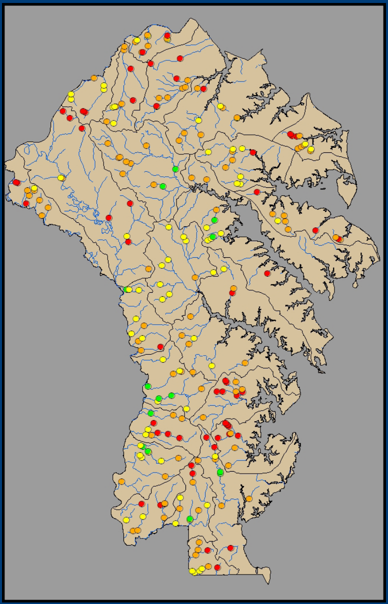

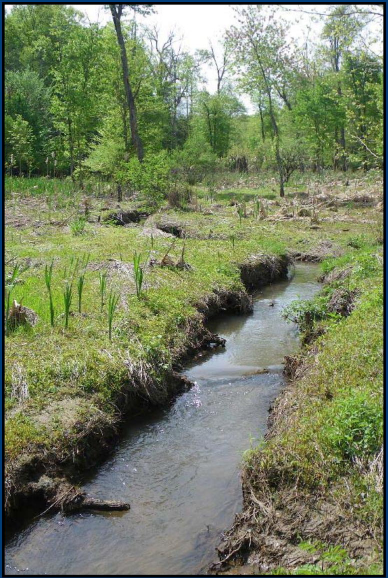

Aquatic Biological Assessment of the Watersheds of Anne Arundel County, Maryland: Round One 2004 - 2008

Anne Arundel County, Maryland
Department of Public Works
Ecological Assessment Program

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Prepared for:
Anne Arundel County
Department of Public Works
Watershed, Ecosystem, and Restoration Services
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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. This effort summarizes the findings of Round One (2004 – 2008) 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 One assessment period were in poor biological condition. Countywide BIBI results indicate that only 6% of the streams in the County were in "Good" condition, 29% were rated "Fair", 43% were rated "Poor", and 22% were classified as "Very Poor", which are consistent with findings of the Maryland Biological Stream Survey (MBSS) during the previous five year period from 2000 to 2004. Physical habitat conditions in County streams were rated "Partially Degraded" using the MBSS Physical Habitat Index (PHI) method, and "Partially Supporting" using the U.S. EPA's Rapid Bioassessment Protocol (RBP).

Biological conditions at the PSU scale resulted in four PSUs rated as "Fair," 17 rated "Poor" and three rated "Very Poor." Physical habitat results using the PHI resulted in 12 PSUs rated as "Partially Degraded," 11 rated as "Degraded," and only one PSU rated as "Minimally Degraded." RBP physical habitat rated 19 PSUs as "Partially Supporting," four as "Supporting," and one was rated "Comparable." Geomorphic assessment data indicate that the majority of streams assessed were classified as Rosgen "E" type (39%) channels followed by "G" (21%), "C" (16%), "B" (15%), and "F" (8%) type channels. Water quality data suggest that many PSUs have pH values consistently below the minimum limit of 6.5, as specified in COMAR, and several of the more developed PSUs had highly elevated conductivity levels. Analysis of land use and imperviousness show 10 PSUs having predominantly developed land use and the remaining 14 PSUs dominated by forested land use. Impervious surface percentages at the PSU scale ranged from 3.2% to 35.4%.

Nonparametric Kendall rank correlations found significant correlations between a number of biotic and abiotic variables. RBP physical habitat index was more strongly correlated with BIBI, while PHI was better correlated to land use. Percent intolerant and percent EPT metrics were better correlated with land use than overall BIBI scores. Overall, geomorphic variables were not strongly correlated with biotic variables. 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

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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 in 2004 (Hill and Stribling, 2004), along with the input of 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 One (2004 – 2008) of the County's Biological Monitoring and Assessment Program and establishes a baseline condition for future comparisons. Round Two began in 2009 and will allow for comparison of stream health conditions over time. 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 (Roberts, et al, 2006; Victoria and Markusic, 2007; Stribling et al., 2008). Specific information regarding the sampling and analysis methods, including the standard operating procedures (SOPs), can be found in the *Sampling and Analysis Plan for Anne Arundel County Biological Monitoring and Assessment Program* (Tetra Tech, 2005) and the *Quality Assurance Projects Plan for Anne Arundel County Biological Monitoring and Assessment Program* (Tetra Tech, 2004).

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 (Tetra Tech, 2004; Hill and Stribling, 2004). 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). 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 One monitoring year can found in the Biological Monitoring and Assessment Program's Annual Reports (Roberts et al., 2006; Victoria and Markusic, 2007; Stribling et al., 2008).

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 One sampling year using geographic information system (GIS) data. The County's land use 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 from 2004 through 2007, land cover was evaluated using countywide land cover and impervious data layers from 2004. Sites sampled in 2008 were evaluated using 2007 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 2004 Land Cover layer

2.4 Data Analysis

Round One 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 (Figure 15). 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 ($p < 0.0001$, $\alpha = 0.05$), and numerous attempts to transform the data (i.e., logarithmic, square root, and Box-Cox transformations) into a normally distributed population were unsuccessful. 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 strongly significant correlations.

3 Results

Results of Round One sampling in Anne Arundel County from 2004 to 2008 are discussed separately 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 (Roberts et al., 2006; Victoria and Markusic, 2007; Stribling et al., 2008).

3.1 Countywide Results

Based on the primary ecological health indicator used by Anne Arundel County, the Benthic Index of Biotic Integrity, the overall condition of Anne Arundel County streams during the Round One assessment period (2004-2008) was "Poor", with a mean BIBI score of 2.61 (standard deviation [SD] = 0.78). The distribution of BIBI scores for each site sampled during Round One (n = 239) are displayed in Figure 1. 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), which was considered a statistical outlier based on the interquartile distributions. 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 Severn River watershed and the less developed southern portion of the County (Figure 2).

Countywide biological assessment results indicate that only 6% of the streams in the County were in "Good" condition, 29% were rated "Fair", 43% were rated "Poor", and 22% were classified as "Very Poor" (Figure 3). These results are similar to findings from the Maryland Department of Natural Resources MBSS sampling efforts during the 2000 – 2004 sampling period. Both assessments classified 22% of streams as being in "Very Poor" condition, and MBSS classified only slightly more (9% vs. 6%) as being in "Good" condition. The primary difference between these two studies occurred in the classification of "Fair" and "Poor" streams, where MBSS found an opposite trend of streams being predominantly in "Fair" condition (42%), followed by "Poor" condition (27%).

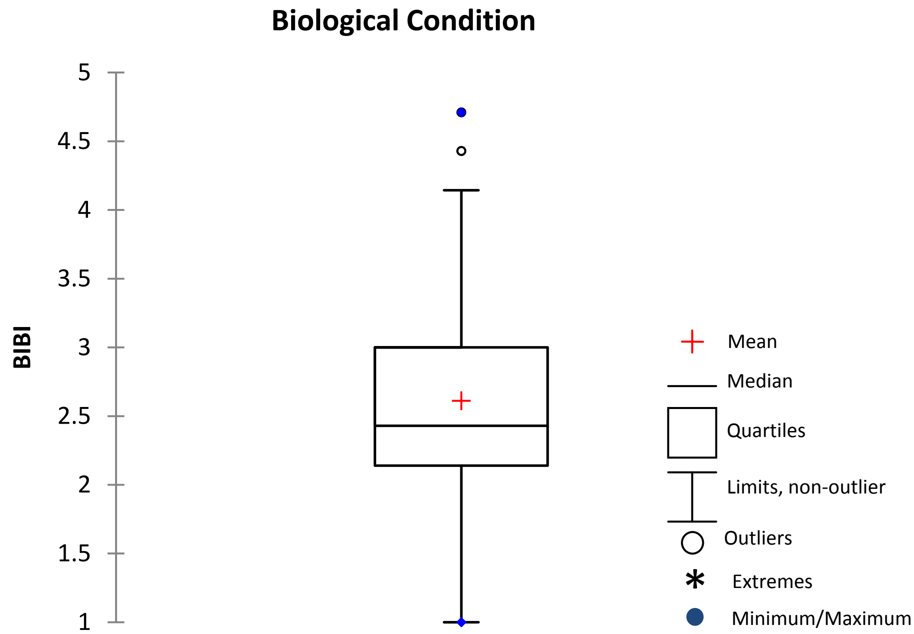

Figure 1. Box Plot of BIBI Scores in Anne Arundel County from 2004-2008 (n = 239).

Physical habitat conditions in Anne Arundel County streams were rated "Partially Degraded" by the PHI, with a mean score of 67.5 (SD = 11.7) and "Partially Supporting" by the RBP (mean = 116, SD = 21; Figure 4). PHI scores ranged from minimum of 31.3, which was considered an outlier based on the quartile distributions, to a maximum of 92.7 on a 100-point scale. On the other hand, RBP scores ranged from a minimum of 68 to a maximum of 177, an outlier value, on a 200-point scale. Figures 5 and 6 show the distribution of sampling sites with their corresponding physical habitat condition ratings for the PHI and RBP, respectively. 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. A similar trend was observed with the RBP, with streams rated as "Comparable" to reference conditions primarily concentrated in the Severn River watershed and along the western border of the County.

Based on the Physical Habitat Index (PHI), 13% of the streams in Anne Arundel County had "Minimally Degraded" habitat, 43% had "Partially Degraded" habitat, and 44% had "Degraded" or "Severely Degraded" habitat (Figure 7). MBSS rated physical habitat conditions in Anne Arundel from 2000 – 2004 were very similar, with no more than 3% difference in each category between the two assessments (Figure 7; Kazyak et al., 2005).

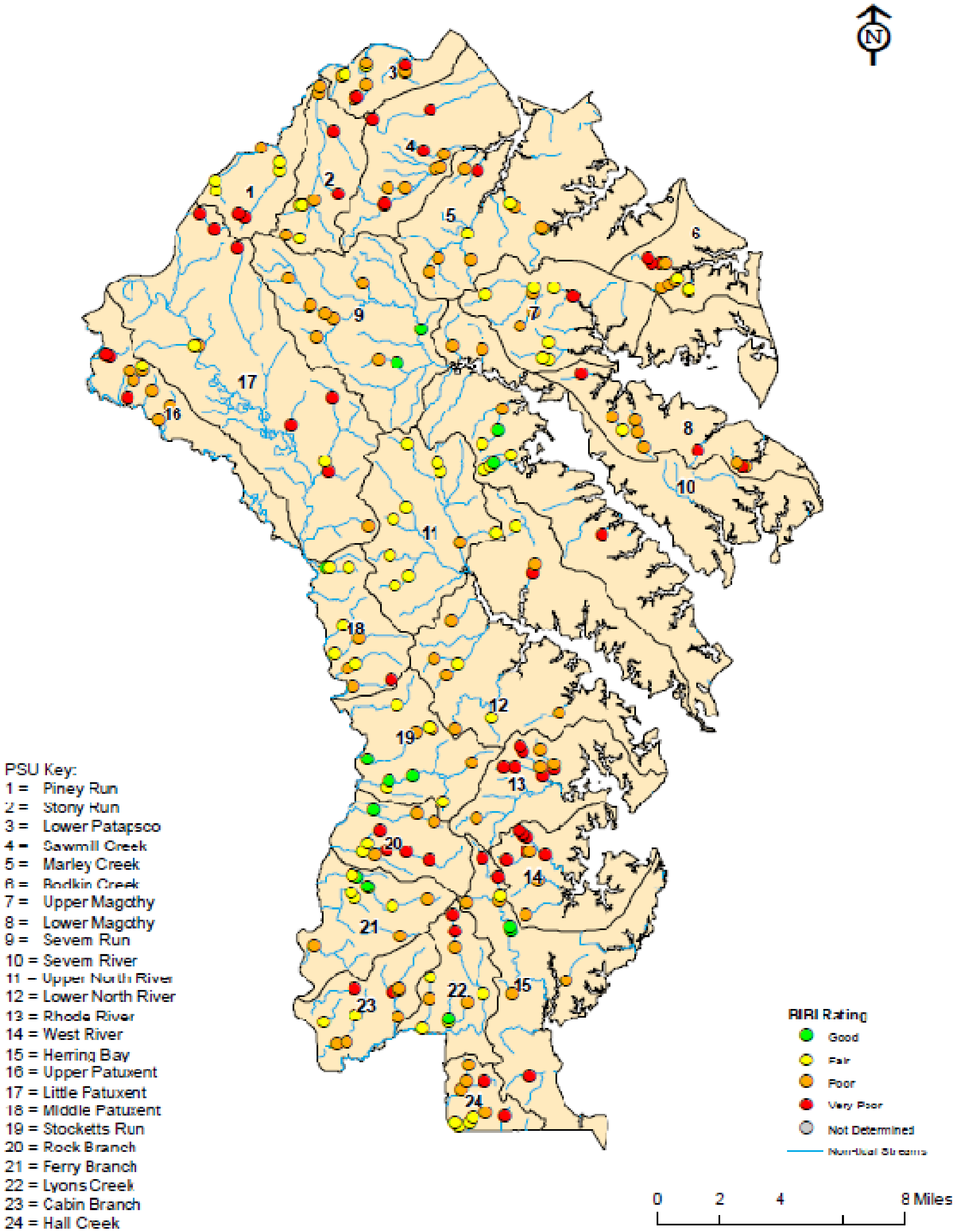

Figure 2. Countywide Biological Assessment (BIBI) Results from 2004-2008.

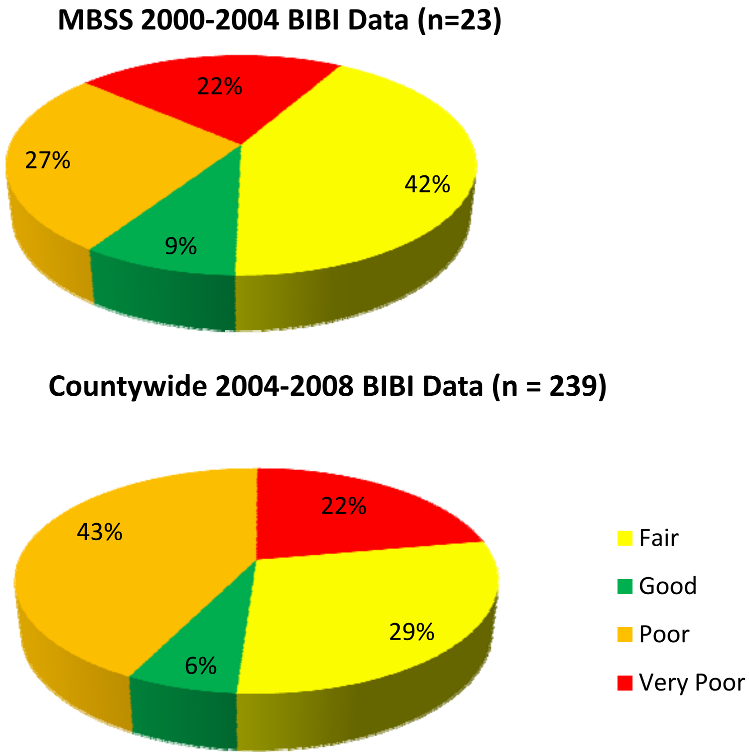

Figure 3. Comparison of Biological Conditions in Anne Arundel County Between MBSS (2000-2004) and Countywide (2004-2008) Assessments.

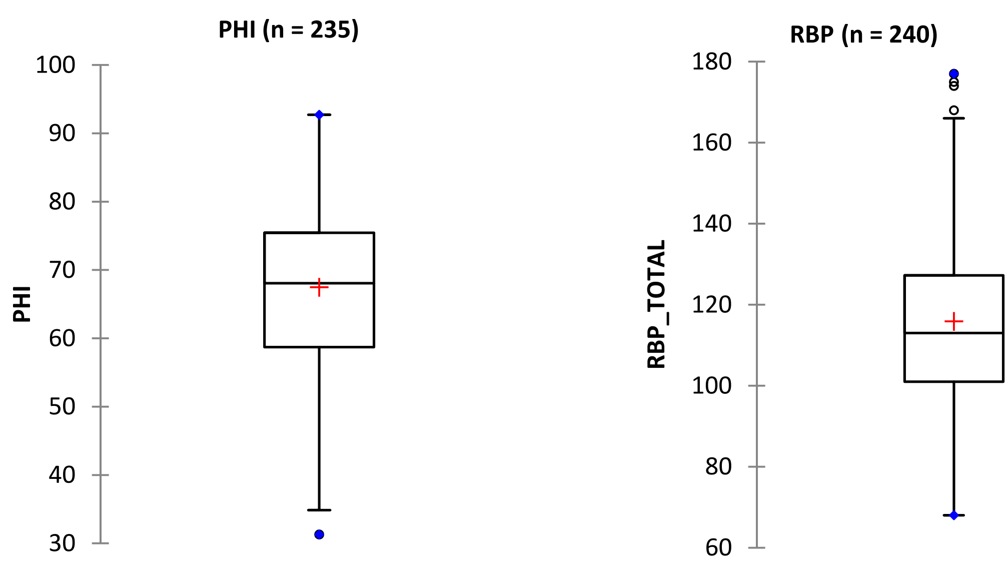

Figure 4. Box Plot of Physical Habitat Index Scores in Anne Arundel County from 2004-2008.

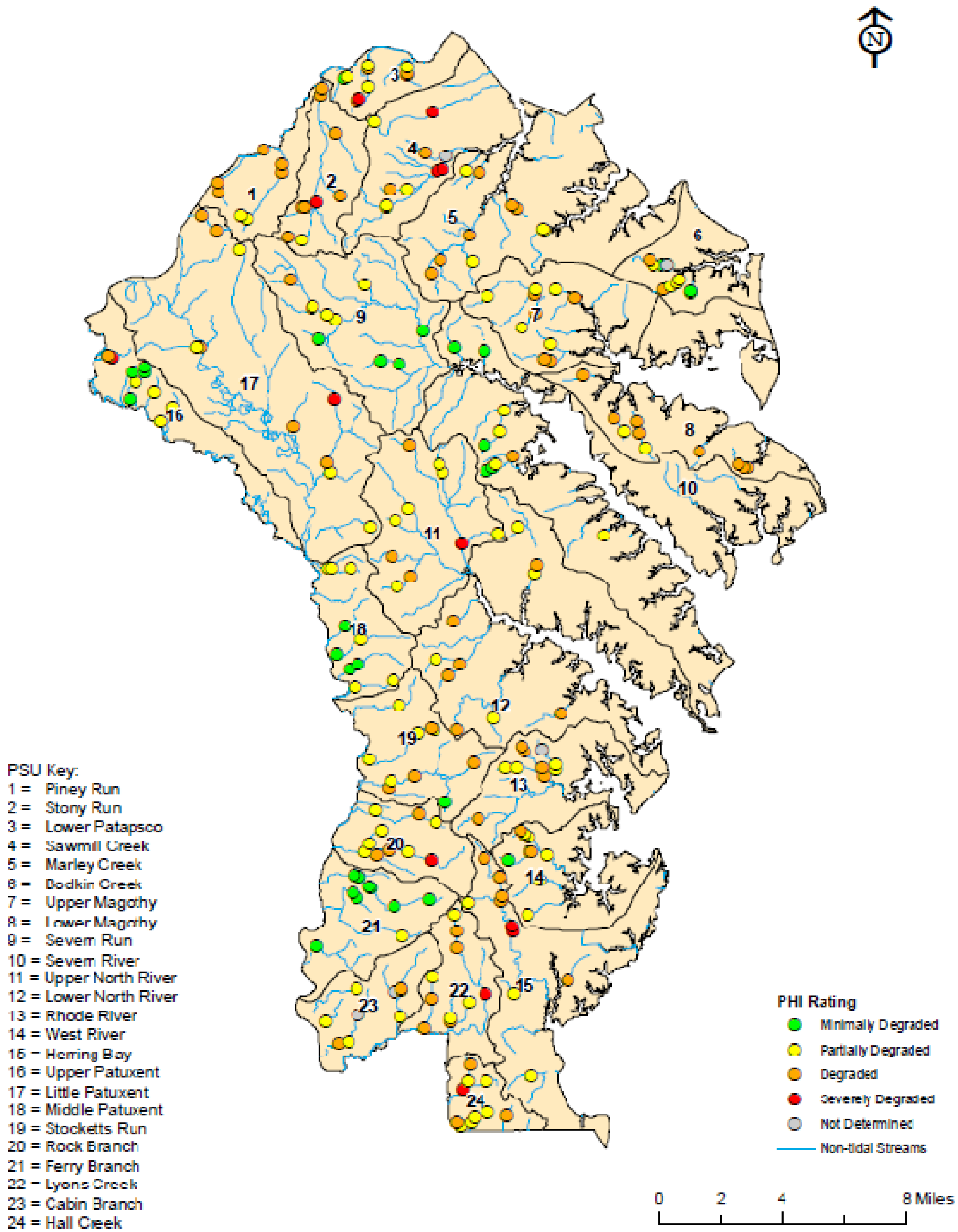

Figure 5. Countywide Physical Habitat Assessment (PHI) Results from 2004-2008.

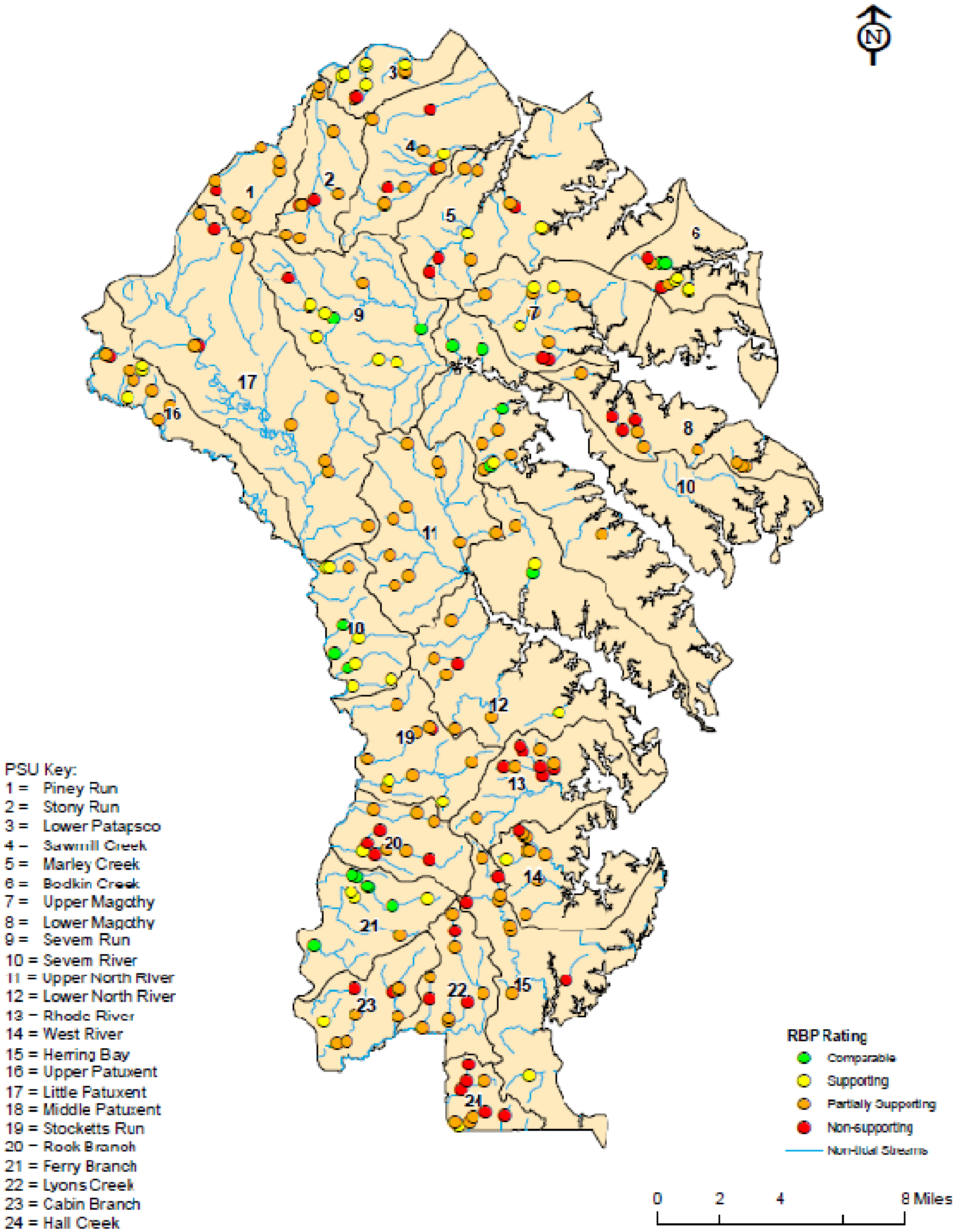

Figure 6. Countywide Physical Habitat Assessment (RBP) Results from 2004-2008.

