**	-0.002	**0.105**	**-0.162**	**0.202**	**0.134**	**0.099**	**0.210**	0.080	**0.189**	0.091	-0.003	**1**	
Drainage area	0.025	0.015	**0.253**	0.041	0.020	**0.303**	**0.411**	-0.007	0.086	**0.336**	**0.211**	**0.374**	**0.277**	0.024	**-0.251**	-0.012	**0.253**	-0.012	**-0.251**	0.021	-0.078	**-0.315**	0.024	**-0.150**	0.084	**0.551**	**0.489**	**0.122**	**0.678**	**-0.403**	**0.533**	-0.075	**0.391**	**0.166**	**1**

Values in bold are different from 0 with a significance level alpha=0.05

Highlighted values are different from 0 with a significance level alpha=0.001

Kendall Correlation Matrix: Physical Habitat Versus Geomorphic Variables (Rural PSUs)

Variables	**Bank Stability**	**Vegetative Protection**	**Channel Flow**	**Channel Alteration**	**Channel Sinuosity**	**Pool Substrate**	**Pool Variability**	**Riparian Zone Width**	**Sediment Deposition**	**Epi. Substrate/Avail. Cover**	**RBP Score**	**Instream Habitat**	**Epifaunal Substrate**	**Bank Stability**	**Percent Shading**	**Remoteness**	**# Woody Debris/Rootwads**	**Remoteness Score**	**Shading Score**	**Epifaunal Substrate Score**	**Instream Habitat Score**	**Woody Debris Score**	**Bank Stability Score**	**PHI Score**	**% Impervious**	**%Developed**	**%Forested**	**%Open**	**%Agriculture**
Bank Stability	**1**																												
Vegetative Protection	**0.758**	**1**																											
Channel Flow	0.123	0.037	**1**																										
Channel Alteration	0.008	-0.046	0.057	**1**																									
Channel Sinuosity	-0.010	0.061	-0.079	0.031	**1**																								
Pool Substrate	0.134	0.135	-0.008	-0.108	**0.160**	**1**																							
Pool Variability	0.046	0.099	0.036	**-0.193**	**0.172**	**0.588**	**1**																						
Riparian Zone Width	0.051	0.077	-0.039	**0.212**	**0.272**	0.120	0.040	**1**																					
Sediment Deposition	0.086	0.053	**0.205**	-0.065	0.034	**0.268**	**0.247**	-0.045	**1**																				
Epi. Substrate/Avail. Cover	0.128	0.118	0.034	-0.024	**0.183**	**0.600**	**0.579**	0.036	**0.150**	**1**																			
RBP Score	**0.422**	**0.441**	**0.193**	0.069	**0.352**	**0.492**	**0.441**	**0.291**	**0.317**	**0.489**	**1**																		
Instream Habitat	0.109	0.097	0.052	-0.051	**0.146**	**0.600**	**0.618**	0.021	**0.162**	**0.911**	**0.457**	**1**																	
Epifaunal Substrate	0.127	**0.192**	0.068	-0.098	**0.332**	**0.563**	**0.570**	**0.157**	**0.223**	**0.735**	**0.577**	**0.658**	**1**																
Bank Stability	**0.967**	**0.754**	0.123	0.009	0.002	0.127	0.040	0.045	0.070	0.131	**0.413**	0.118	0.133	**1**															
Percent Shading	-0.042	-0.028	**-0.331**	0.040	0.061	**-0.212**	**-0.156**	**0.167**	**-0.181**	**-0.188**	-0.116	**-0.184**	**-0.163**	-0.041	**1**														
Remoteness	-0.035	-0.041	0.012	**0.204**	**0.261**	0.130	0.051	**0.526**	-0.098	0.015	**0.170**	0.009	0.140	-0.040	0.068	**1**													
# Woody Debris/Rootwads	0.069	**0.148**	0.082	-0.003	0.126	**0.368**	**0.394**	0.083	0.139	**0.390**	**0.347**	**0.414**	**0.420**	0.073	-0.110	0.050	**1**												
Remoteness Score	-0.034	-0.039	0.011	**0.204**	**0.262**	0.132	0.052	**0.526**	-0.097	0.016	**0.171**	0.010	0.141	-0.039	0.069	**0.999**	0.052	**1**											
Shading Score	-0.042	-0.028	**-0.327**	0.039	0.066	**-0.214**	**-0.155**	**0.168**	**-0.184**	**-0.188**	-0.116	**-0.185**	**-0.158**	-0.041	**0.997**	0.072	-0.109	0.073	**1**										
Epifaunal Substrate Score	0.106	**0.168**	-0.056	-0.045	**0.371**	**0.450**	**0.389**	**0.182**	**0.173**	**0.514**	**0.471**	**0.440**	**0.738**	0.116	-0.079	**0.200**	**0.295**	**0.202**	-0.075	**1**									
Instream Habitat Score	0.092	0.068	**-0.179**	0.022	**0.149**	**0.383**	**0.261**	0.022	0.068	**0.489**	**0.243**	**0.471**	**0.307**	0.094	0.023	0.066	**0.150**	0.067	0.021	**0.474**	**1**								
Woody Debris Score	0.022	0.081	**-0.149**	0.081	0.086	-0.016	-0.125	0.063	-0.055	-0.080	0.006	-0.102	-0.033	0.027	**0.189**	0.080	**0.288**	0.081	**0.190**	**0.147**	**0.229**	**1**							
Bank Stability Score	**0.967**	**0.754**	0.123	0.009	0.002	0.127	0.040	0.045	0.070	0.131	**0.413**	0.118	0.133	**1.000**	-0.041	-0.040	0.073	-0.039	-0.041	0.116	0.094	0.027	**1**						
PHI Score	**0.277**	**0.302**	-0.135	0.088	**0.301**	**0.208**	0.107	**0.325**	-0.046	**0.204**	**0.362**	**0.171**	**0.286**	**0.281**	**0.292**	**0.394**	**0.194**	**0.395**	**0.295**	**0.440**	**0.417**	**0.374**	**0.281**	**1**					
% Impervious	0.051	0.116	-0.063	**-0.156**	0.086	-0.085	-0.006	-0.033	0.092	-0.130	0.024	-0.131	0.014	0.051	0.003	**-0.181**	-0.018	**-0.181**	0.005	0.038	-0.078	0.023	0.051	-0.055	**1**				
%Developed	0.031	0.082	-0.089	-0.143	0.062	-0.042	-0.029	-0.083	0.103	-0.119	-0.022	-0.127	0.004	0.035	-0.036	**-0.212**	-0.030	**-0.213**	-0.034	0.036	-0.030	0.040	0.035	-0.081	**0.729**	**1**			
%Forested	0.079	-0.019	**0.214**	**0.385**	-0.051	-0.106	-0.130	0.046	-0.012	-0.007	0.043	-0.001	-0.071	0.081	-0.051	0.060	-0.027	0.059	-0.049	-0.126	-0.076	-0.042	0.081	-0.015	**-0.314**	**-0.358**	**1**		
%Open	-0.075	-0.016	0.057	-0.089	**0.165**	0.046	0.130	0.064	0.120	0.084	0.115	0.058	0.130	-0.072	-0.087	-0.122	0.107	-0.123	-0.085	0.117	0.055	0.024	-0.072	-0.034	**0.334**	**0.368**	**-0.233**	**1**	
%Agriculture	-0.089	-0.042	**-0.198**	**-0.233**	-0.101	**0.168**	**0.199**	-0.053	-0.005	0.094	-0.040	0.120	0.069	-0.087	0.108	0.034	0.094	0.035	0.106	0.031	0.017	-0.043	-0.087	0.018	**-0.225**	**-0.241**	**-0.368**	**-0.170**	**1**

Values in bold are different from 0 with a significance level alpha=0.05

Highlighted values are different from 0 with a significance level alpha=0.001

Kendall Correlation Matrix: Physical Habitat Versus Biological Variables (Rural PSUs)

Variables	No. Taxa	No. EPT Taxa	% Ephem	No. Ephem Taxa	% Intolerant	No. Scraper Taxa	% climbers	BIBI	Bank Stability	Vegetative Protection	Channel Flow	Channel Alteration	Channel Sinuosity	Pool Substrate	Pool Variability	Riparian Zone Width	Sediment Deposition	Epi. Substrate/Avail. Cover	RBP Score	Instream Habitat	Epifaunal Substrate	Bank Stability	Percent Shading	Remoteness	# Woody Debris/Rootwads	Remoteness Score	Shading Score	Epifaunal Substrate Score	Instream Habitat Score	Woody Debris Score	Bank Stability Score	PHI Score
No. Taxa	**1**																															
No. EPT Taxa	**0.397**	**1**																														
% Ephem	**0.200**	**0.300**	**1**																													
No. Ephem Taxa	**0.228**	**0.341**	**0.912**	**1**																												
% Intolerant	0.104	**0.296**	0.040	0.020	**1**																											
No. Scraper Taxa	**0.200**	0.131	**0.351**	**0.365**	-0.012	**1**																										
% climbers	**0.191**	-0.048	-0.046	-0.032	**-0.202**	-0.103	**1**																									
BIBI	**0.525**	**0.578**	**0.618**	**0.645**	**0.215**	**0.428**	0.044	**1**																								
Bank Stability	0.056	-0.050	-0.036	-0.059	0.079	-0.116	0.129	-0.002	**1**																							
Vegetative Protection	0.055	-0.086	0.010	-0.014	0.049	-0.007	0.065	0.008	**0.758**	**1**																						
Channel Flow	-0.119	-0.140	0.042	0.013	0.087	-0.053	-0.031	-0.018	0.123	0.037	**1**																					
Channel Alteration	-0.091	-0.010	-0.086	-0.102	0.141	**-0.209**	-0.098	-0.114	0.008	-0.046	0.057	**1**																				
Channel Sinuosity	0.003	0.049	-0.041	-0.047	-0.006	**0.167**	0.010	0.021	-0.010	0.061	-0.079	0.031	**1**																			
Pool Substrate	0.122	0.121	**0.249**	**0.235**	-0.027	**0.192**	0.132	**0.247**	0.134	0.135	-0.008	-0.108	**0.160**	**1**																		
Pool Variability	0.088	0.047	**0.304**	**0.296**	-0.101	**0.352**	0.071	**0.244**	0.046	0.099	0.036	**-0.193**	**0.172**	**0.588**	**1**																	
Riparian Zone Width	0.043	-0.023	0.060	0.037	-0.091	-0.027	0.112	-0.010	0.051	0.077	-0.039	**0.212**	**0.272**	0.120	0.040	**1**																
Sediment Deposition	-0.124	-0.122	**0.173**	**0.171**	-0.039	0.094	-0.068	0.011	0.086	0.053	**0.205**	-0.065	0.034	**0.268**	**0.247**	-0.045	**1**															
Epi. Substrate/Avail. Cover	**0.207**	**0.291**	**0.311**	**0.301**	0.112	**0.239**	0.037	**0.385**	0.128	0.118	0.034	-0.024	**0.183**	**0.600**	**0.579**	0.036	**0.150**	**1**														
RBP Score	0.066	-0.007	**0.178**	0.145	0.007	0.138	0.098	0.136	**0.422**	**0.441**	**0.193**	0.069	**0.352**	**0.492**	**0.441**	**0.291**	**0.317**	**0.489**	**1**													
Instream Habitat	**0.193**	**0.237**	**0.285**	**0.268**	0.071	**0.225**	0.064	**0.341**	0.109	0.097	0.052	-0.051	**0.146**	**0.600**	**0.618**	0.021	**0.162**	**0.911**	**0.457**	**1**												
Epifaunal Substrate	0.075	0.120	**0.336**	**0.310**	0.021	**0.360**	-0.024	**0.284**	0.127	**0.192**	0.068	-0.098	**0.332**	**0.563**	**0.570**	**0.157**	**0.223**	**0.735**	**0.577**	**0.658**	**1**											
Bank Stability	0.062	-0.052	-0.042	-0.066	0.078	-0.117	0.118	-0.002	**0.967**	**0.754**	0.123	0.009	0.002	0.127	0.040	0.045	0.070	0.131	**0.413**	0.118	0.133	**1**										
Percent Shading	0.112	-0.010	-0.087	-0.064	-0.088	-0.059	**0.207**	-0.049	-0.042	-0.028	**-0.331**	0.040	0.061	**-0.212**	**-0.156**	**0.167**	**-0.181**	**-0.188**	-0.116	**-0.184**	**-0.163**	-0.041	**1**									
Remoteness	0.014	0.046	-0.061	-0.077	-0.078	-0.064	0.118	-0.035	-0.035	-0.041	0.012	**0.204**	**0.261**	0.130	0.051	**0.526**	-0.098	0.015	**0.170**	0.009	0.140	-0.040	0.068	**1**								
# Woody Debris/Rootwads	0.063	-0.013	**0.296**	**0.274**	**-0.142**	**0.194**	0.113	**0.166**	0.069	**0.148**	0.082	-0.003	0.126	**0.368**	**0.394**	0.083	0.139	**0.390**	**0.347**	**0.414**	**0.420**	0.073	-0.110	0.050	**1**							
Remoteness Score	0.014	0.047	-0.060	-0.075	-0.078	-0.063	0.119	-0.034	-0.034	-0.039	0.011	**0.204**	**0.262**	0.132	0.052	**0.526**	-0.097	0.016	**0.171**	0.010	0.141	-0.039	0.069	**0.999**	0.052	**1**						
Shading Score	0.110	-0.010	-0.085	-0.064	-0.087	-0.055	**0.204**	-0.048	-0.042	-0.028	**-0.327**	0.039	0.066	**-0.214**	**-0.155**	**0.168**	**-0.184**	**-0.188**	-0.116	**-0.185**	**-0.158**	-0.041	**0.997**	0.072	-0.109	0.073	**1**					
Epifaunal Substrate Score	0.049	0.123	**0.183**	**0.171**	0.054	**0.253**	-0.058	**0.170**	0.106	**0.168**	-0.056	-0.045	**0.371**	**0.450**	**0.389**	**0.182**	**0.173**	**0.514**	**0.471**	**0.440**	**0.738**	0.116	-0.079	**0.200**	**0.295**	**0.202**	-0.075	**1**				
Instream Habitat Score	**0.182**	**0.218**	0.016	0.016	**0.136**	0.005	0.046	**0.151**	0.092	0.068	**-0.179**	0.022	**0.149**	**0.383**	**0.261**	0.022	0.068	**0.489**	**0.243**	**0.471**	**0.307**	0.094	0.023	0.066	**0.150**	0.067	0.021	**0.474**	**1**			
Woody Debris Score	-0.023	-0.088	-0.097	-0.102	-0.056	-0.118	0.077	-0.136	0.022	0.081	**-0.149**	0.081	0.086	-0.016	-0.125	0.063	-0.055	-0.080	0.006	-0.102	-0.033	0.027	**0.189**	0.080	**0.288**	0.081	**0.190**	**0.147**	**0.229**	**1**		
Bank Stability Score	0.062	-0.052	-0.042	-0.066	0.078	-0.117	0.118	-0.002	**0.967**	**0.754**	0.123	0.009	0.002	0.127	0.040	0.045	0.070	0.131	**0.413**	0.118	0.133	**1.000**	-0.041	-0.040	0.073	-0.039	-0.041	0.116	0.094	0.027	**1**	
PHI Score	0.106	0.049	-0.050	-0.069	0.000	-0.020	**0.162**	0.012	**0.277**	**0.302**	-0.135	0.088	**0.301**	**0.208**	0.107	**0.325**	-0.046	**0.204**	**0.362**	**0.171**	**0.286**	**0.281**	**0.292**	**0.394**	**0.194**	**0.395**	**0.295**	**0.440**	**0.417**	**0.374**	**0.281**	**1**

Values in bold are different from 0 with a significance level alpha=0.05

Highlighted values are different from 0 with a significance level alpha=0.001

Kendall Correlation Matrix: Biological Versus Water Quality, Geomorphic & Land Use Variables (Rural PSUs)

Variables	BIBI	No. Taxa	No. EPT Taxa	% Ephem	No. Ephem Taxa	% Intolerant	No. Scraper Taxa	% climbers	RBP_TOTAL	PHI	Conductivity	Dissolved Oxygen	pH	Turbidity	Water Temperature	Entrenchment Ratio	Bankfull Width	Mean Depth	Width:Depth Ratio	Bankfull Area	Water Surface Slope	Bankfull Discharge	Sinuosity	Flood-Prone Width	D50	% Impervious	%Developed	%Forested	%Open	%Agriculture	Drainage Area
BIBI	**1**																														
No. Taxa	**0.683**	**1**																													
No. EPT Taxa	**0.703**	**0.605**	**1**																												
% Ephem	**0.511**	0.065	**0.225**	**1**																											
No. Ephem Taxa	**0.740**	**0.291**	**0.480**	**0.615**	**1**																										
% Intolerant	**0.263**	0.122	**0.381**	0.054	-0.048	**1**																									
No. Scraper Taxa	**0.523**	**0.263**	0.134	**0.262**	**0.375**	-0.046	**1**																								
% climbers	-0.135	0.031	-0.192	-0.160	-0.121	**-0.350**	**-0.212**	**1**																							
RBP_TOTAL	0.166	0.065	-0.013	**0.236**	0.137	-0.042	0.109	0.068	**1**																						
PHI	0.076	0.178	0.140	0.050	-0.034	-0.001	-0.014	0.183	**0.485**	**1**																					
Conductivity	**-0.268**	-0.120	**-0.221**	-0.134	-0.077	**-0.314**	-0.030	0.159	-0.013	0.019	**1**																				
Dissolved Oxygen	-0.078	-0.105	0.077	-0.050	0.016	-0.089	0.070	0.086	-0.019	-0.004	**0.224**	**1**																			
pH	0.051	-0.058	-0.068	0.135	0.123	-0.116	0.121	-0.026	0.163	-0.123	-0.058	0.102	**1**																		
Turbidity	-0.109	**-0.259**	-0.209	0.207	0.057	0.027	**-0.267**	-0.133	-0.190	**-0.302**	0.010	**-0.380**	0.166	**1**																	
Water Temperature	0.051	0.004	-0.085	0.070	-0.049	-0.014	0.106	-0.148	0.075	-0.099	**-0.382**	**-0.498**	**0.199**	0.090	**1**																
Entrenchment Ratio	**-0.273**	**-0.246**	**-0.323**	0.025	-0.157	0.014	**-0.246**	**0.206**	**0.327**	0.004	0.137	0.011	**0.202**	0.218	0.022	**1**															
Bankfull Width	**0.334**	0.105	0.145	**0.290**	**0.343**	-0.134	**0.350**	0.026	**0.411**	-0.103	-0.064	**0.258**	**0.264**	-0.217	0.059	-0.027	**1**														
Mean Depth	**0.387**	**0.229**	0.183	**0.406**	**0.311**	-0.155	**0.256**	0.044	0.190	-0.183	-0.177	0.019	**0.268**	-0.010	0.135	-0.028	**0.546**	**1**													
Width:Depth Ratio	-0.042	-0.168	-0.090	-0.014	0.055	0.038	0.115	-0.008	**0.360**	0.041	0.095	**0.250**	0.017	**-0.232**	0.015	0.108	**0.584**	**-0.256**	**1**												
Bankfull Area	**0.355**	0.155	0.134	**0.379**	**0.341**	-0.189	**0.336**	0.019	**0.309**	-0.117	-0.096	0.120	**0.251**	-0.102	0.080	-0.032	**0.859**	**0.814**	0.161	**1**											
Water Surface Slope	-0.050	-0.053	0.146	-0.140	-0.050	-0.013	-0.162	-0.064	**-0.257**	-0.065	0.133	0.007	-0.168	-0.107	0.050	-0.075	**-0.201**	-0.042	-0.183	-0.110	**1**										
Bankfull Discharge	0.165	-0.014	0.192	0.124	0.145	-0.104	0.068	-0.057	-0.066	**-0.287**	0.020	0.077	0.197	-0.063	0.138	-0.060	**0.313**	**0.494**	-0.092	**0.419**	**0.763**	**1**									
Sinuosity	0.095	**0.241**	0.142	-0.102	-0.080	0.021	0.099	-0.027	**0.255**	**0.336**	**-0.201**	-0.141	-0.015	**-0.267**	0.183	-0.072	-0.084	-0.084	-0.067	-0.100	-0.025	-0.103	**1**								
Flood-Prone Width	-0.177	**-0.261**	**-0.317**	0.139	-0.066	0.016	-0.139	0.131	**0.485**	0.008	0.021	0.025	0.166	0.083	0.150	**0.817**	**0.313**	0.125	**0.427**	**0.238**	-0.141	0.012	-0.098	**1**							
D50	**0.198**	0.072	**0.209**	0.104	**0.216**	-0.048	**0.219**	-0.115	0.180	0.091	**0.211**	**0.226**	0.040	-0.193	-0.197	-0.122	**0.246**	0.150	0.122	0.183	0.066	**0.272**	-0.006	-0.094	**1**						
% Impervious	-0.050	0.063	-0.099	-0.109	-0.043	-0.126	**0.223**	-0.165	0.053	0.014	**0.592**	0.019	**0.225**	-0.146	-0.071	0.004	-0.093	-0.137	0.033	-0.124	0.034	0.008	0.155	-0.079	**0.200**	**1**					
%Developed	-0.092	-0.100	-0.169	-0.086	-0.015	-0.142	0.192	-0.158	-0.043	-0.081	**0.594**	0.089	0.174	-0.129	-0.149	-0.026	-0.034	-0.138	0.099	-0.083	0.089	0.071	0.029	-0.069	**0.227**	**0.837**	**1**				
%Forested	0.035	-0.007	0.105	0.023	-0.065	**0.382**	**-0.285**	0.013	0.057	0.029	**-0.250**	-0.109	-0.056	**0.418**	-0.101	0.139	-0.141	-0.016	-0.161	-0.092	-0.174	-0.162	-0.077	0.041	**-0.245**	**-0.484**	**-0.595**	**1**			
%Open	-0.103	-0.080	-0.043	-0.021	0.038	**-0.241**	0.074	-0.085	0.064	0.015	0.148	0.084	-0.036	-0.190	-0.109	0.007	-0.051	-0.150	0.079	-0.090	-0.063	-0.129	0.173	-0.028	0.126	**0.410**	**0.429**	**-0.413**	**1**		
%Agriculture	0.080	0.127	0.039	0.056	0.075	**-0.233**	0.143	0.156	-0.056	0.030	**-0.275**	0.018	-0.069	**-0.254**	**0.293**	-0.146	**0.218**	**0.198**	0.073	**0.217**	0.154	0.163	-0.004	0.022	0.044	**-0.314**	**-0.330**	**-0.506**	**-0.285**	**1**	
Drainage Area	**0.315**	0.075	0.082	**0.474**	**0.342**	-0.124	**0.286**	-0.047	**0.347**	-0.132	-0.130	0.048	**0.209**	0.036	0.066	0.030	**0.785**	**0.727**	0.155	**0.937**	**-0.250**	**0.244**	-0.118	**0.301**	0.104	-0.174	-0.143	-0.011	-0.077	0.167	**1**

Values in bold are different from 0 with a significance level alpha=0.05

Highlighted values are different from 0 with a significance level alpha=0.001

Kendall Correlation Matrix: Physical Habitat Versus Geomorphic Variables (Rural PSUs)