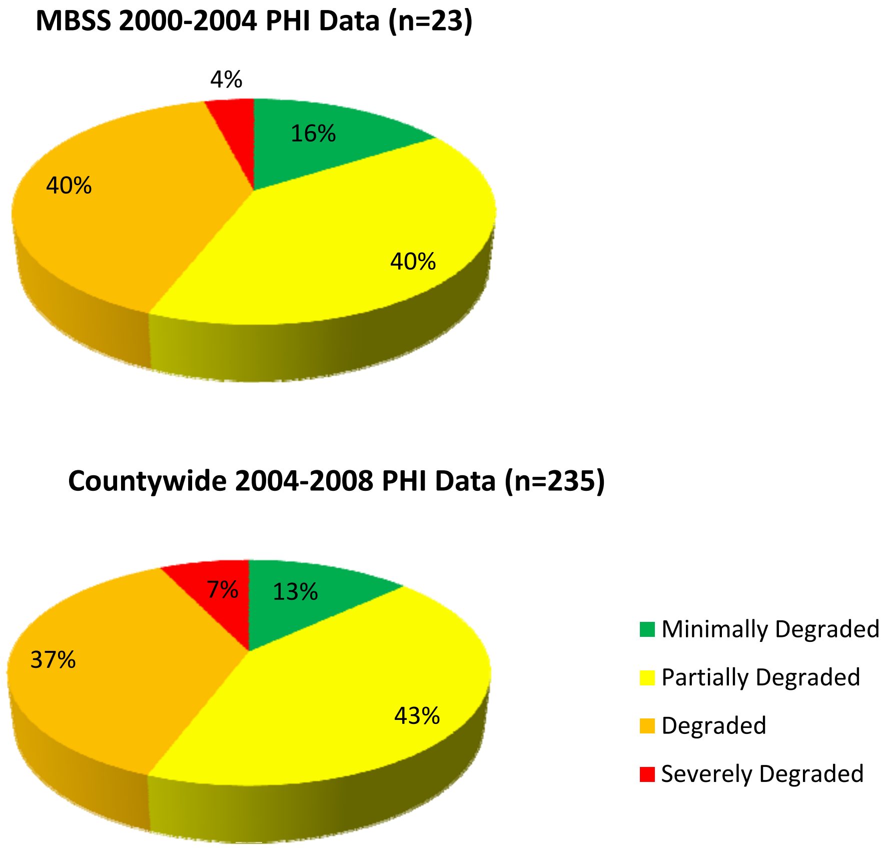

Figure 7. Comparison of Physical Habitat Conditions in Anne Arundel County between MBSS (2000-2004) and Countywide (2004-2008) assessments.

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 One is displayed in Figure 8.The geomorphic assessment component was added to the Biological Monitoring and Assessment Program in 2005; therefore, PSUs assessed in 2004 (Ferry Branch, Lower Patapsco, Middle Patuxent, Severn River, and Severn Run) were not classified with regard to geomorphological characteristics. Since the addition of the geomorphic assessment component in 2005, Rosgen channel type was not determined (i.e., classified as ND) for 12 additional 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. Of the remaining 178 sites that were surveyed and assessed, the majority were classified as "E" type (39%), followed by "G" (21%), "C" (16%), "B" (15%), and "F" (8%) channels (Figure 9). There were no sites classified as "A", "D", or "DA" types during the Round One sampling effort.

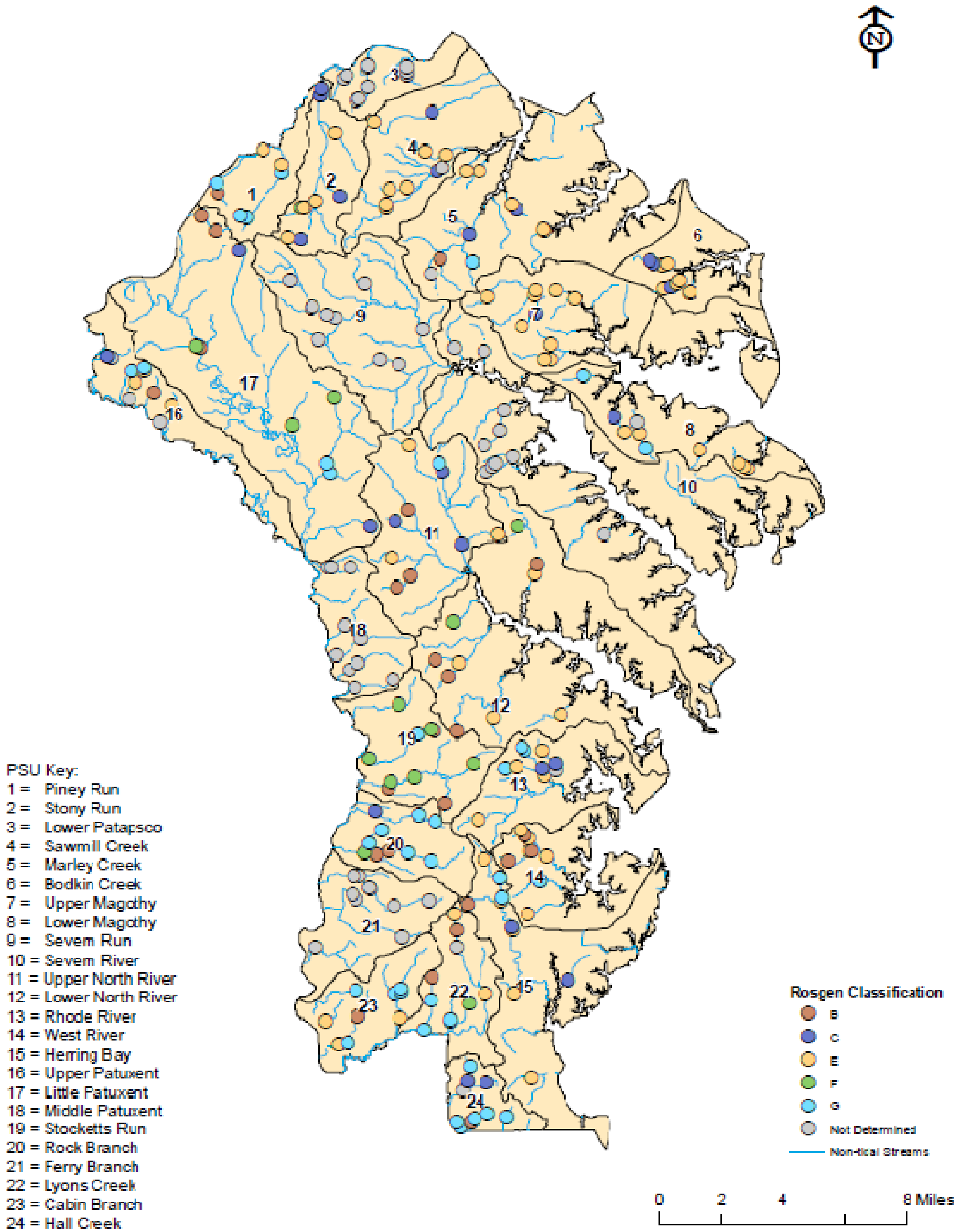

Figure 8. Countywide Geomorphic Classification (Rosgen) Results from 2004-2008.

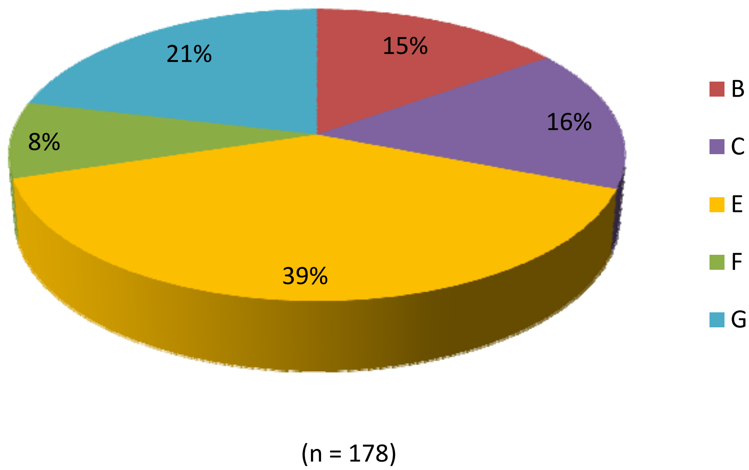

Figure 9. Distribution of Rosgen Stream Types in Sites Sampled from 2005-2008.

3.2 Primary Sampling Unit Results

This section displays the comprehensive results of Round One sampling of Anne Arundel County's 24 PSUs from 2004 to 2008. Following a brief synopsis of land use and impervious cover conditions within each PSU, results are discussed separately in the following sections for each of the primary descriptive parameters; biology, physical habitat, water quality, geomorphology, and land use and land cover characteristics.

3.2.1 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). For a description of land cover types that comprise each land use category see Section 2.3 *Land Use/Land Cover and Imperviousness Analysis.*

Table 2. Characterization of Anne Arundel County Primary Sampling Units from 2004-2008.

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
Bodkin Creek	06	2006	5872	14.7	49.4	40.3	0.2	10.2	P	PD	S
Cabin Branch	23	2008	6443	3.2	18.0	46.8	21.6	13.6	P	PD	PS
Ferry Branch	21	2004	8038	6.7	23.1	48.5	19.5	8.9	F	MD	C
Hall Creek	24	2006	3168	5.3	26.5	48.4	21.5	3.7	P	PD	PS
Herring Bay	15	2005	14595	7.5	28.1	54.0	10.3	7.7	P	D	PS
Little Patuxent	17	2007	28196	20.4	36.3	49.0	3.2	11.5	P	D	PS
Lower Magothy	08	2007	12697	21.2	63.0	30.5	0.7	5.8	P	D	PS
Lower North River	12	2005	23681	18.2	49.1	39.9	4.6	6.5	P	D	PS
Lower Patapsco	03	2004	4040	31.6	59.5	29.1	0.0	11.4	P	PD	PS
Lyons Creek	22	2005	6154	5.5	22.1	41.2	31.4	5.2	P	D	PS
Marley Creek	05	2006	19425	29.4	62.3	31.0	0.4	6.3	P	D	PS
Middle Patuxent	18	2004	6332	7.4	24.8	42.5	20.8	12.0	P	PD	S
Piney Run	01	2007	4868	19.1	36.6	53.5	0.0	9.9	P	D	PS
Rhode River	13	2008	8737	6.1	24.8	56.5	11.9	6.9	VP	D	NS
Rock Branch	20	2008	6131	3.5	22.2	46.7	22.8	8.3	P	D	PS
Sawmill Creek	04	2008	11044	35.4	60.0	21.8	0.0	18.2	VP	D	PS
Severn River	10	2004	28920	21.0	55.0	35.3	3.0	6.7	F	PD	S
Severn Run	09	2004	15424	20.5	49.6	42.4	2.8	5.2	P	PD	S
Stocketts Run	19	2005	8714	6.3	27.7	45.8	18.1	8.4	F	PD	PS
Stony Run	02	2007	6203	31.0	50.6	34.0	0.5	14.8	P	D	PS
Upper Magothy	07	2006	10031	19.0	62.8	33.1	0.0	4.0	P	PD	PS
Upper North River	11	2005	12797	7.5	28.4	58.9	9.2	3.6	F	PD	PS
Upper Patuxent	16	2007	6957	9.0	16.	77.4	0.9	5.0	P	PD	PS
West River	14	2008	7558	6.9	29.6	46.4	19.5	4.5	VP	PD	PS

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

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

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

Figure 10 shows the proportion of land use classes for each PSU. A total of 10 PSUs were predominantly comprised of developed land use, ranging from 63.0% in Lower Magothy to 49.1% in Lower North River. Only two PSUs, Upper Patuxent and Cabin Branch were less than 20% developed. Forested land use was dominant in the remaining 14 PSUs, which ranged from 77.4% in Upper Patuxent to 41.2% in Lyons Creek. Sawmill Creek and Lower Patapsco had the smallest proportion of forested land at 21.8% and 29.1%, 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 (31.4%), followed by Rock Branch (22.8%), Cabin Branch (21.6%), and Hall Creek (21.5%). Open land use was the least dominant, with the highest proportions observed in Sawmill Creek (18.2%) and Stony Run (14.8%), due in large part to the open space surrounding Baltimore-Washington International (BWI) Airport. A map displaying land use throughout the County, based on the 2007 Land Cover layer, is shown in Figure 11.

The percentage of impervious cover was quite variable, ranging from a maximum of 35.4% in Sawmill Creek to a minimum of 3.2% in Cabin Branch. Two other PSUs, Lower Patapsco and Stony Run, had impervious cover exceeding 30% of their respective drainage areas. A total of five PSUs had impervious cover between 20% and 30% (Marley Creek, Lower Magothy, Severn River, Severn Run, and Little Patuxent), and four more PSUs exceeded 14% (Piney Run, Upper Magothy, Lower North River, and Bodkin Creek). The remaining 12 PSUs all had impervious cover that was below 10%, two of which had less than five percent impervious cover (Rock Branch and Cabin Branch). A map of impervious cover throughout the County, based on the 2007 impervious cover layer, is displayed in Figure 12.

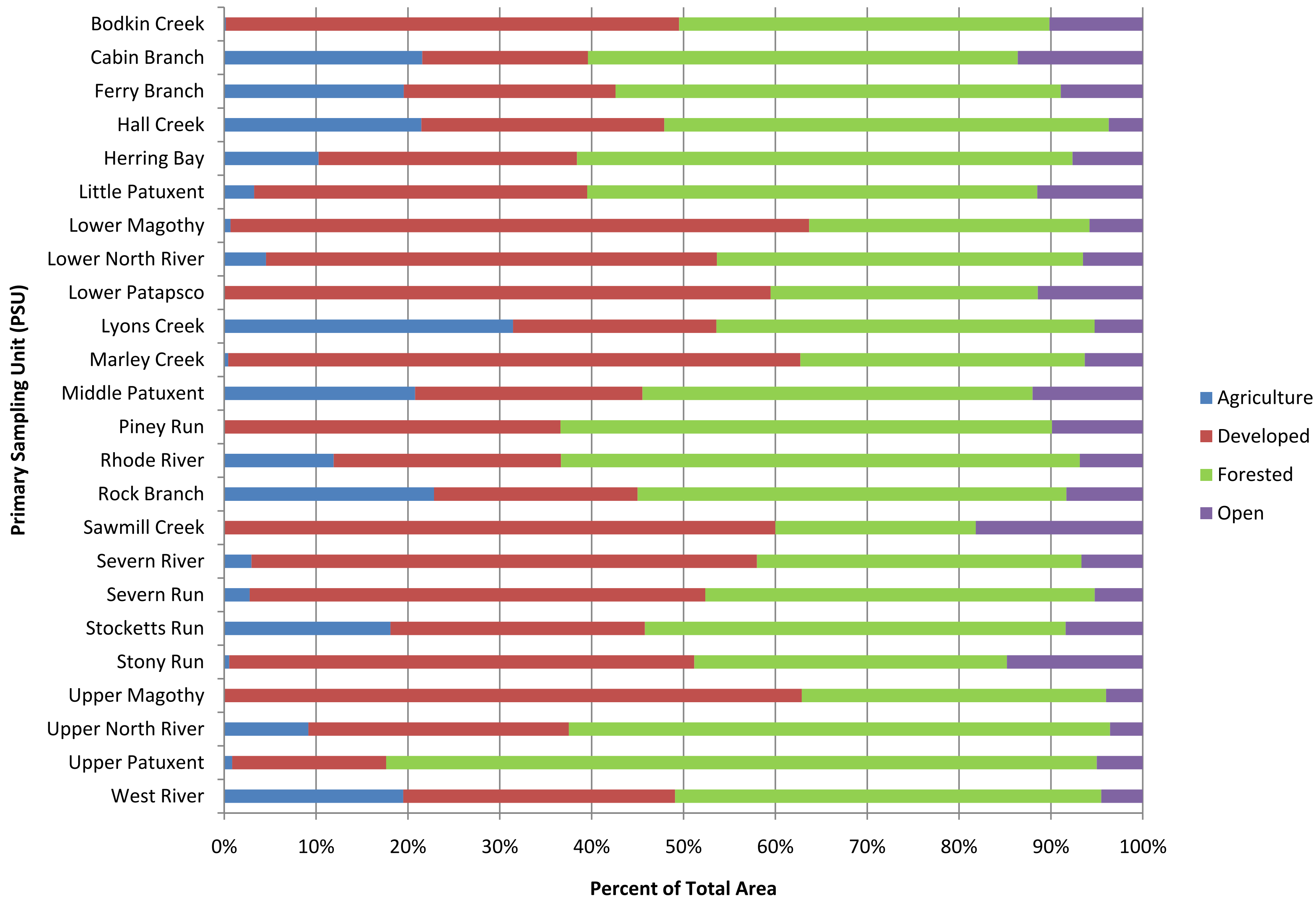

Figure 10. Percentage of Land Use Types for each PSU

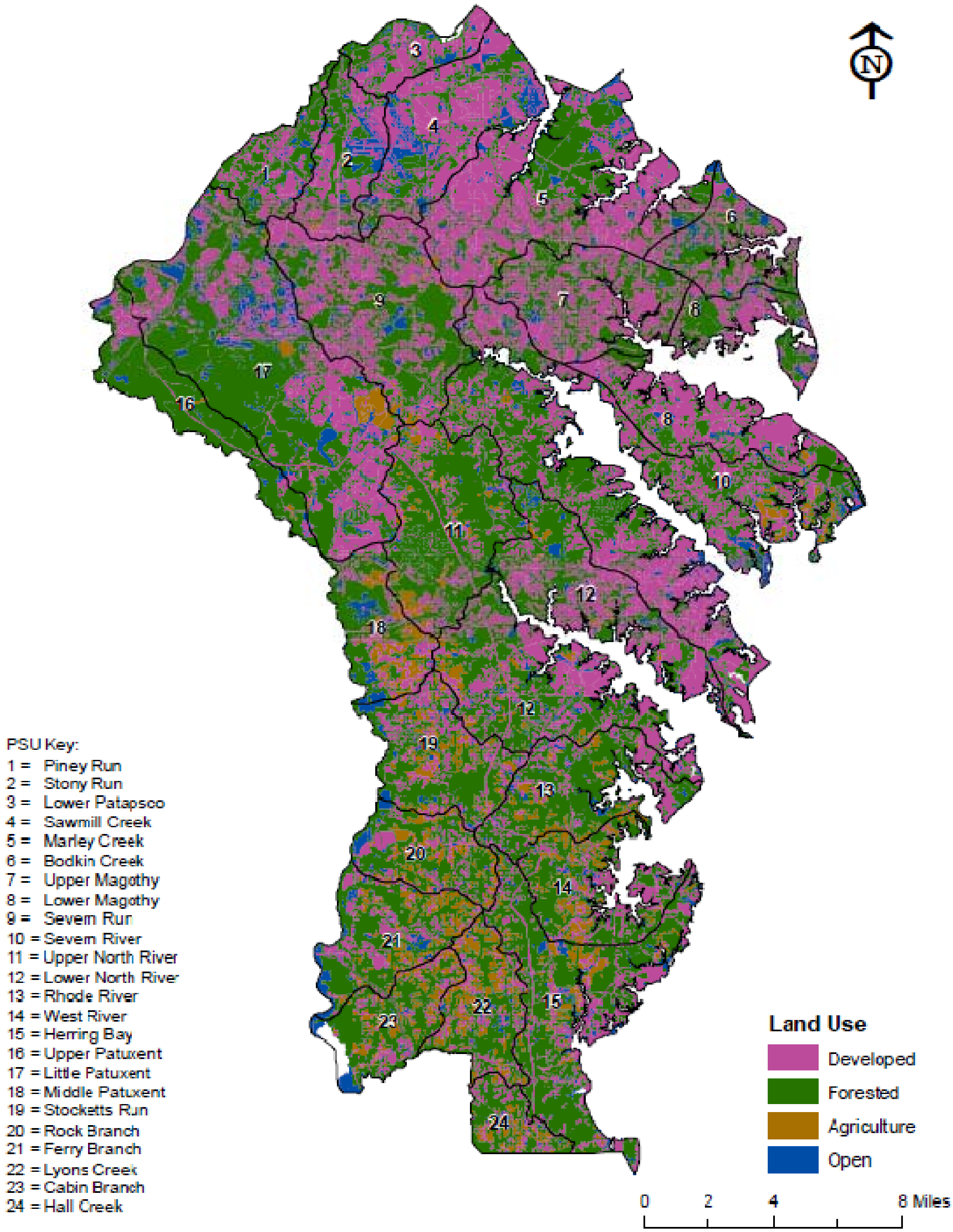

Figure 11. Anne Arundel County Land Use from 2007.

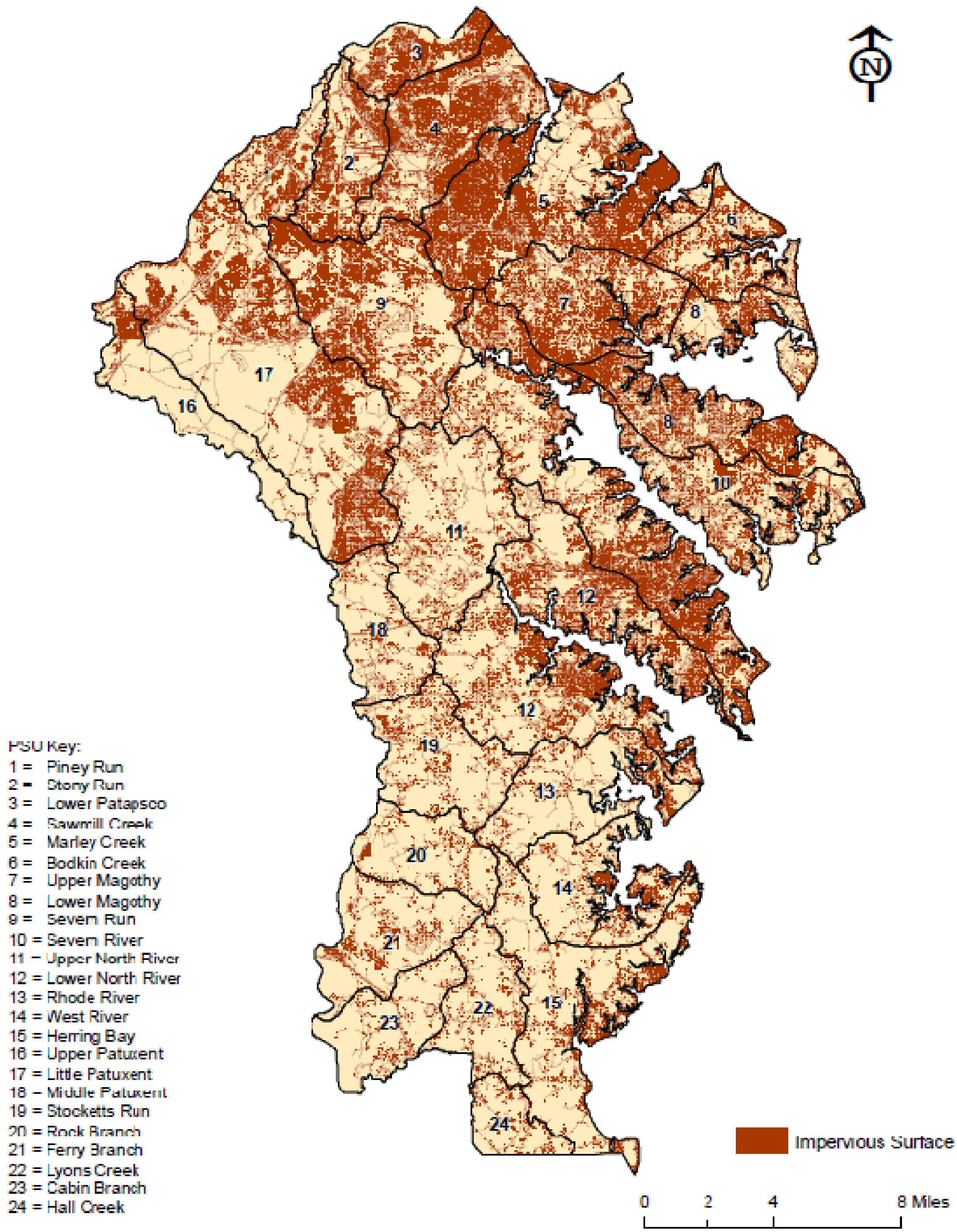

Figure 12. Anne Arundel County Impervious Cover from 2007.

3.2.2 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. A total of four PSUs were rated "Fair" (17%), seventeen were rated "Poor" (71%), and three were rated "Very Poor" (13%; Figure 13). Stocketts Run had the highest mean BIBI score of 3.51, followed by Upper North River (3.34), Ferry Branch (3.20), and Severn River (3.09), all rated "Fair". On the opposite end of the spectrum, West River had the lowest BIBI score of 1.86, followed by Sawmill Creek (1.92), and Rhode River (1.97), all of which were rated "Very Poor**".**

Table 3. Mean BIBI Scores Ordered by Relative Rank for Anne Arundel County PSUs from 2004-2008

PSU	Sample Size	Mean BIBI	Std Dev	Rating	Rank
Stocketts Run	10	3.51	0.87	Fair	1
Upper North River	10	3.34	0.46	Fair	2
Ferry Branch	10	3.20	0.81	Fair	3
Severn River	10	3.09	0.86	Fair	4
Middle Patuxent	10	2.94	0.71	Poor	5
Upper Magothy	10	2.86	0.65	Poor	6
Herring Bay	10	2.80	1.07	Poor	7
Severn Run	10	2.80	0.74	Poor	7
Hall Creek	10	2.77	0.75	Poor	9
Lyons Creek	10	2.77	0.78	Poor	9
Lower Patapsco	10	2.69	0.61	Poor	11
Piney Run	10	2.69	0.80	Poor	11
Lower North River	10	2.63	0.54	Poor	13
Marley Creek	10	2.57	0.54	Poor	14
Bodkin Creek	10	2.43	0.60	Poor	15
Rock Branch	10	2.43	0.97	Poor	15
Stony Run	10	2.37	0.70	Poor	17
Upper Patuxent	10	2.37	0.38	Poor	17
Cabin Branch	10	2.31	0.51	Poor	19
Lower Magothy	10	2.20	0.46	Poor	20
Little Patuxent	10	2.09	0.79	Poor	21
Rhode River	10	1.97	0.34	Very Poor	22
Sawmill Creek	9	1.92	0.40	Very Poor	23
West River	10	1.86	0.30	Very Poor	24

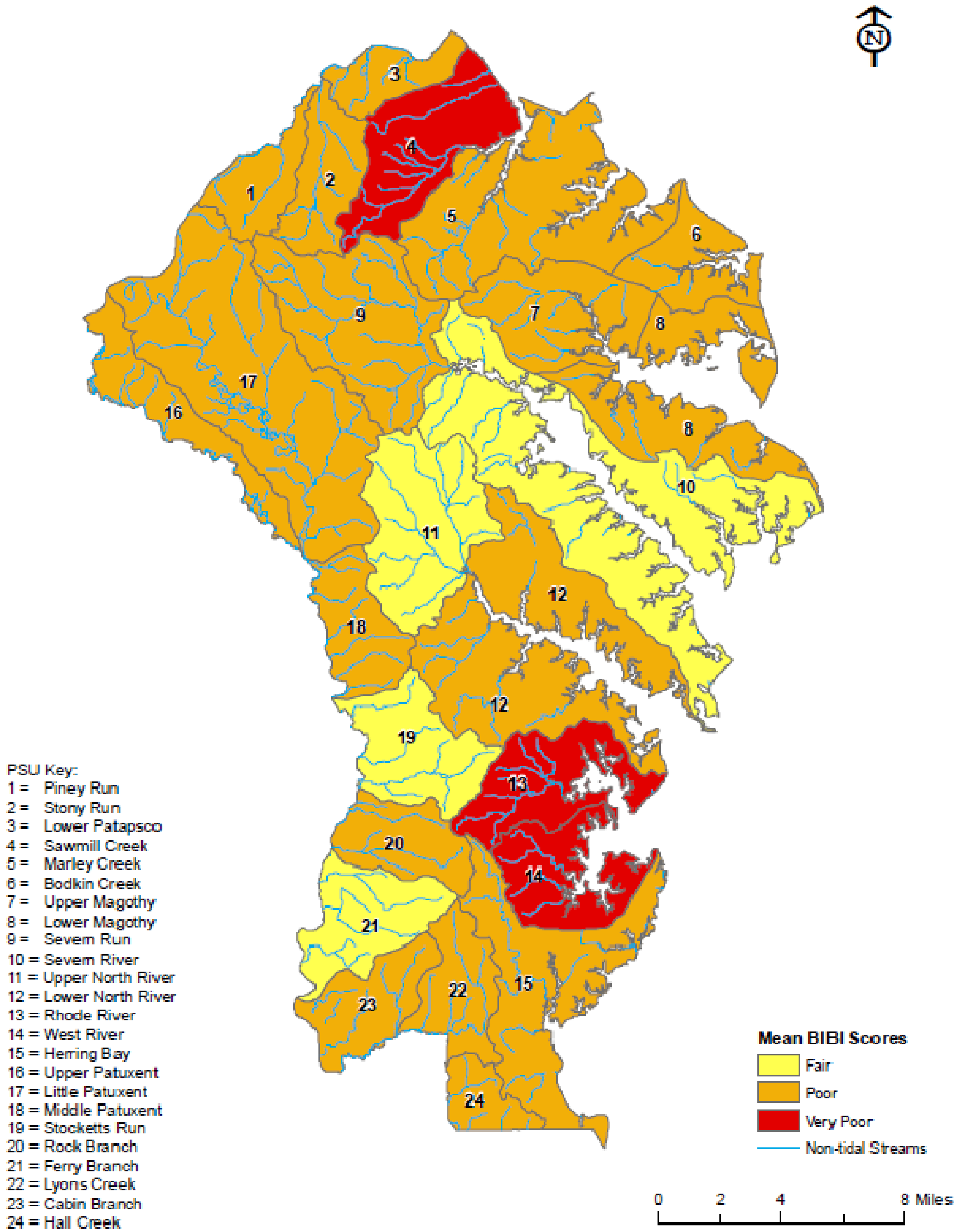

Figure 13. Average Biological Conditions for Primary Sampling Units.

A summary of site-specific biological condition ratings as a percentage of total sites within each PSU is displayed in Figure 14. Four PSUs (Upper North River, Stocketts Run, Severn Run, and Ferry Branch) had at least 10 percent of sites rated "Good" with no sites rated as "Very Poor". Two more PSUs (Severn River and Middle Patuxent) had at least 10 percent of sites rated "Good" with only 10 percent of sites rated as "Very Poor." Conversely, 12 PSUs had ≥ 20 percent of sites rated as "Very Poor" and no sites rated as "Good", three of which had 100 percent of sites rated as either "Poor" or "Very Poor" (West River, Rhode River, and Sawmill Creek).

Box plots showing the distribution of BIBI scores for each PSU are shown in Figure 15. The broadest range of BIBI scores - where the difference between the maximum and minimum values was greater than 2.5 - were observed in Piney Run (PSU 01), Stony Run (02), Severn River (10), Herring Bay (15), Middle Patuxent (18), and Lyons Creek (22) PSUs, indicating greater variability between sites. In contrast, Rhode River (PSU 13) and West River (14) had the smallest range of BIBI scores (i.e., less than 1.0), indicating less variability between sites.

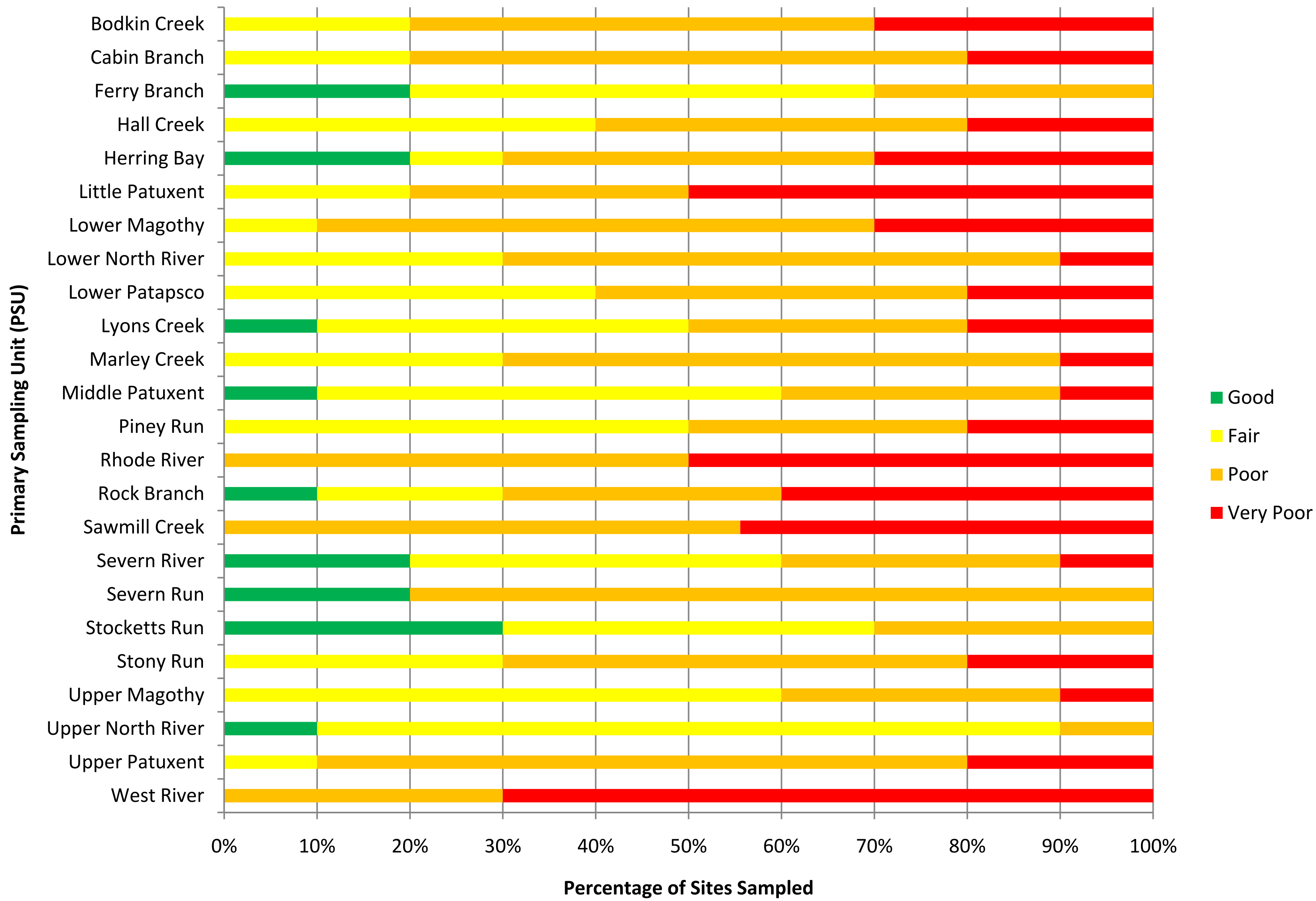

Figure 14. Biological Condition Ratings as a Percentage of Total Sites Within Each PSU.

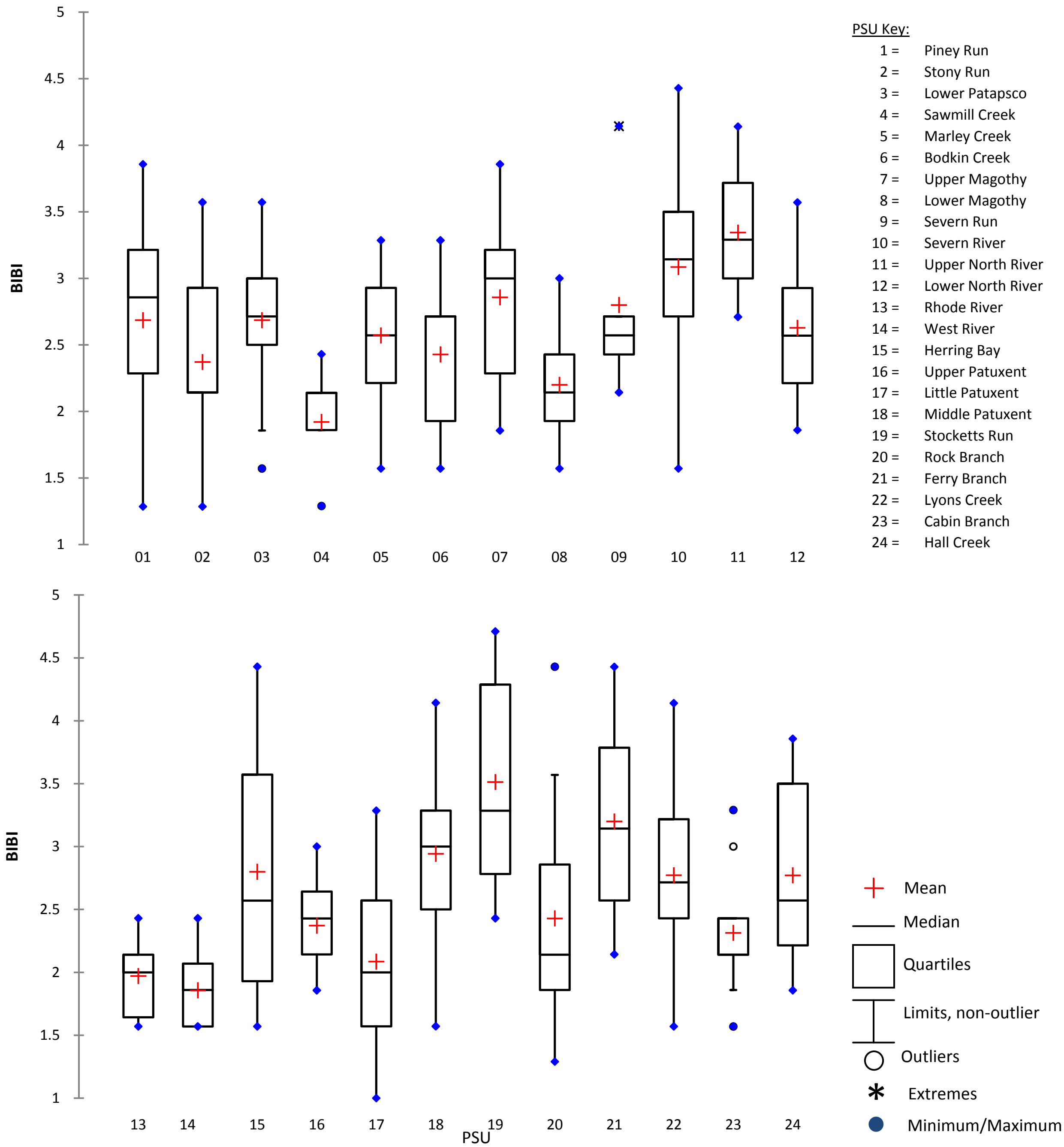

Figure 15. Box Plots of PSU BIBI Scores.

3.2.3 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.

3.2.3.1 RBP Habitat

Mean RBP habitat scores and relative rankings (1 = best, 24 = worst), for each PSU are presented in Table 4. The majority of PSUs, 18 total, were rated as “Partially Supporting”, four were rated “Supporting”, and one each were rated “Comparable” and “Non-supporting” (Figure 16). Ferry Branch had the highest mean RBP score of 153.0, and was the only PSU to receive a physical habitat condition rating of “Comparable”. Rounding out the top five PSUs, Middle Patuxent (RBP = 144.2), Severn River (139.2), Severn Run (136.3) and Bodkin Creek (128.8) were all rated “Supporting”. Conversely, Rhode River received the lowest RBP score of 98.5 and was the only PSU classified as “Non-supporting”. Lower Magothy (101.7), Lyons Creek (103.9), and Rock Branch (104.9), all classified as “Partially Supporting”, were also ranked among the worst PSUs by the RBP habitat index.

Table 4. Mean RBP Habitat Scores Ordered by Relative Rank for Anne Arundel County PSUs from 2004-2008

PSU	Sample Size	Mean RBP	Std Dev	Rating	Rank
Ferry Branch	10	153.0	15.1	Comparable	1
Middle Patuxent	10	144.2	11.1	Supporting	2
Severn River	10	139.2	25.4	Supporting	3
Severn Run	10	136.3	22.0	Supporting	4
Bodkin Creek	10	128.8	26.0	Supporting	5
Lower Patapsco	10	123.8	17.8	Partially Supporting	6
Lower North River	10	119.2	19.3	Partially Supporting	7
Upper Patuxent	10	117.0	14.8	Partially Supporting	8
West River	10	114.5	9.8	Partially Supporting	9
Cabin Branch	10	114.3	16.8	Partially Supporting	10
Stocketts Run	10	114.2	17.6	Partially Supporting	11
Upper Magothy	10	113.3	16.8	Partially Supporting	12
Piney Run	10	109.1	10.0	Partially Supporting	13
Sawmill Creek	10	108.9	18.2	Partially Supporting	14
Upper North River	10	107.8	10.2	Partially Supporting	15
Marley Creek	10	107.0	18.4	Partially Supporting	16
Hall Creek	10	106.0	16.1	Partially Supporting	17
Herring Bay	10	105.2	12.9	Partially Supporting	18
Stony Run	10	105.1	8.4	Partially Supporting	19
Little Patuxent	10	105.0	10.7	Partially Supporting	20
Rock Branch	10	104.9	11.4	Partially Supporting	21
Lyons Creek	10	103.9	15.1	Partially Supporting	22
Lower Magothy	10	101.7	8.6	Partially Supporting	23
Rhode River	10	98.5	16.9	Non-supporting	24

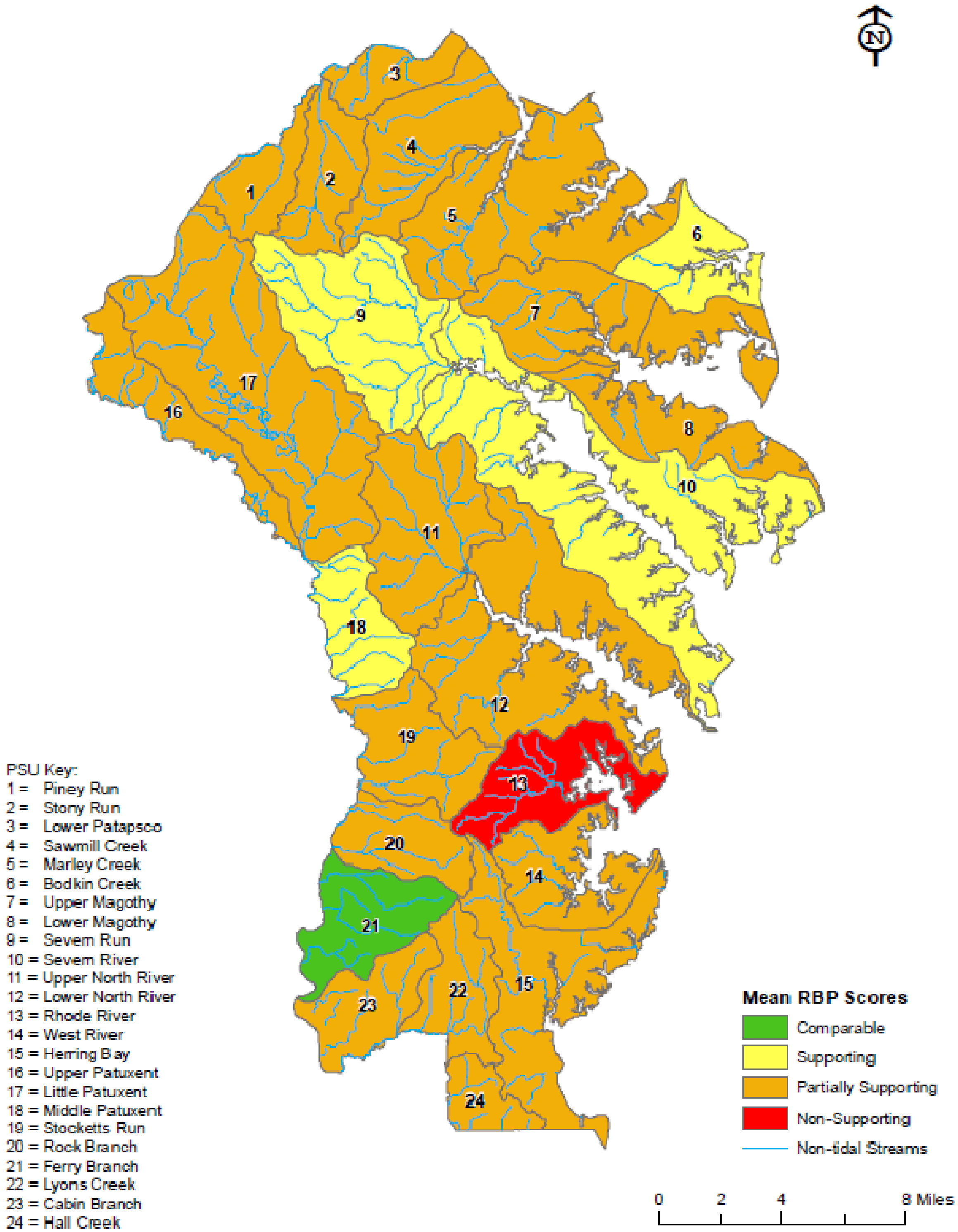

Figure 16. Average RBP Physical Habitat Conditions for Primary Sampling Units.

A summary of site-specific physical habitat conditions, as a percentage of total sites within each PSU, is displayed in Figure 17. Only three PSUs (Ferry Branch, Middle Patuxent, and Severn River), had all sites rated as either “Comparable”, “Supporting”, or “Partially Supporting”. Bodkin Creek, Lower North River, and Severn Run were the only other PSUs to have at least 10% of sites rated as “Comparable”. On the other hand, seven PSUs (Stony Run, Lyons Creek, Rhode River, Lower Magothy, Little Patuxent, Piney Run and Upper North River) had all sites rated as either “Non-supporting” or “Partially Supporting”. Of those PSUs, Rhode River, and Lower Magothy has the largest proportion of sites (60%) rated as “Non-supporting”.

Figure 18 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 Stony Run (PSU = 02), West River (14), Lower Magothy (08), and Upper North River (11). The broadest range of RBP scores (i.e., greater than 70 points between lowest and highest scores) were observed in Bodkin Creek (PSU 06), Severn Run (09), and Severn River (10) PSUs; however, the minimum values in Bodkin Creek and Severn Run PSUs were determined to be a outliers based on the quartile distributions in each PSU.

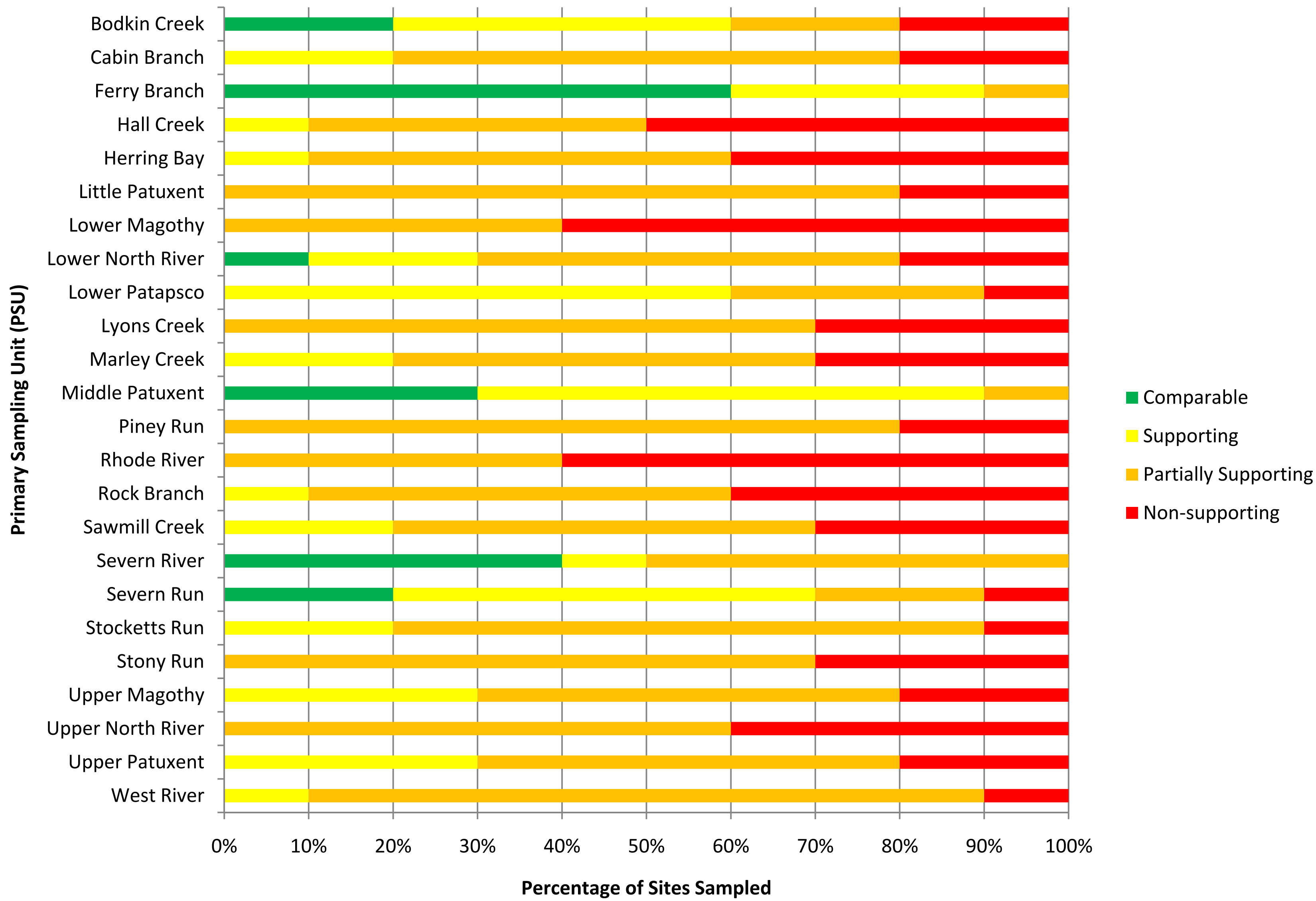

Figure 17. RBP Physical Habitat Conditions as a Percentage of Total Sites Within Each PSU

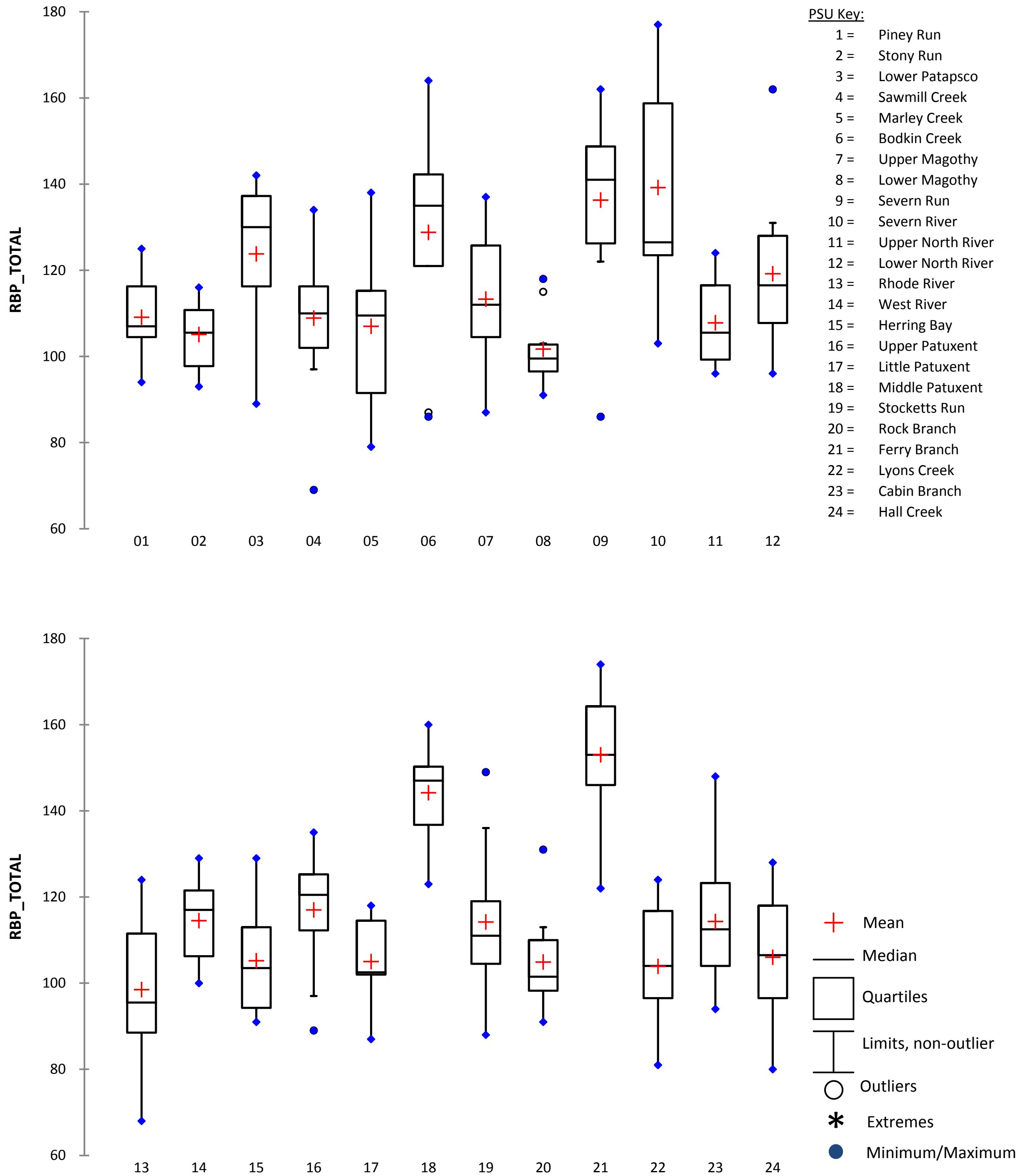

Figure 18. Box Plot of PSU RBP Scores.