Variables	Bank Stability	Vegetative Protection	Channel Flow	Channel Alteration	Channel Sinuosity	Pool Substrate	Pool Variability	Riparian Zone Width	Sediment Deposition	Epi. Substrate/Avail. Cover	RBP Score	Instream Habitat	Epifaunal Substrate	Bank Stability	Percent Shading	Remoteness	# Woody Debris/Rootwads	Remoteness Score	Shading Score	Epifaunal Substrate Score	Instream Habitat Score	Woody Debris Score	Bank Stability Score	PHI Score	Entrenchment Ratio	Bankfull Width	Mean Depth	Width:Depth Ratio	Bankfull Area	Water Surface Slope	Bankfull Discharge	Sinuosity	Flood-Prone Width	D50	Drainage area
Bank Stability	**1**																																		
Vegetative Protection	**0.758**	**1**																																	
Channel Flow	0.123	0.037	**1**																																
Channel Alteration	0.008	-0.046	0.057	**1**																															
Channel Sinuosity	-0.010	0.061	-0.079	0.031	**1**																														
Pool Substrate	0.134	0.135	-0.008	-0.108	**0.160**	**1**																													
Pool Variability	0.046	0.099	0.036	**-0.193**	**0.172**	**0.588**	**1**																												
Riparian Zone Width	0.051	0.077	-0.039	**0.212**	**0.272**	0.120	0.040	**1**																											
Sediment Deposition	0.086	0.053	**0.205**	-0.065	0.034	**0.268**	**0.247**	-0.045	**1**																										
Epi. Substrate/Avail. Cover	0.128	0.118	0.034	-0.024	**0.183**	**0.600**	**0.579**	0.036	**0.150**	**1**																									
RBP Score	**0.422**	**0.441**	**0.193**	0.069	**0.352**	**0.492**	**0.441**	**0.291**	**0.317**	**0.489**	**1**																								
Instream Habitat	0.109	0.097	0.052	-0.051	**0.146**	**0.600**	**0.618**	0.021	**0.162**	**0.911**	**0.457**	**1**																							
Epifaunal Substrate	0.127	**0.192**	0.068	-0.098	**0.332**	**0.563**	**0.570**	**0.157**	**0.223**	**0.735**	**0.577**	**0.658**	**1**																						
Bank Stability	**0.967**	**0.754**	0.123	0.009	0.002	0.127	0.040	0.045	0.070	0.131	**0.413**	0.118	0.133	**1**																					
Percent Shading	-0.042	-0.028	**-0.331**	0.040	0.061	**-0.212**	**-0.156**	**0.167**	**-0.181**	**-0.188**	-0.116	**-0.184**	**-0.163**	-0.041	**1**																				
Remoteness	-0.035	-0.041	0.012	**0.204**	**0.261**	0.130	0.051	**0.526**	-0.098	0.015	**0.170**	0.009	0.140	-0.040	0.068	**1**																			
# Woody Debris/Rootwads	0.069	**0.148**	0.082	-0.003	0.126	**0.368**	**0.394**	0.083	0.139	**0.390**	**0.347**	**0.414**	**0.420**	0.073	-0.110	0.050	**1**																		
Remoteness Score	-0.034	-0.039	0.011	**0.204**	**0.262**	0.132	0.052	**0.526**	-0.097	0.016	**0.171**	0.010	0.141	-0.039	0.069	**0.999**	0.052	**1**																	
Shading Score	-0.042	-0.028	**-0.327**	0.039	0.066	**-0.214**	**-0.155**	**0.168**	**-0.184**	**-0.188**	-0.116	**-0.185**	**-0.158**	-0.041	**0.997**	0.072	-0.109	0.073	**1**																
Epifaunal Substrate Score	0.106	**0.168**	-0.056	-0.045	**0.371**	**0.450**	**0.389**	**0.182**	**0.173**	**0.514**	**0.471**	**0.440**	**0.738**	0.116	-0.079	**0.200**	**0.295**	**0.202**	-0.075	**1**															
Instream Habitat Score	0.092	0.068	**-0.179**	0.022	**0.149**	**0.383**	**0.261**	0.022	0.068	**0.489**	**0.243**	**0.471**	**0.307**	0.094	0.023	0.066	**0.150**	0.067	0.021	**0.474**	**1**														
Woody Debris Score	0.022	0.081	**-0.149**	0.081	0.086	-0.016	-0.125	0.063	-0.055	-0.080	0.006	-0.102	-0.033	0.027	**0.189**	0.080	**0.288**	0.081	**0.190**	**0.147**	**0.229**	**1**													
Bank Stability Score	**0.967**	**0.754**	0.123	0.009	0.002	0.127	0.040	0.045	0.070	0.131	**0.413**	0.118	0.133	**1.000**	-0.041	-0.040	0.073	-0.039	-0.041	0.116	0.094	0.027	**1**												
PHI Score	**0.277**	**0.302**	-0.135	0.088	**0.301**	**0.208**	0.107	**0.325**	-0.046	**0.204**	**0.362**	**0.171**	**0.286**	**0.281**	**0.292**	**0.394**	**0.194**	**0.395**	**0.295**	**0.440**	**0.417**	**0.374**	**0.281**	**1**											
Entrenchment Ratio	**0.260**	**0.150**	**0.196**	0.134	-0.062	-0.012	-0.089	-0.033	**0.245**	-0.006	0.117	0.008	-0.096	**0.272**	-0.130	-0.134	0.014	-0.133	-0.132	-0.092	0.027	0.035	**0.272**	-0.038	**1**										
Bankfull Width	0.091	0.113	0.066	**-0.160**	0.057	**0.328**	**0.476**	0.067	0.124	**0.395**	**0.292**	**0.434**	**0.371**	0.086	**-0.172**	-0.017	**0.295**	-0.016	**-0.170**	0.117	-0.025	**-0.336**	0.086	-0.088	**-0.150**	**1**									
Mean Depth	-0.087	-0.130	0.071	-0.105	0.036	**0.242**	**0.350**	-0.043	0.057	**0.373**	0.130	**0.410**	**0.234**	-0.092	-0.085	-0.030	**0.271**	-0.031	-0.088	0.015	0.009	**-0.239**	-0.092	-0.113	-0.040	**0.373**	**1**								
Width:Depth Ratio	**0.149**	**0.243**	-0.047	-0.106	0.019	**0.143**	**0.208**	0.085	0.060	0.115	**0.184**	0.120	**0.199**	**0.146**	-0.124	-0.006	0.083	-0.005	-0.121	0.126	-0.039	**-0.173**	**0.146**	-0.014	**-0.180**	**0.456**	**-0.175**	**1**							
Bankfull Area	0.003	-0.004	0.089	-0.148	0.060	**0.329**	**0.468**	0.035	0.114	**0.442**	**0.248**	**0.479**	**0.355**	-0.002	**-0.149**	-0.023	**0.319**	-0.023	**-0.150**	0.089	-0.019	**-0.331**	-0.002	-0.106	-0.118	**0.711**	**0.663**	**0.163**	**1**						
Water Surface Slope	-0.129	-0.095	**-0.296**	-0.025	0.051	-0.084	**-0.185**	-0.071	-0.025	**-0.140**	**-0.191**	**-0.171**	**-0.185**	-0.125	**0.148**	0.033	**-0.245**	0.034	**0.146**	0.047	**0.265**	**0.235**	-0.125	0.123	0.011	**-0.409**	**-0.260**	**-0.206**	**-0.394**	**1**					
Bankfull Discharge	-0.148	**-0.163**	0.087	-0.056	0.058	**0.189**	**0.288**	0.002	**0.186**	**0.310**	0.110	**0.358**	**0.301**	-0.146	-0.155	-0.061	**0.194**	-0.061	-0.156	0.062	-0.085	**-0.377**	-0.146	**-0.212**	-0.054	**0.501**	**0.656**	0.006	**0.690**	**-0.222**	**1**				
Sinuosity	0.008	0.091	**-0.167**	0.104	**0.736**	0.139	0.078	**0.289**	0.008	**0.172**	**0.300**	0.123	**0.268**	0.022	0.140	**0.233**	0.077	**0.234**	0.142	**0.356**	**0.199**	**0.152**	0.022	**0.347**	-0.069	-0.020	-0.038	-0.009	-0.021	0.123	-0.029	**1**			
Flood-Prone Width	**0.255**	**0.211**	**0.192**	-0.019	0.041	**0.250**	**0.333**	0.069	**0.239**	**0.347**	**0.363**	**0.374**	**0.267**	**0.258**	**-0.221**	-0.084	**0.245**	-0.083	**-0.222**	0.053	-0.031	**-0.265**	**0.258**	-0.078	**0.246**	**0.625**	**0.303**	**0.318**	**0.538**	**-0.362**	**0.431**	-0.016	**1**		
D50	0.018	0.058	**-0.281**	-0.138	0.125	**0.329**	**0.250**	-0.047	-0.017	**0.337**	**0.144**	**0.310**	**0.322**	0.020	0.012	0.097	0.082	0.098	0.012	**0.325**	**0.292**	-0.010	0.020	**0.209**	**-0.258**	**0.202**	**0.138**	0.134	**0.205**	0.094	**0.159**	**0.161**	0.041	**1**	
Drainage area	0.046	0.041	**0.243**	-0.069	0.039	**0.332**	**0.477**	0.023	**0.176**	**0.442**	**0.315**	**0.479**	**0.434**	0.046	**-0.268**	-0.018	**0.351**	-0.018	**-0.266**	0.120	-0.091	**-0.381**	0.046	**-0.135**	-0.038	**0.658**	**0.530**	**0.217**	**0.730**	**-0.483**	**0.641**	-0.058	**0.544**	0.110	**1**

Values in bold are different from 0 with a significance level alpha=0.05

Highlighted values are different from 0 with a significance level alpha=0.001

Kendall Correlation Matrix: Biological Versus Bed Surface (Rural PSUs)

Variables	**Drainage Area**	**No. Taxa**	**No. EPT Taxa**	**% Ephem**	**No. Ephem Taxa**	**% Intolerant**	**No. Scraper Taxa**	**% climbers**	**BIBI**	**Bed Surface D16**	**Bed Surface D35**	**Bed Surface D50**	**Bed Surface D65**	**Bed Surface D84**	**Bed Surface D95**	**Bed Surface % Silt/Clay**	**Bed Surface % Sand**	**Bed Surface % Gravel**	**Bed Surface % Cobble**	**Bed Surface % Boulder**
Drainage Area	**1**																			
No. Taxa	0.066	**1**																		
No. EPT Taxa	0.105	**0.397**	**1**																	
% Ephem	**0.359**	**0.200**	**0.300**	**1**																
No. Ephem Taxa	**0.331**	**0.228**	**0.341**	**0.912**	**1**															
% Intolerant	-0.047	0.104	**0.296**	0.040	0.020	**1**														
No. Scraper Taxa	**0.271**	**0.200**	0.131	**0.351**	**0.365**	-0.012	**1**													
% climbers	0.021	**0.191**	-0.048	-0.046	-0.032	**-0.202**	-0.103	**1**												
BIBI	**0.282**	**0.525**	**0.578**	**0.618**	**0.645**	**0.215**	**0.428**	0.044	**1**											
Bed Surface D16	0.047	**0.172**	**0.331**	0.042	0.049	0.067	0.050	-0.014	**0.176**	**1**										
Bed Surface D35	0.046	0.122	**0.329**	0.057	0.068	0.057	0.125	-0.029	**0.191**	**0.708**	**1**									
Bed Surface D50	0.067	**0.140**	**0.303**	0.093	0.108	0.020	**0.208**	-0.028	**0.224**	**0.542**	**0.789**	**1**								
Bed Surface D65	0.077	**0.184**	**0.269**	0.100	0.110	0.042	**0.244**	-0.044	**0.234**	**0.455**	**0.659**	**0.803**	**1**							
Bed Surface D84	0.096	0.125	**0.185**	0.088	0.092	0.086	**0.202**	-0.039	**0.182**	**0.315**	**0.492**	**0.569**	**0.707**	**1**						
Bed Surface D95	0.025	0.086	0.123	0.025	0.032	0.029	**0.155**	-0.068	0.088	**0.261**	**0.397**	**0.430**	**0.556**	**0.771**	**1**					
Bed Surface % Silt/Clay	-0.008	**-0.199**	**-0.309**	-0.053	-0.059	-0.046	-0.097	-0.016	**-0.188**	**-0.721**	**-0.666**	**-0.548**	**-0.502**	**-0.356**	**-0.297**	**1**				
Bed Surface % Sand	-0.015	**0.164**	**0.153**	-0.031	-0.042	-0.012	-0.071	**0.186**	0.068	**0.315**	**0.213**	0.129	0.020	**-0.142**	**-0.198**	**-0.430**	**1**			
Bed Surface % Gravel	0.057	0.099	**0.216**	0.081	0.084	0.054	**0.207**	-0.063	**0.163**	**0.310**	**0.464**	**0.522**	**0.639**	**0.718**	**0.700**	**-0.302**	**-0.160**	**1**		
Bed Surface % Cobble	0.076	0.099	0.052	0.132	0.165	0.005	0.066	**0.180**	0.107	0.060	**0.195**	**0.166**	**0.225**	**0.331**	**0.392**	-0.102	-0.130	**0.266**	**1**	
Bed Surface % Boulder	-0.089	0.066	0.072	-0.117	-0.121	0.032	**-0.189**	-0.034	-0.050	0.142	**0.187**	0.156	0.117	0.100	0.083	-0.144	0.008	-0.040	0.110	**1**

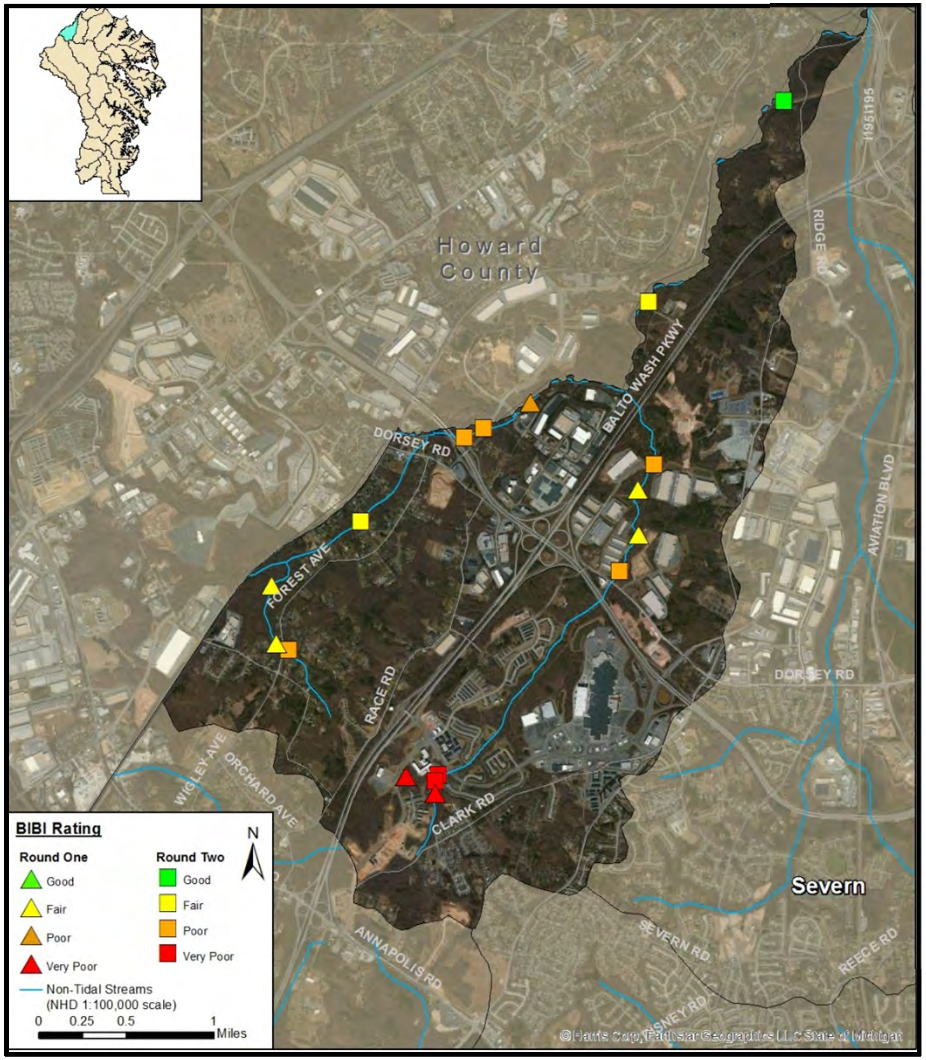
Values in bold are different from 0 with a significance level alpha=0.05

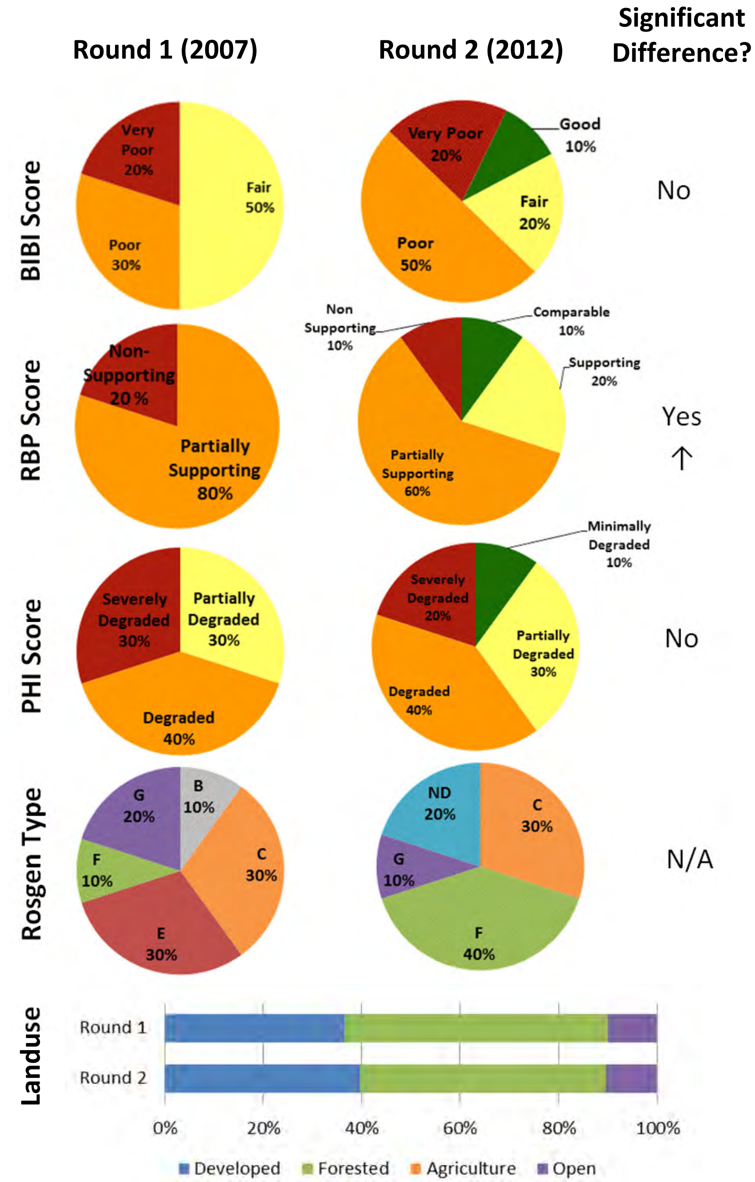
Highlighted values are different from 0 with a significance level alpha=0.001

Appendix C: PSU Summaries

PSU 1: Piney Run

The Piney Run sampling unit is located in the northwestern portion of the County along the border with Howard County, and has a total drainage area of 4,868 acres. In 2012, impervious surfaces comprise 21.4 % of the overall sampling unit, with individual sites ranging from 6.8 % to 25.0 %.

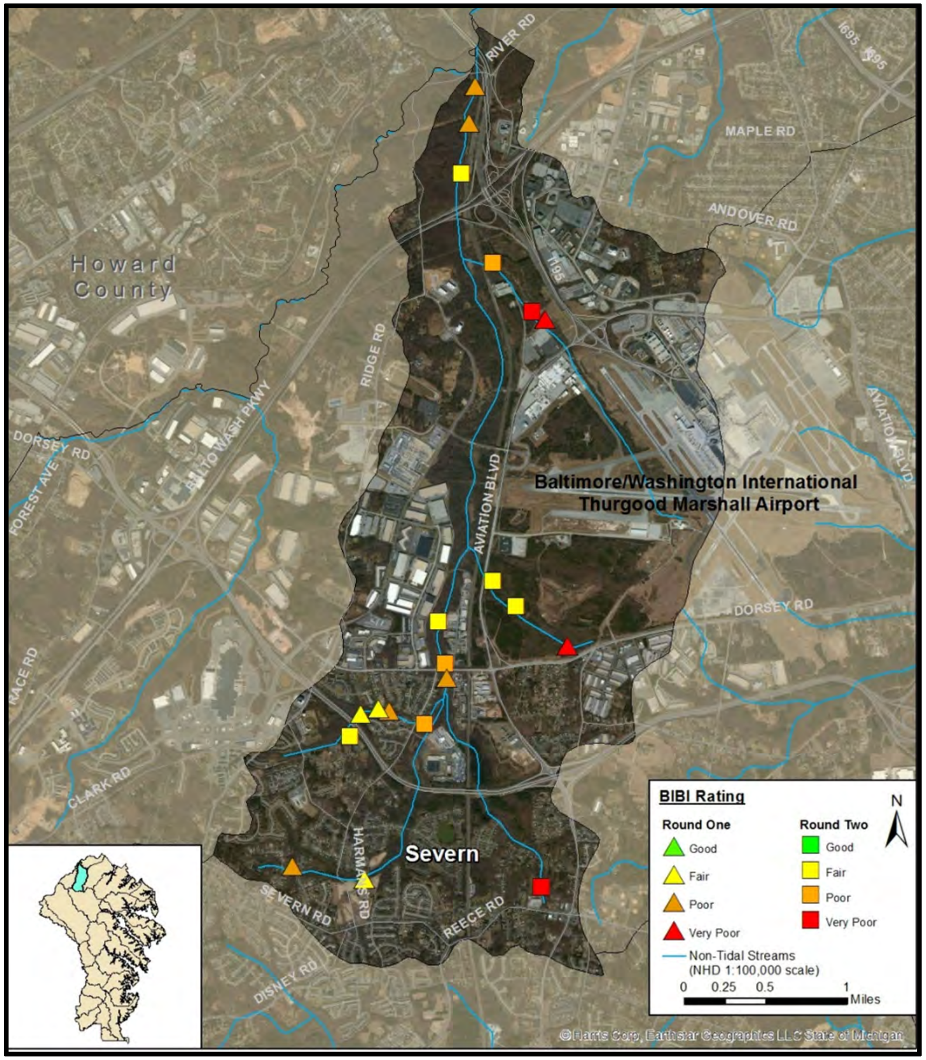


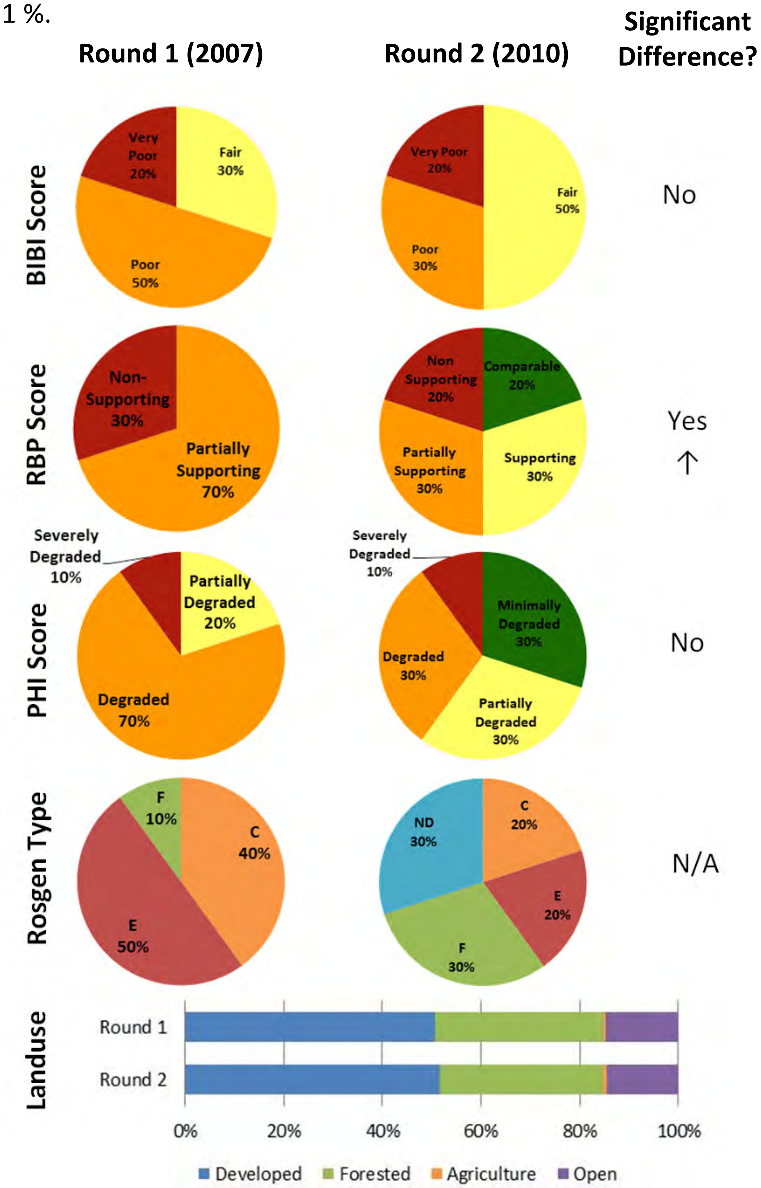


*Landuse for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2007

PSU 2: Stony Run

The Stony Run sampling unit is located in the northern part of the County near the town of Severn and has a drainage area of 6,203 acres. T his sampling unit also contains a large portion of BWI Airport and drains north to the Patapsco River. In 2010, 30.6 % of the overall sampling unit was comprised of impervious surfaces, with individual sites ranging from 23.7 % to 54.1 %.