3.2.3.2 PHI Habitat

Physical habitat conditions of streams in Anne Arundel County are 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. Twelve PSUs were rated as “Partially Degraded”, 11 were considered “Degraded”, and only one PSU was rated “Minimally Degraded” (Figure 19). Ferry Branch had the highest mean PHI score of 86.72 and was rated “Minimally Degraded”, followed by Middle Patuxent (PHI = 79.15) and Severn River (PHI = 77.24) both classified as “Partially Degraded”. The lowest PHI score of 57.68 occurred in Sawmill Creek, which was classified as “Degraded”. Stony Run (58.66), Lower Magothy (58.67), and Piney Run (58.72), all classified as “Degraded”, round out the worst rated PSUs.

Table 5. Mean Physical Habitat Index Scores Ordered by Relative Rank for Anne Arundel County PSUs from 2004-2008

PSU	Sample Size	Mean PHI	Std Dev	Rating	Rank
Ferry Branch	10	86.72	5.61	Minimally Degraded	1
Middle Patuxent	10	79.15	6.68	Partially Degraded	2
Severn River	10	77.24	12.14	Partially Degraded	3
Severn Run	10	75.96	8.10	Partially Degraded	4
Upper Patuxent	10	75.88	12.97	Partially Degraded	5
Bodkin Creek	9	72.81	12.08	Partially Degraded	6
West River	10	70.09	5.66	Partially Degraded	7
Stocketts Run	10	68.99	10.12	Partially Degraded	8
Rock Branch	10	67.81	6.77	Partially Degraded	9
Hall Creek	10	67.27	9.09	Partially Degraded	10
Lower Patapsco	10	67.14	11.79	Partially Degraded	11
Upper North River	10	66.75	10.01	Partially Degraded	12
Cabin Branch	8	66.62	6.38	Partially Degraded	13
Upper Magothy	10	65.22	8.04	Degraded	14
Lower North River	10	64.98	8.49	Degraded	15
Marley Creek	10	63.88	7.48	Degraded	16
Little Patuxent	10	62.91	7.80	Degraded	17
Rhode River	9	62.54	9.00	Degraded	18
Lyons Creek	10	62.31	12.06	Degraded	19
Herring Bay	10	60.17	9.41	Degraded	20
Piney Run	10	58.72	14.01	Degraded	21
Lower Magothy	10	58.67	6.01	Degraded	22
Stony Run	10	58.66	7.92	Degraded	23
Sawmill Creek	9	57.68	16.27	Degraded	24

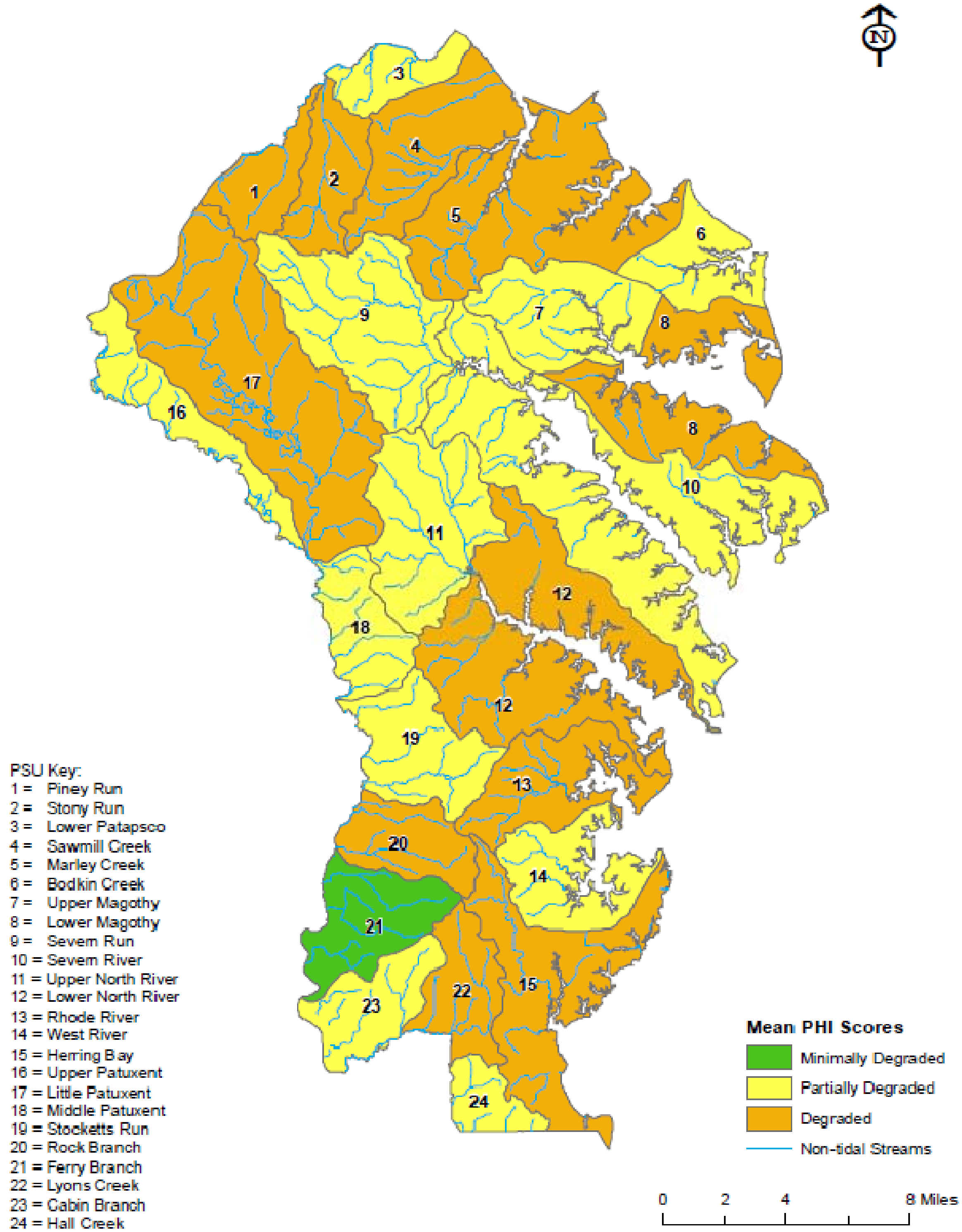

Figure 19. Average PHI Physical Habitat Conditions for Primary Sampling Units.

A summary of site-specific physical habitat conditions, as a percentage of total sites within each PSU, is displayed in Figure 20. Only two PSUs (Ferry Branch and Middle Patuxent), had all sites rated as either “Minimally Degraded” or “Partially Degraded”. Five more PSUs (Bodkin Creek, Stocketts Run, Severn Run, and Severn River, and West River) had at least 10 percent of sites rated “Minimally Degraded” and no sites rated as “Severely Degraded”. In contrast, 10 PSUs had at least 10% of sites rated as “Severely Degraded” and no sites rated as “Minimally Degraded”.

Box plots displaying the distribution of PHI scores within each PSU are included in Figure 21. The broadest range of PHI scores (i.e., the difference between the maximum and minimum values was greater than 40) were observed in Sawmill Creek (PSU 04), Bodkin Creek (06), and Lyons Creek (22) PSUs; however, the minimum value in Lyons Creek was determined to be an extreme outlier based on the distribution of data in that PSU. The smallest range of PHI scores (i.e., less than 20) were observed in Marley Creek (05), West River (14), Rock Branch (20), Ferry Branch (21), and Cabin Branch(23), indicating less variability between sites.

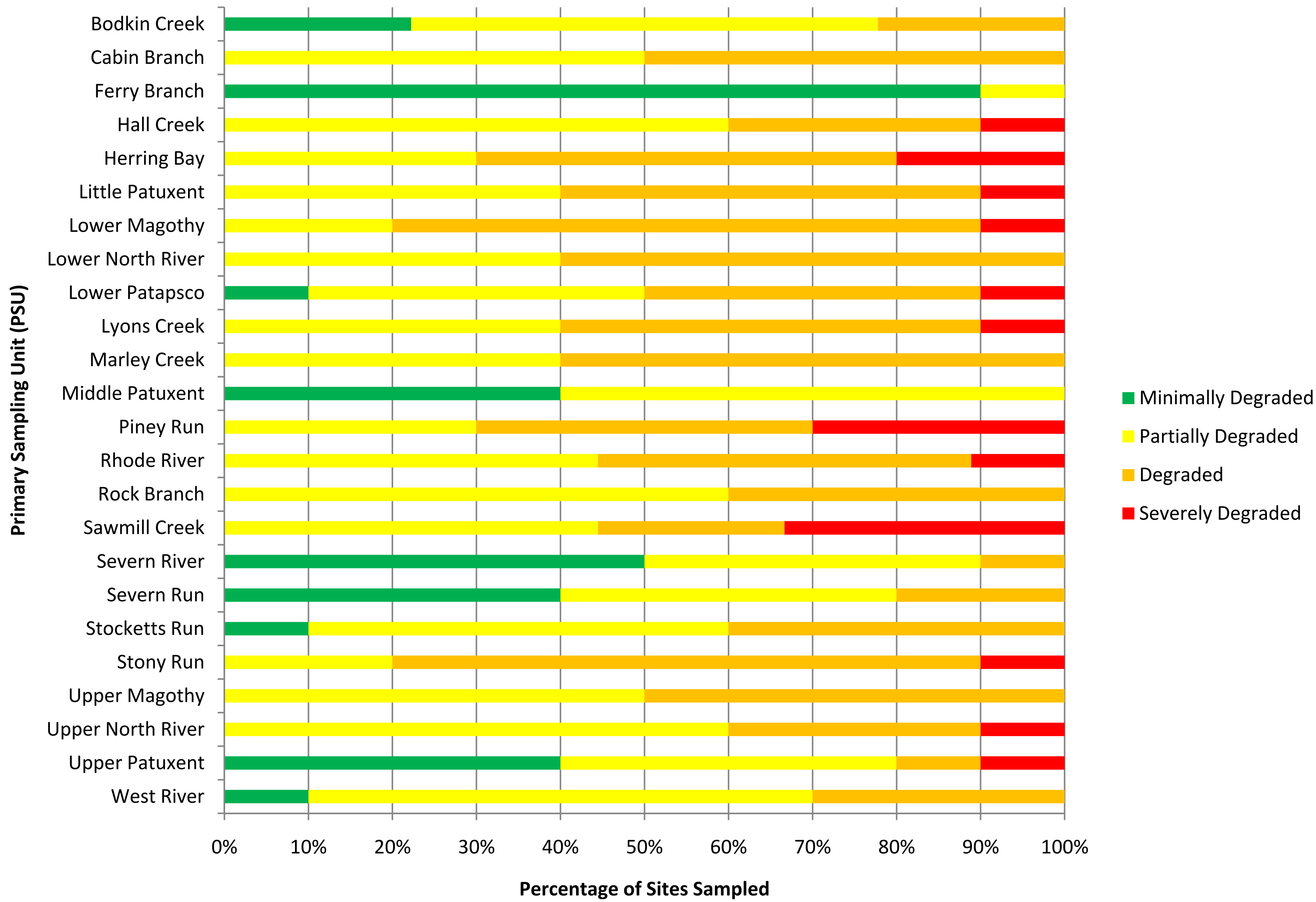

Figure 20. PHI Physical Habitat Conditions as a Percentage of Total Sites Within Each PSU.

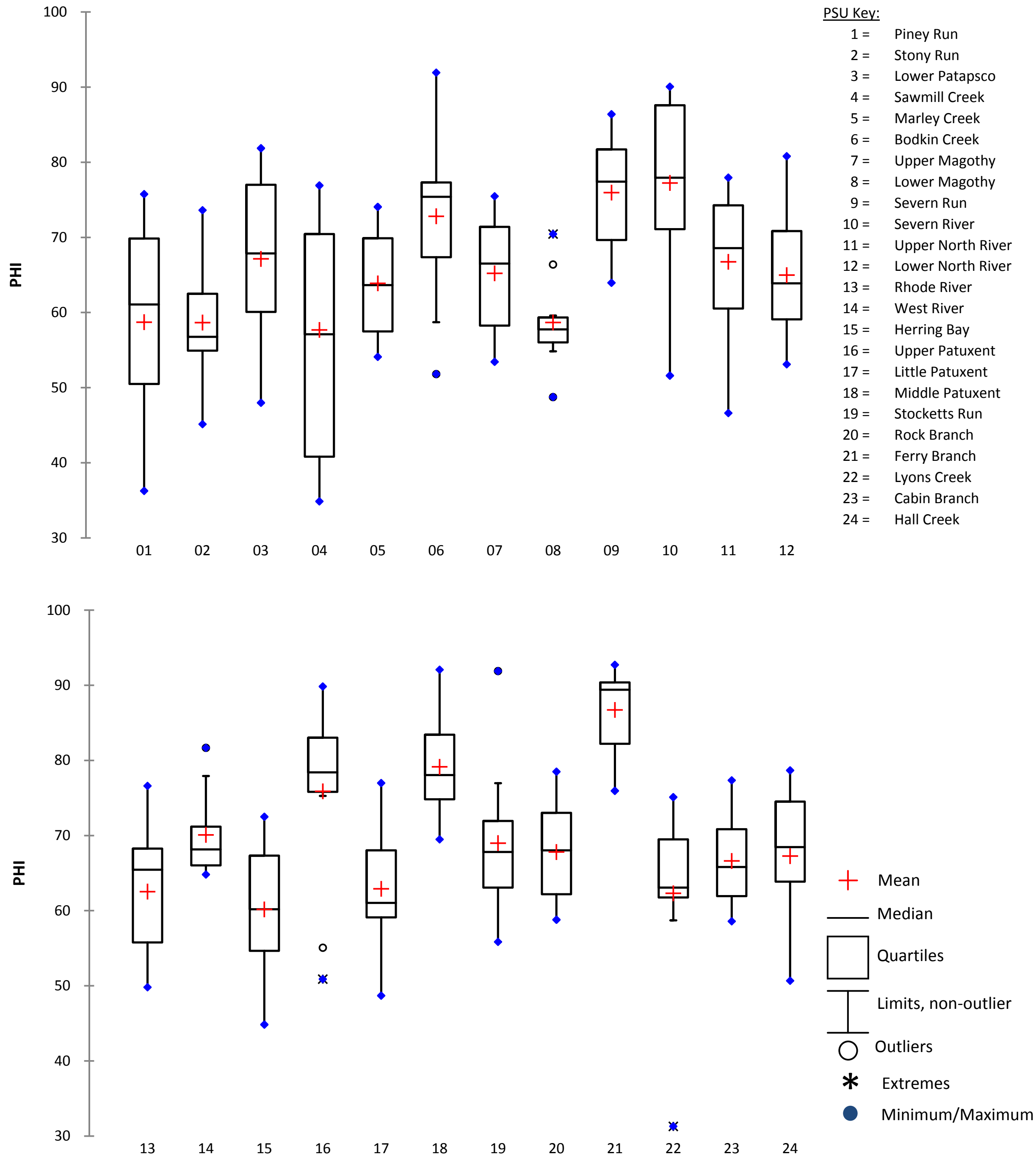

Figure 21. Box plot of PSU PHI Scores.

3.2.4 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 in 2004 and 2005. 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.

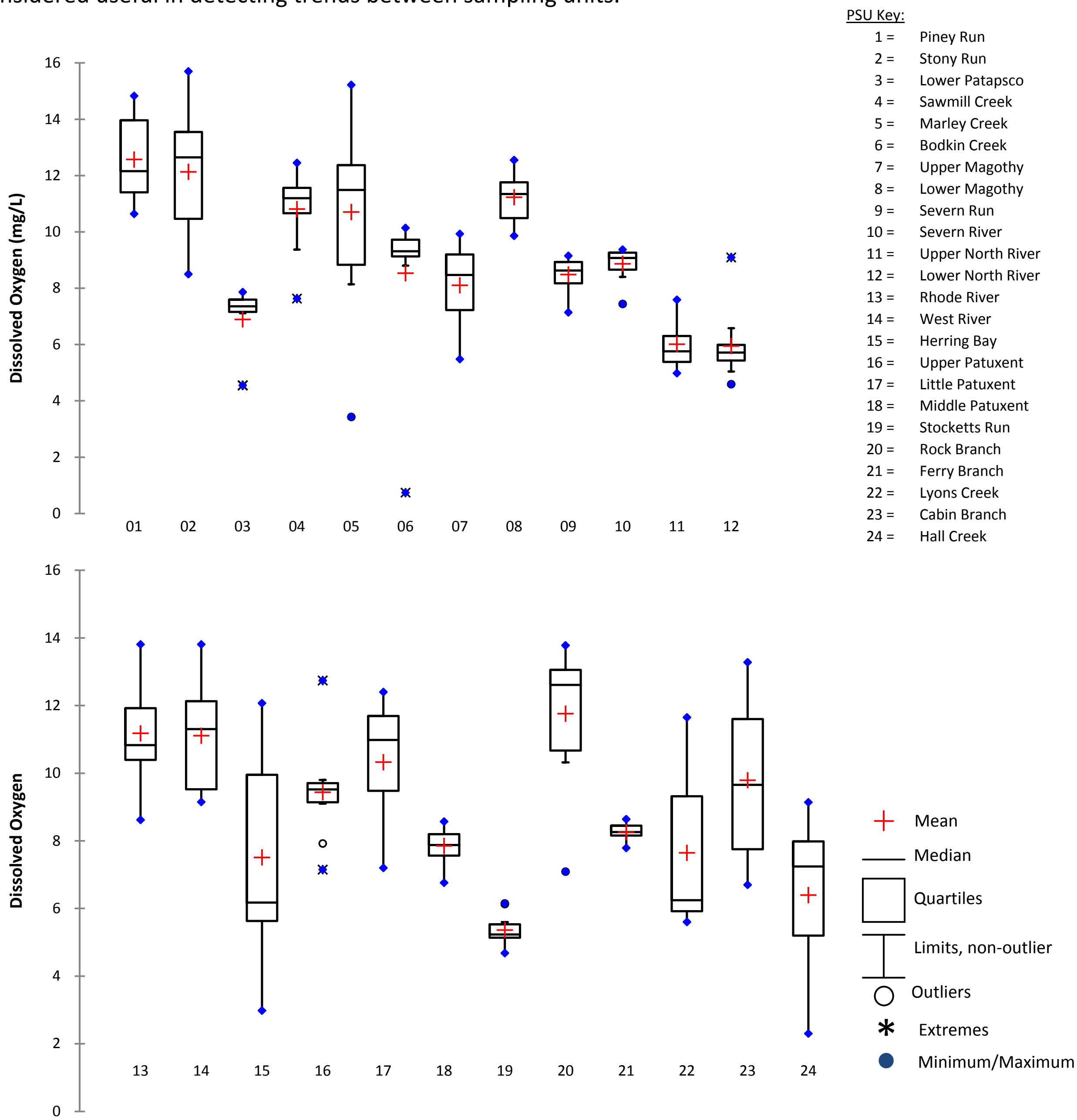

Figure 22. Box Plot of Dissolved Oxygen Values for Each PSU.

A comparison of DO values both within and across PSUs shows a broad range of values as well as numerous outliers and extreme outliers (Figure 22). For example, DO values in Herring Bay (PSU 15) ranged from a minimum of 2.98 mg/L to a maximum of 12.07 mg/L. Several 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 the following PSUs; Lower Patapsco, Sawmill Creek, Bodkin Creek, Severn River, Upper North River, Herring Bay, Stocketts Run, and Hall Creek. However, it should be noted that low DO values in Lower Patapsco, Marley Creek, and Bodkin Creek PSUs, were considered outliers or 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, and 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 23. However, it should be noted that 2007 data (Piney Run, Stony Run, Lower Magothy, Upper Patuxent, and Little Patuxent PSUs) have been omitted because they did not meet the project's data quality objectives. In general, the majority of PSUs were acidic (pH < 7), with only four PSUs (Lower Patapsco, Sawmill Creek, Middle Patuxent, and Ferry Branch) having mean pH values above 7.0. A total of ten PSUs (Marley Creek, Bodkin Creek, Upper Magothy, Upper North River, Rhode River, West River, Herring Bay, Stocketts Run, Rock Branch, and Lyons Creek) had mean pH values at or below 6.5, which is the minimum threshold stated in COMAR (2010; Figure 24). 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.

Conductivity values were fairly consistent for the majority of PSUs, with the majority of mean values falling between the range of 100 µS/cm and 300 µS/cm (Figure 25). However, several PSUs (Piney Run, Stony Run, and Lower Magothy) had mean conductivity values that exceeded 600 µS/cm and non-outlier values exceeding 1000 µS/cm. Values exceeding 1000 µS/cm were also observed in Lower Patapsco and Sawmill Creek; however, those measurements were considered outliers based on the quartile distributions. It should also be noted that one extreme outlier value of 4384 µS/cm (PSU 08) was removed from the data set in order to avoid skewing the overall scale of the box plot. 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 26).

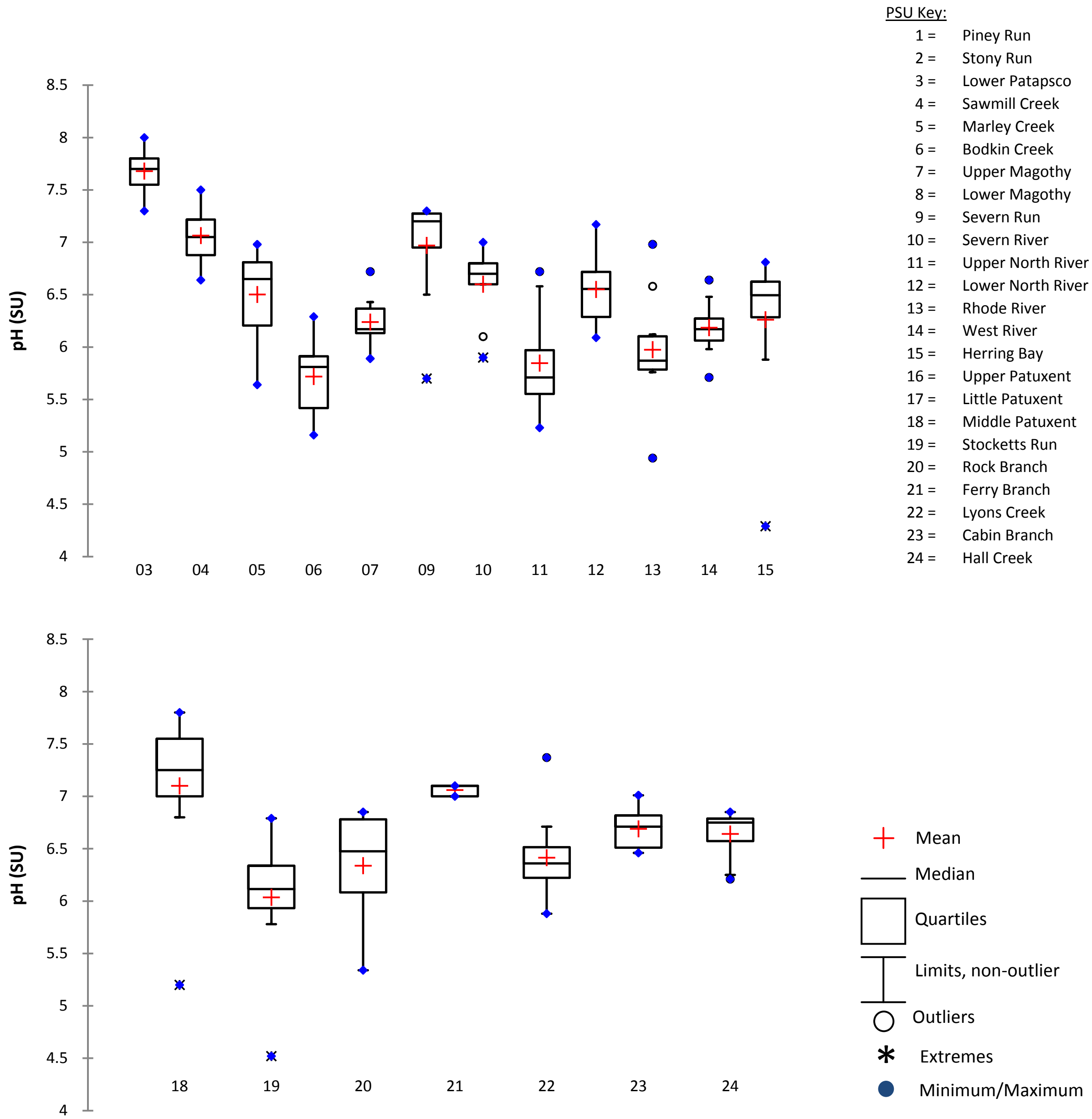

Figure 23. Box Plot pH Values for Each PSU.

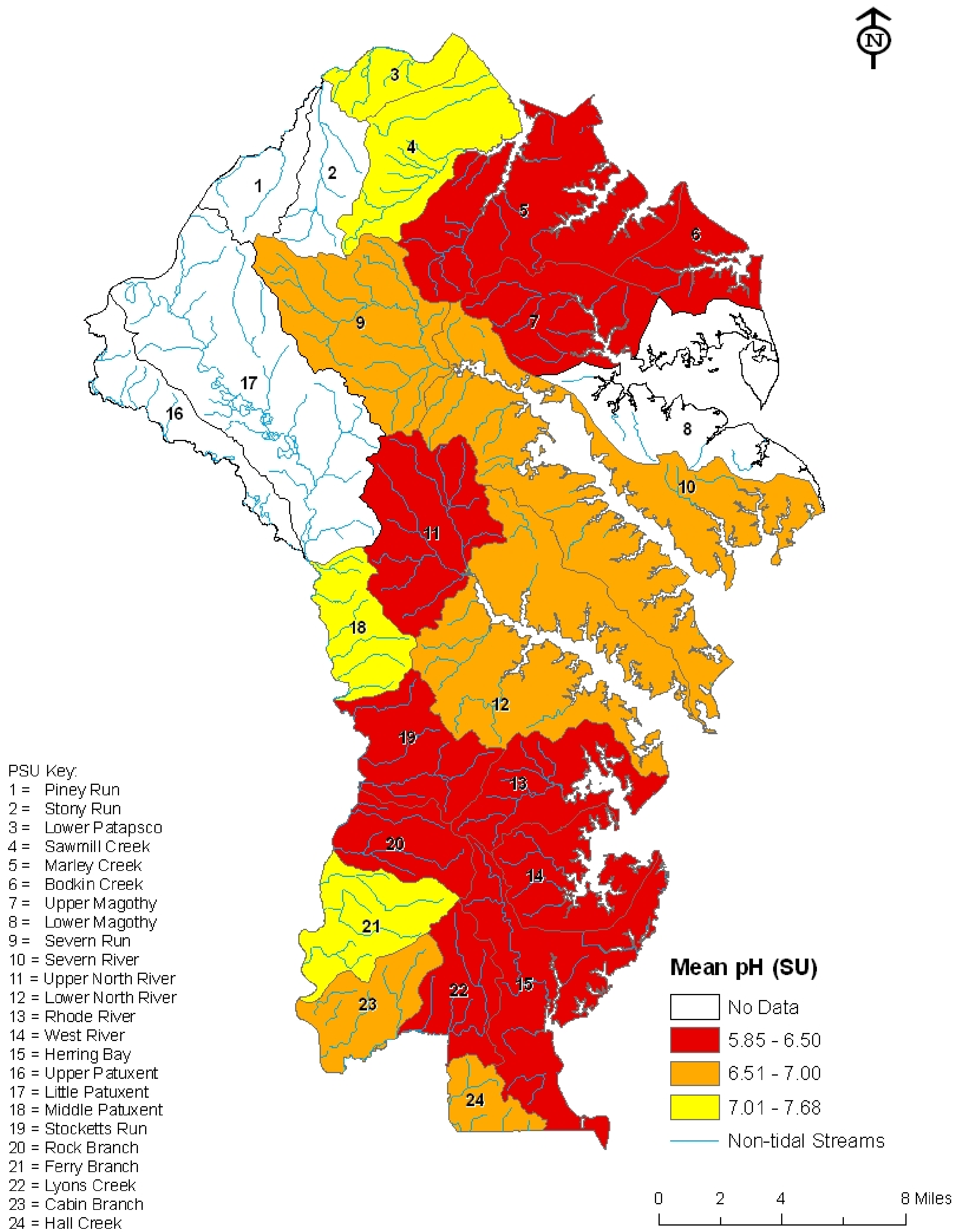

Figure 24. Average pH Values for Primary Sampling Units.

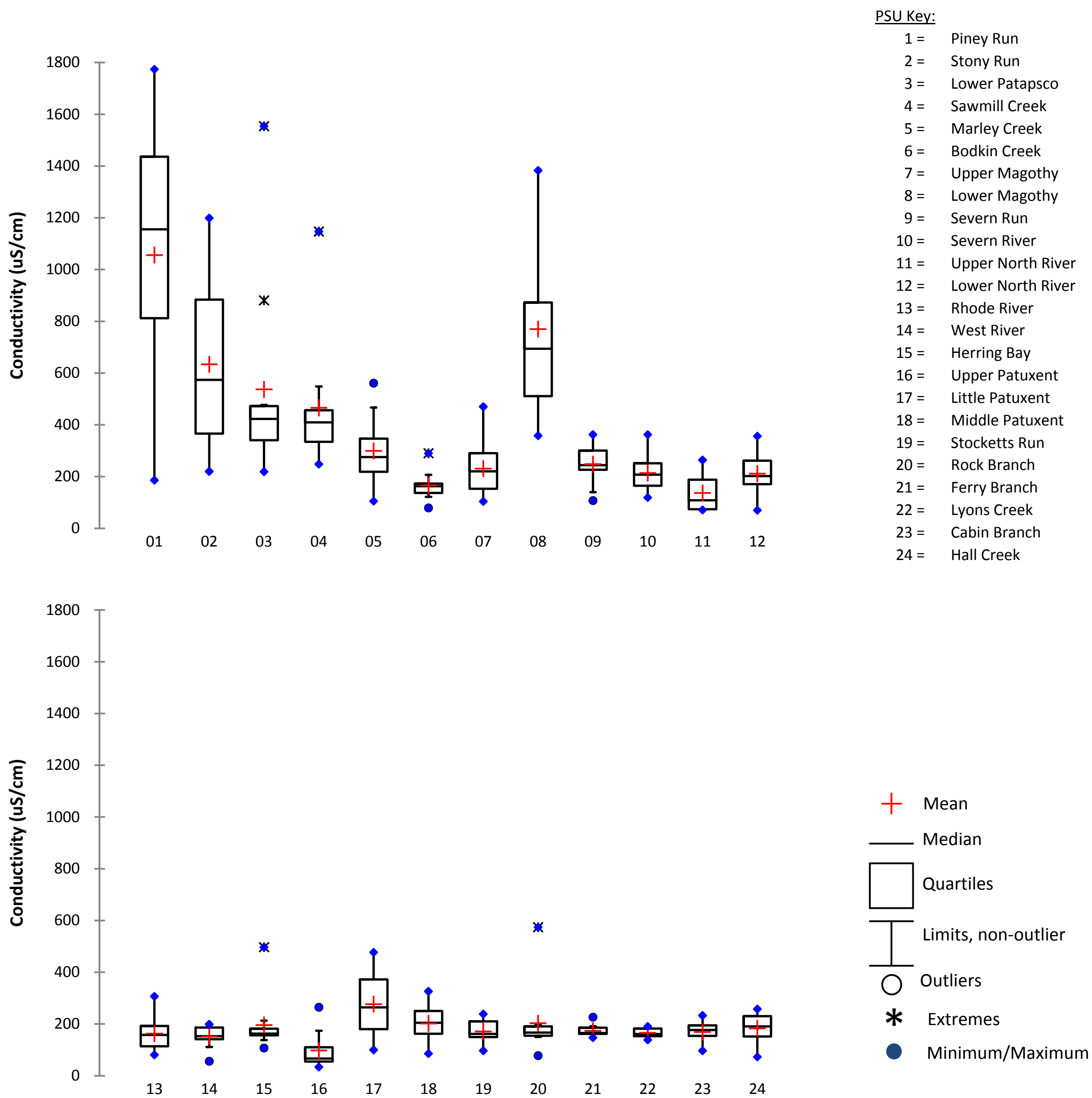

Figure 25. Box Plot of Specific Conductivity Values for Each PSU.

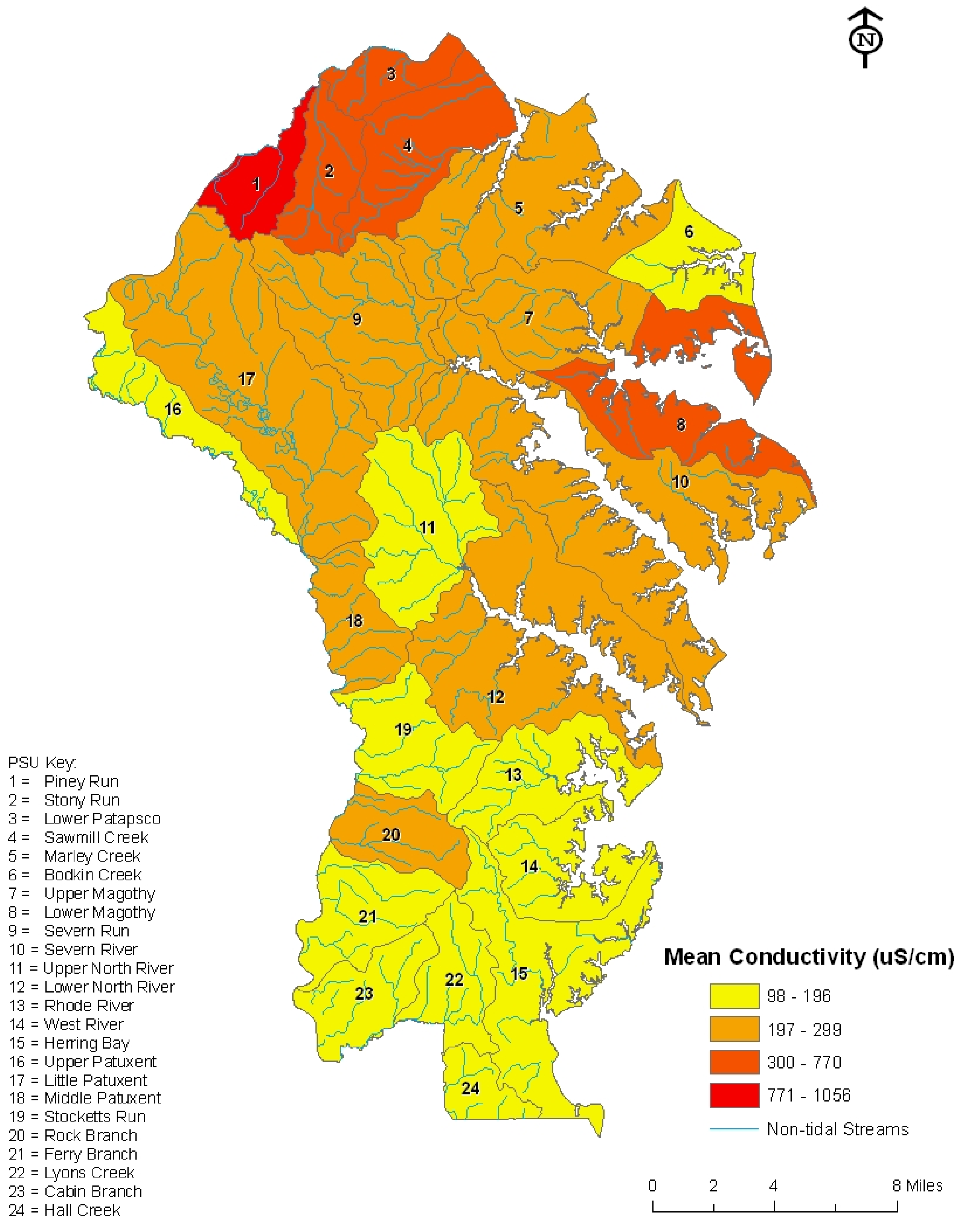

Figure 26. Average Conductivity Values for Primary Sampling Units.

3.2.5 Fluvial Geomorphology

The proportion of Rosgen stream types within each PSU is presented in Figure 27. 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, Herring Bay, Lower Magothy, Marley Creek, Sawmill Creek, Stony Run, Upper Magothy, and West River PSUs, where they comprised at least 50% of sites sampled. The "B" type channel was most frequently observed in the Lower North River PSU of the South River watershed. Although dominated by "E" channels, Stony Run also had the highest percentage of "C" type channels at 40%. While "F" type channels were the least common stream type observed, a large proportion of sites designated as "F" channels (60%) occurred in Stocketts Run. "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 Cabin Branch, Hall Creek, and Rock Branch PSUs. The "G" type channel was also the predominant stream type identified in Lyons Creek PSU.

Figure 28 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 both the Maryland Coastal Plain (MCP) regional relationships of bankfull channel geometry (McCandless, 2003) and the relationship for urban streams developed specifically for Anne Arundel County (AADPW, 2002) in order to determine how bankfull characteristics observed in the field compare to those predicted by the MCP and urban curves. Comparisons of bankfull cross-sectional area, bankfull width, and mean bankfull depth are shown in Figures 29, 30, and 31, respectively. Bankfull cross-sectional area values indicate that the majority of field data points fall in between the MCP curve and urban curves, but that the trendline more 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 tended to fall in between the two curves, but the overall trendline more closely resembled the MCP predictions where drainage area exceeds two square miles. Field data of mean bankfull depth, on the other hand, were far more variable with many points falling both above and below the MCP and urban curves. While the field data trended more toward the MCP curve, the data were a relatively poor fit for the trendline (R^2 = 0.4004), even for sites draining more than two square miles. This 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 dimensions were more often slightly larger than the MCP predictions yet much smaller than urban curve predictions.

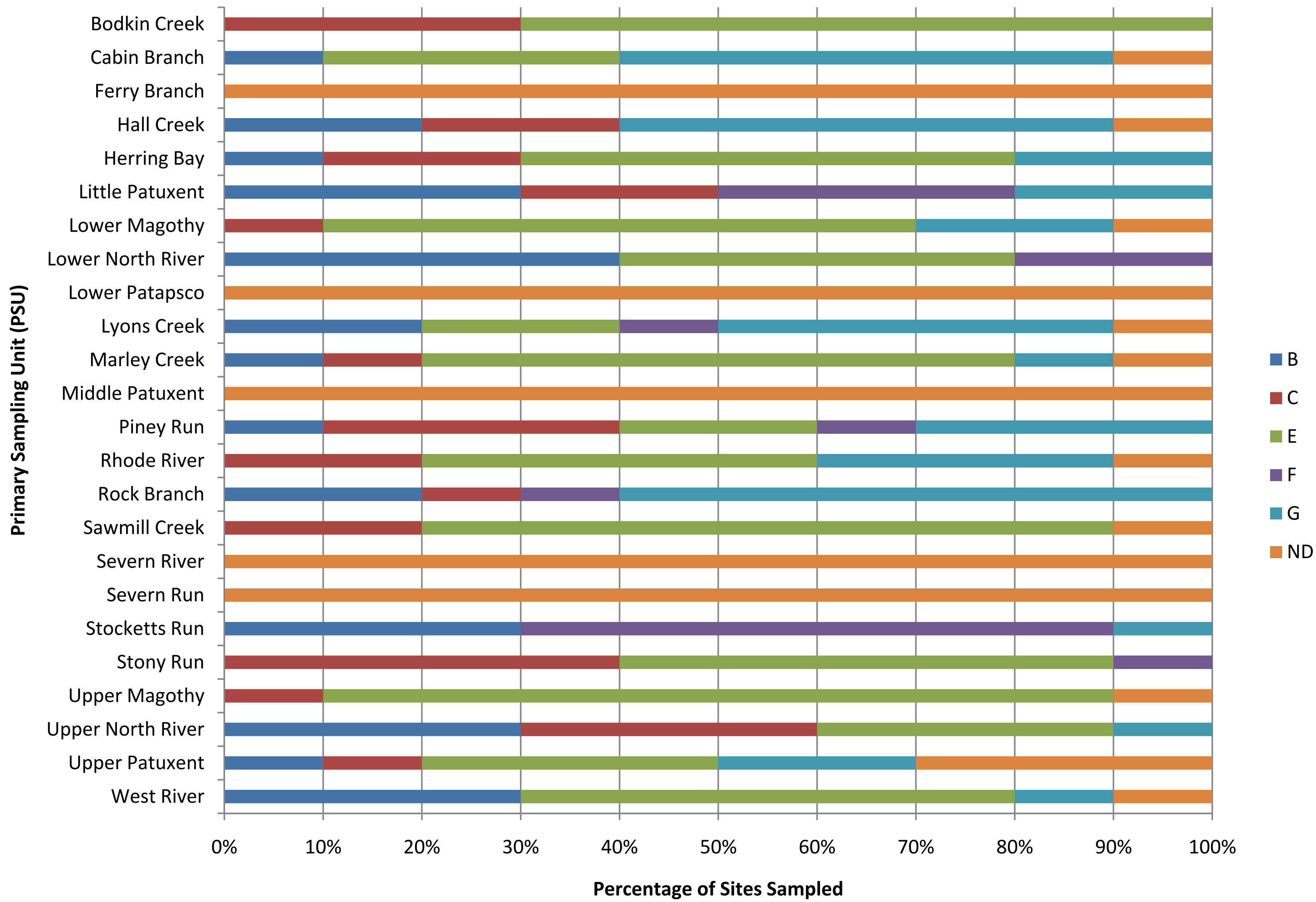

Figure 27. Proportion of Rosgen stream types identified within each PSU. ND indicates that Rosgen stream type was not determined.

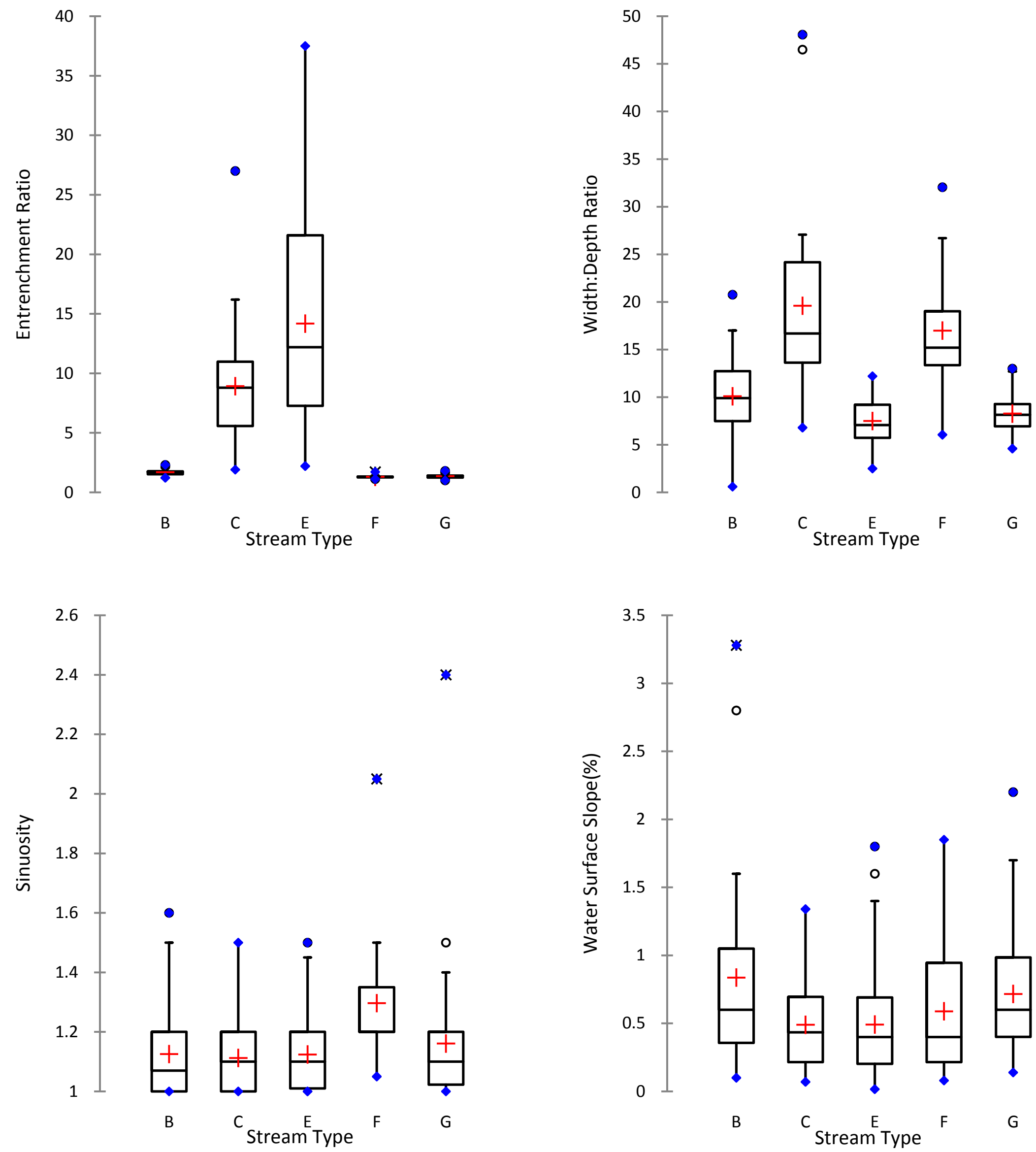

Figure 28. Box Plots of Geomorphic Parameters Used for Rosgen Stream Classification.

The differences between field measured bankfull dimensions and the MCP and urban curve predictions is somewhat expected considering the County has more suburban/rural land use, compared to urban land use, and many drainage areas have a mix of urban and suburban/rural characteristics. 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.

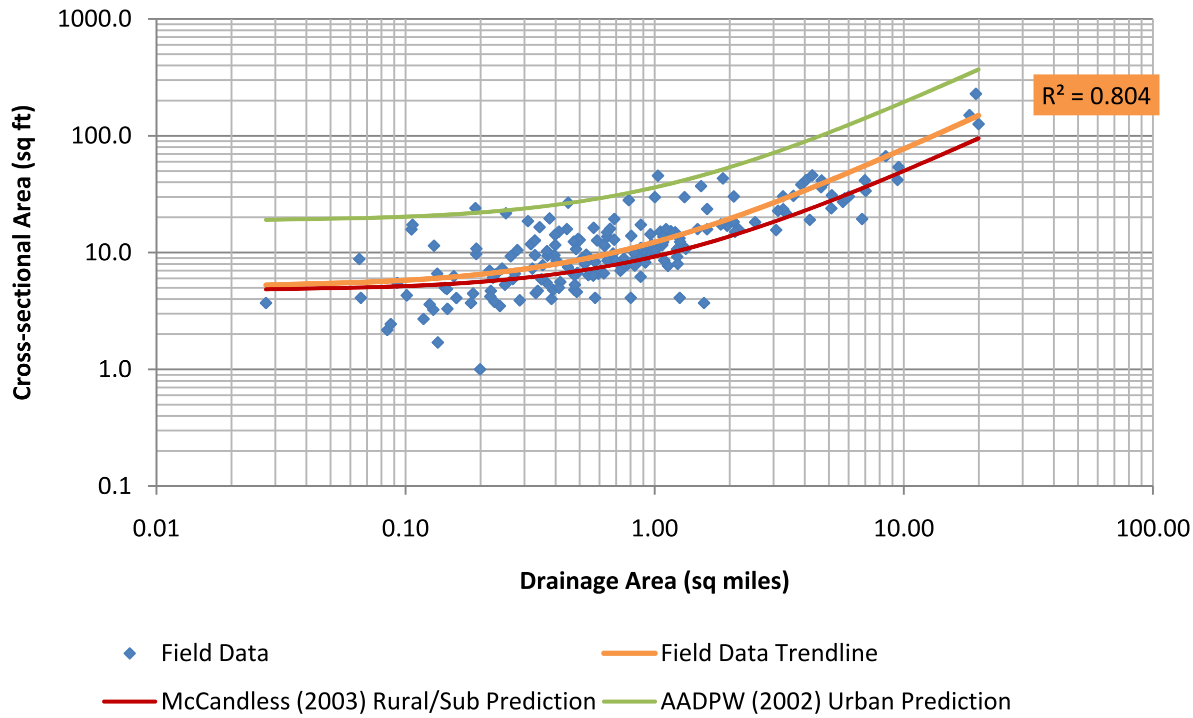

Figure 29. Comparison of the Bankfull Cross-Sectional Area - Drainage Area Relationship between Field Data and Regional Relationship Curve Data.