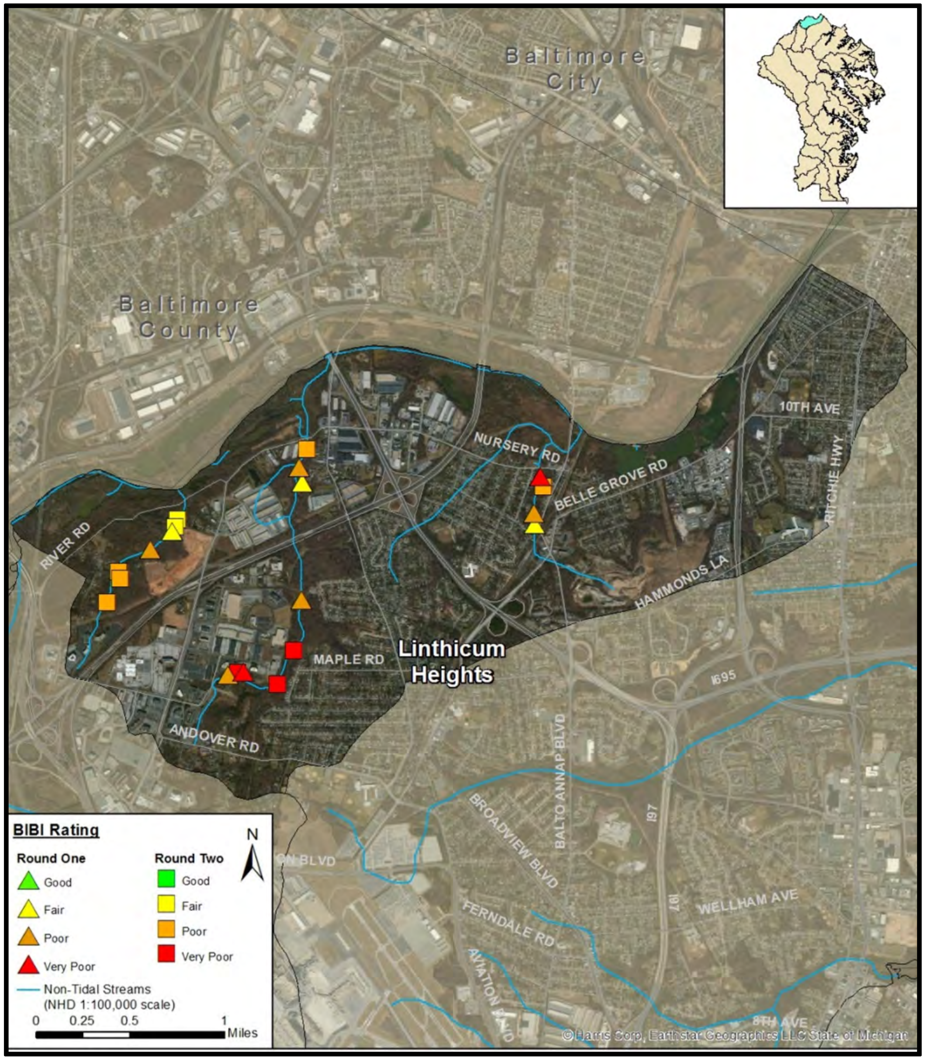


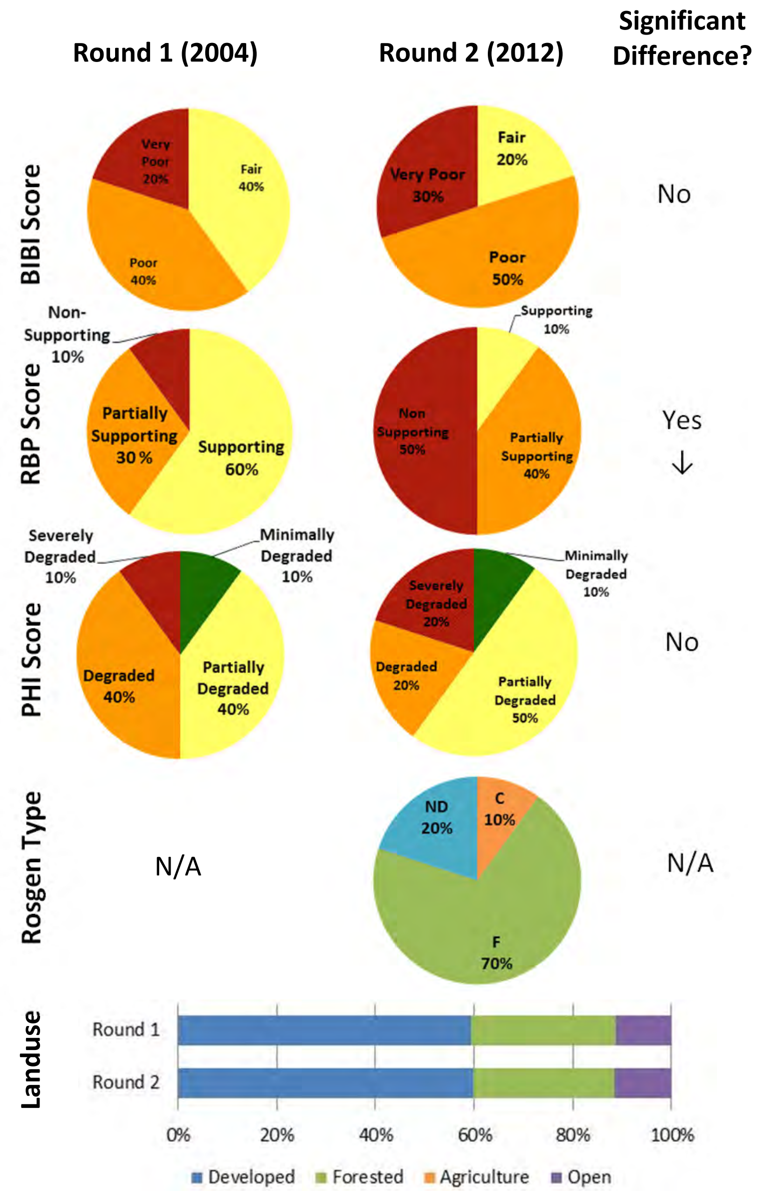


*Landuse for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2007

PSU 3: Lower Patapsco

The Lower Patapsco sampling unit is located on the northern edge of the County, due north of Baltimore/Washington International Thurgood Marshall Airport, and has a drainage area of 4,040 acres. In 2012, impervious surfaces comprised 32.0% of the overall sampling unit, with individual sites ranging from 17.1% to 51.4%.

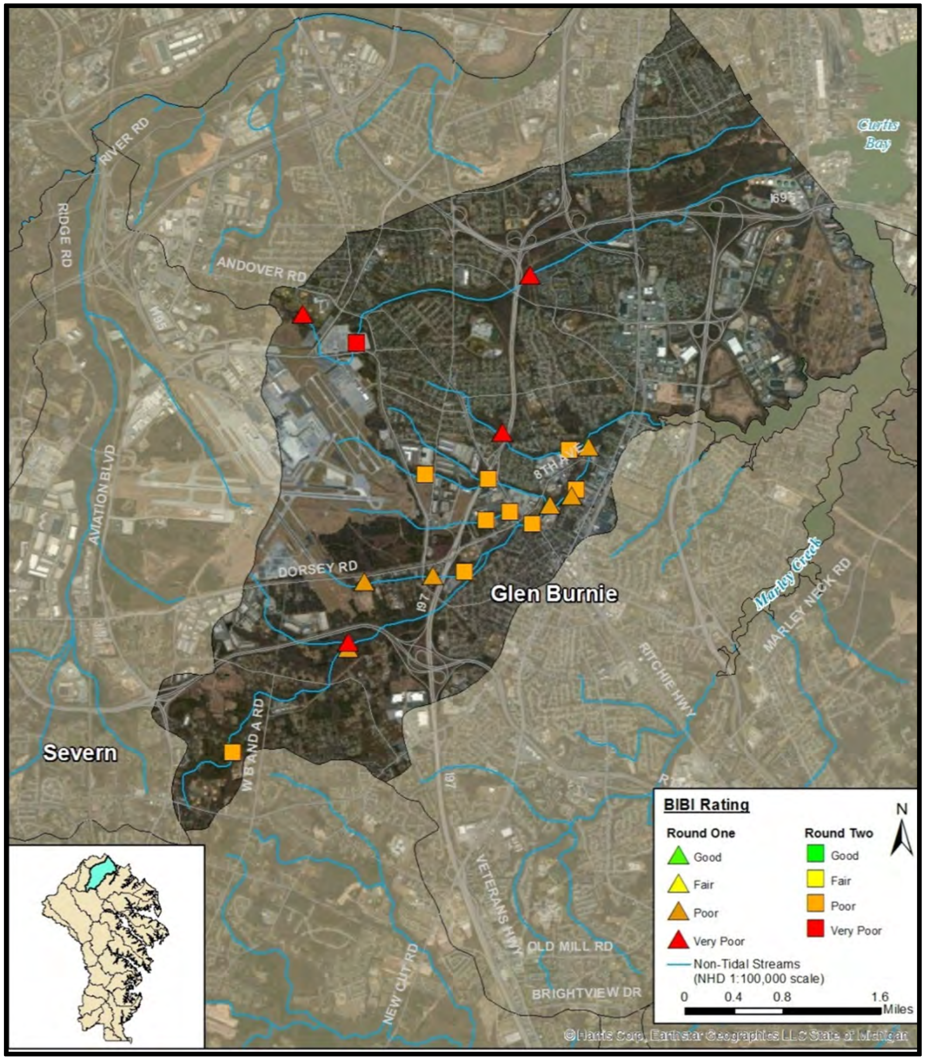


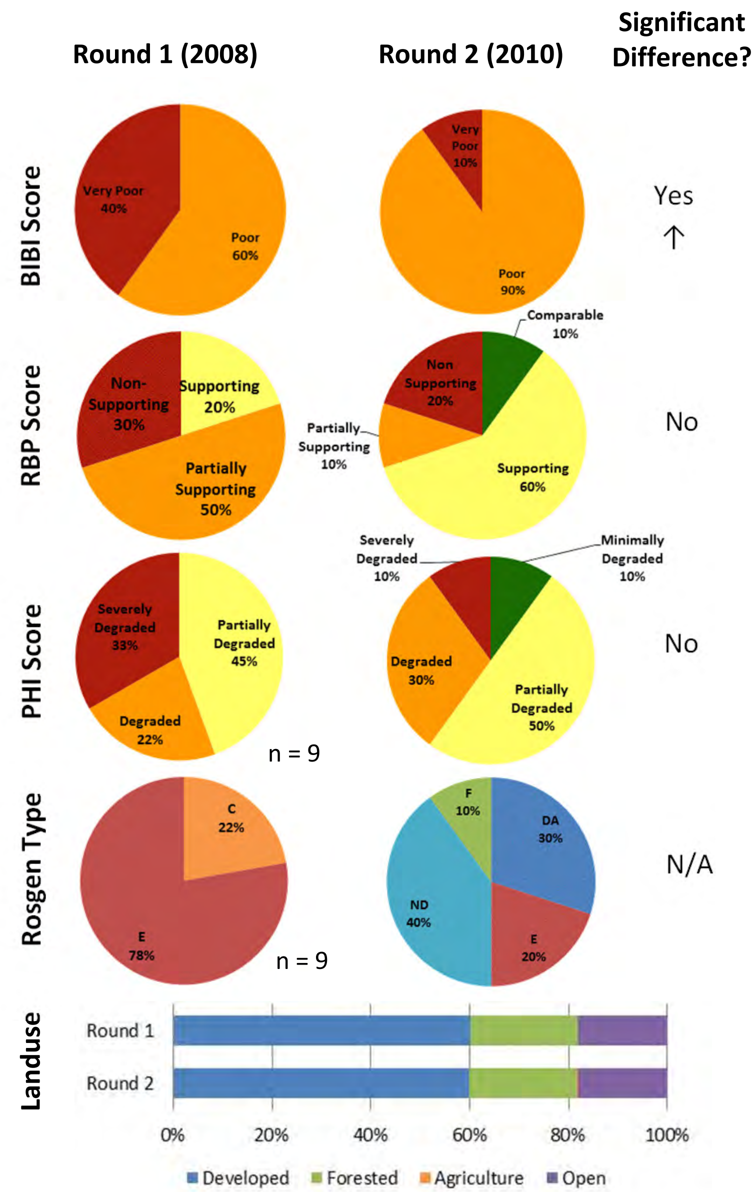


*Landuse for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2007

PSU 4: Sawmill Creek

The Sawmill Creek sampling unit is located in the northern portion of the County in the vicinity of Ferndale and Glen Burnie, and has a total drainage area of 11,044 acres. T his sampling unit also contains a large portion of BWI Airport. In 2010, impervious surfaces comprised 35.4 % of the overall sampling unit, with individual sites ranging from 11.4 % to 59.6 %.

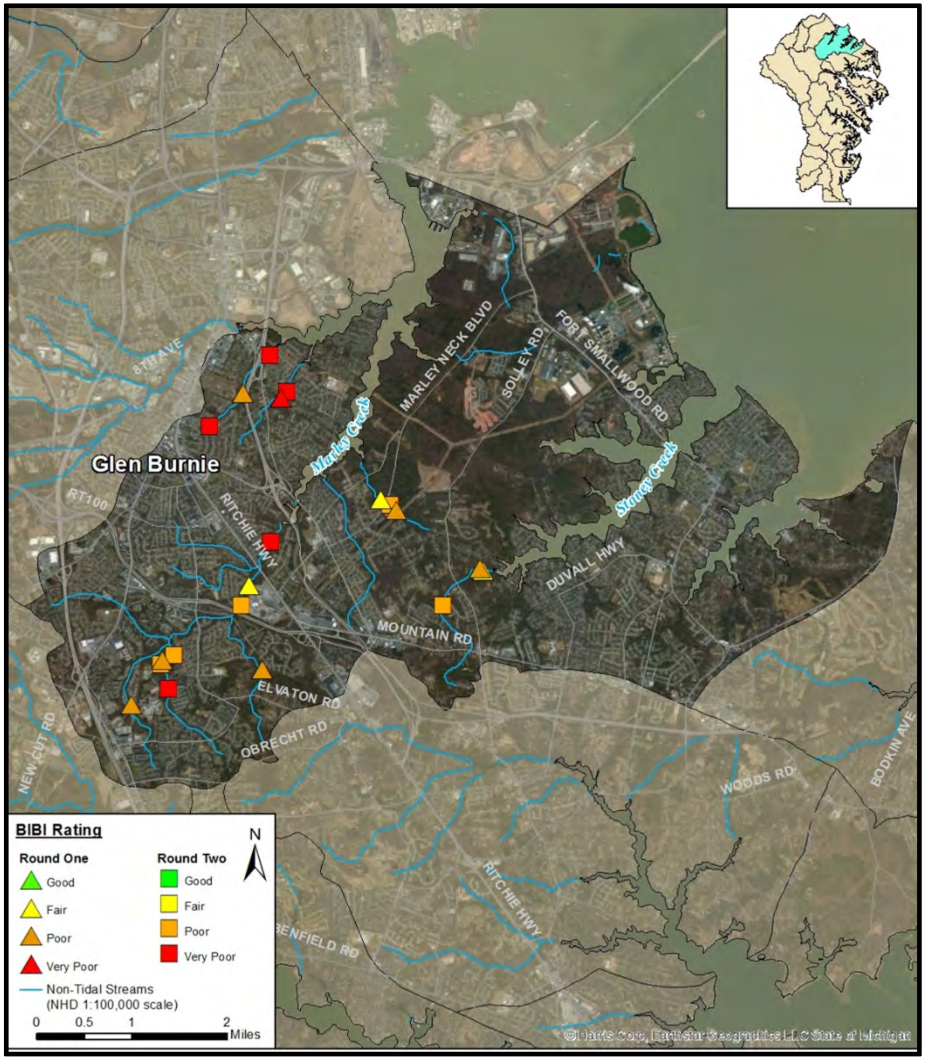




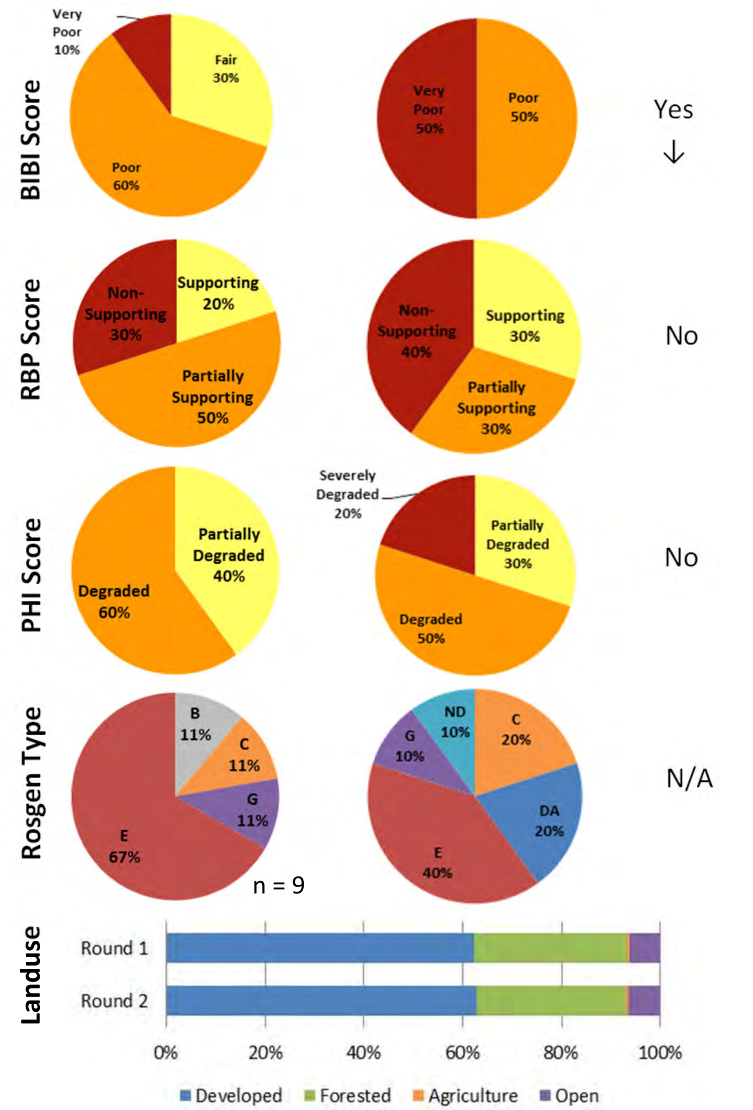
*Landuse for entire PSU, not sites sampled. GIS layer: R1 = 2007; R2 = 2007

PSU 5: Marley Creek

The Marley Creek watershed sampling unit is located in the northern part of the County, with a total drainage area of 19,425 acres. In 2009, 28.6 % of the overall sampling unit was comprised of impervious surfaces, with individual sites ranging from 13.6 % to 56.5 %.



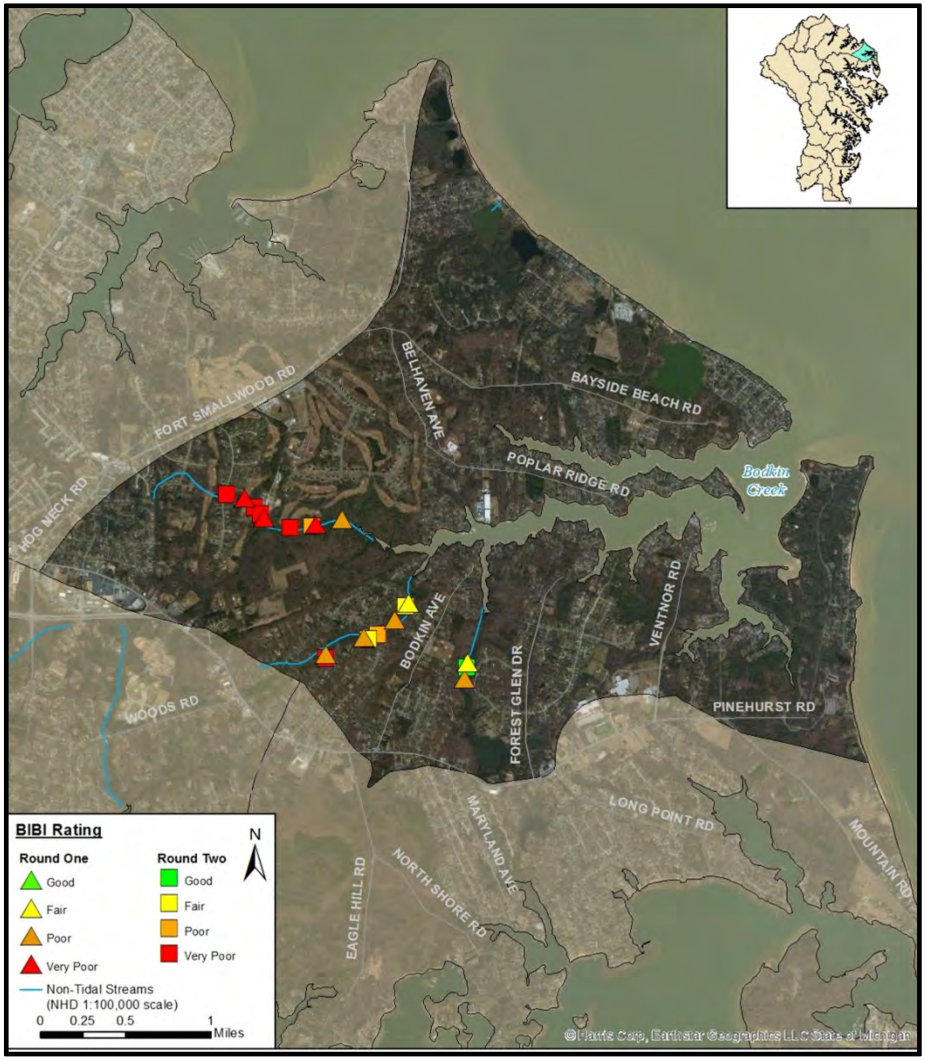
Round 1 (2006) | Round 2 (2009) | Significant Difference?

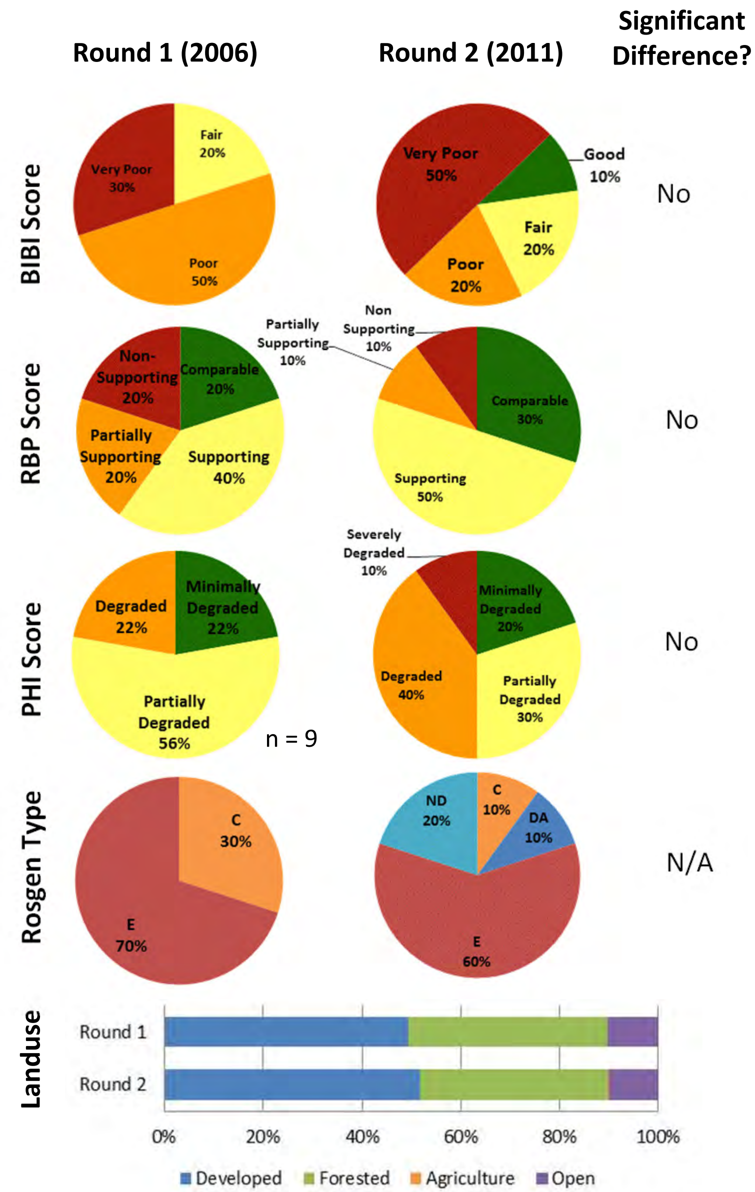


*Landuse for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2007

PSU 6: Bodkin Creek

The Bodkin Creek sampling unit, located in the northeastern portion of the County, has a total drainage area of 5,872 acres. In 2011, impervious surfaces comprised 12.6 % of the overall sampling unit, with individual sites ranging from 11.9 % to 17.5 %.