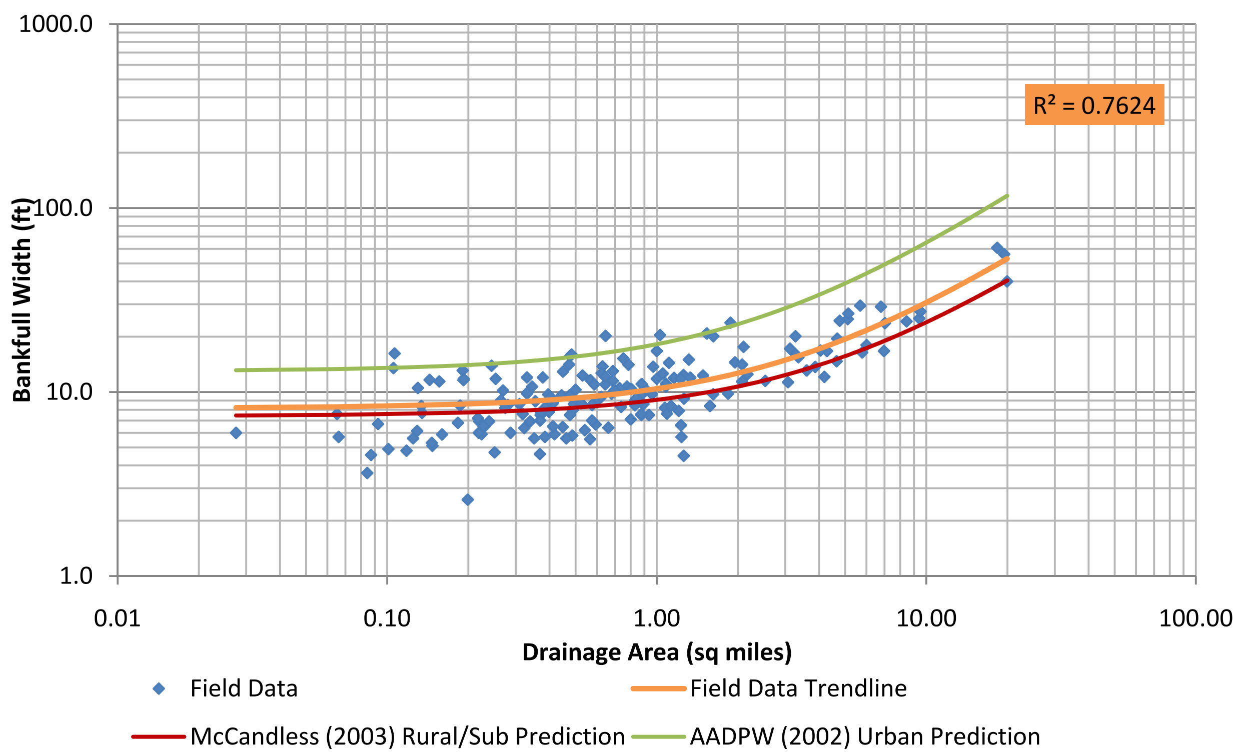

Figure 30. Comparison of the Bankfull Width - Drainage Area Relationship between Field Data and Regional Relationship Curve Data.

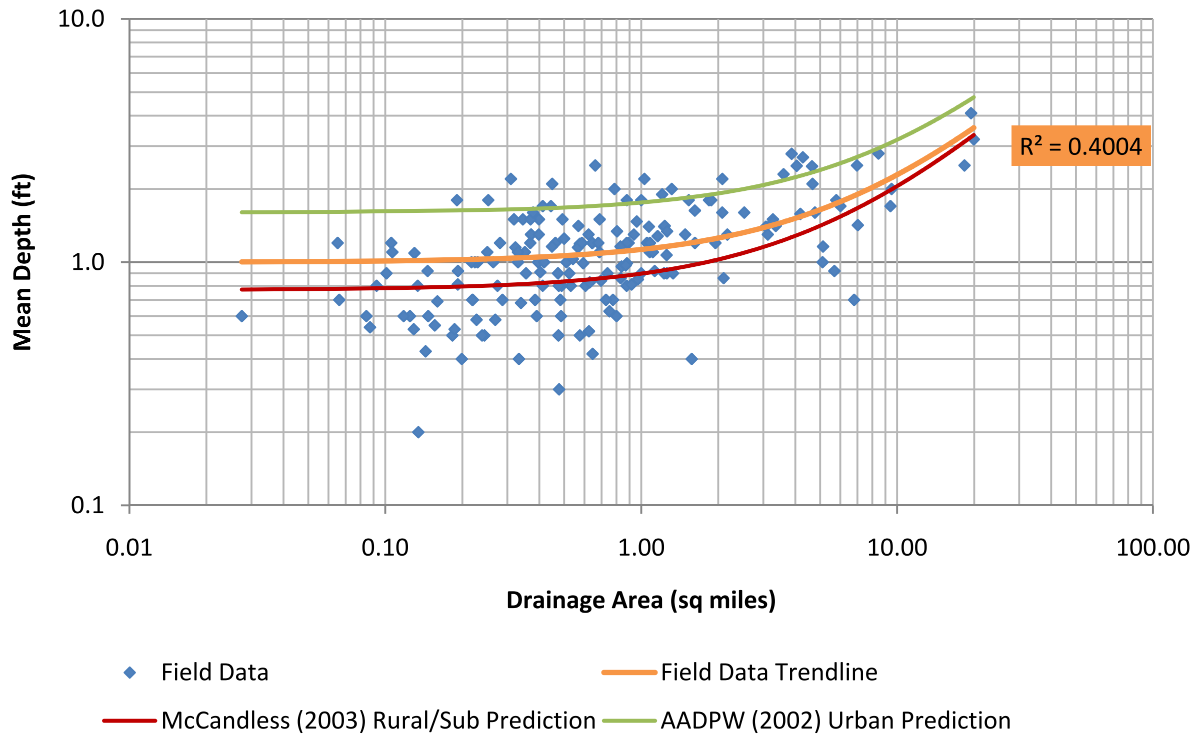

Figure 31. Comparison of the Mean Bankfull Depth - Drainage Area Relationship between Field Data and Regional Relationship Curve Data.

3.2.6 Land Use/Land Cover and Imperviousness

Results of land use analysis by land use class and percent imperviousness for each PSU is presented in Section 4.2.1 *Primary Sampling Unit Characterization*. Complete land cover data for each PSU is included in Appendix A. Within each PSU, the dominant land use type representing each site sampled is shown, as a percentage of total sites, in Figure 32. One hundred percent of sites sampled in Upper Magothy, Stony Run, and Lower Magothy were predominantly developed land use. Eighty percent of sites in Bodkin Creek, Lower Patapsco, and Marley Creek were also dominated by developed land use. Two PSUs, Herring Bay and Upper Patuxent, had 100% of sites dominated by forested land use. Additionally, three PSUs had 90% of sites that were predominantly forested (West River, Upper North River, and Piney Run). Sixty percent of sites in Lyons Creek were dominated by agricultural land use, followed by 50% in Middle Patuxent and 40% in Hall Creek. The proportions of dominant land use types sampled differ slightly from the proportions that characterize each PSU, as shown in Figure 10 in Section 3.2.1, 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.

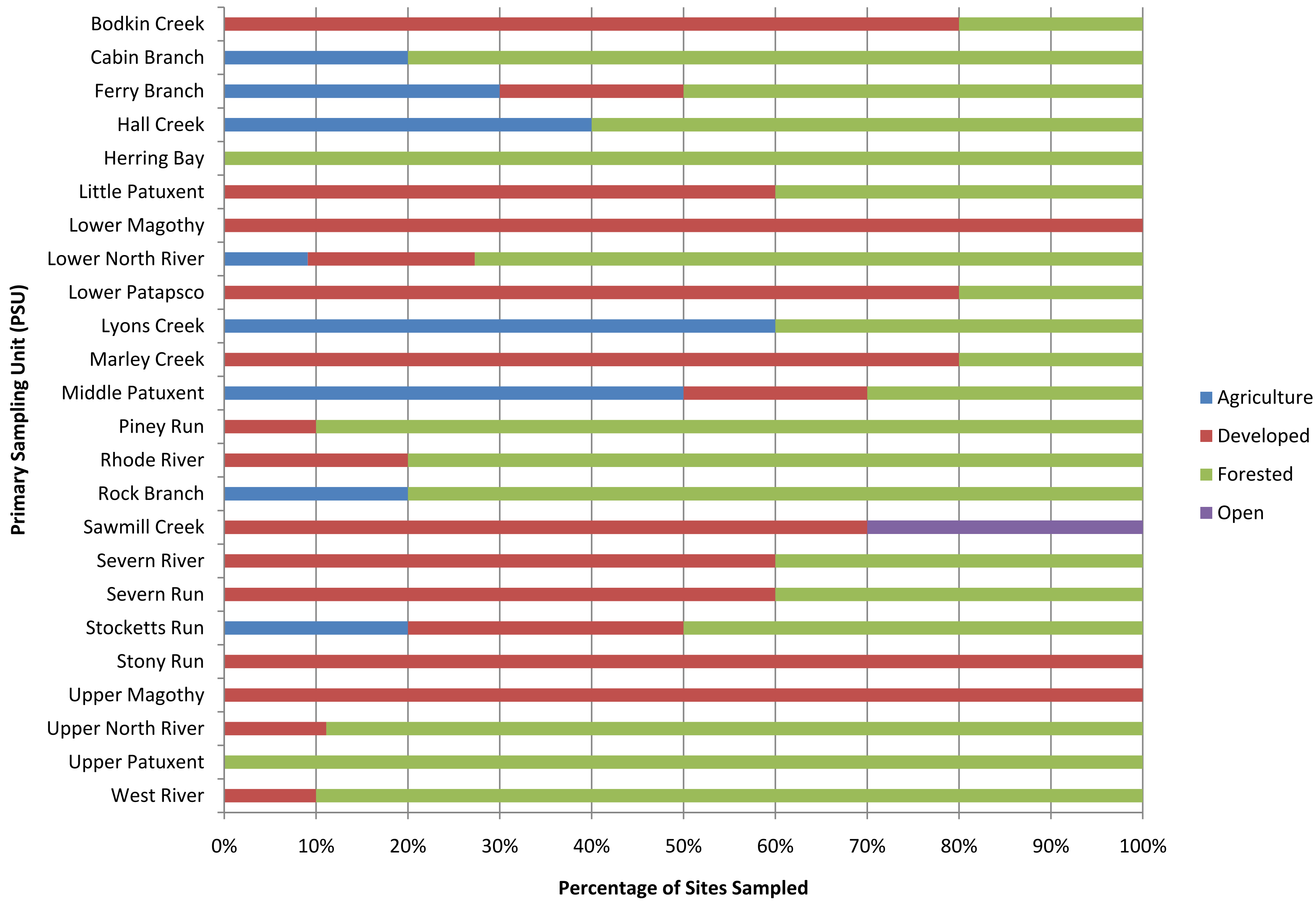

Figure 32. Dominant Land Use Draining to Each Site as a Proportion of Total Sites Sampled in Each PSU.

4 Data Analysis

4.1 Exploratory Trend Analysis

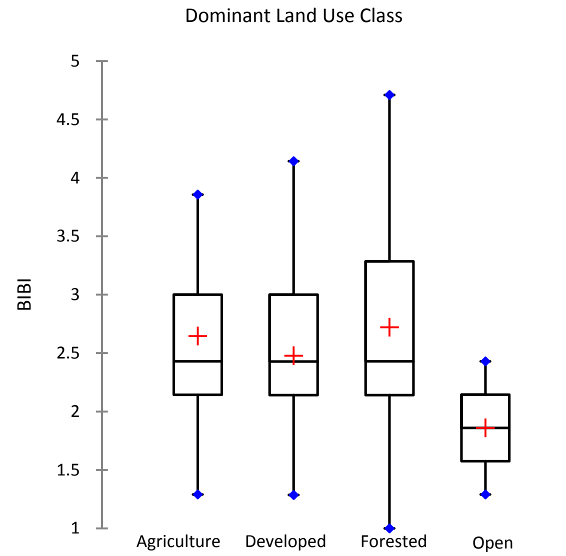

Figure 33. BIBI Data Stratified by Dominant Land Use Class.

To examine differences in BIBI data based on strata or classification types, 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, with exception of open land use (Figure 33). 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. But the range also extends on the low end as evidenced by the low 1st quartile value, which is consistent with agriculture and developed land uses. 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.

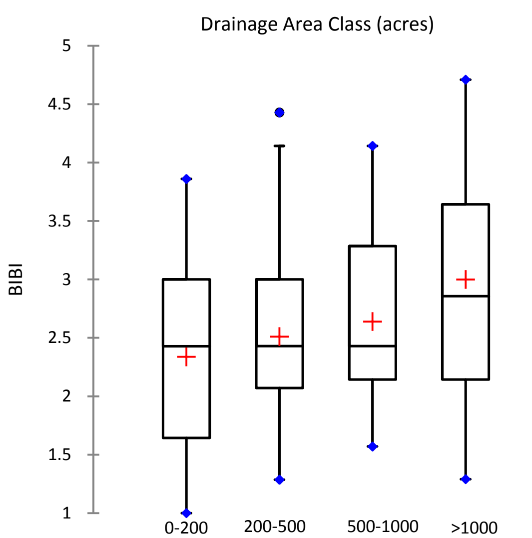

Figure 34. BIBI Data Stratified by Drainage Area Class.

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 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 34). This suggests that drainage area may influence 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 (Figure 35). 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 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).

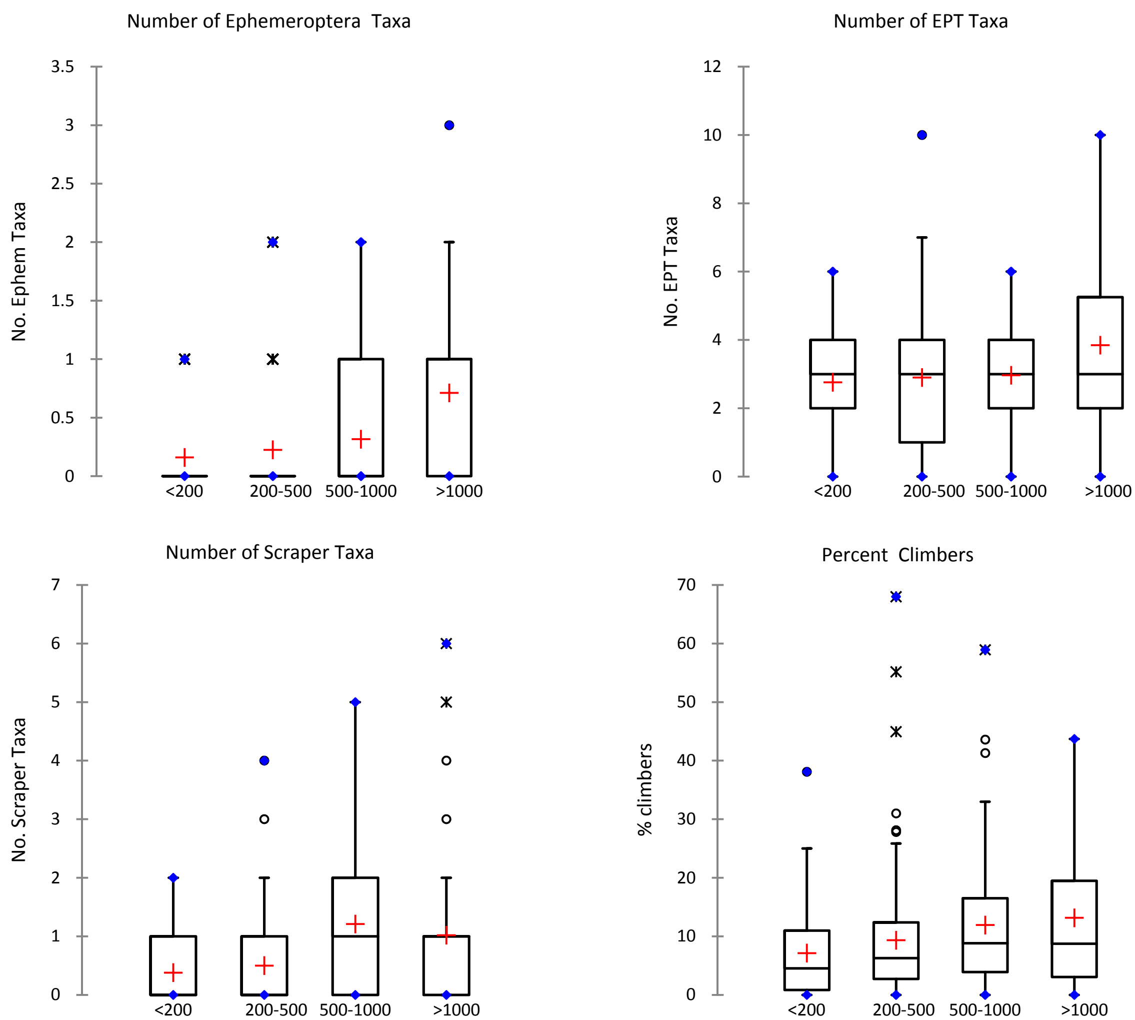

Figure 35. Box Plots of Benthic Macroinvertebrate Metrics Stratified by Drainage Area Class.

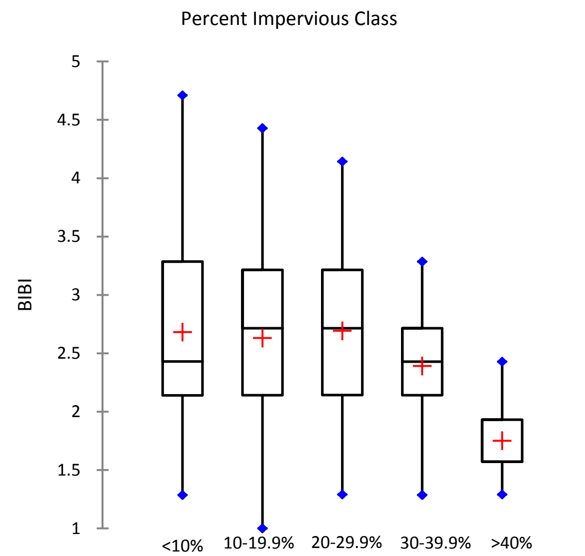

Figure 36. BIBI Data Stratified by Percent Impervious Class.

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 more than 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 considerable reduction in BIBI scores among sites where imperviousness exceeded 30% (Figure 36), indicating a pronounced influence of 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 37). These findings are consistent 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 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.

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 38). 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, and E). However, this data set shows the highest

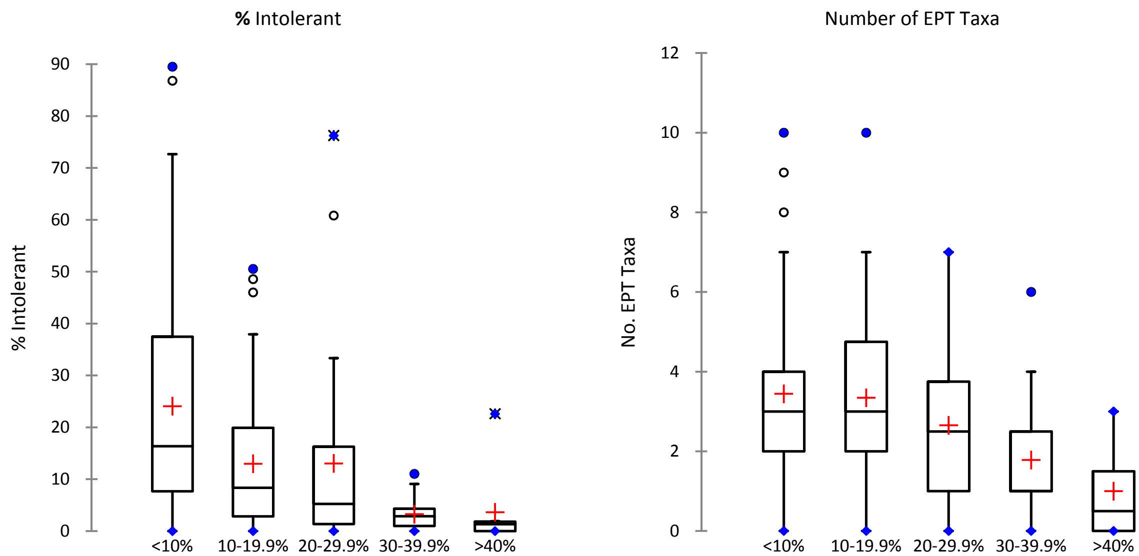

Figure 37. Box Plots of Percent Intolerant and EPT Taxa Metrics Stratified by Imperviousness Class.

mean, median, 1st quartile, 3rd quartile, and maximum values were all obtained from F type streams. G type streams also fared better than expected, receiving the second highest 3rd quartile values behind F type streams.

Box plots of percent developed and agricultural land use stratified by Rosgen stream type shows that there are considerable differences in land use between F and G streams as compared to C and E streams (Figure 39). Both F and G streams occurred in drainages with generally less developed land than C and E type streams. Additionally, C and E type streams occurred in drainages with far less agriculture land use than F and G streams. These results suggest that perhaps the differences in stressors between agricultural and developed land uses are likely influencing the biota more than stream geomorphology. Furthermore, 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, 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.

In the more developed watersheds the abundance of C and E 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

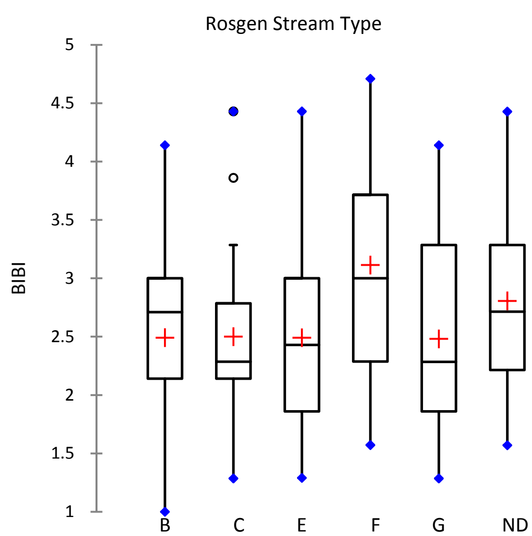

Figure 38. BIBI Data Stratified by Rosgen Stream Type.

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 stable or evolving. Only through continued monitoring can one ultimately determine the evolutionary trajectory of these systems.

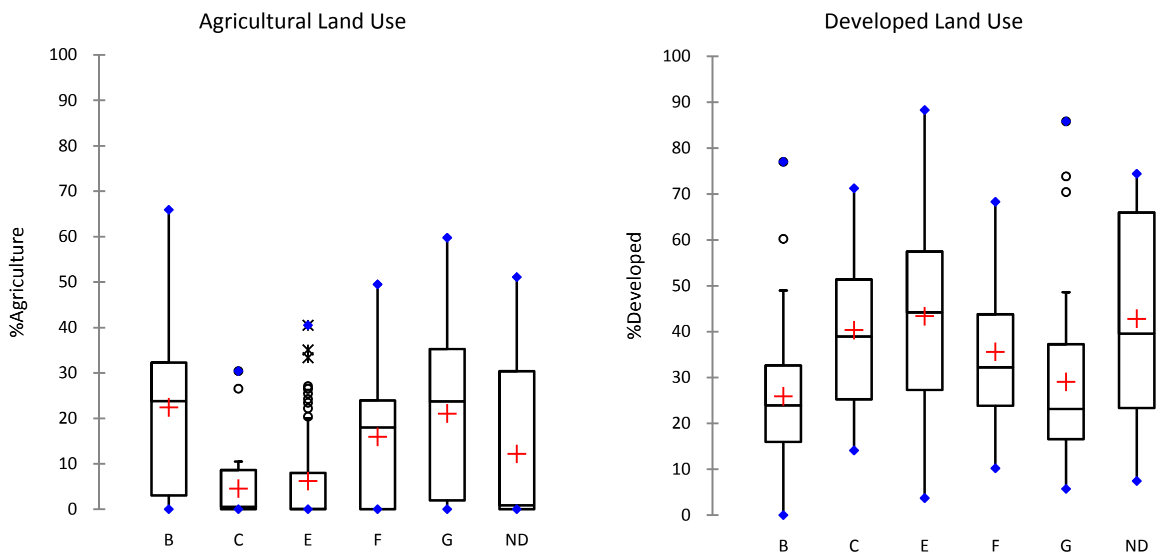

Figure 39. Percent Agriculture and Developed Land Use Stratified by Rosgen Stream Type.

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 correlated strongly (p-values less than 0.001) with RBP habitat index score (τ = 0.18), as well as with several individual habitat metrics including bank vegetative protection, channel sinuosity, and pool variability (Table 6). Pool substrate characterization was also correlated at the 0.05 level. Three individual macroinvertebrate metrics, Percent Climbers, Scraper Taxa, and EPT Taxa were also correlated strongly with RBP index score. Channel sinuosity and pool variability were consistently correlated with all macroinvertebrate metrics, with the exception of Percent Intolerant which was not strongly correlated with any RBP habitat variable.

The overall RBP index score did not correlate with any land use characteristics, although two individual habitat parameters, channel alteration and combined riparian vegetative zone width, were well correlated with numerous land use characteristics (Table 7). Channel alteration was strongly negatively correlated with percent imperviousness, and percent developed, and strongly positively correlated with percent agriculture. At the 0.05 level, channel alteration was positively correlated with percent forested and negatively correlated with percent open land. A similar pattern was observed with combined riparian vegetative zone width with strong negative correlations with percent imperviousness and percent developed, and strong positive correlations with percent forested land. Percent agriculture was positively correlated at the 0.05 level.

4.2.1.2 PHI Habitat Index

The PHI score was strongly correlated with RBP score (τ = 0.475), but was only correlated at the 0.05 level with BIBI score (τ = 0.14). However, two individual PHI parameters, epifaunal substrate and remoteness, were strongly correlated with BIBI score (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. Three macroinvertebrate metrics, EPT Taxa, Percent Intolerant, and Percent Climbers were strongly correlated with at least two PHI variables. Epifaunal substrate, remoteness, and woody debris were the parameters most commonly correlated with individual benthic metrics, although woody debris was negatively correlated with all but one metric, which is contrary to the expected trend. However, since correlations with macroinvertebrate metrics were not consistent between the raw woody debris counts and calculated woody debris scores, it is possible that these results are due to an artifact of 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). The raw woody debris count and woody debris score were both strongly correlated with Percent Intolerants.

Land use characteristics correlated much better with the PHI habitat index, as compared to the RBP index (Table 7). The overall PHI score was strongly negatively correlated with percent imperviousness, percent developed land and drainage area, and correlated at the 0.05 level with percent open land. Two parameters, percent shading score and remoteness score, were strongly correlated with nearly all land use characteristics. For both parameters, percent impervious, percent developed, and percent open were strongly negatively correlated, and percent forested was strongly positively correlated. Remoteness was also strongly positively correlated to percent agriculture. Woody debris count was also well correlated with several land use characteristics and performed slightly better than the calculated woody debris score. Woody debris counts showed strong negative correlations with percent imperviousness and percent developed, and a strong positive correlation with percent agriculture.

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	-0.08	-0.01	**-0.11**	**-0.12**	0.03	0.10	0.06	0.01
Vegetative Protection	0.07	**0.15**	0.08	0.08	0.09	**0.13**	**0.20**	**0.19**
Channel Flow	0.00	**-0.14**	**-0.12**	**-0.14**	-0.03	-0.02	-0.03	**-0.10**
Channel Alteration	-0.07	**0.15**	0.03	0.00	**0.09**	0.05	0.04	0.03
Channel Sinuosity	**0.14**	**0.24**	**0.20**	**0.18**	0.02	**0.20**	**0.30**	**0.29**
Pool Substrate	**0.12**	**0.10**	0.07	0.06	-0.09	0.09	**0.17**	**0.09**
Pool Variability	**0.21**	**0.17**	**0.20**	**0.19**	**-0.10**	**0.22**	**0.26**	**0.24**
Riparian Zone Width	**-0.14**	**0.12**	0.03	0.02	0.07	**0.15**	0.08	0.08
Sediment Deposition	-0.05	**0.10**	0.06	0.04	-0.02	**0.11**	**0.09**	0.05
Epi. Substrate/Avail. Cover	**0.11**	**0.10**	0.09	0.09	-0.07	0.06	**0.10**	0.07
RBP Score	0.07	**0.18**	0.09	0.08	0.01	**0.20**	**0.23**	**0.18**
PHI Habitat Variables								
Instream Habitat	**0.10**	**0.11**	**0.11**	**0.11**	-0.07	0.05	**0.11**	0.08
Epifaunal Substrate	**0.15**	**0.19**	**0.17**	**0.17**	**-0.10**	**0.17**	**0.26**	**0.21**
Bank Stability	-0.08	0.04	-0.05	-0.05	0.02	**0.16**	**0.11**	0.08
Percent Shading	0.02	**0.11**	0.03	0.02	0.09	**-0.12**	0.05	0.02
Remoteness	0.02	**0.24**	**0.16**	**0.17**	**0.25**	0.10	**0.16**	**0.23**
# Woody Debris/Rootwads	-0.05	0.05	-0.05	-0.07	**0.16**	0.01	0.01	0.01
Remoteness Score	0.00	**0.22**	**0.12**	**0.12**	**0.23**	**0.11**	**0.18**	**0.21**
Shading Score	0.02	**0.10**	0.03	0.03	0.09	**-0.12**	0.05	0.02
Epifaunal Substrate Score	**0.10**	**0.17**	**0.11**	**0.11**	-0.07	**0.13**	**0.22**	**0.16**
Instream Habitat Score	0.01	0.06	0.00	0.00	-0.01	-0.03	0.03	0.00
Woody Debris Score	**-0.16**	-0.04	**-0.25**	**-0.26**	**0.19**	**-0.13**	**-0.11**	**-0.14**
Bank Stability Score	**-0.09**	0.04	-0.05	-0.05	0.07	**0.16**	**0.11**	0.08
PHI Score	0.00	**0.19**	0.03	0.03	**0.14**	0.08	**0.18**	**0.14**

Bold values indicate significance at 0.05 level
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	%Agriculture	%Forested	%Open	Drainage area
RBP Habitat Variables						
Bank Stability	-0.028	0.006	0.020	0.000	-0.018	-0.014
Vegetative Protection	-0.026	-0.009	**0.095**	0.014	**-0.114**	-0.002
Channel Flow	**0.100**	0.070	-0.089	0.005	0.053	**0.155**
Channel Alteration	**-0.235**	**-0.198**	**0.184**	**0.141**	**-0.143**	0.022
Channel Sinuosity	0.023	0.025	0.059	-0.011	-0.070	**0.105**
Pool Substrate	**0.121**	0.084	-0.051	**-0.095**	**0.102**	**0.232**
Pool Variability	**0.127**	0.076	-0.027	-0.072	0.052	**0.394**
Riparian Zone Width	**-0.198**	**-0.223**	**0.101**	**0.210**	-0.075	-0.015
Sediment Deposition	0.014	0.000	-0.023	-0.004	0.025	0.032
Epi. Substrate/Avail. Cover	**0.090**	0.047	-0.067	-0.045	0.061	**0.250**
RBP Score	-0.003	-0.022	0.037	0.023	-0.029	**0.174**
PHI Habitat Variables						
Instream Habitat	0.057	0.001	-0.030	-0.008	0.046	**0.281**
Epifaunal Substrate	**0.163**	**0.111**	-0.081	**-0.098**	0.037	**0.226**
Bank Stability	-0.048	-0.009	0.078	-0.023	-0.030	0.030
Percent Shading	**-0.224**	**-0.197**	0.087	**0.169**	**-0.151**	**-0.146**
Remoteness	**-0.274**	**-0.261**	**0.193**	**0.217**	**-0.179**	0.018
# Woody Debris/Rootwads	**-0.187**	**-0.162**	**0.164**	0.079	-0.029	**0.100**
Remoteness Score	**-0.290**	**-0.295**	**0.228**	**0.201**	**-0.161**	-0.023
Shading Score	**-0.225**	**-0.197**	0.089	**0.168**	**-0.156**	**-0.149**
Epifaunal Substrate Score	**0.146**	**0.100**	**-0.098**	**-0.105**	0.009	0.006
Instream Habitat Score	0.024	-0.022	-0.049	-0.028	0.014	-0.063
Woody Debris Score	**-0.147**	**-0.116**	0.023	0.048	-0.052	**-0.480**
Bank Stability Score	-0.074	-0.050	**0.094**	0.010	-0.036	-0.032
PHI Score	**-0.150**	**-0.168**	0.080	0.085	**-0.115**	**-0.156**

Bold values indicate significance at 0.05 level
Highlighted values indicate significance at 0.001 level

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 (dissolved oxygen, temperature) are influenced by daily cycles of ambient temperature and stream metabolism. However, several individual macroinvertebrate metrics showed strong correlations with water chemistry parameters (Table 8). Both Number of EPT Taxa and Percent Intolerant metrics were strongly negatively correlated with conductivity. Percent Intolerant was also strongly correlated (negatively) to pH; however, since pH is also strongly correlated with conductivity (see Appendix B) the result is possibly due to intercorrelation between conductivity and pH. Dissolved oxygen was negatively correlated to Percent Climbers and BIBI score, which was contrary to the expected outcome and is likely the result of intercorrelation between DO and conductivity, since they were correlated to one another. Furthermore, the data set appeared to contain some questionable dissolved oxygen measurements, and coupled with its dependency on temperature and, consequently, the time of day sampling occurs, this parameter is not a useful predictor of overall benthic macroinvertebrate community conditions.

Conductivity was the variable that showed the strongest correlations with land use characteristics (Table 9), suggesting a strong link between conductivity and land use characteristics. Percent imperviousness ($\tau = 0.526$) and percent developed land ($\tau = 0.448$) were strongly positively correlated, while percent agriculture ($\tau = -0.269$) and percent forested ($\tau = -0.336$) were strongly negatively correlated. Percent open land also showed a strong positive correlation ($\tau = 0.241$), which was expected given that the 'open land' land cover in Anne Arundel County often includes institutional land and land adjacent to roadways and is strongly correlated with both percent imperviousness and percent developed land. These results suggest that conductivity is a good indicator of urban runoff. 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).

4.2.3 Geomorphic Variables

Geomorphic variables were not well correlated with the overall BIBI score or individual macroinvertebrate metrics (Table 8). No variables were strongly correlated with the overall BIBI score; however, sinuosity and D_{50} were positively correlated at the 0.05 level. Sinuosity, a unitless measure of a stream's plan form pattern, was also positively correlated with EPT taxa, Percent Intolerant, and Percent Climbers metrics. The D_{50} value, the average intermediate axis width of the 50^{th} percentile substrate particle size, was positively correlated with Percent Ephemeroptera, Ephemeroptera Taxa, and Scraper Taxa metrics. Only one macroinvertebrate metric, Percent Intolerant, showed a strong correlation (negative) to geomorphic variables, more specifically bankfull cross-section area. This metric was also negatively correlated (at the 0.05 level) to bankfull width and mean depth, but positively correlated with sinuosity. Mean depth was also positively correlated with Number of Taxa and Ephemeroptera Taxa metrics.

Few geomorphic variables correlated well with land use characteristics (Table 9). Flood-prone width was strongly positively correlated with percent impervious and percent developed land, and strongly negatively correlated with percent agriculture. Entrenchment ratio, the ratio of flood-prone width to bankfull width, showed a similar trend of a strong positive correlation with percent developed land, a strong negative correlation with percent agriculture, and a positive correlation at the 0.05 level with percent imperviousness. These results suggest that streams impacted by agricultural land use tend to be more entrenched, or vertically contained, and have less flood plain access than streams in developed areas.

Table 8. 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 Chemistry Variables								
Conductivity	0.08	**-0.20**	-0.07	-0.05	**-0.29**	0.07	-0.04	**-0.11**
Dissolved Oxygen	0.09	-0.05	-0.01	-0.01	**-0.10**	**-0.16**	**-0.21**	**-0.13**
pH	0.06	-0.02	0.08	0.10	**-0.27**	**0.21**	**0.19**	0.06
Turbidity	0.02	-0.05	**-0.16**	**-0.16**	0.12	-0.05	0.01	-0.10
Water Temperature	**-0.09**	**0.09**	0.02	0.00	0.06	**0.11**	**0.13**	0.07
Geomorphic Variables								
Entrenchment Ratio	0.06	**-0.11**	-0.09	-0.09	-0.05	-0.04	-0.10	-0.07
Bankfull Width	0.05	0.02	**0.14**	**0.14**	**-0.15**	0.10	0.07	0.05
Mean Depth	**0.15**	0.02	**0.15**	**0.16**	**-0.15**	0.04	0.05	0.08
Width: Depth Ratio	-0.07	0.00	-0.02	-0.05	-0.01	0.06	0.00	-0.03
Bankfull Area	**0.13**	0.02	**0.18**	**0.18**	**-0.18**	0.08	0.08	0.07
Water Surface Slope	-0.07	0.02	-0.10	-0.09	**0.11**	-0.08	**-0.11**	-0.03
Sinuosity	0.09	**0.18**	0.11	0.11	**0.18**	0.00	**0.15**	**0.18**
Flood-Prone Width	0.10	-0.07	0.01	0.01	**-0.11**	0.01	-0.05	-0.01
D50	0.09	**0.14**	**0.17**	**0.19**	0.02	**0.16**	0.09	**0.17**
Land Use/ Drainage Area Variables								
%Impervious	**0.10**	**-0.20**	-0.05	-0.04	**-0.33**	**0.13**	0.02	-0.07
%Developed	**0.09**	**-0.18**	-0.08	-0.09	**-0.27**	**0.12**	0.00	-0.07
%Agriculture	-0.08	**0.18**	0.07	0.06	**0.16**	0.01	0.09	0.08
%Forested	-0.03	**0.17**	0.07	0.08	**0.27**	-0.08	**-0.09**	0.08
%Open	-0.03	**-0.15**	**-0.14**	**-0.14**	**-0.10**	0.00	-0.06	**-0.14**
Drainage area	**0.16**	**0.09**	**0.23**	**0.23**	**-0.11**	**0.17**	**0.15**	**0.17**

Bold values indicate significance at 0.05 level

Highlighted values indicate significance at 0.001 level

4.2.4 Land Use Variables

In general, land use variables (i.e., developed, agriculture, forested, open) were not well correlated with biological data. Drainage area was strongly positively correlated to all but two metrics (EPT taxa and % Intolerant) including the BIBI (see section 4.2.5 for a full analysis of drainage area effects). None of the land use variables were strongly correlated to BIBI score, and only percent open land was correlated (negatively) at the 0.05 level (Table 8). Two individual macroinvertebrate metrics, EPT Taxa and Percent Intolerant, were strongly correlated with all land use variables, with exception to percent open land. Both metrics were strongly negatively correlated with percent impervious and percent developed, and strongly positively correlated with percent agriculture and percent forested. It should also be noted that percent impervious was strongly positively correlated to percent developed and percent open land, and strongly negatively correlated to percent forested and percent agricultural land (Appendix B).

Table 9. Correlation coefficients (Kendall τ) for water chemistry and geomorphic variables versus land use variables.

Variables	% Impervious	%Developed	%Agriculture	%Forested	%Open
Water Chemistry Variables					
Conductivity	**0.526**	**0.448**	**-0.269**	**-0.336**	**0.241**
Dissolved Oxygen	0.079	**0.091**	**-0.149**	0.036	**0.089**
pH	**0.205**	0.092	-0.060	**-0.148**	0.074
Turbidity	**-0.200**	**-0.200**	**0.162**	0.117	-0.061
Water Temperature	**-0.123**	-0.079	**0.201**	-0.075	-0.038
Geomorphic Variables					
Entrenchment Ratio	**0.144**	**0.194**	**-0.257**	-0.023	0.075
Bankfull Width	0.079	0.003	0.030	0.029	0.077
Mean Depth	0.069	0.070	0.002	-0.033	0.022
Width:Depth Ratio	0.009	-0.063	0.025	0.059	0.082
Bankfull Area	0.093	0.045	0.016	-0.008	0.064
Water Surface Slope	-0.002	-0.033	-0.099	0.032	-0.021
Sinuosity	**-0.121**	**-0.109**	**0.158**	0.088	**-0.141**
Flood-Prone Width	**0.199**	**0.192**	**-0.242**	-0.022	**0.135**
D50	-0.053	**-0.131**	0.071	0.057	0.062

Bold values indicate significance at 0.05 level
Highlighted values indicate significance at 0.001 level

The negative relationship between the EPT taxa and percent intolerant metrics, and the open land variable, was somewhat unexpected, because this land cover category includes open wetlands and water land covers. However, a closer inspection of the land cover revealed that a large portion of the land designated as 'open' occurred on large developed parcels (i.e., BWI Airport, US Naval Academy and Naval Station, Fort Meade, US Army General Services Depot, US Airforce Transmitter Station), golf courses, cemeteries, and land adjacent to interstates. Furthermore, open land was strongly positively correlated with percent developed and percent imperviousness and strongly negatively correlated with percent forested and agriculture (Appendix B). This suggests that much of what is currently classified as open land in Anne Arundel County is more representative of developed land than undeveloped land, and consequently, exhibits a similar stressor response on stream biota. Nonetheless, 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).

Although unexpected, the positive relationship between agriculture and EPT Taxa and Percent Intolerant 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).

4.2.5 Biological Index Associations

Few consistent patterns emerged between biological data and other environmental variables. Two individual macroinvertebrate metrics, Number of EPT Taxa and Percent Intolerant Urban, showed the strongest correlations with land use variables (percentage of impervious surface area, in particular), although the remaining five metrics as well as the BIBI score were uncorrelated or weakly correlated. 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 only individual metrics strongly correlated to specific conductivity. But given that conductivity is strongly correlated with all four land use types (positively with developed and open, negatively with forested and agriculture) including percent imperviousness, it is possible that the results are due to covariance between the environmental variables. However, since 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), it is likely that these metrics are responding to the degraded water quality resulting from increased imperviousness.

While the overall BIBI score was not strongly correlated with any of the water quality, geomorphic, or land use variables, several physical habitat parameters were correlated. Total RBP habitat score, which incorporated 10 individual habitat variables, was strongly correlated with the BIBI score. The individual RBP habitat variables that were most strongly correlated with BIBI included channel sinuosity, pool variability, and combined bank vegetative protection. In coastal plain streams, a high degree of sinuosity provides for diverse habitat and fauna, and improves the streams capacity to handle surges when the flow fluctuates due to storms (Barbour et al., 1999). Pool variability rates the overall mixture of pool types found in streams, with a greater diversity of pool types able to support a wide range of aquatic species (Barbour et al., 1999). Bank vegetative protection, with right and left bank scores combined, measures the amount of vegetative protection afforded to the stream banks, and banks that have full, natural plant growth are better for fish and macroinvertebrates than banks with little or no vegetative protection (Barbour et al., 1999). Additionally, two PHI habitat parameters, remoteness and epifaunal substrate, were strongly correlated to the BIBI score. Epifaunal substrate rates the availability and variety of hard, stable substrates usable by benthic macroinvertebrates for colonization. While not a true measure of physical habitat quality, remoteness assesses the proximity of the sampling reach to roadways, which is a surrogate measure of urbanization. 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.

What is most surprising, perhaps, is the correlation between drainage area and biological indicators. The BIBI score and five of the seven metrics were strongly positively correlated with drainage area. Number of EPT Taxa and Percent Intolerant were both weakly correlated, with Percent Intolerant negatively correlated to drainage area. These results suggest 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, 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 lack of larger streams networks due to the predominance of first order streams, which drain directly to the flooded river valleys of the Chesapeake Bay.

5 Conclusions and Recommendations

The current ecological status of County streams can best be described as poor, with nearly two-thirds (65%) of the County's streams in "Poor" or "Very Poor" condition. 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) and again in 2000 - 2004 (Kazyak et al., 2005). 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 Stocketts Run, Upper North River, Ferry Branch, and Severn River, all of which were rated "Fair". In contrast, the PSUs rated in the worst biological condition, "Very Poor", are West River, Sawmill Creek, and Rhode River. It should be noted, however, that the ecological status of streams and PSUs is based on a single biological assemblage (i.e., benthic macroinvertebrates), and the overall ecological status may differ with the inclusion of additional biological assemblages (e.g., fish, periphyton, herpetofauna) residing in these streams.

Over 80% of the County's PSUs are considered impaired, being rated as either "Poor" or "Very Poor" by the BIBI. This trend 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, 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 and developed land use. 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 provided herein 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.

5.1 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 in a stream or PSU is a challenging task, given that many stressors co-exist and synergistic effects can occur. 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 or legacy land use may be factors limiting the biological community. As an example, Rhode River with only 6.1 percent imperviousness, suffers from 'Degraded/Non-Supporting' physical habitat which explains the impaired biological conditions 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 15 sites rated "Good" for biological condition, four exceeded 10% imperviousness, and one site in Severn Run approached 24% imperviousness. This unexpected response to high percentages of imperviousness can be explained by two 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; and 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. Unfortunately, neither of these factors was fully accounted for in this study. 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 Ferry Branch and Middle Patuxent PSUs, physical habitat was rated as either "Partially Supporting" or "Non-supporting" by the RBP, suggesting that physical habitat condition is a limiting factor to the biota in this region of the County. 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 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, in particular, may be a stressor of concern. Water quality sampling by MBSS (2000 – 2004) found that 28% of the County's streams had phosphorus concentrations at high levels associated with biological impacts (i.e., $\geq$ 0.07 mg/L), the majority of which were located in the southern part of the County (Kazyak et al., 2005). These results, coupled with the continued impaired biological conditions observed in Round One of this sampling program, suggest that phosphorus continues 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 phosphorus 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.

5.2 Recommendations for Future Program Consideration

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.

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. For County data to be incorporated into State datasets for items such as 303(d) listings, TMDL development, and listings of Tier II waters, the FIBI and the CIBI are major required components.

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, sites sampled in Round One should be re-visited and cross sections should be surveyed again after a period of time (e.g., 5 years) so that changes in channel dimensions can be quantified and determinations made regarding the dominant process occurring in each stream. It is likely that an association between biological impairment and aggrading or degrading streams would be observed.

Additional Stressor Analysis

While this report examines associations between potential stressors and biological indicators at the Countywide scale, it would also be beneficial to examine similar relationships at the PSU or watershed scale. However, due to the small sample size (n = 10 sites per PSU), it is often difficult to identify statistically significant relationships even when a strong association between two or more variables may indeed exist. Fortunately, the County is currently developing a Watershed Management Statistical Analysis Tool ([WMT] AA DPW, 2010) that can be used to examine relationships between stressors and response indicators for individual watersheds. The statistical analysis tool was created to assist in developing multiple variable linear regression models to predict IBI scores via linear regression (AA DPW, 2010). While developing linear regression models are far more labor intensive than correlation techniques, they specifically examine relationships between a dependent variable (e.g., BIBI) and one or more predictor variables (e.g., nutrients, sedimentation, percent imperviousness), while minimizing the effects of covariance and confounding variables. It is recommended that data be merged between the two programs, with additional parameters collected (i.e., nutrients, total suspended solids) as part of the Biological Monitoring Program to create a more comprehensive data set that can be used to develop a linear regression model for each PSU. While the regression model will identify the best explanatory variables for predicting biological condition, often the predominant watershed stressors, it does not automatically indicate causality and the results would still need to be interpreted with caution.

The County could also benefit from additional data analysis using multivariate analysis techniques such as principal component analysis (PCA) or nonparametric multidimensional scaling (MDS) to examine relationships between benthic macroinvertebrate community data and environmental variables. PCA analysis can be used to determine the primary environmental factors that explain the largest amount of variation among sites. MDS is an ordination technique used to represent complex biological relations accurately in a small dimensional space, and could be used to examine whether or not a distinct separation of sites exists based on a rural or urban land use gradient.

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Appendix A:Land Use and Land Cover Data

Table A-1. Total Acres Per Land Cover Type for Each Primary Sampling Unit Based on 2004 Anne Arundel County Land Cover Layer. Note: PSUs shaded gray were calculated using 2007 land cover data.

Primary Sampling Unit	PSU #	Airport	Commercial	Forested Wetlands	Industrial	Open Space	Open Wetland	Pasture/Hay	Residential 1-ac	Residential 1/2-ac	Residential 1/4-ac	Residential 1/8-ac	Residential 2-ac	Residential Woods*	Row Crops	Transportation	Utility	Water	Woods	Total Acres
Piney Run	1		232.7	5.0	330.0	468.7		2.2	246.6	304.7	269.5		60.0			331.1	5.1	12.3	2600.0	4,868
Stony Run	2	533.9	350.9	2.7	564.8	903.5	5.9		71.8	291.5	850.0	34.9	34.3		33.7	402.6	5.9	8.0	2108.4	6,203
Lower Patapsco	3		318.9	27.2	376.5	312.4	44.6		45.2	165.2	1108.3	72.7	10.2			271.0	33.8	104.4	1147.4	4,038
Sawmill Creek	4	565.7	911.8		875.2	1976.4	3.0		156.3	81.9	1272.4	1693.5	251.3	51.4	4.5	729.5	75.0	26.4	2355.7	11,030
Marley Creek	5		1322.4		949.9	1037.7	23.4	5.3	171.7	1173.9	5818.4	1489.5	58.6		78.9	939.6	175.8	164.9	6013.8	19,424
Bodkin Creek	6	8.4	190.0			421.2	33.9	10.3	136.5	1634.6	795.9	2.6	3.2			126.4		141.7	2366.8	5,872
Upper Magothy	7		486.6	3.0	8.9	375.1	2.3		442.4	2793.2	2063.9	21.3	25.4		4.7	461.1		22.6	3320.8	10,031
Lower Magothy	8		573.0		11.7	616.6	17.2	4.8	275.8	2493.1	3691.5	514.2	22.7		82.6	415.7		102.3	3876.0	12,697
Severn Run	9		522.8	9.1	676.8	785.8	6.6	178.5	465.5	2246.3	2160.4	703.4	82.7		249.4	710.1	81.5	14.1	6531.2	15,424
Severn River	10		1977.0	3.8	192.8	1644.8	55.5	344.3	916.2	5916.7	4881.2	712.9	121.8		511.5	1148.7	49.3	231.1	10212.1	28,920
Upper North River	11		162.8		12.8	386.7	40.0	515.9	640.0	1830.2	146.4	45.2	161.8		656.6	388.6	241.2	29.3	7539.9	12,797
Lower North River	12	24.8	1219.2		192.7	1282.3	105.2	332.2	1116.7	3802.8	3456.3	649.5	163.9		745.8	807.3	190.1	154.8	9437.8	23,681
Rhode River	13		116.5		17.6	452.0	77.8	444.0	322.2	124.5	209.3	284.5	865.4	49.6	596.4	160.2	61.7	69.4	4883.5	8,735
West River	14		144.4			280.6	36.8	471.2	259.6	293.3	129.4	266.1	929.0		1001.4	171.6	40.9	24.6	3505.5	7,554
Herring Bay	15		243.9	3.2	64.4	662.1	325.5	507.7	797.4	1688.1	337.0		411.3		992.2	288.1	274.2	129.0	7870.7	14,595
Upper Patuxent	16	13.8	179.5	77.5	135.8	293.4	24.6	1.6	73.3	8.4	314.1	50.5	12.7		58.3	198.9	177.7	30.0	5301.1	6,951
Little Patuxent	17	65.9	2190.7	53.6	1056.8	2948.4	147.7	402.5	322.9	525.6	2585.9	1824.3	38.2		513.6	1222.7	393.8	141.1	13762.2	28,196
Middle Patuxent	18		137.6	3.8	20.9	720.3	4.1	407.0	531.5	478.3	69.7	11.4	167.5		908.8	150.7		35.8	2684.8	6,332
Stocketts Run	19		84.9		23.1	721.8		690.8	697.3	886.2	130.6		321.8		885.6	171.6	99.0	10.5	3990.4	8,714
Rock Branch	20		26.2		216.1	456.7	8.7	279.4	181.7	20.5	63.2		764.4		1121.0	86.7		44.7	2862.1	6,131
Ferry Branch	21		80.9		164.6	428.3	185.0	511.8	408.6	628.3	18.4	170.3	182.4		1039.5	178.3		95.0	3849.1	7,941
Lyons Creek	22		78.5		1.9	311.3	4.0	471.9	455.9	493.5			201.9		1462.8	130.2		7.4	2534.2	6,154
Cabin Branch	23		10.8		6.7	145.7	242.4	398.6	119.8	35.8		57.9	793.7		990.6	137.4		488.8	3014.7	6,050
Hall Creek	24		30.7			114.5		249.6	304.1	274.2			120.7		430.2	75.4	32.8	2.9	1532.6	3,168

Footnote: Jug Bay was not included in 2004/2007 land cover classification, thus 393.3 acres not originally classified for Cabin Branch but manually added to water category.
*Residential Woods category added in 2007

Table A-2. Percentage of Land Cover Types for Each Primary Sampling Unit Based on 2004 Anne Arundel County Land Cover Layer. Note: PSUs shaded gray were calculated using 2007 land cover data.