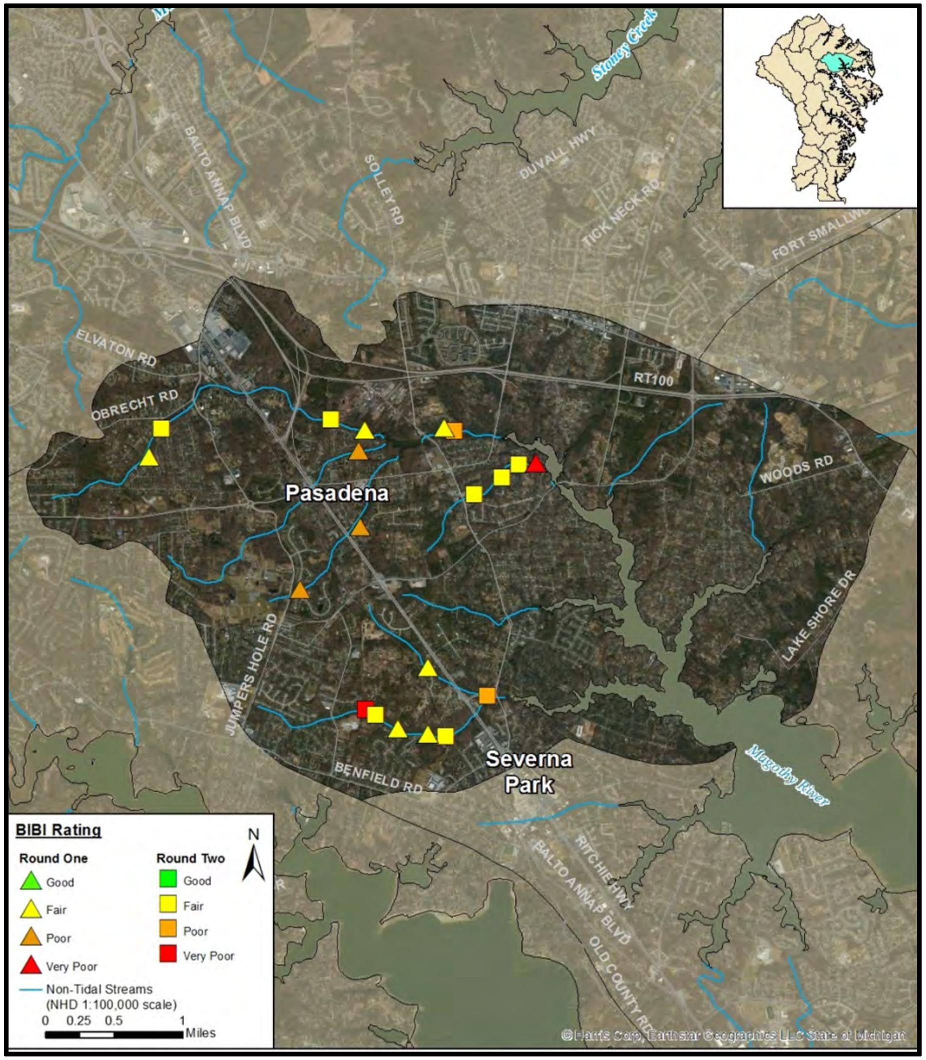


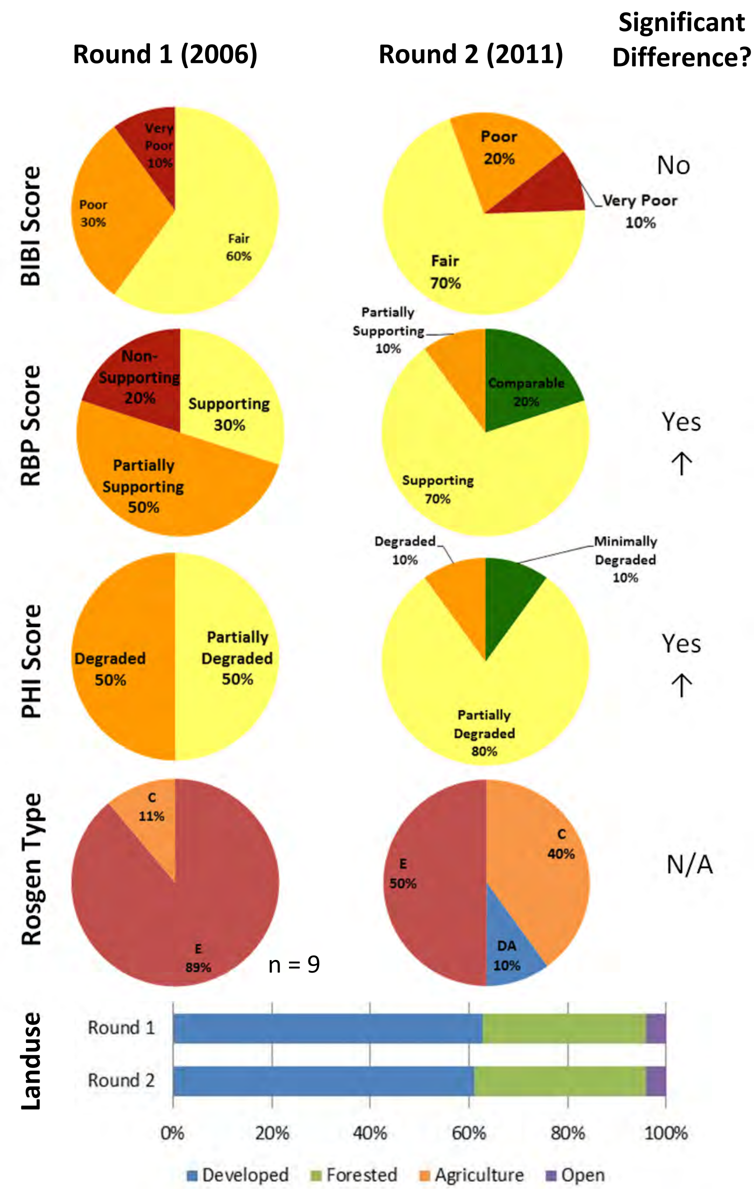


*Landuse for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2007

PSU 7: Upper Magothy

The Upper Magothy sampling unit is located in the eastern central portion of the County in the vicinity of Pasadena, and has a total drainage area of 10,031 acres. In 2011, impervious surfaces comprised 19.7 % of the overall sampling unit, with individual sites ranging from 12.6 % to 32.1 %.

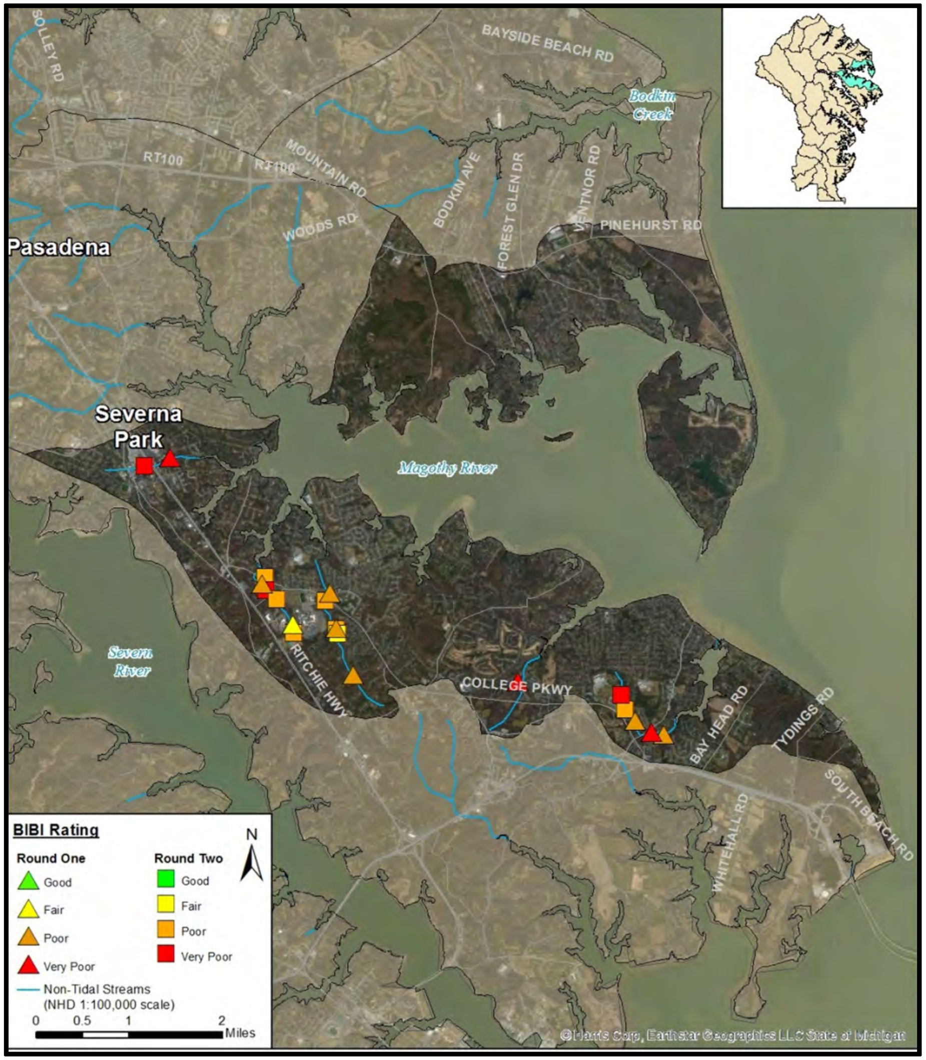


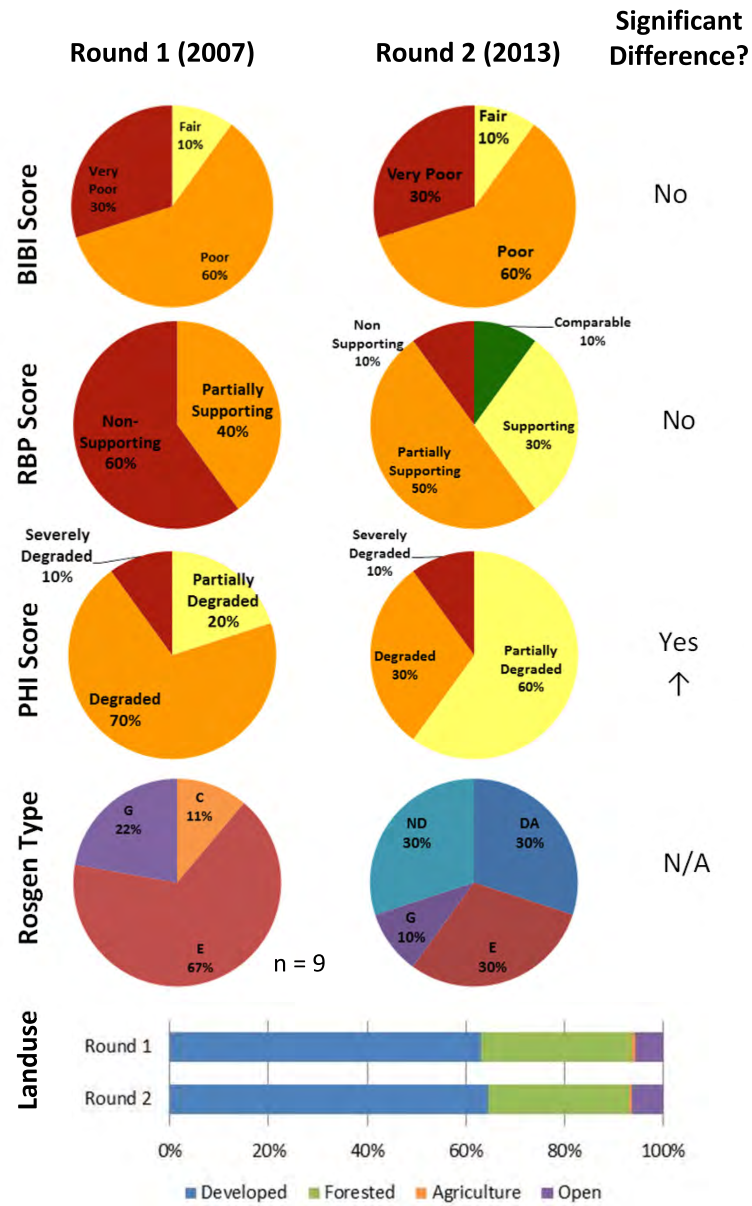


*Landuse for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2007

PSU 8: Lower Magothy

The Lower Magothy sampling unit has a drainage area of 12,697 acres and drains directly into the Magothy River, which empties into the Chesapeake Bay. In 2013, impervious surfaces comprised 19.1 % of the overall sampling unit, with individual sites ranging from 18.0 % to 47.9 %.

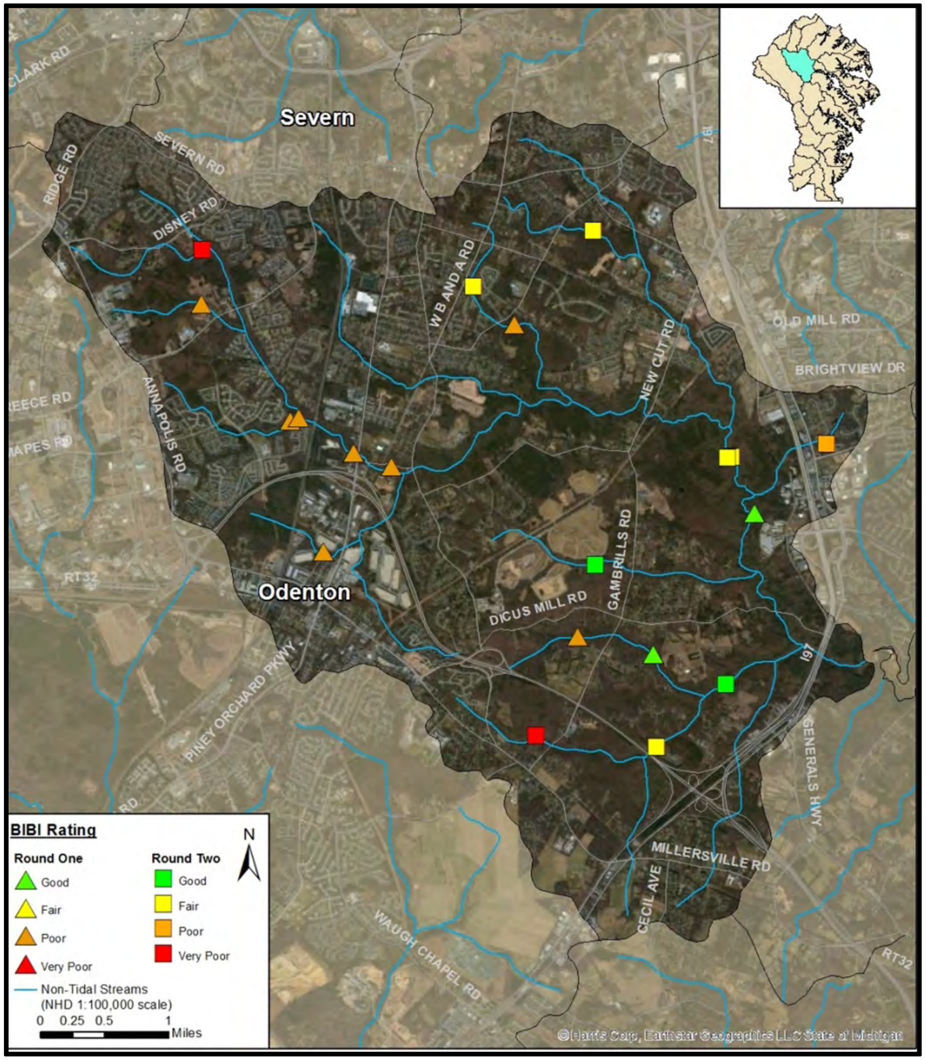


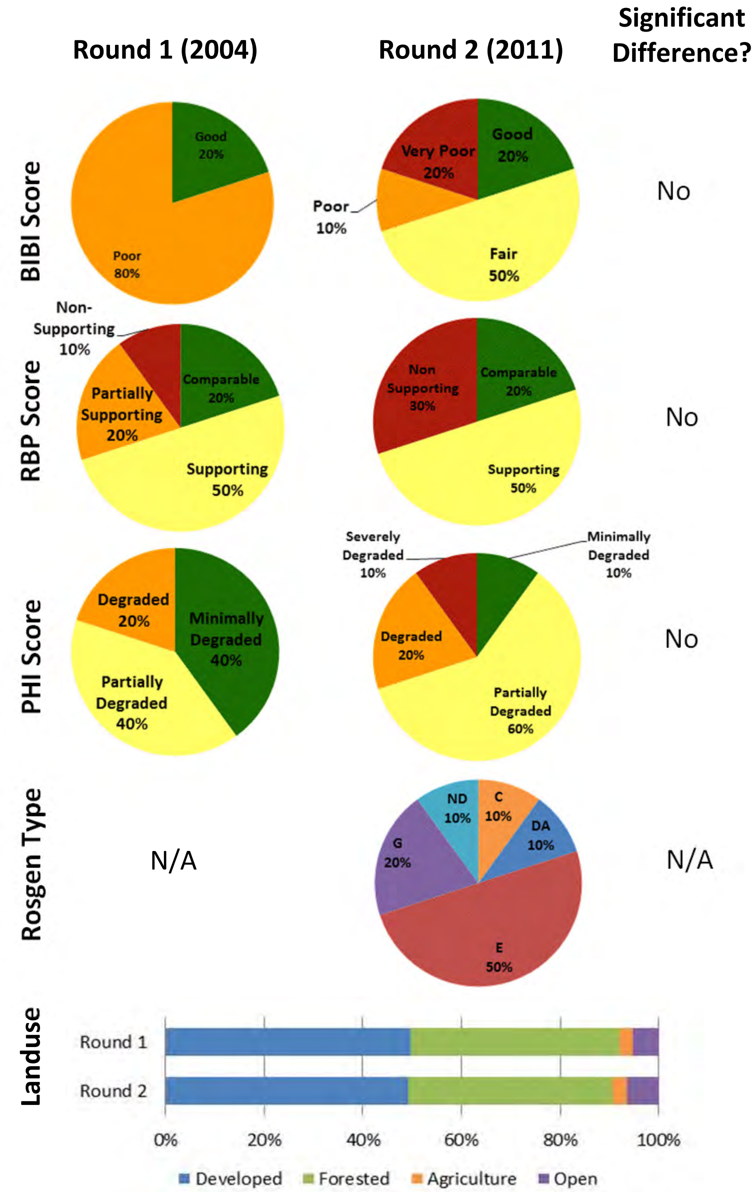


*Landuse for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2011

PSU 9: Severn Run

The Severn Run sampling unit is located in the central part of the County to the east of the Fort George G. Meade Military Reservation, and has a drainage area of 15,424 acres. In 2011, impervious surfaces comprised 17.5 % of the overall sampling unit, with individual sites ranging from 8 % to 22.8 %.

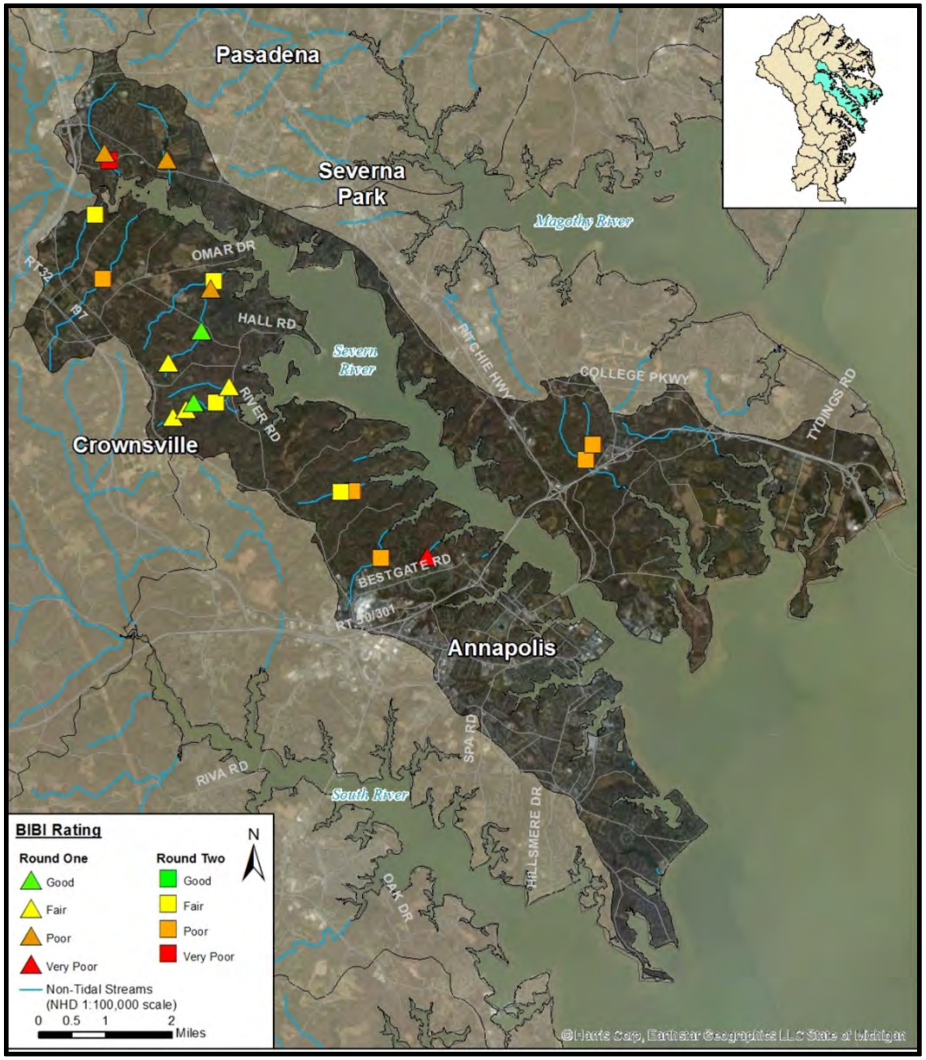




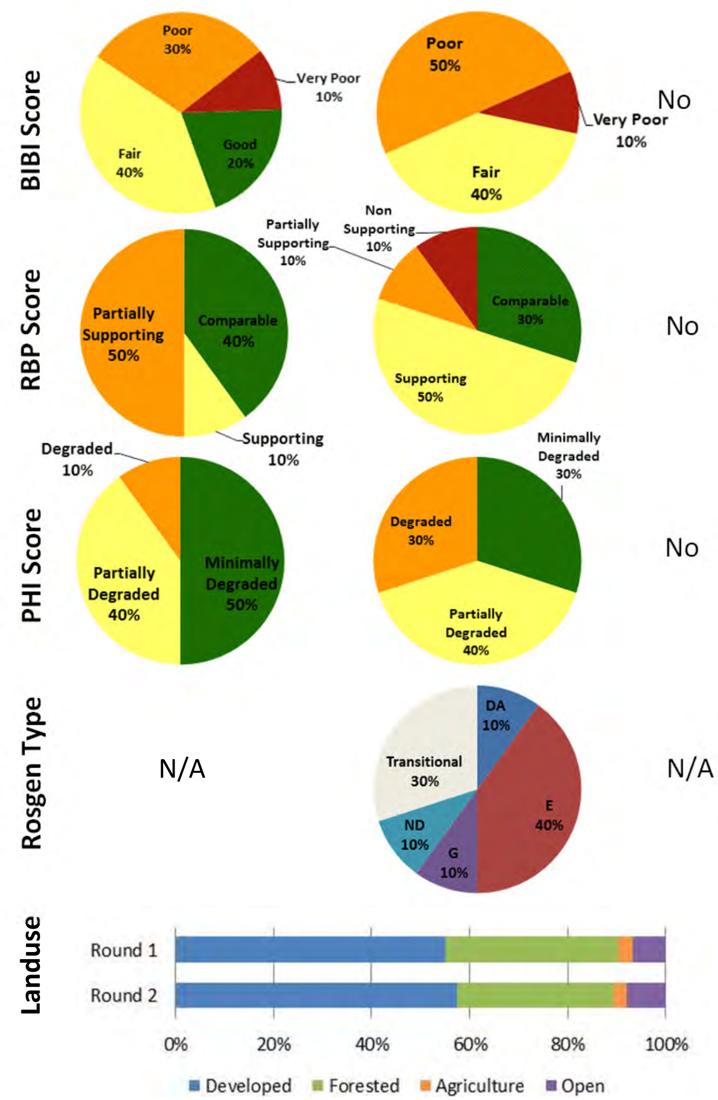
*Landuse for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2007

PSU 10: Severn River

The Severn River sampling unit, which consists of direct tributaries to the Severn River, is located in the vicinity of Annapolis and Crownsville and has a drainage area of 28,920 acres. In 2013, impervious surfaces comprised 18.9 % of the overall sampling unit, with individual sites ranging from 6.4 % to 36.0 %.



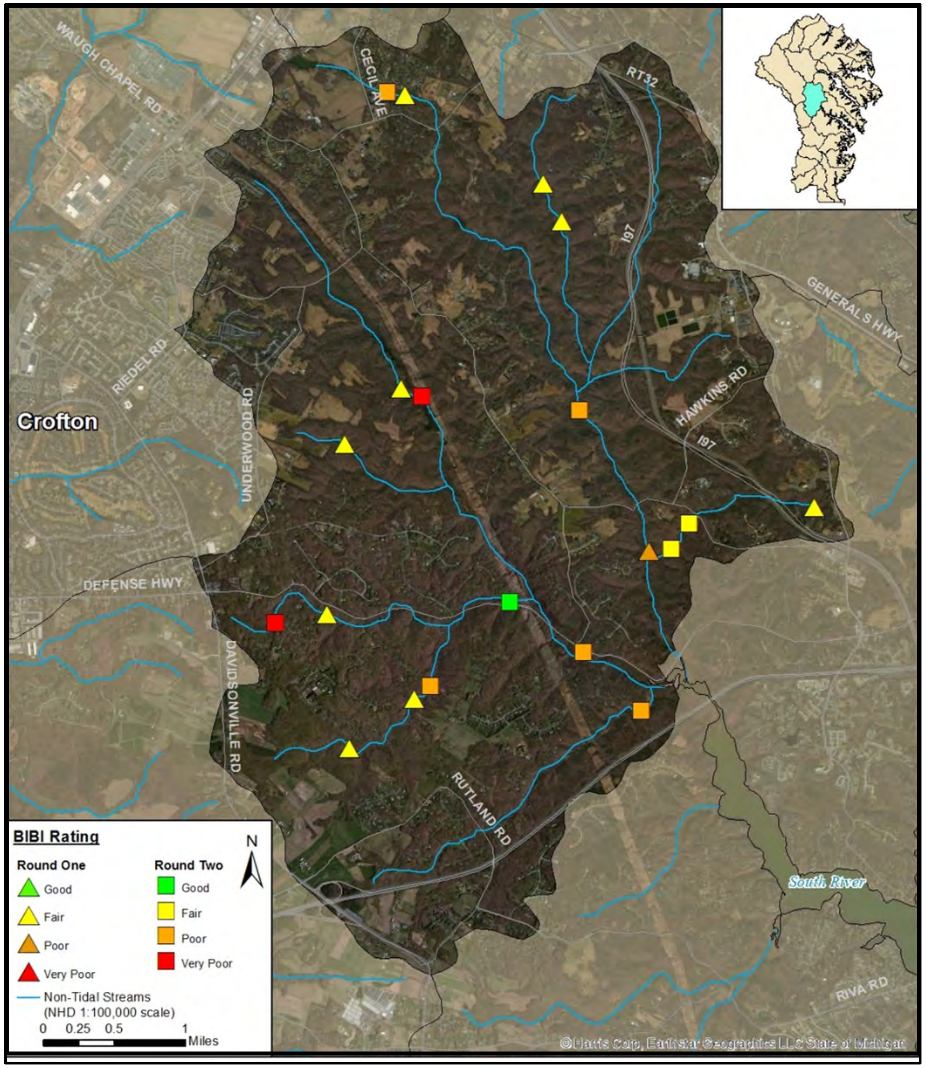
Round 1 (2004) **Round 2 (2013)** **Significant Difference?**

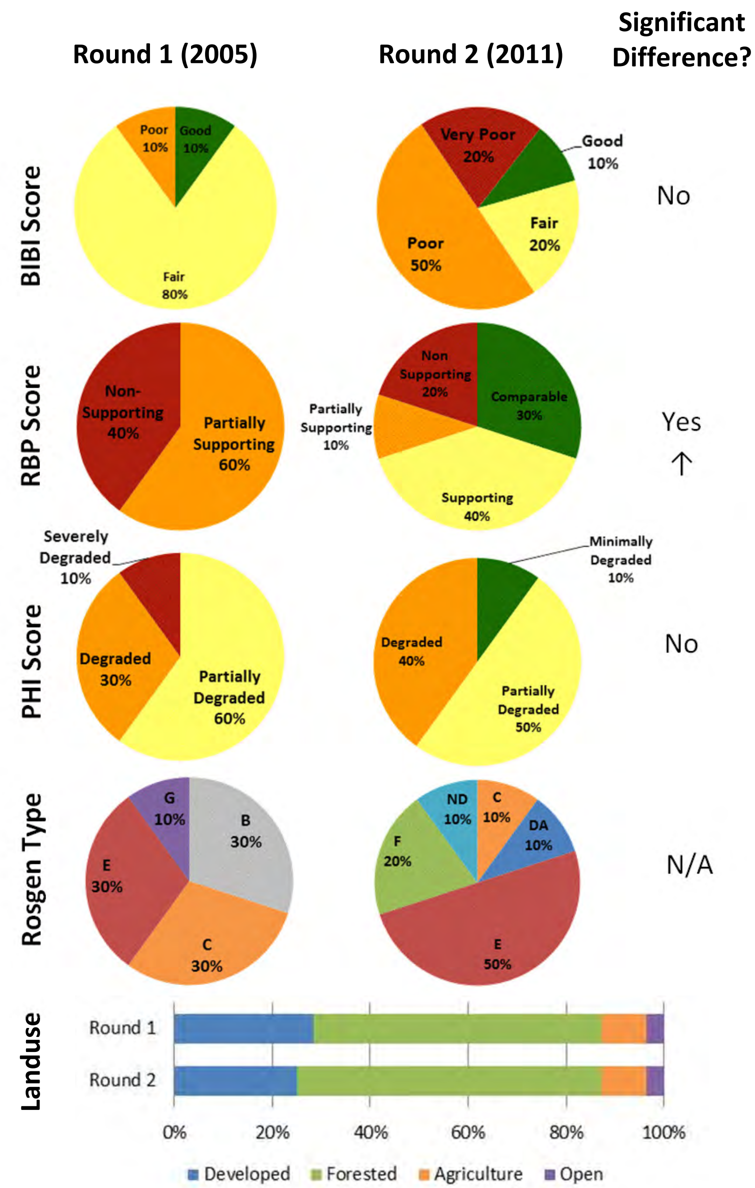


*Landuse for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2011

PSU 11: Upper North River

The Upper North River sampling unit is located in the central part of the County between Crofton and Crownsville, and has a drainage area of 12,795 acres. In 2011, impervious surfaces comprised 6.4 % of the overall sampling unit, with individual sites ranging from 5.1 % to 13.6 %.

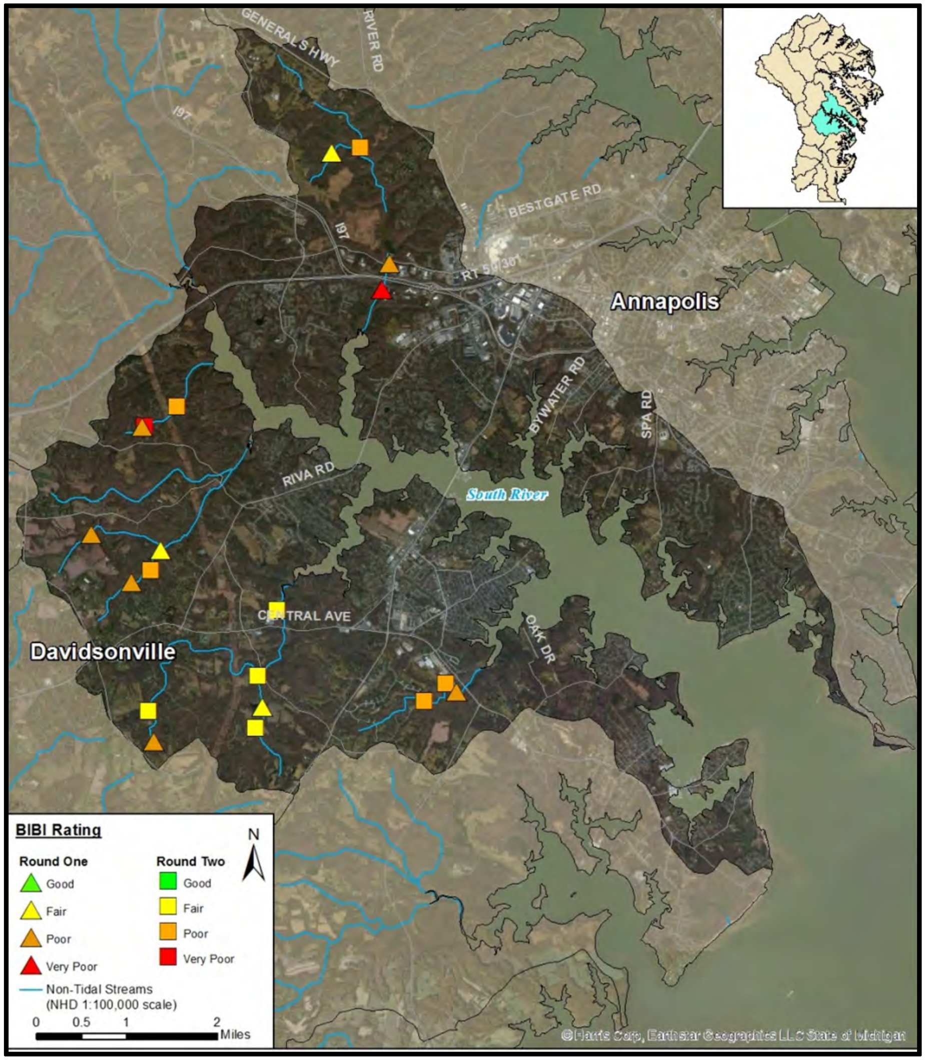


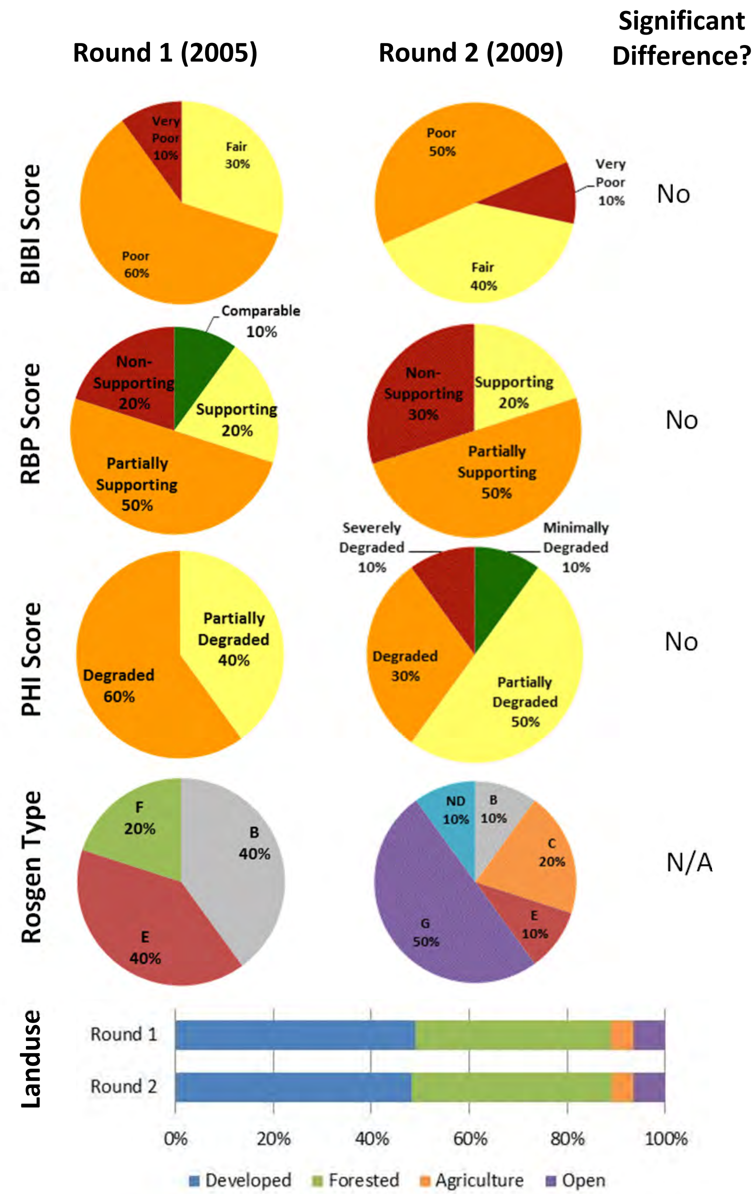


*Landuse for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2007

PSU 12: Lower North River

The Lower North River sampling unit, located between Annapolis and Davidsonville, has a drainage area of 23,681 acres and drains directly into the South River, which empties into the Chesapeake Bay. In 2009, impervious surfaces comprised 16.9 % of the overall sampling unit, with individual sites ranging from 3.4 % to 15.5 %.

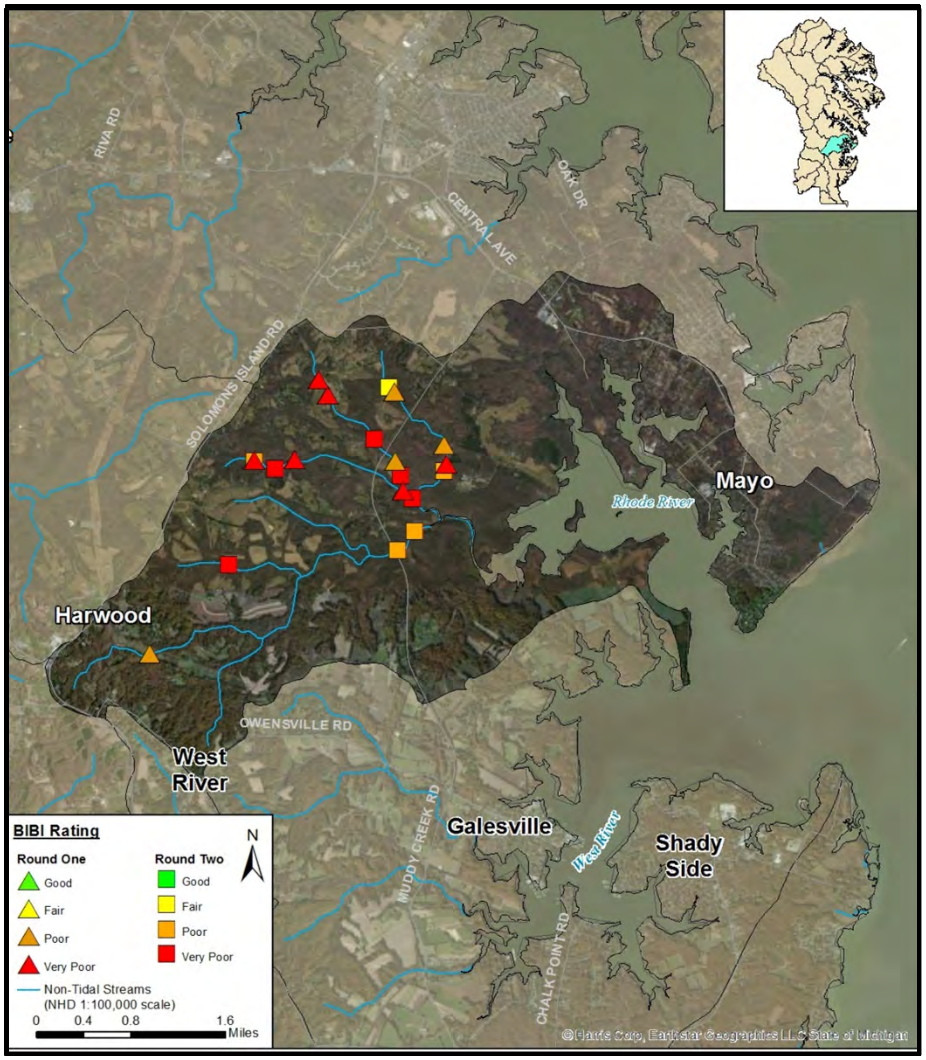


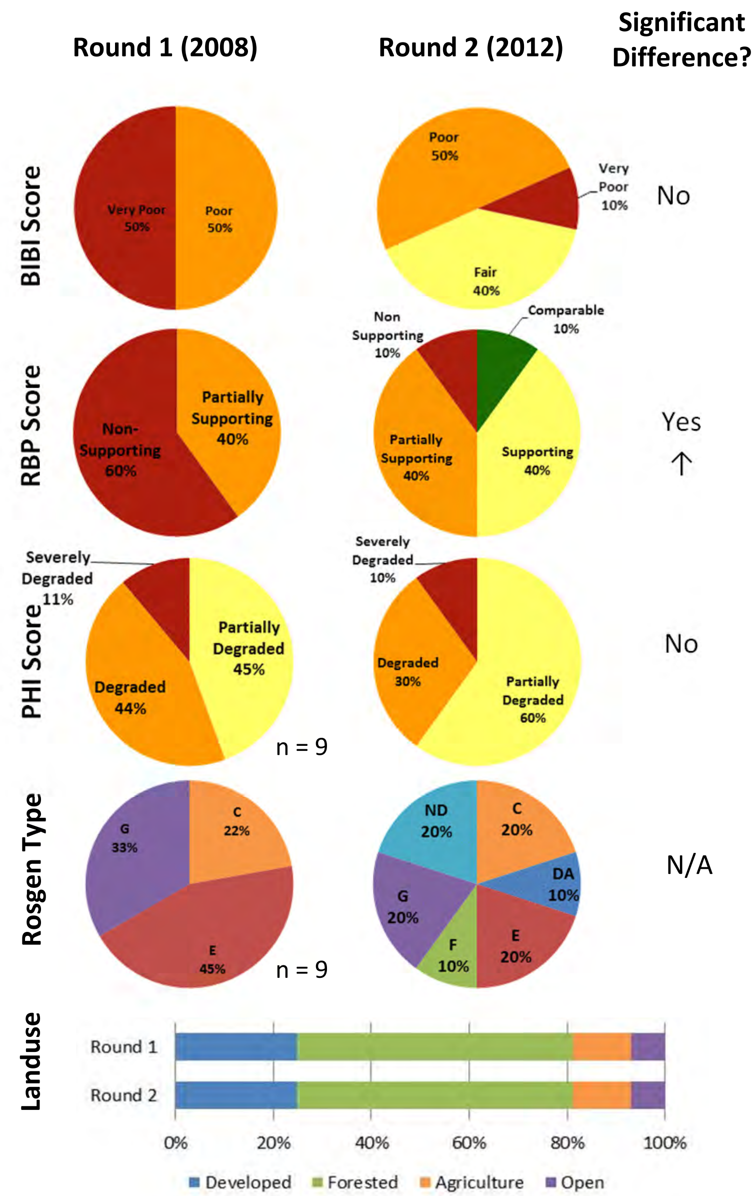


*Landuse for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2007

PSU 13: Rhode River

The Rhode River sampling unit is located in the southeastern part of the County south of Edgewater, and has a drainage area of 8,737 acres. In 2012, impervious surfaces comprised 5.2 % of the overall sampling unit, with individual sites ranging from 3.0 % to 6.8 %.

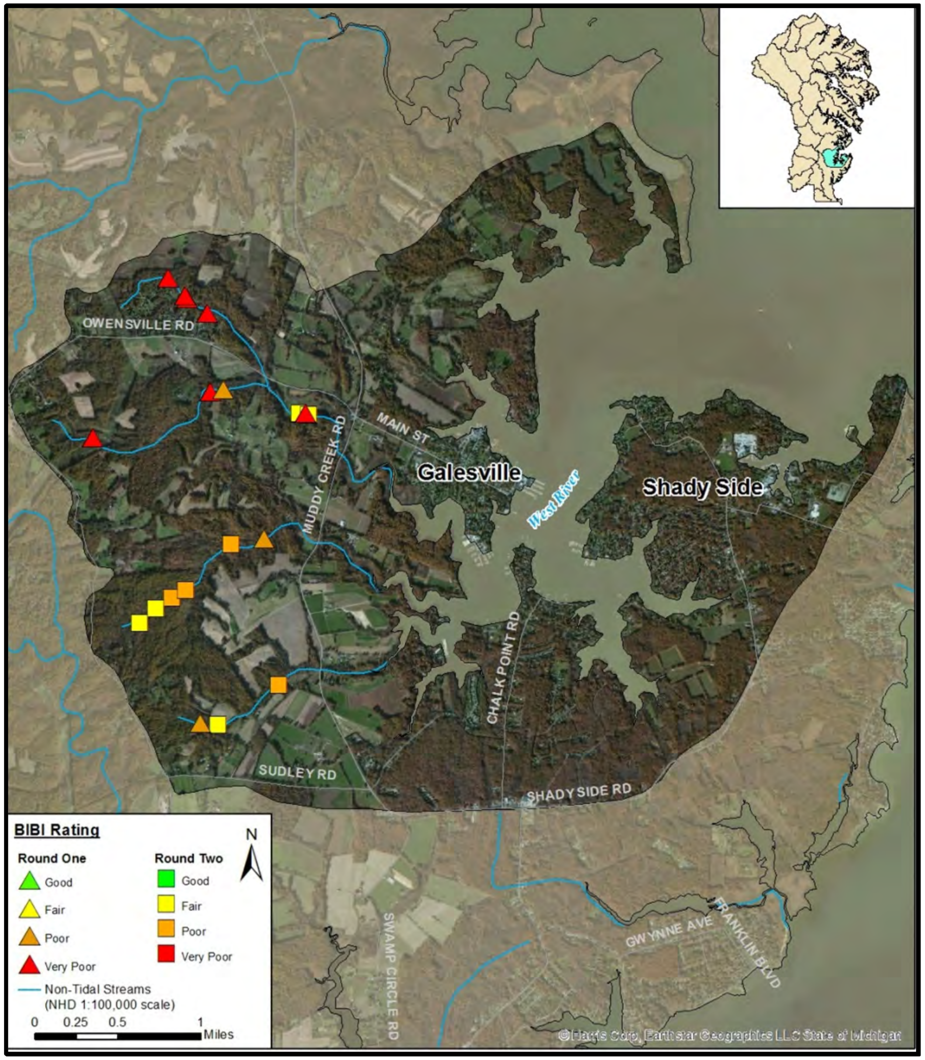


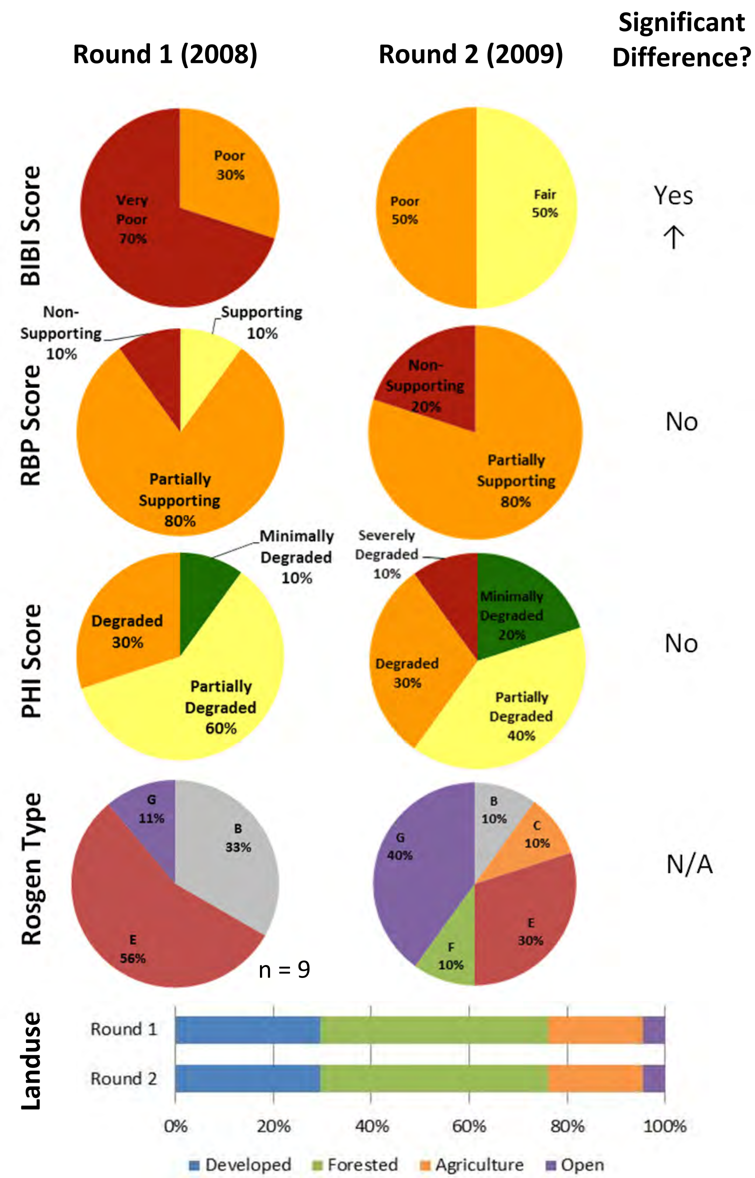


*Landuse for entire PSU, not sites sampled. GIS layer: R1 = 2007; R2 = 2007

PSU 14: West River

The West River sampling unit is located in the southeastern part of the County in the vicinity of Galesville, with a drainage area of 7,558 acres. In 2009, 6.9 % of the overall sampling unit was comprised of impervious surfaces, with individual sites ranging from 1.0 % to 3.5 %.