Primary Sampling Unit	PSU #	Airport	Commercial	Forested Wetlands	Industrial	Open Space	Open Wetland	Pasture/Hay	Residential 1-ac	Residential 1/2-ac	Residential 1/4-ac	Residential 1/8-ac	Residential 2-ac	Residential Woods*	Row Crops	Transportation	Utility	Water	Woods
Piney Run	1	0.0%	4.8%	0.1%	6.8%	9.6%	0.0%	0.0%	5.1%	6.3%	5.5%	0.0%	1.2%		0.0%	6.8%	0.1%	0.3%	53.4%
Stony Run	2	8.6%	5.7%	0.0%	9.1%	14.6%	0.1%	0.0%	1.2%	4.7%	13.7%	0.6%	0.6%		0.5%	6.5%	0.1%	0.1%	34.0%
Lower Patapsco	3	0.0%	7.9%	0.7%	9.3%	7.7%	1.1%	0.0%	1.1%	4.1%	27.4%	1.8%	0.3%		0.0%	6.7%	0.8%	2.6%	28.4%
Sawmill Creek	4	5.1%	8.3%	0.0%	7.9%	17.9%	0.0%	0.0%	1.4%	0.7%	11.5%	15.4%	2.3%	0.5%	0.0%	6.6%	0.7%	0.2%	21.4%
Marley Creek	5	0.0%	6.8%	0.0%	4.9%	5.3%	0.1%	0.0%	0.9%	6.0%	30.0%	7.7%	0.3%		0.4%	4.8%	0.9%	0.8%	31.0%
Bodkin Creek	6	0.1%	3.2%	0.0%	0.0%	7.2%	0.6%	0.2%	2.3%	27.8%	13.6%	0.0%	0.1%		0.0%	2.2%	0.0%	2.4%	40.3%
Upper Magothy	7	0.0%	4.9%	0.0%	0.1%	3.7%	0.0%	0.0%	4.4%	27.8%	20.6%	0.2%	0.3%		0.0%	4.6%	0.0%	0.2%	33.1%
Lower Magothy	8	0.0%	4.5%	0.0%	0.1%	4.9%	0.1%	0.0%	2.2%	19.6%	29.1%	4.0%	0.2%		0.7%	3.3%	0.0%	0.8%	30.5%
Severn Run	9	0.0%	3.4%	0.1%	4.4%	5.1%	0.0%	1.2%	3.0%	14.6%	14.0%	4.6%	0.5%		1.6%	4.6%	0.5%	0.1%	42.3%
Severn River	10	0.0%	6.8%	0.0%	0.7%	5.7%	0.2%	1.2%	3.2%	20.5%	16.9%	2.5%	0.4%		1.8%	4.0%	0.2%	0.8%	35.3%
Upper North River	11	0.0%	1.3%	0.0%	0.1%	3.0%	0.3%	4.0%	5.0%	14.3%	1.1%	0.4%	1.3%		5.1%	3.0%	1.9%	0.2%	58.9%
Lower North River	12	0.1%	5.1%	0.0%	0.8%	5.4%	0.4%	1.4%	4.7%	16.1%	14.6%	2.7%	0.7%		3.1%	3.4%	0.8%	0.7%	39.9%
Rhode River	13	0.0%	1.3%	0.0%	0.2%	5.2%	0.9%	5.1%	3.7%	1.4%	2.4%	3.3%	9.9%	0.6%	6.8%	1.8%	0.7%	0.8%	55.9%
West River	14	0.0%	1.9%	0.0%	0.0%	3.7%	0.5%	6.2%	3.4%	3.9%	1.7%	3.5%	12.3%	0.0%	13.3%	2.3%	0.5%	0.3%	46.4%
Herring Bay	15	0.0%	1.7%	0.0%	0.4%	4.5%	2.2%	3.5%	5.5%	11.6%	2.3%	0.0%	2.8%		6.8%	2.0%	1.9%	0.9%	53.9%
Upper Patuxent	16	0.2%	2.6%	1.1%	2.0%	4.2%	0.4%	0.0%	1.1%	0.1%	4.5%	0.7%	0.2%		0.8%	2.9%	2.6%	0.4%	76.3%
Little Patuxent	17	0.2%	7.8%	0.2%	3.7%	10.5%	0.5%	1.4%	1.1%	1.9%	9.2%	6.5%	0.1%		1.8%	4.3%	1.4%	0.5%	48.8%
Middle Patuxent	18	0.0%	2.2%	0.1%	0.3%	11.4%	0.1%	6.4%	8.4%	7.6%	1.1%	0.2%	2.6%		14.4%	2.4%	0.0%	0.6%	42.4%
Stocketts Run	19	0.0%	1.0%	0.0%	0.3%	8.3%	0.0%	7.9%	8.0%	10.2%	1.5%	0.0%	3.7%		10.2%	2.0%	1.1%	0.1%	45.8%
Rock Branch	20	0.0%	0.4%	0.0%	3.5%	7.4%	0.1%	4.6%	3.0%	0.3%	1.0%	0.0%	12.5%	0.0%	18.3%	1.4%	0.0%	0.7%	46.7%
Ferry Branch	21	0.0%	1.0%	0.0%	2.1%	5.4%	2.3%	6.4%	5.1%	7.9%	0.2%	2.1%	2.3%		13.1%	2.2%	0.0%	1.2%	48.5%
Lyons Creek	22	0.0%	1.3%	0.0%	0.0%	5.1%	0.1%	7.7%	7.4%	8.0%	0.0%	0.0%	3.3%		23.8%	2.1%	0.0%	0.1%	41.2%
Cabin Branch	23	0.0%	0.2%	0.0%	0.1%	2.3%	3.8%	6.2%	1.9%	0.6%	0.0%	0.9%	12.3%	0.0%	15.4%	2.1%	0.0%	7.6%	46.8%
Hall Creek	24	0.0%	1.0%	0.0%	0.0%	3.6%	0.0%	7.9%	9.6%	8.7%	0.0%	0.0%	3.8%		13.6%	2.4%	1.0%	0.1%	48.4%

Footnote: Jug Bay was not included in 2004/2007 land cover classification, thus 393.3 acres not originally classified for Cabin Branch but manually added to water category.
*Residential Woods category added in 2007

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
Bank Stability	1														
Vegetative Protection	0.432	1													
Channel Flow	0.216	0.056	1												
Channel Alteration	0.114	0.149	0.003	1											
Channel Sinuosity	0.103	0.306	-0.016	0.230	1										
Pool Substrate	0.157	0.135	0.183	0.191	0.202	1									
Pool Variability	0.054	0.057	0.123	0.048	0.223	0.420	1								
Riparian Zone Width	0.110	0.028	-0.012	0.430	0.207	0.052	0.051	1							
Sediment Deposition	0.223	0.132	0.128	0.199	0.093	0.304	0.146	0.090	1						
Epi. Substrate/Avail. Cover	0.130	0.072	0.158	0.251	0.172	0.522	0.389	0.077	0.378	1					
RBP Score	0.409	0.395	0.276	0.407	0.432	0.489	0.379	0.327	0.380	0.462	1				
Instream Habitat	0.150	0.058	0.214	0.254	0.191	0.521	0.427	0.132	0.292	0.790	0.483	1			
Epifaunal Substrate	0.114	0.192	0.064	0.139	0.323	0.487	0.416	0.010	0.373	0.699	0.447	0.568	1		
Bank Stability	0.934	0.481	0.232	0.150	0.110	0.180	0.116	0.140	0.277	0.165	0.443	0.177	0.148	1	
Percent Shading	0.012	0.077	-0.067	0.318	0.055	0.027	-0.033	0.246	0.114	0.123	0.147	0.090	0.072	0.035	1
Remoteness	0.108	0.309	-0.032	0.399	0.297	0.119	0.143	0.304	0.201	0.223	0.361	0.180	0.209	0.112	0.262
# Woody Debris/Rootwads	0.133	0.043	0.106	0.123	0.015	0.125	0.122	0.109	0.037	0.145	0.161	0.208	0.049	0.082	0.077
Remoteness Score	0.064	0.263	-0.070	0.319	0.258	0.013	0.034	0.319	0.109	0.060	0.250	0.035	0.086	0.112	0.209
Shading Score	0.008	0.073	-0.072	0.317	0.050	0.024	-0.035	0.246	0.111	0.120	0.144	0.086	0.068	0.035	1.000
Epifaunal Substrate Score	0.124	0.197	0.019	0.127	0.290	0.403	0.289	0.016	0.380	0.587	0.383	0.459	0.824	0.146	0.121
Instream Habitat Score	0.168	0.062	0.137	0.266	0.142	0.402	0.221	0.138	0.294	0.601	0.401	0.692	0.444	0.187	0.177
Woody Debris Score	0.123	0.042	-0.019	0.074	-0.059	-0.087	-0.218	0.083	0.011	-0.084	-0.010	-0.068	-0.136	0.052	0.185
Bank Stability Score	0.803	0.445	0.170	0.091	0.128	0.101	0.039	0.130	0.159	0.041	0.363	0.083	0.060	1.000	-0.025
PHI Score	0.299	0.315	0.018	0.367	0.272	0.264	0.119	0.280	0.308	0.375	0.475	0.360	0.377	0.316	0.413
% Impervious	-0.028	-0.026	0.100	-0.235	0.023	0.121	0.127	-0.198	0.014	0.090	-0.003	0.057	0.163	-0.048	-0.224
%Developed	0.006	-0.009	0.070	-0.198	0.025	0.084	0.076	-0.223	0.000	0.047	-0.022	0.001	0.111	-0.009	-0.197
%Agriculture	0.020	0.095	-0.089	0.184	0.059	-0.051	-0.027	0.101	-0.023	-0.067	0.037	-0.030	-0.081	0.078	0.087
%Forested	0.000	0.014	0.005	0.141	-0.011	-0.095	-0.072	0.210	-0.004	-0.045	0.023	-0.008	-0.098	-0.023	0.169
%Open	-0.018	-0.114	0.053	-0.143	-0.070	0.102	0.052	-0.075	0.025	0.061	-0.029	0.046	0.037	-0.030	-0.151
Drainage area	-0.014	-0.002	0.155	0.022	0.105	0.232	0.394	-0.015	0.032	0.250	0.174	0.281	0.226	0.030	-0.146

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 Land Use Variables

Variables	Remoteness	# Woody Debris/Rootwads	Remoteness Score	Shading Score	Epifaunal Substrate Score	Instream Habitat Score	Woody Debris Score	Bank Stability Score	PHI Score	% Impervious	%Developed	%Agriculture	%Forested	%Open	Drainage area
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	1														
# Woody Debris/Rootwads	0.105	1													
Remoteness Score	1.000	0.051	1												
Shading Score	0.261	0.077	0.207	1											
Epifaunal Substrate Score	0.192	0.031	0.083	0.121	1										
Instream Habitat Score	0.161	0.161	0.040	0.177	0.482	1									
Woody Debris Score	0.027	0.441	0.031	0.185	0.008	0.170	1								
Bank Stability Score	0.112	0.130	0.109	-0.025	0.083	0.114	0.133	1							
PHI Score	0.489	0.220	0.417	0.413	0.467	0.495	0.290	0.291	1						
% Impervious	-0.274	-0.187	-0.290	-0.225	0.146	0.024	-0.147	-0.074	-0.150	1					
%Developed	-0.261	-0.162	-0.295	-0.197	0.100	-0.022	-0.116	-0.050	-0.168	0.692	1				
%Agriculture	0.193	0.164	0.228	0.089	-0.098	-0.049	0.023	0.094	0.080	-0.487	-0.450	1			
%Forested	0.217	0.079	0.201	0.168	-0.105	-0.028	0.048	0.010	0.085	-0.401	-0.471	-0.008	1		
%Open	-0.179	-0.029	-0.161	-0.156	0.009	0.014	-0.052	-0.036	-0.115	0.283	0.210	-0.151	-0.251	1	
Drainage area	0.018	0.100	-0.023	-0.149	0.006	-0.063	-0.480	-0.032	-0.156	0.050	0.028	0.090	-0.009	0.043	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
No. Taxa	1																		
No. EPT Taxa	0.255	1																	
% Ephem	0.262	0.372	1																
No. Ephem Taxa	0.282	0.383	0.919	1															
% Intolerant	0.040	0.308	0.039	0.035	1														
No. Scraper Taxa	0.018	0.149	0.188	0.183	-0.058	1													
% climbers	0.251	0.231	0.291	0.285	-0.050	0.273	1												
BIBI	0.388	0.551	0.575	0.587	0.248	0.386	0.446	1											
Bank Stability	-0.084	-0.006	-0.111	-0.120	0.033	0.100	0.062	0.006	1										
Vegetative Protection	0.072	0.148	0.085	0.083	0.086	0.135	0.199	0.192	0.432	1									
Channel Flow	-0.005	-0.142	-0.117	-0.136	-0.030	-0.023	-0.032	-0.100	0.216	0.056	1								
Channel Alteration	-0.073	0.151	0.029	-0.005	0.093	0.055	0.041	0.034	0.114	0.149	0.003	1							
Channel Sinuosity	0.139	0.244	0.196	0.184	0.022	0.202	0.298	0.292	0.103	0.306	-0.016	0.230	1						
Pool Substrate	0.117	0.096	0.066	0.057	-0.087	0.089	0.169	0.094	0.157	0.135	0.183	0.191	0.202	1					
Pool Variability	0.205	0.173	0.201	0.194	-0.102	0.222	0.263	0.236	0.054	0.057	0.123	0.048	0.223	0.420	1				
Riparian Zone Width	-0.136	0.115	0.034	0.022	0.075	0.148	0.079	0.080	0.110	0.028	-0.012	0.430	0.207	0.052	0.051	1			
Sediment Deposition	-0.052	0.101	0.055	0.041	-0.017	0.115	0.091	0.046	0.223	0.132	0.128	0.199	0.093	0.304	0.146	0.090	1		
Epi. Substrate/Avail. Cover	0.113	0.100	0.087	0.086	-0.067	0.056	0.104	0.069	0.130	0.072	0.158	0.251	0.172	0.522	0.389	0.077	0.378	1	
RBP Score	0.067	0.177	0.094	0.076	0.012	0.197	0.235	0.179	0.409	0.395	0.276	0.407	0.432	0.489	0.379	0.327	0.380	0.462	1
Instream Habitat	0.096	0.113	0.112	0.113	-0.066	0.054	0.114	0.083	0.150	0.058	0.214	0.254	0.191	0.521	0.427	0.132	0.292	0.790	0.483
Epifaunal Substrate	0.151	0.193	0.168	0.170	-0.096	0.173	0.263	0.208	0.114	0.192	0.064	0.139	0.323	0.487	0.416	0.010	0.373	0.699	0.447
Bank Stability	-0.079	0.037	-0.048	-0.055	0.015	0.160	0.105	0.076	0.934	0.481	0.232	0.150	0.110	0.180	0.116	0.140	0.277	0.165	0.443
Percent Shading	0.016	0.106	0.028	0.025	0.087	-0.123	0.046	0.017	0.012	0.077	-0.067	0.318	0.055	0.027	-0.033	0.246	0.114	0.123	0.147
Remoteness	0.017	0.237	0.162	0.169	0.252	0.097	0.165	0.229	0.108	0.309	-0.032	0.399	0.297	0.119	0.143	0.304	0.201	0.223	0.361
# Woody Debris/Rootwads	-0.049	0.046	-0.052	-0.071	0.164	0.012	0.006	0.011	0.133	0.043	0.106	0.123	0.015	0.125	0.122	0.109	0.037	0.145	0.161
Remoteness Score	-0.004	0.217	0.116	0.124	0.230	0.108	0.182	0.214	0.064	0.263	-0.070	0.319	0.258	0.013	0.034	0.319	0.109	0.060	0.250
Shading Score	0.017	0.105	0.030	0.027	0.086	-0.121	0.047	0.018	0.008	0.073	-0.072	0.317	0.050	0.024	-0.035	0.246	0.111	0.120	0.144
Epifaunal Substrate Score	0.099	0.168	0.107	0.108	-0.073	0.129	0.220	0.159	0.124	0.197	0.019	0.127	0.290	0.403	0.289	0.016	0.380	0.587	0.383
Instream Habitat Score	0.009	0.058	-0.001	0.000	-0.009	-0.025	0.031	-0.002	0.168	0.062	0.137	0.266	0.142	0.402	0.221	0.138	0.294	0.601	0.401
Woody Debris Score	-0.164	-0.042	-0.248	-0.263	0.188	-0.130	-0.112	-0.137	0.123	0.042	-0.019	0.074	-0.059	-0.087	-0.218	0.083	0.011	-0.084	-0.010
Bank Stability Score	-0.094	0.042	-0.051	-0.055	0.069	0.159	0.113	0.082	0.803	0.445	0.170	0.091	0.128	0.101	0.039	0.130	0.159	0.041	0.363
PHI Score	-0.004	0.189	0.028	0.027	0.141	0.076	0.178	0.140	0.299	0.315	0.018	0.367	0.272	0.264	0.119	0.280	0.308	0.375	0.475

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	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													
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	1												
Epifaunal Substrate	0.568	1											
Bank Stability	0.177	0.148	1										
Percent Shading	0.090	0.072	0.035	1									
Remoteness	0.180	0.209	0.112	0.262	1								
# Woody Debris/Rootwads	0.208	0.049	0.082	0.077	0.105	1							
Remoteness Score	0.035	0.086	0.112	0.209	1.000	0.051	1						
Shading Score	0.086	0.068	0.035	1.000	0.261	0.077	0.207	1					
Epifaunal Substrate Score	0.459	0.824	0.146	0.121	0.192	0.031	0.083	0.121	1				
Instream Habitat Score	0.692	0.444	0.187	0.177	0.161	0.161	0.040	0.177	0.482	1			
Woody Debris Score	-0.068	-0.136	0.052	0.185	0.027	0.441	0.031	0.185	0.008	0.170	1		
Bank Stability Score	0.083	0.060	1.000	-0.025	0.112	0.130	0.109	-0.025	0.083	0.114	0.133	1	
PHI Score	0.360	0.377	0.316	0.413	0.489	0.220	0.417	0.413	0.467	0.495	0.290	0.291	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

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
BIBI	1																		
No. Taxa	0.388	1																	
No. EPT Taxa	0.551	0.255	1																
% Ephem	0.575	0.262	0.372	1															
No. Ephem Taxa	0.587	0.282	0.383	0.919	1														
% Intolerant	0.248	0.040	0.308	0.039	0.035	1													
No. Scraper Taxa	0.386	0.018	0.149	0.188	0.183	-0.058	1												
% climbers	0.446	0.251	0.231	0.291	0.285	-0.050	0.273	1											
RBP_TOTAL	0.179	0.067	0.177	0.094	0.076	0.012	0.197	0.235	1										
PHI	0.140	-0.004	0.189	0.028	0.027	0.141	0.076	0.178	0.475	1									
Conductivity	-0.106	0.082	-0.202	-0.068	-0.053	-0.294	0.073	-0.042	-0.037	-0.178	1								
Dissolved Oxygen	-0.129	0.086	-0.055	-0.013	-0.012	-0.096	-0.162	-0.207	-0.068	-0.124	0.144	1							
pH	0.063	0.060	-0.017	0.080	0.104	-0.266	0.213	0.189	0.229	0.078	0.281	0.047	1						
Turbidity	-0.096	0.016	-0.046	-0.162	-0.158	0.122	-0.047	0.010	-0.213	-0.119	-0.075	-0.151	-0.121	1					
Water Temperature	0.070	-0.092	0.093	0.020	0.004	0.057	0.113	0.133	0.119	0.118	-0.121	-0.256	0.005	0.138	1				
Entrenchment Ratio	-0.067	0.056	-0.107	-0.090	-0.092	-0.049	-0.041	-0.097	0.179	-0.046	0.123	0.098	-0.011	0.147	-0.075	1			
Bankfull Width	0.052	0.053	0.020	0.143	0.137	-0.152	0.101	0.072	0.044	-0.219	0.155	0.143	0.218	-0.181	-0.085	-0.052	1		
Mean Depth	0.076	0.149	0.023	0.150	0.164	-0.152	0.036	0.049	0.120	-0.152	0.187	0.217	0.263	-0.199	-0.153	0.072	0.304	1	
Width:Depth Ratio	-0.027	-0.071	0.002	-0.022	-0.046	-0.006	0.064	-0.002	-0.074	-0.079	-0.002	-0.020	-0.027	-0.036	0.004	-0.130	0.370	-0.329	1
Bankfull Area	0.072	0.127	0.021	0.177	0.178	-0.181	0.075	0.081	0.100	-0.230	0.199	0.205	0.295	-0.204	-0.131	0.004	0.633	0.674	0.005
Water Surface Slope	-0.032	-0.071	0.020	-0.101	-0.094	0.105	-0.079	-0.112	-0.090	0.200	-0.051	-0.040	-0.187	-0.075	0.009	-0.100	-0.273	-0.178	-0.045
Sinuosity	0.176	0.091	0.178	0.105	0.115	0.177	0.004	0.151	0.205	0.142	-0.082	-0.114	0.000	-0.097	0.087	-0.094	0.020	0.020	0.037
Flood-Prone Width	-0.014	0.099	-0.067	0.012	0.009	-0.108	0.005	-0.045	0.215	-0.131	0.196	0.166	0.107	0.017	-0.087	0.659	0.295	0.205	0.068
D50	0.166	0.087	0.142	0.172	0.188	0.015	0.158	0.090	0.047	0.031	0.025	0.052	0.040	-0.063	0.002	-0.165	0.166	0.099	0.108
% Impervious	-0.074	0.105	-0.204	-0.046	-0.041	-0.333	0.133	0.022	-0.003	-0.150	0.526	0.079	0.205	-0.200	-0.123	0.144	0.079	0.069	0.009
%Developed	-0.072	0.092	-0.175	-0.080	-0.086	-0.268	0.122	-0.002	-0.022	-0.168	0.448	0.091	0.092	-0.200	-0.079	0.194	0.003	0.070	-0.063
%Agriculture	0.083	-0.084	0.184	0.073	0.062	0.163	0.012	0.086	0.037	0.080	-0.269	-0.149	-0.060	0.162	0.201	-0.257	0.030	0.002	0.025
%Forested	0.076	-0.027	0.169	0.072	0.078	0.267	-0.077	-0.089	0.023	0.085	-0.336	0.036	-0.148	0.117	-0.075	-0.023	0.029	-0.033	0.059
%Open	-0.139	-0.031	-0.149	-0.142	-0.138	-0.104	-0.002	-0.059	-0.029	-0.115	0.241	0.089	0.074	-0.061	-0.038	0.075	0.077	0.022	0.082
Drainage area	0.166	0.156	0.094	0.235	0.234	-0.111	0.170	0.154	0.174	-0.156	0.084	0.080	0.197	0.056	0.056	0.036	0.476	0.397	0.085

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 (cont'd): Biological Versus Water Quality, Geomorphic & Land Use Variables

Variables	Bankfull Area	Water Surface Slope	Sinuosity	Flood-Prone Width	D50	% Impervious	%Developed	%Agriculture	%Forested	%Open	Drainage area
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	1										
Water Surface Slope	-0.278	1									
Sinuosity	0.025	-0.022	1								
Flood-Prone Width	0.279	-0.232	-0.064	1							
D50	0.158	0.093	0.093	-0.077	1						
% Impervious	0.093	-0.002	-0.121	0.199	-0.053	1					
%Developed	0.045	-0.033	-0.109	0.192	-0.131	0.692	1				
%Agriculture	0.016	-0.099	0.158	-0.242	0.071	-0.487	-0.450	1			
%Forested	-0.008	0.032	0.088	-0.022	0.057	-0.401	-0.471	-0.008	1		
%Open	0.064	-0.021	-0.141	0.135	0.062	0.283	0.210	-0.151	-0.251	1	
Drainage area	0.537	-0.332	0.042	0.264	0.056	0.050	0.028	0.090	-0.009	0.043	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