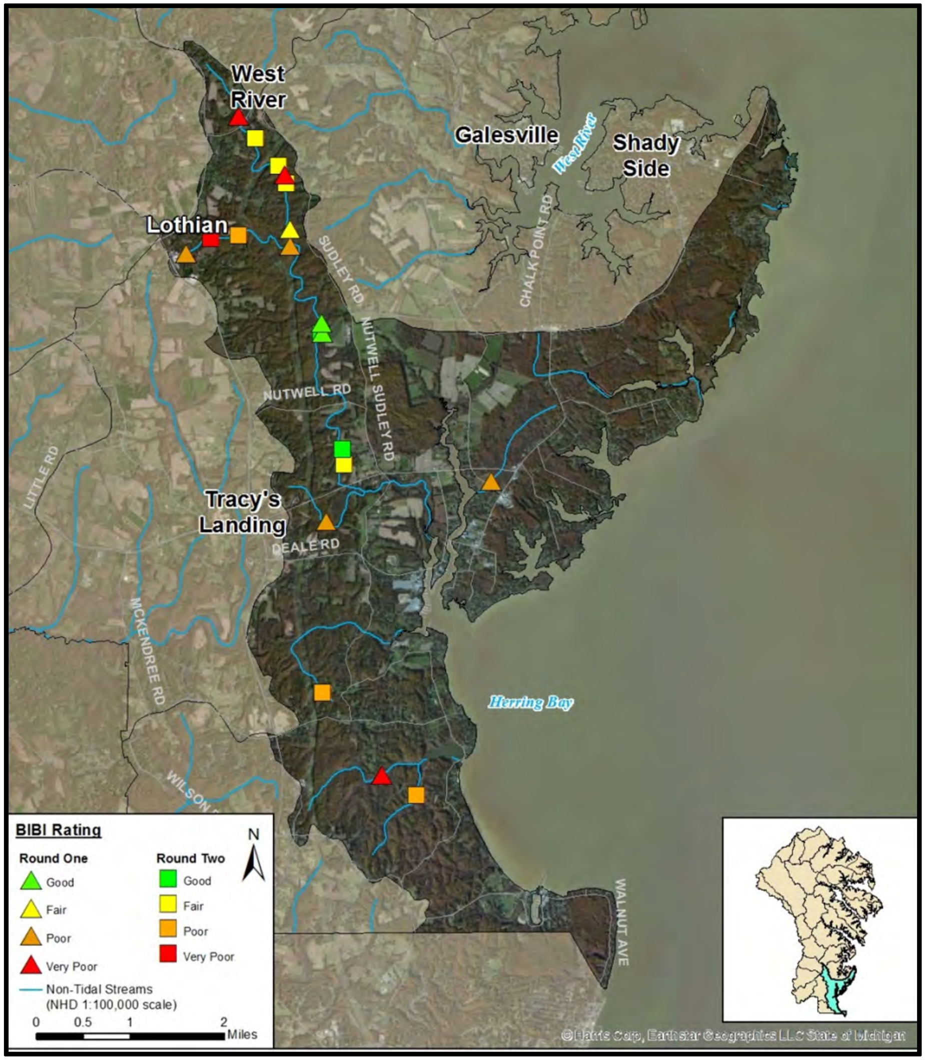


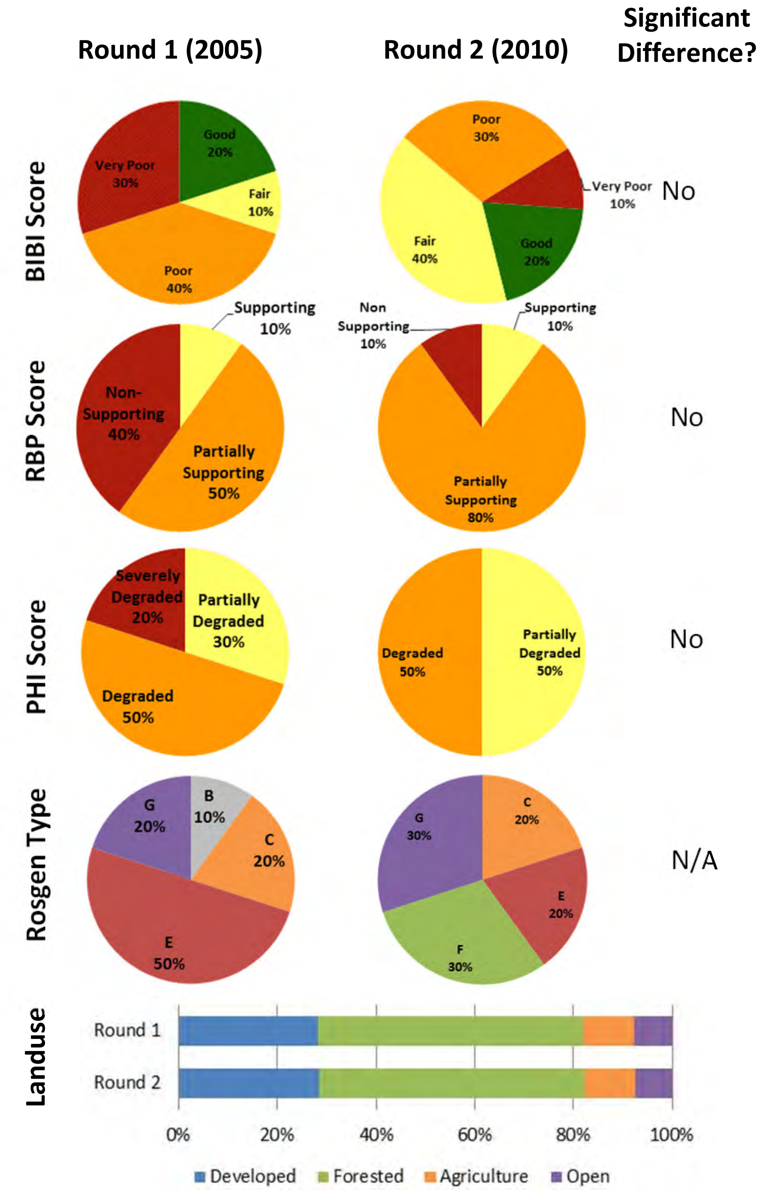


*Landuse for entire PSU, not sites sampled. GIS layer: R1 = 2007; R2 = 2007

PSU 15: Herring Bay

The Herring Bay sampling unit has a drainage area of 14,595 acres and is located in the southeastern extent of the County bordering the Chesapeake Bay. In 2010, impervious surfaces comprised 6.2 % of the overall sampling unit, with individual sites ranging from 1.6 % to 9.3 %.

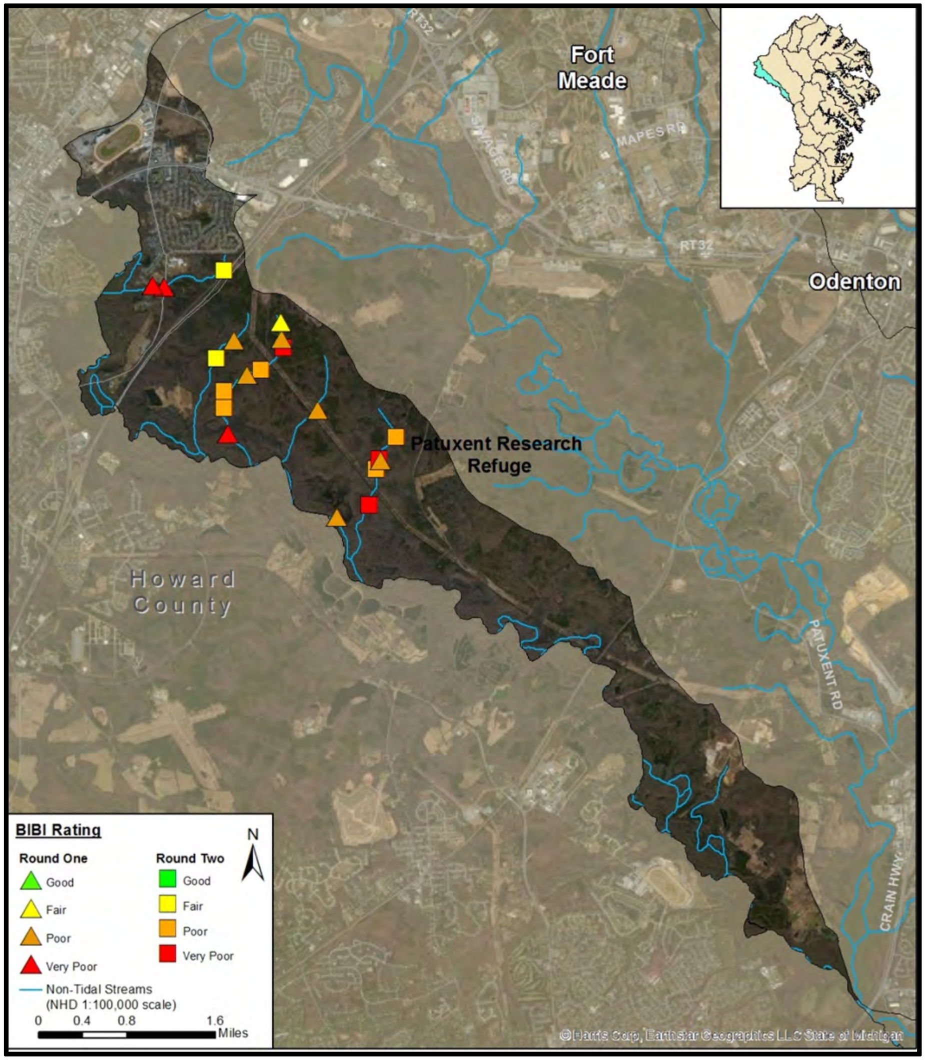


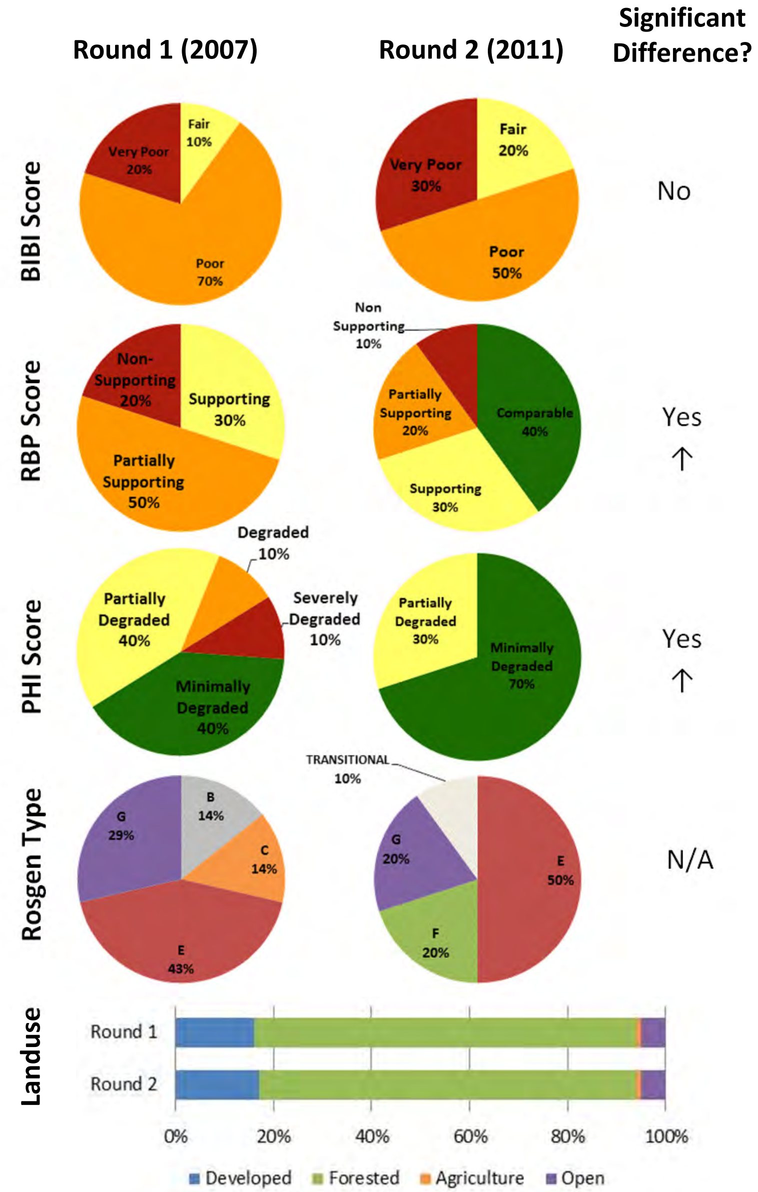


*Landuse for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2007

PSU 16: Upper Patuxent

The Upper Patuxent sampling unit has a drainage area of 6,905 acres and is located along the northwestern border of the County and drains directly to the Patuxent River. In 2011, impervious surfaces comprised 5.1 % of the overall sampling unit, with individual sites ranging from 0.4 % to 15.9 %.

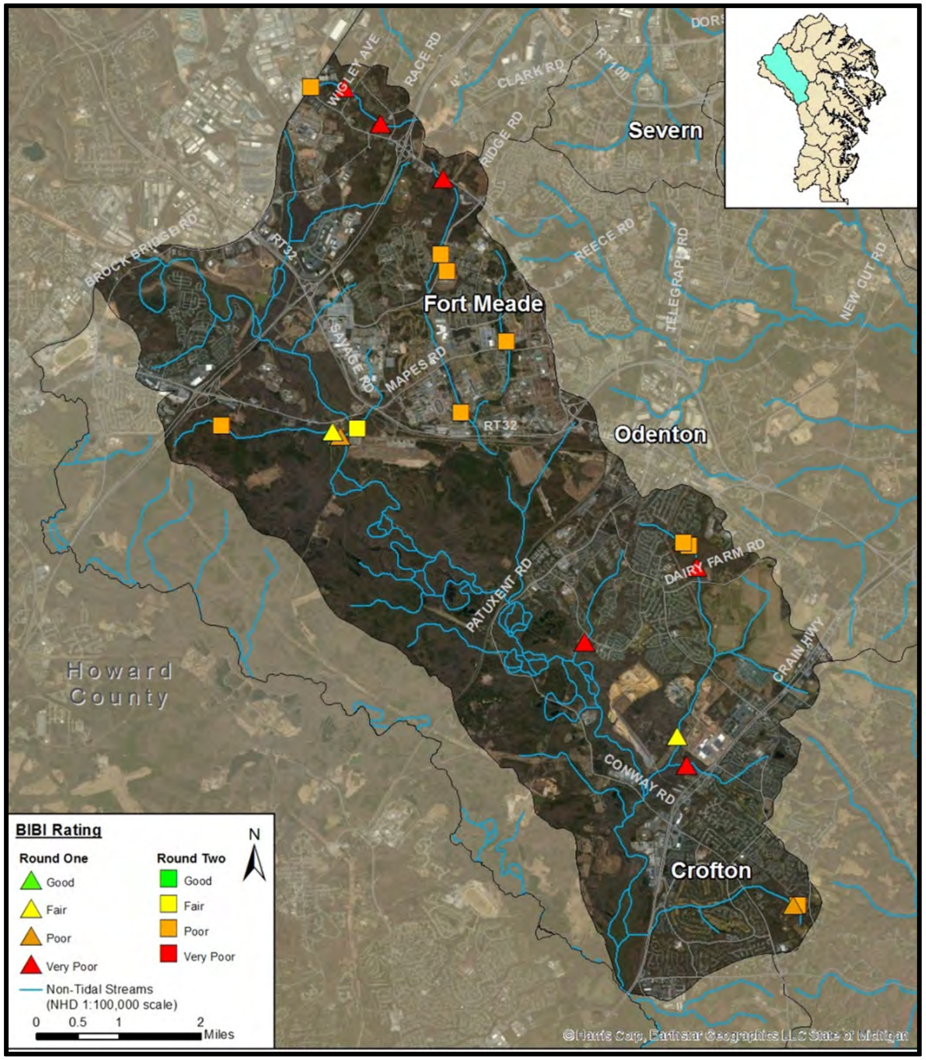


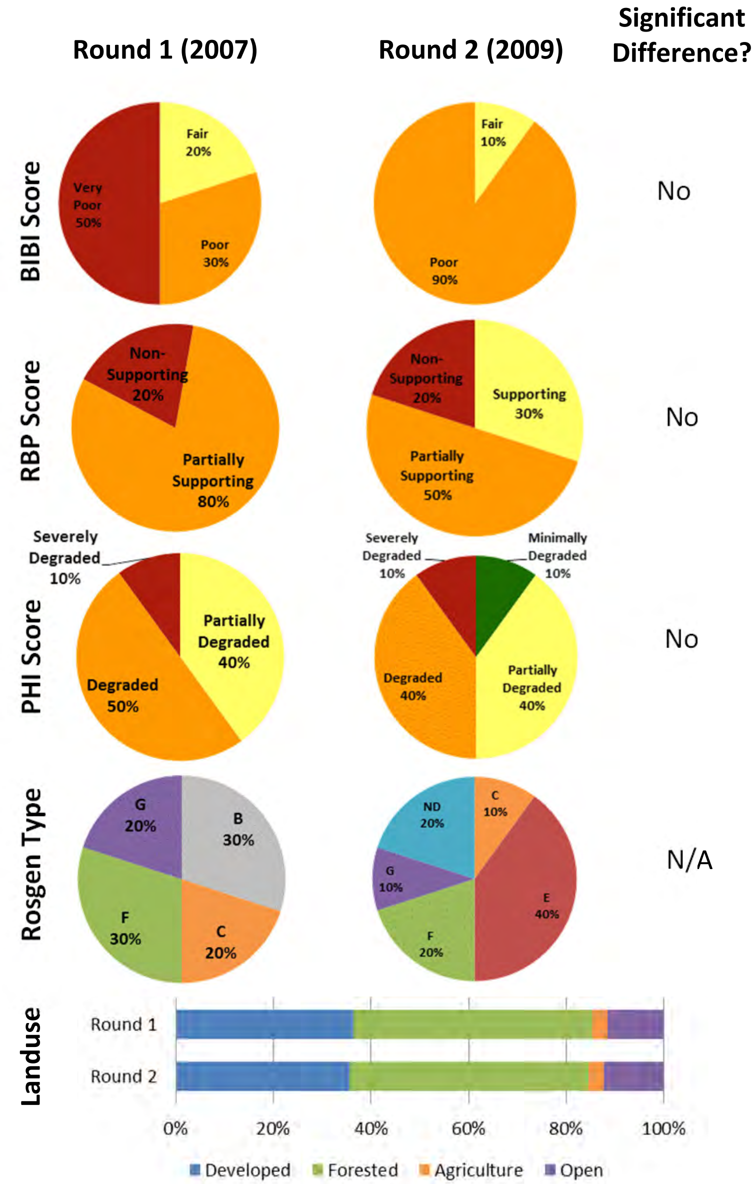


*Landuse for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2007

PSU 17: Little Patuxent

The Little Patuxent PSU is in the northwestern part of the County in the vicinity of Fort Meade and Crofton, and has a drainage area of 28,196 acres. In 2009, 17.4 % of the overall sampling unit was comprised of impervious surfaces, with individual sites ranging from 10.9 % to 33.6 %.

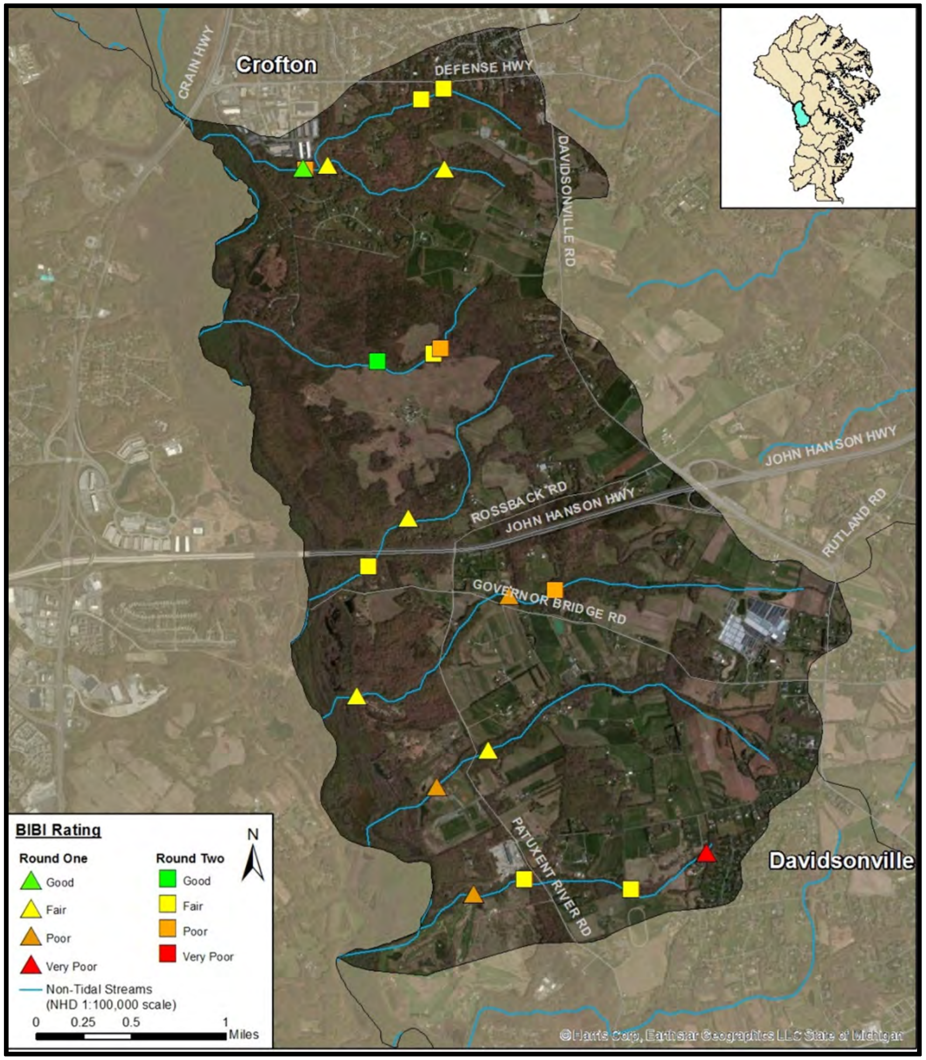


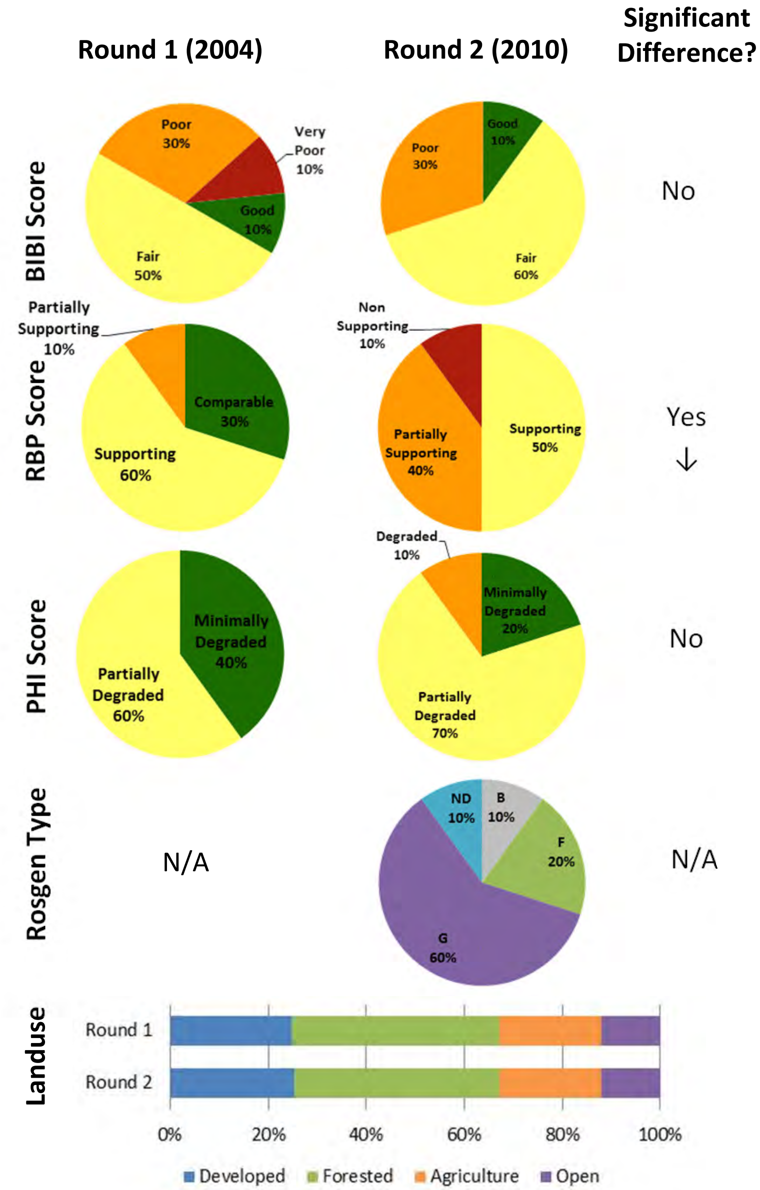


*Landuse for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2007

PSU 18: Middle Patuxent

The Middle Patuxent sampling unit is located in the west central part of the County between Crofton and Davidsonville, and has a drainage area of 6,332 acres. In 2010, impervious surfaces comprised 7.1 % of the overall sampling unit, with individual sites ranging from 1.3 % to 17.2 %.

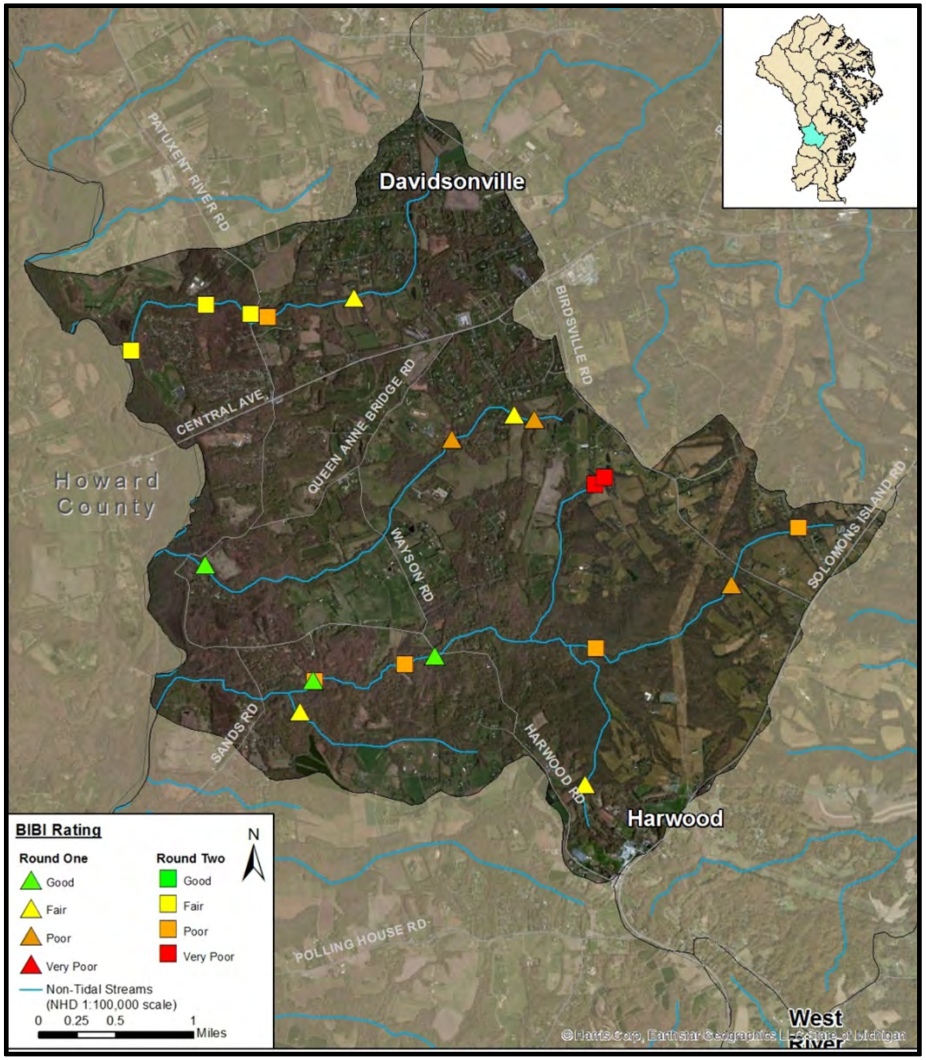




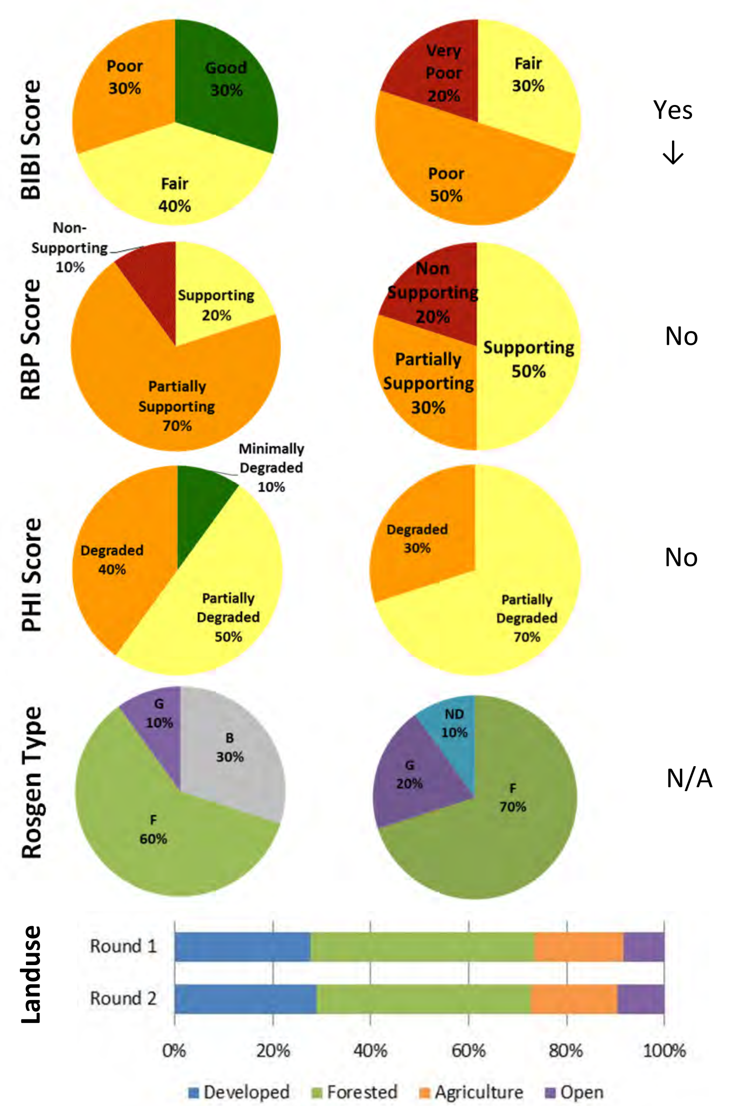
*Landuse for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2007

PSU 19: Stocketts Run

The Stocketts Run sampling unit, which drains to the Patuxent River and has a drainage area of 8,714 acres, is located in the south central portion of the County between Davidsonville and Harwood. In 2013, impervious surfaces comprised 4.9 % of the overall sampling unit, with individual sites ranging from 3.9 % to 11.5 %.



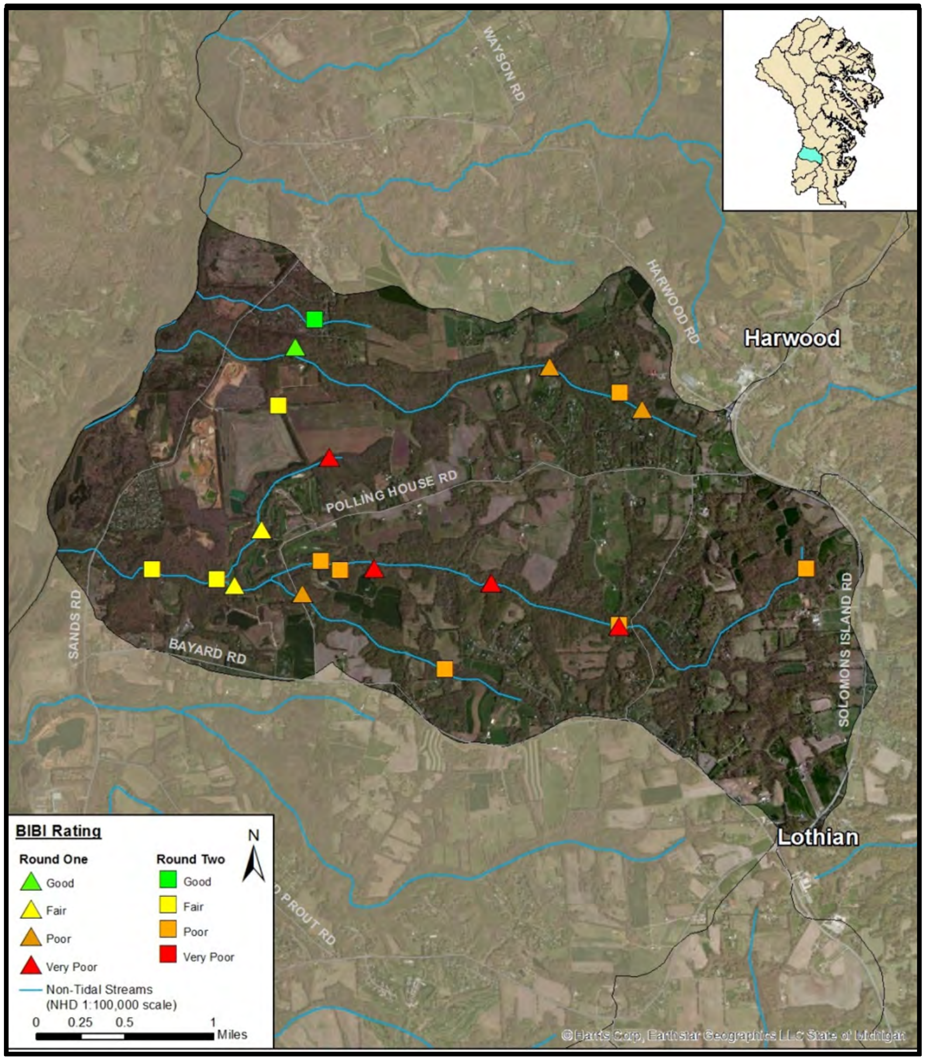
	Round 1 (2005)	Round 2 (2013)	Significant Difference?

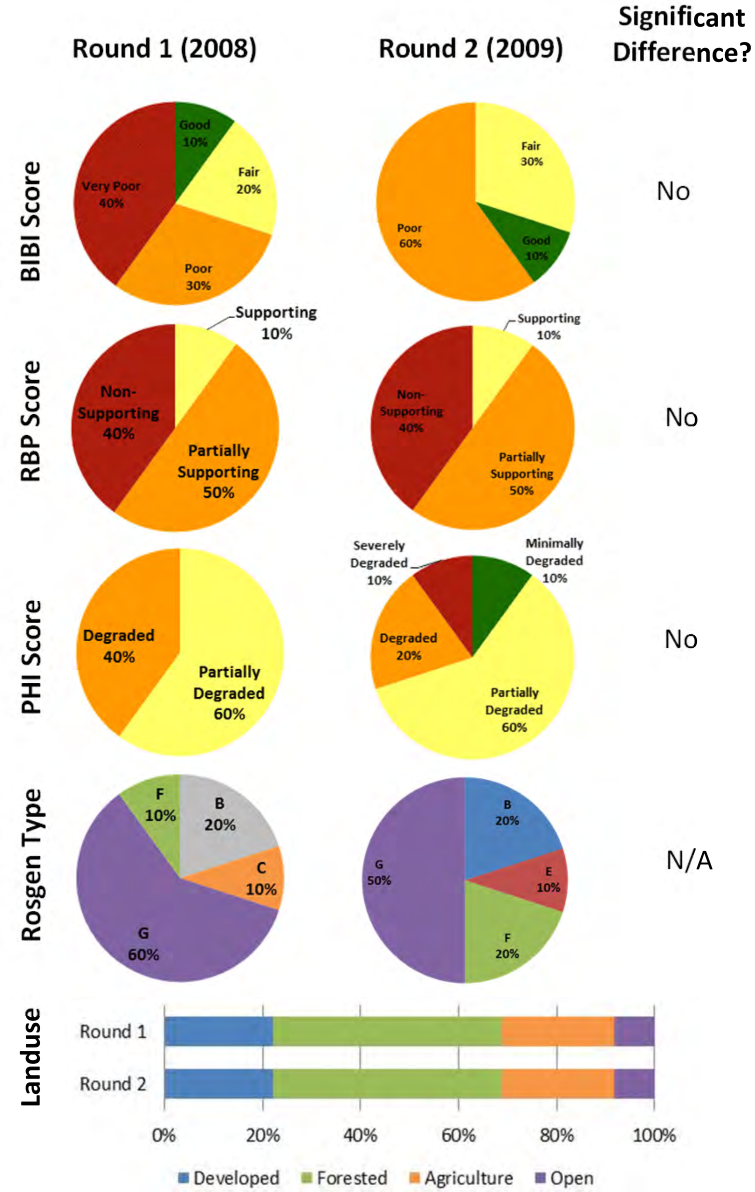


*Landuse for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2011

PSU 20: Rock Branch

The Rock Branch sampling unit has a drainage area of 6,131 acres, and is located in the south central portion of the County between Harwood and Lothian. In 2009, 3.6 % of the overall sampling unit was comprised of impervious surfaces, with individual sites ranging from 1.3 % to 5.7 %.

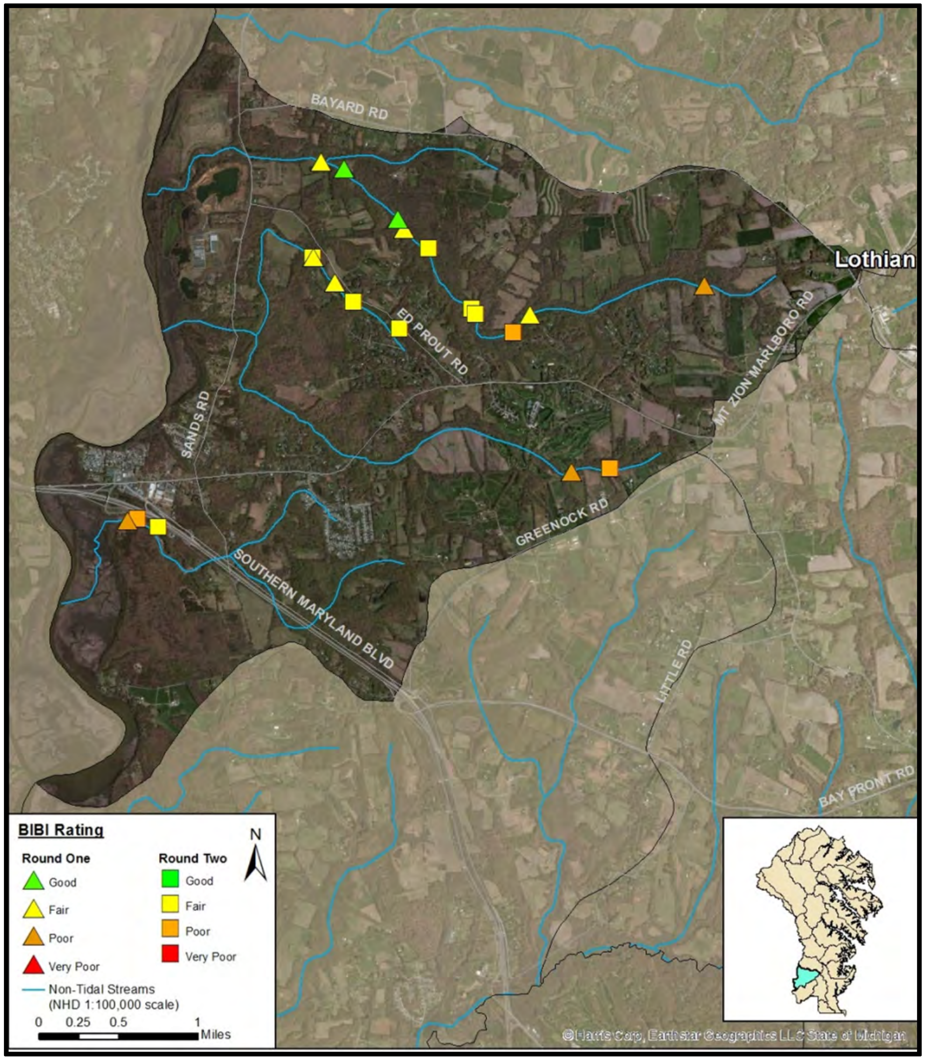


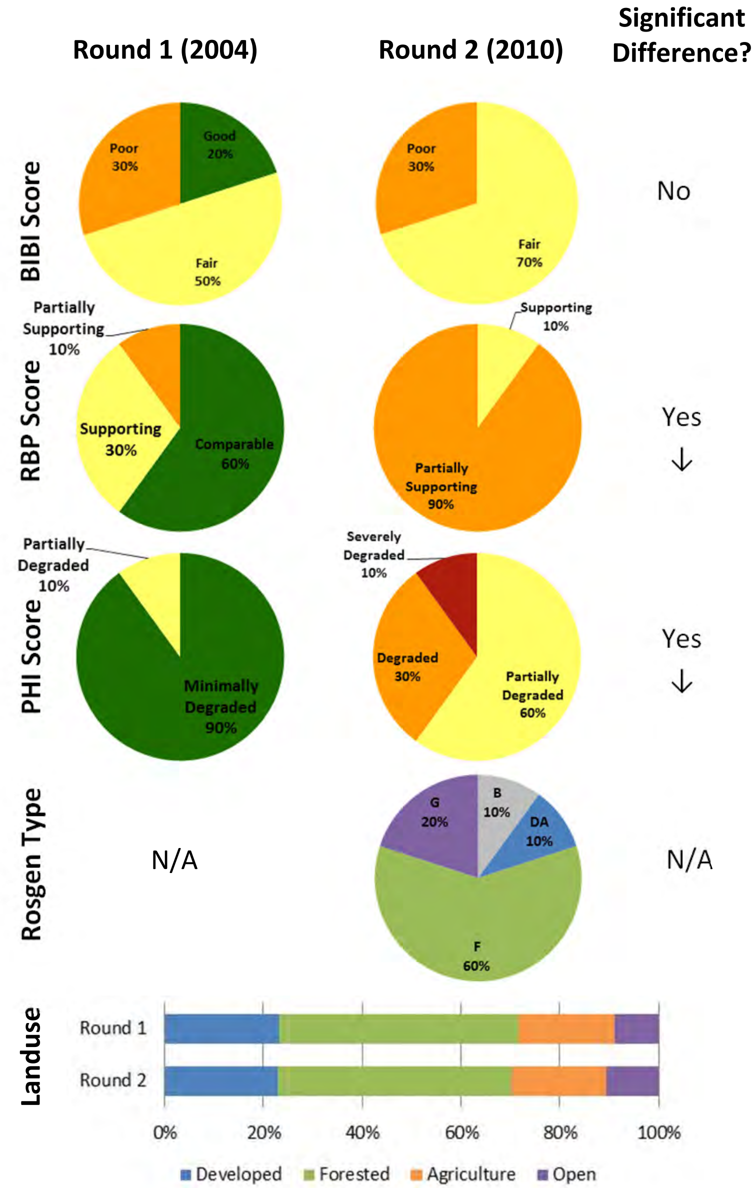


*Landuse for entire PSU, not sites sampled. GIS layer: R1 = 2007; R2 = 2007

PSU 21: Ferry Branch

The Ferry Branch sampling unit, located in the southwestern portion of the County due west of Lothian, has a total drainage area of 8,038 acres. In 2010, impervious surfaces comprised 5.3 % of the overall sampling unit, with individual sites ranging from 3.3 % to 9.6 %.

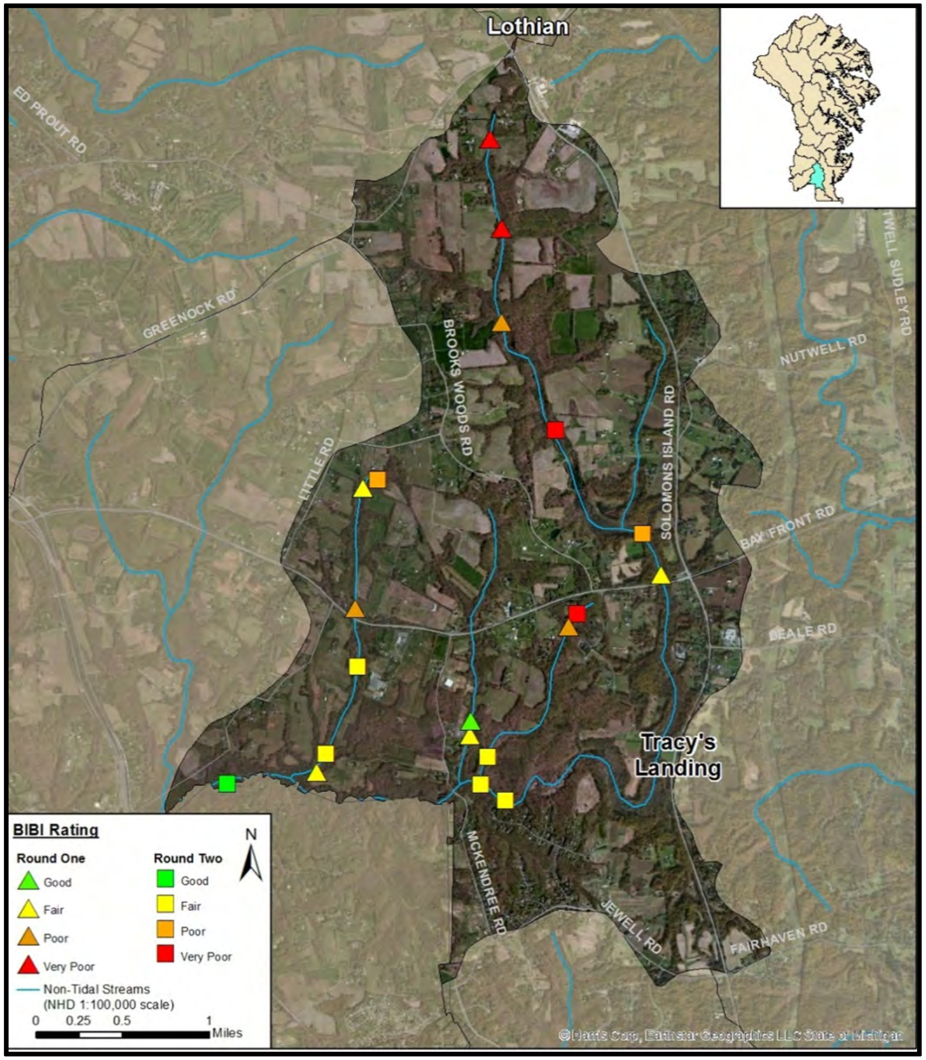


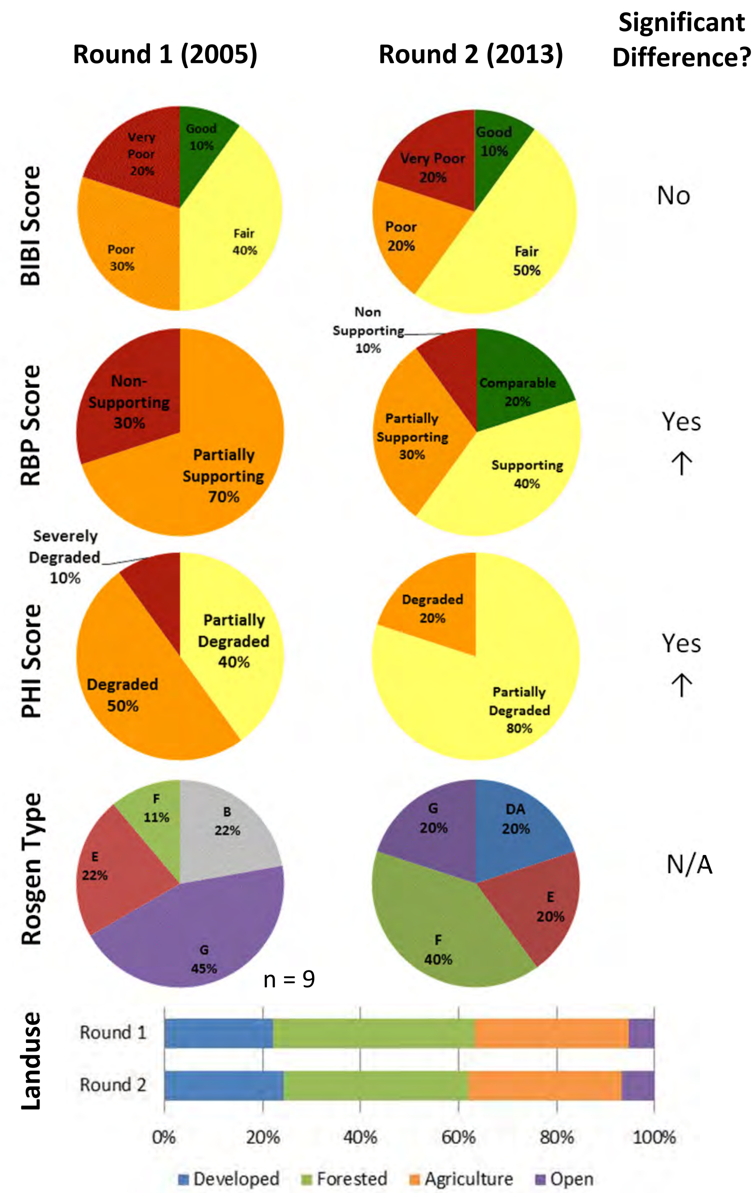


*Landuse for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2007

PSU 22: Lyons Creek

The Lyons Creek sampling unit is located in the southern portion of the County along the border with Calvert County, and has a total drainage area of 6,154 acres. In 2013, impervious surfaces comprised 4.4 % of the overall sampling unit, with individual sites ranging from 3.1 % to 7.3%.

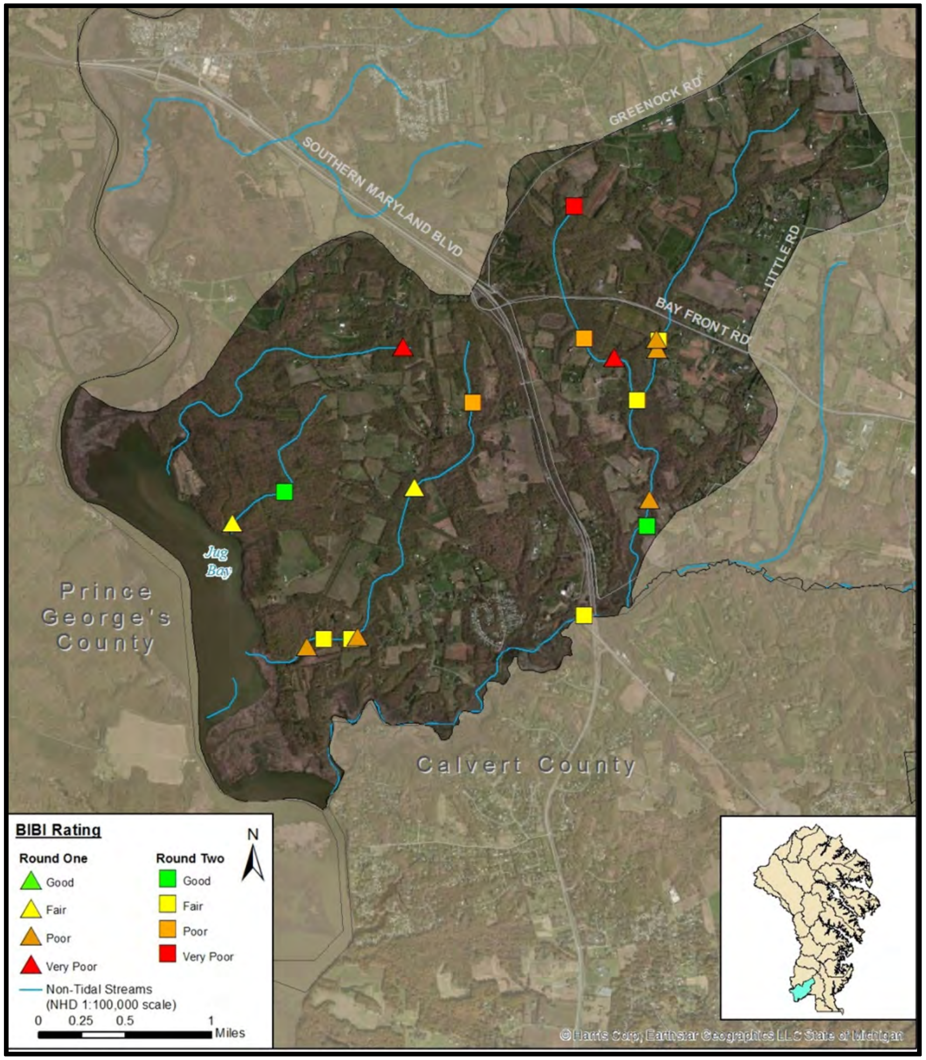


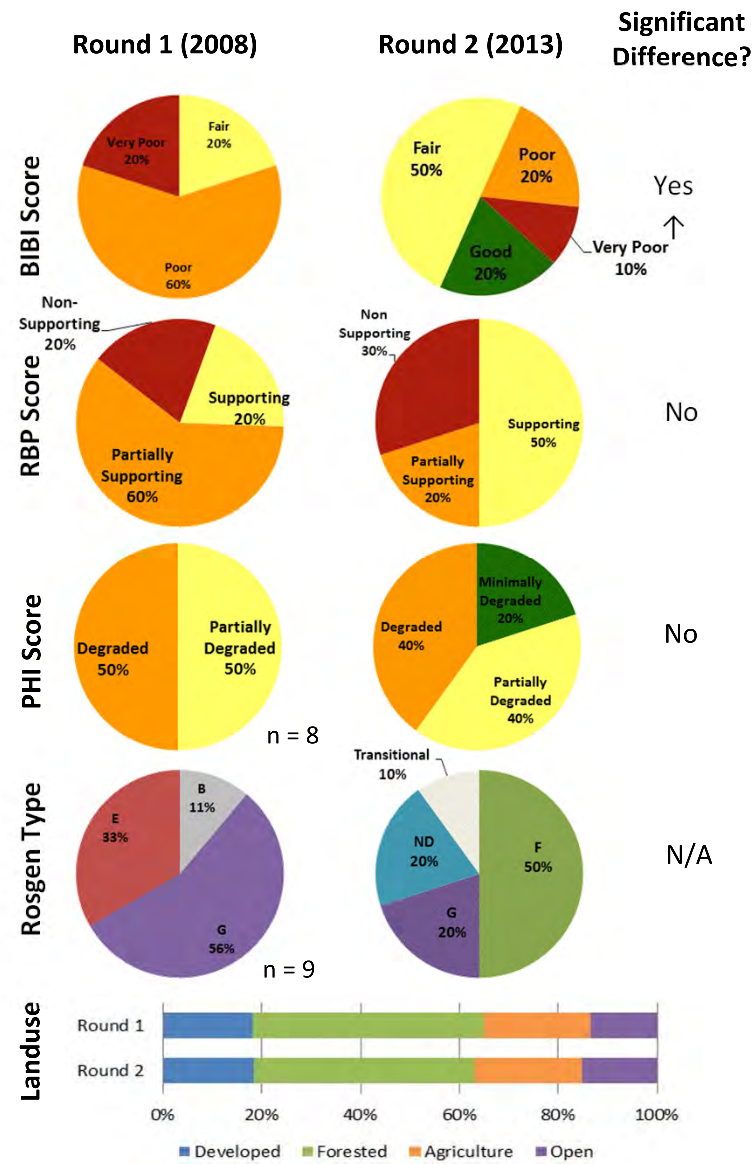


*Landuse for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2011

PSU 23: Cabin Branch

The Cabin Branch sampling unit is located in the southwestern most tip of the County adjacent to Jug Bay, and has a total drainage area of 6,443 acres. In 2013, impervious surfaces comprised2.9 % of the overall sampling unit, with individual sites ranging from 0.5 % to 3.8 %.

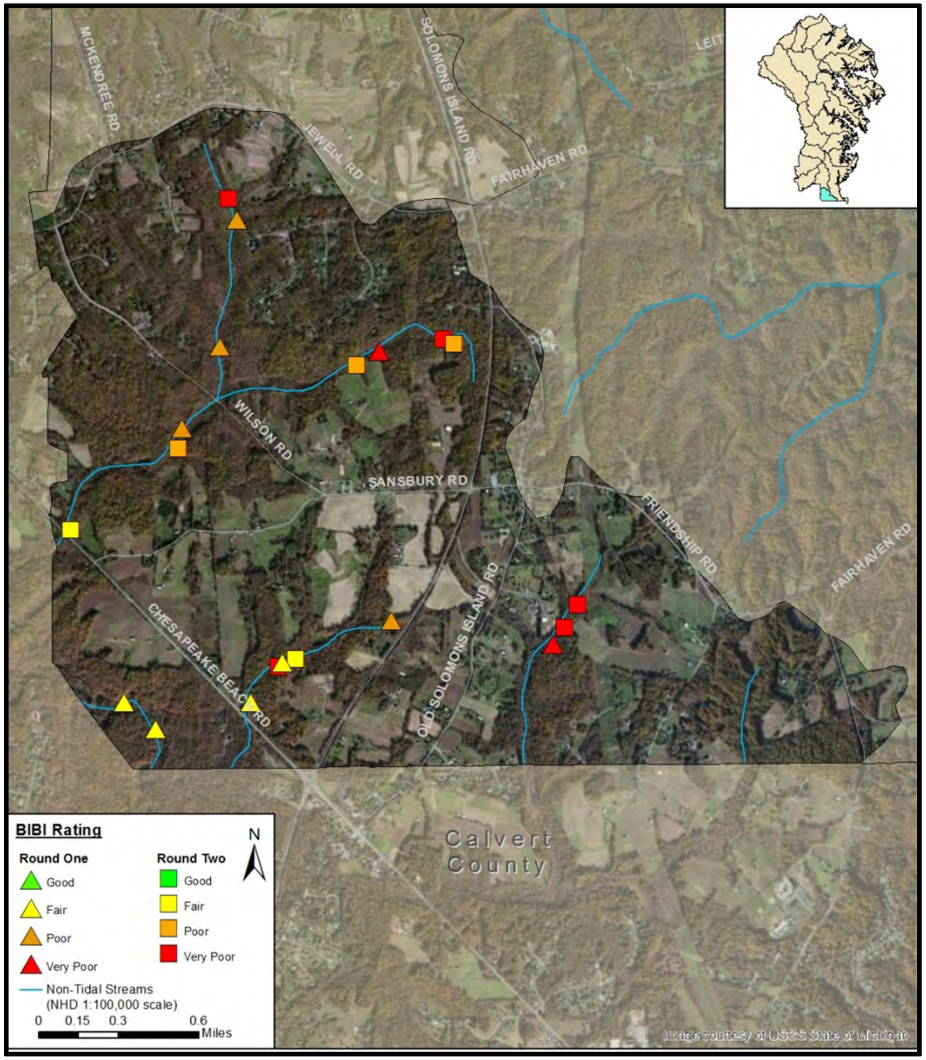


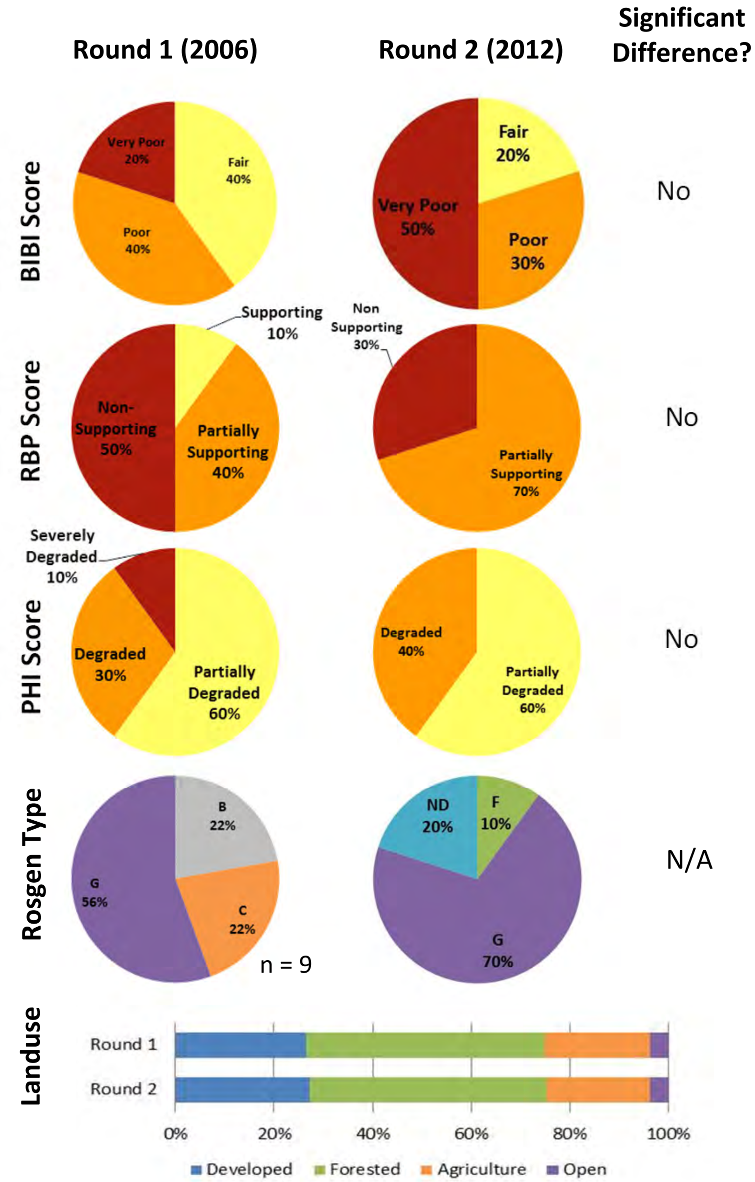


*Landuse for entire PSU, not sites sampled. GIS layer: R1 = 2007; R2 = 2011

PSU 24: Hall Creek

The Hall Creek sampling unit, located in the southern tip of the County along the Calvert County border, has a total drainage area of 3,168 acres. In 2012, impervious surfaces comprised 4.3 % of the overall sampling unit, with individual sites ranging from 3.2 % to 10.2 %.





*Landuse for entire PSU, not sites sampled. GIS layer: R1 = 2004; R2 = 2007

Appendix D: Cross Section Comparisons

Lower Magothy Site Survey Data

Site ID: R1-08-11a
Year: 2007

Station	Elevation	Notes
0.7	95.36	Left Monument
0.7	94.85	ground @ Monument
2	95.00	Left Bank
6.2	95.18	
8.5	94.88	
10	94.73	Left Top of Bank
10.7	94.21	Left Bankfull
10.8	93.95	Left Edge of Water
12.3	92.81	
14.1	91.95	
16.1	91.88	
18	91.85	Thalweg
19.5	92.44	
20	93.86	Right Edge of Water
20.3	94.16	Right Bankfull
21	94.55	Right Top of Bank
23	94.90	Right Bank
26.2	94.98	
28.9	94.95	ground @ Pin
28.9	95.51	Bank Pin

Site ID: R2-08-10
Year: 2013

Station	Elevation	Notes
0	95.38	lpin
0	94.95	ground
2	94.73	fldpln
4	95.12	fldpln
6	95.22	fldpln
8	94.87	fldpln
9	94.87	ltob
10	94.62	lb
10.7	93.76	lbkf
11.5	93.11	lb
12	92.61	lew
13	92.23	bed
14	92.21	bed
15	91.97	wd = 0.72
16	91.82	wd=0.88
17	91.72	th wd=0.98
18	91.87	bed
19	92.35	bed
19.9	92.52	rew
19.6	93.97	undercut=0.4ft at toe
20	94.34	rb
21	94.66	rb
22	94.78	rtob
24	94.92	fldpln
27	94.95	fldpln
28.5	94.94	grnd
28.5	95.48	rpin

Herring Bay Site Survey Data

Site ID: R1-15-19a
Year: 2005

Station	Elevation	Notes
0	95.96	
0	95.64	
10	95.74	
11.5	94.96	
12.5	94.46	
13.6	93.65	
15.2	93.42	
18	92.84	
19.5	92.6	
20.9	92.67	
22.8	92.51	
25.3	92.88	
26.7	93.23	
27.9	93.9	
28	95.22	
28.4	95.42	
30.6	95.36	
33.9	95.28	
33.9	95.7	

Site ID: R2-15-10
Year: 2010

Station	Elevation	Notes
0	95.66	top pin
0	95.45	ground
2	95.48	fldpn
4	95.38	fldpn
5	95.41	ltob
5.7	94.88	bank
6.2	94.68	rbf
7.8	93.95	lbob
9.6	93.96	clay/silt dep. bar
11.1	93.9	lew, ws
13	93.38	deep riffle/run
15	93.33	deep riffle/run
17	93.22	thw, wd=0.72
19	93.41	deep riffle/run
20.8	93.29	rbob
21.8	93.93	rew, ws
23.6	95.56	bank
25	95.88	rtob
28	95.82	fldpn
30	95.82	fldpn
32	95.75	fldpn
34	95.73	ground
34	95.96	top pin

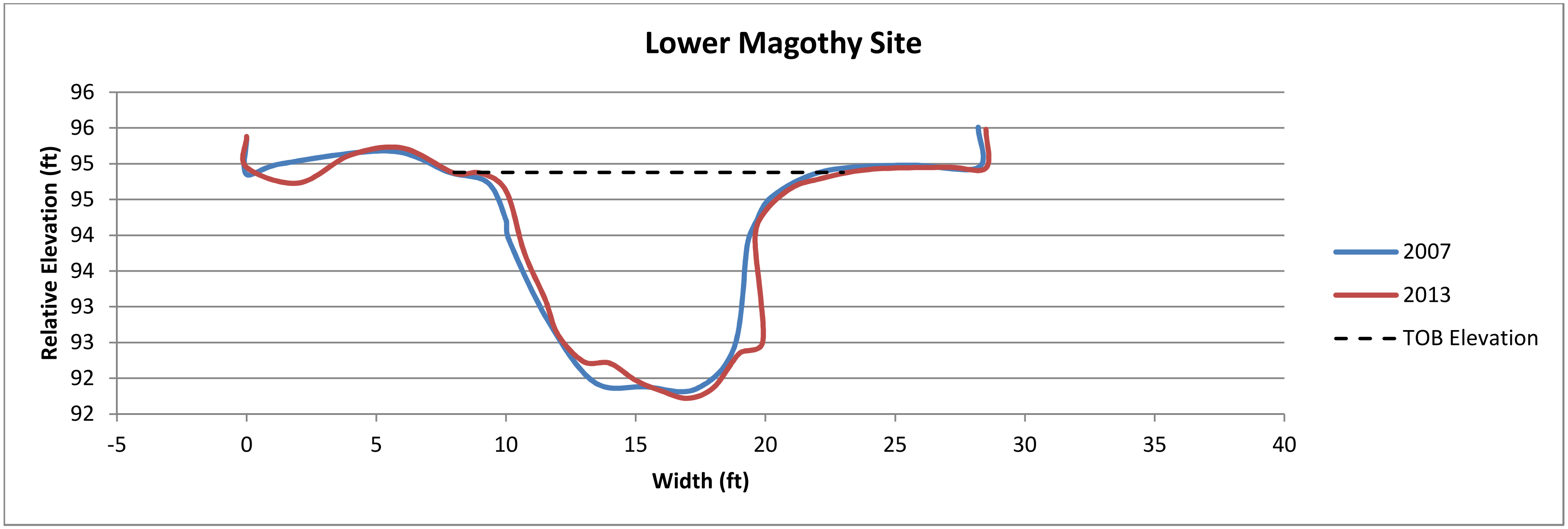


Figure D-1. Cross-section overlay of Lower Magothy site (R1-08-11a; R2-08-10).

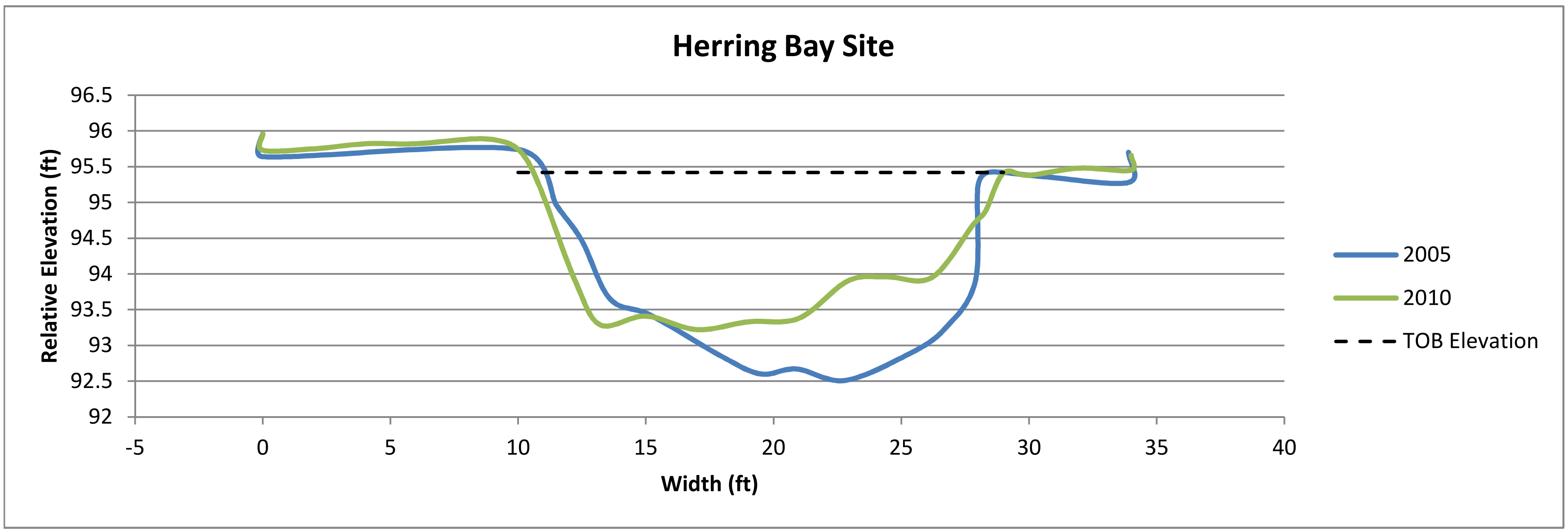


Figure D-2. Cross-section overlay of Herring Bay site (R1-15-19a; R2-15-10).